Between the Lines

Reading Difficulties in Homonymous Hemianopia: A Systematic Review

Master’s Thesis

Author: Sushane Gupta
Student Number: s3329232
Supervisor: Sarah Tol
Date: 11-03-2021
Program: Clinical Neuropsychology,
Faculty of Behavioral & Social Sciences,
University of Groningen

Disclaimer

"A thesis is an aptitude test for students. The approval of the thesis is proof that the student has sufficient research and reporting skills to graduate, but does not guarantee the quality of the research and the results of the research as such, and the thesis is therefore not necessarily suitable to be used as an academic source to refer to. If you would like to know more about the research discussed in this thesis and any publications based on it, to which you could refer, please contact the supervisor mentioned."

Abstract

Reading is an essential skill for employability, mobility, and sociability. Disorders that impact an individual's ability to read can severely restrict their ability to function independently. Homonymous Hemianopia (HH) is a visual field disorder that can cause uniform, bilateral loss of vision. This can lead to severe deficiencies in tasks that involve visual search, such as reading. Commonly reported reading problems in HH include slowed reading speed, inability to find the correct line while reading, and reduced reading accuracy. This investigation strives to summarize the available literature on reading difficulties in HH, and identify the key objective and subjective markers of reading difficulties. A systematic review was conducted using the PRISMA 2020 guidelines. Twenty-one studies were included, the majority of which only reported objective difficulties. Individuals with HH read slower with lower accuracy. They also adopt ineffective oculomotor strategies including shorter, more frequent saccades and longer, more frequent fixations. Reported subjective difficulties included inability to perform reading-centric tasks such as shopping and financial transactions, along with avoidance of social situations involving reading tasks. More research on the relationships between different oculomotor measures, reading speed in natural environments and non-standard reading tasks is needed to understand the potential causes and manifestations of performance deficits. Subjective difficulties must be investigated more frequently in a standardized manner. Findings on subjective difficulties must be reported in detail to understand how deficits translate into disabilities.

Between the Lines

As our lives get busier, less thought goes into each action that we perform. We're only awake for sixteen hours a day, and so we don't have time to mull over everything slowly and consciously. So, through repetition, our brain learns to automate certain tasks that are essential but can take up too much time and attention (Young & Santon, 2002). One such task is what you're doing right now, reading.

As eyes move from left to right across the lines of this page with text, little thought goes into how you're able to turn letters on a screen or paper into a voice in your head that can potentially explain a world of concepts and ideas to you (Clay, 1969). In the information age, the ability to read and write has become crucial to understanding the world around us and interacting with it (Boland, 1993). Whether it's buying groceries or understanding the news, the ability to turn letters bunched-up letters into coherent sentences is essential. What happens then, if a skill that is so fundamental is impaired due to unforeseeable circumstances?

Reading Problems

The acquired inability to recognize written letters and subsequently read words and sentences is known as Alexia (Friedman, Ween and Albert, 1993), and is usually the result of acquired brain injury. This can be contrasted with the more commonly known dyslexia, which is classified as a neurodevelopmental disorder and connotes a failure to acquire reading as a skill during early education (Shaywitz,1998; Petretto & Masala, 2017). Though alexia is a multifactorial condition (Kiran, 2006), one of its most common causes is the occurrence of a cerebrovascular accident (CVA). Alternatively, alexia and dyslexia can result from infarcts in the visual cortices, leading to visual field loss, where parts of our combined vision from both eyes may become imperceptible. This visual field loss may also stem from acquired brain injury (ABI), leading to conditions that may impact reading due to visual field defects (VFDs). One of these conditions is called Hemianopia.

Hemianopia and its Effects on Reading

Hemianopia can be defined as a uniform, bilateral loss of sight in one or more quadrants of the visual field. The "visual field" can be thought of as the entire image that can be perceived when vision is fixated at a single point in space (Smythies, 1996). Hemianopia is usually diagnosed by conducting a visual field exam using some form of perimetry (Meienberg et al., 1986). It results from damage to the visual system past the optic chiasm. Hemianopia can be heteronymous, where different parts of the visual field are affected in each eye. However, the more common type is Homonymous Hemianopia (HH), where both eyes suffer from loss of the same side of the visual field (Zhang et al., 2006). HH can have different forms. It can be complete; where an individual loses the entire half of their visual field, partial; where they lose half the field with some sparing, or quadrantanopia; where the individuals lose vision in one-quarter of their visual field.

Hemianopia can be caused by a myriad of complications resulting from acquired brain injury. The most common cause of hemianopia in adults is the onset of CVAs. 52-70% of homonymous hemianopia (HH) cases are caused by CVAs, and about 8-10% of Individuals who suffer from CVAs will have permanent HH (Goodwin, 2014). Other prominent causes of hemianopia are traumatic brain injury (14% cases) and brain tumors (11% cases). Less prominent causes include conditions like Alzheimer's Disease, Shaken baby syndrome, and neurosyphilis (Zhang et al., 2006). HH can sometimes occur with other visual complications, such as macular degeneration, which causes blurring of vision in the center of the visual field (Monteiro et al., 2014; NIH, 2013). Poor reading ability following the onset of HH may be maladaptive eye movements, or other perceptual abnormalities arising from a combination of these symptoms (Schuett et al., 2008). A holistic understanding of HH also requires an investigation into co-morbid deficits, but these are often difficult to disentangle, and difficult to study in isolation.

From early research, we know that left-to-right readers suffering from right-HH (loss of right visual field), tend to have greater difficulty reading than individuals with left-HH, especially if they suffer from comorbid macular degeneration (Goodwin, 2014). To read, readers must be able to see 3 letters to the left and 7 letters to the right of a fixation point (Kerkhof, 2000). Individuals with HH have trouble performing systematic saccades and altering fixation points quickly enough to read in a comprehensible manner. Prolonged fixation and regressive saccades (moving the eyes back to the beginning) reduce reading speed and impact comprehension (Zihl, 1995).

Left-to-right readers with left-HH, on the other hand, exhibit a different pattern of impairment. The beginning of a word (letters on the left side) helps us identify the word before it has been fully read. Individuals with left-HH often misidentify and hence misread words if they are trying to read quickly (Grunda & Marsalek et al., 2013). Individuals with HH can also suffer from an increased word-length effect when compared to individuals without visual defects. The word-length effect describes how readers take longer to read words that have more letters in them. Of the individuals that suffer visual field loss, approximately half experience some difficulties in reading (Rowe et al., 2013). The nature and severity of difficulties experienced by the individuals are dependent on the degree of visual field loss, (Goodwin, 2014), the direction of reading (left to right or top-down, de Jong et al., 2016), and possible comorbid ocular conditions (Schuett, 2009). Greater field loss leads to greater deficits in reading ability, and individuals with right-HH experience a greater reduction in reading ability (Goodwin, 2014).

Subjective and Objective Reading Problems

The reading difficulties experienced by individuals with HH can be classified into 2 broad categories: subjective reading problems and objective reading problems. Subjective reading problems are those that are reported by individuals with HH. These include trouble with finding the correct line on the page, trouble concentrating on reading-based tasks, and being able to follow sentences. Objective reading problems, on the other hand, may go unnoticed by the individual but can be measured using standardized testing procedures. These include slowed reading speed, word-length effects, and problems with saccades and fixations during reading. These problems are not entirely separable, as difficulties in one can worsen the other. An individual with HH that struggles to find the correct line in a paragraph may naturally have a slower reading speed. Subjective reading problems are documented by interviewing and surveying individuals with HH, who can link them to difficulties in performing activities of daily living, such as shopping or driving. Objective problems, on the other hand, allow us to systematically measure and understand changes in physiology that can lead to reductions in reading performance.

Options for Intervention and Management

Many treatments for HH are not specific to reading but can improve performance by treating or compensating for the core deficit of visual field loss. The three most common treatment approaches are substitution, compensation, and restitution (Pelak et al., 2007). Substitution methods include training the individual to use vision alteration devices such as optical prism glasses, that can condense images in the damaged parts of the visual field into those that are still functioning (Giorgi et al., 2009). Compensation methods rely on learning deficit-specific saccade patterns that can reduce the impact of visual field loss. These work by altering visual search and eye-movement patterns in a way that includes parts of the image lost due to HH into the visual field (Roth et al., 2009). Finally, restitution strategies rely on stimulating lost parts of the visual field. This can include visual prosthetics, electrical field stimulation of the cortices to encourage neuro-regeneration, and neuromodulation using pharmaceutical or electrical agents to alter neural activity in the visual cortices affected by the ABI.

Though these treatment methods have been in use for more than 20 years, there is considerable debate regarding a standardized approach that incorporates one or more of these methods into a comprehensive treatment program for HH (Liu et al., 2019). Most available interventions tend to focus on objective measures of reading problems (Warren, 2009). Comparative research has highlighted the impact of ancillary treatments for HH-related VFD, such as cognitive remediation and rehabilitation that can significantly influence outcomes measures such as independence and return to work (Bowers & Peli et al., 2017; Code & Hermann, 2003).

Consequently, it may be necessary to fully assess not just physiological (objective) but also the psychosomatic and psychological (subjective) factors impacting VFDs. Reading itself is a multifaceted skill that can be influenced by a variety of psychosocial factors (Vincenzi, 1987). Hence, we must also consider how alterations in these factors due to CVAs, combined with HH-related impairments can influence reading ability.

Current Study

Although there is no dearth of research on the etiology and treatment of reading difficulties in HH, the different methods used to investigate deficits and progression have made it difficult to maintain an overview and identify the difficulties in reading faced by individuals with HH and the intervention we can use to treat them. Reading and writing are essential skills in daily life, and losing the ability to perform them can result in failure to perform at work and impairments in activities of daily living, both of which can lead to increased dependence and cause burden to the individual and their caregivers (Gallagher et al., 2011).

Conducting a review can help us ascertain the most prevalent causes by studying and combining all the existing literature on reading difficulties in HH. Given that there is no clear consensus on an effective treatment strategy for reading deficits caused by HH (Schuett, 2009), this information can guide future research and treatment, and improve independent quality of life in individuals with HH. Such a review would provide an overview of the difficulties experienced by individuals within a specific population and outline how pathological features translate to difficulties in everyday functioning. This can help identify treatment goals, allowing us to focus on the issues most relevant to patient well-being that can be addressed by clinicians in practice.

A comprehensive review must study deficits in performance and the impairments they may cause. To this end, it is important to investigate both subjective and objective problems experienced by individuals with HH while reading. Subjective and objective problems may influence each other, but may cause different impairments and may require different interventions. Hence, studying them separately will provide us with a more precise and detailed understanding of the deficits in reading caused by homonymous hemianopia.

This investigation aims to contribute to the following research question: What is the nature of reading difficulties that are caused by homonymous hemianopia in individuals with CVAs? This question can be further broken down into 2 major categories; What are the reported subjective reading problems? And; what are the reported objective reading problems?

Methodology

Eligibility criteria

This review adheres to the PRISMA 2020 guidelines for the conduction of systematic review (Page et al., 2021) and will focus exclusively on individuals with Homonymous Hemianopia (HH) caused by a cerebrovascular accident (CVAs). Investigations must contain documented measures of objective or subjective reading difficulties caused by the visual field loss. Randomized Controlled Trials, Case-Control, Quasi-Experimental and Cross-Sectional studies were included. This review focuses exclusively on adults, and papers that report their findings in English. The review excludes minors as there is little research on children with HH caused by CVAs. Furthermore, children are still undergoing neural development and may have vastly different disease presentations and prognoses when compared to adults, prompting a separate review. Case studies have been excluded due to small sample sizes and inconsistent methodologies for quantifying and documenting deficits. Studies including individuals with HH with comorbidities such as Scotomas, Visuospatial Neglect, and Macular Degeneration have also been excluded as they may impact reading abilities via different mechanisms separate from visual field loss.

Search Strategy

Studies were indexed from 3 directories, PubMed, ScienceDirect, and Web of Science. The search terms (“Hemianopia*” OR “Hemianopsia*” AND “Reading Difficulties”) OR (“Visual Field Disorders” OR “Homonymous Visual Field Disorders” AND “Alexia*”) OR (“Hemianopic Alexia” OR “Hemianopia Alexia”) were used to search for literature by title and abstract for each directory. The directories were indexed on the 10th of January 2022, and the results were imported as citations into the review tracking software Rayyan AI (Kellermeyer et al.,2018). Relevant articles were also reviewed for citations that could be included in the review.

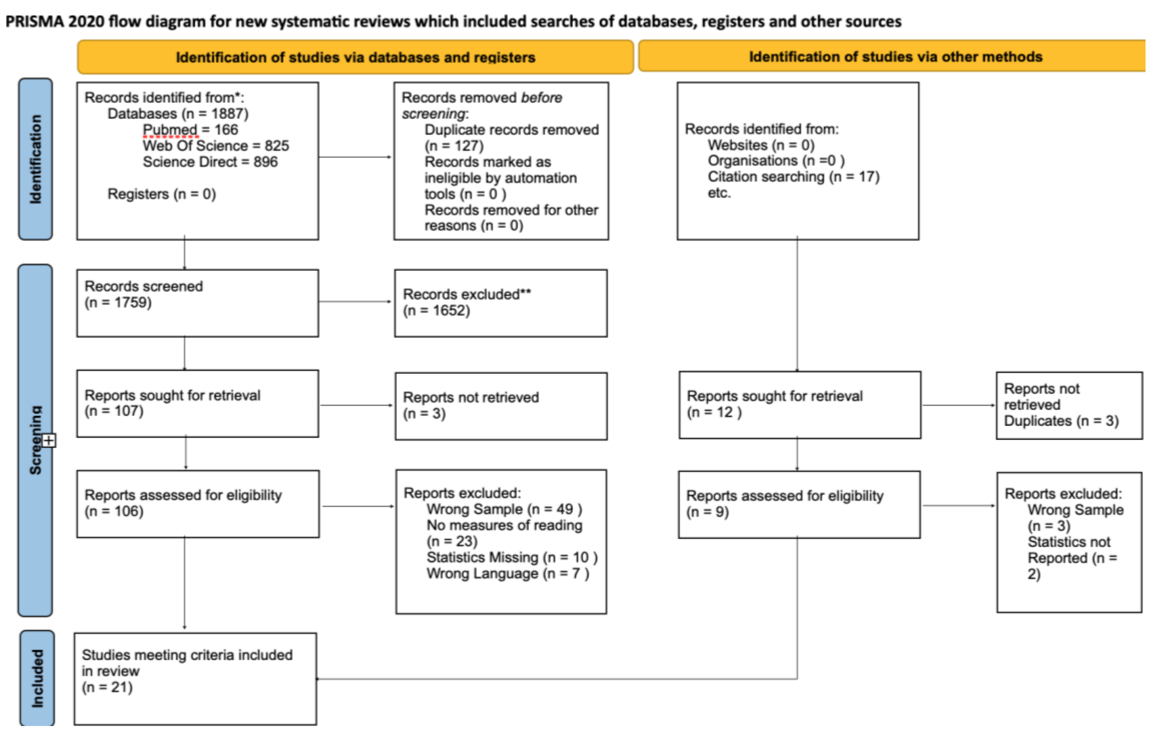
Screening

A total of 1887 citations were important in Rayyan AI, of which 143 were flagged as duplicates by the software. A single reviewer checked the flagged literature by reviewing titles, abstracts and authors. It was determined that 128 out of 143 were in fact duplicates, and 15 were false flags. The remaining 1759 entries were reviewed by the same reviewer to determine if they met the inclusion criteria. Titles and abstracts were reviewed to determine if papers were in English, used adult samples, and focused on individuals with HH. Methods were reviewed to check if the HH in the sample was caused primarily by CVAs and that the individuals didn't suffer from comorbid conditions. Results sections were also scanned to ensure that statistics on reading abilities were reported, as many treatment focused investigations tend to report differences but not raw data.

Studies that made it through the filtration process were also reviewed for relevant citations that might not have appeared in the initial directory search; these papers were then put through the same filtration process as those that were indexed and added to Rayyan. In total, 21 studies were included in the review. A summary of the filtration process can be seen in the PRISMA flow diagram (Page et al., 2021), shown in Figure 1.

Figure 1

Prisma Flow Diagram of Studies included in the Review



Data Extraction and Quality Assessment

Data were extracted by reviewing the tables, charts, and text presented in the results sections. Where reported, data from samples with left and right-HH was extracted separately to identify possible differences in reading difficulties. Outcome measures for both Subjective and Objective problems were compiled into separate spreadsheets.

For the papers that were included, quality assessment was performed using critical appraisal tools developed by the Joanna Briggs Institute (Munn et al., 2020). Checklists for Case-control, Quasi-Experimental, RCT, and Cross-Sectional studies were used. In the critical appraisal forms, a "yes" was given a value of 1 and a "no" was given a 0. These values were then added up to calculate the total relative score of each study out of 100%. To be included in the review, studies must achieve a score of at least 40% (Sharif et al., 2013). Questions that were not applicable or where the information provided was unclear for a given study were not included in the final score calculations.

Objective Reading Problems

To investigate objective reading problems, data on reading speed, reading errors (omissions, repetitions, and misreads), saccade patterns, fixation patterns, and lexical decision tasks were extracted. These measures were chosen because they are commonly reported quantitative indicators of reading performance in the literature, making them appropriate data points for a comparative review. Additional reported objective measures were also extracted to identify possible targets for future investigations, these have been reported separately. The types of reading tests administered and descriptions of the reading tasks were also extracted to identify possible differences between different measures of reading ability. Due to inconsistencies in reporting on parametric testing and effect sizes, means comparing individuals with HH with healthy populations as a measure of central tendency were used to compare findings between investigations. Where measures of central tendency are not reported, findings have been summarized by averaging reported scores for quantitative measures.

Subjective Reading Problems

To investigate subjective reading problems, reported results from surveys such as the Visual Functioning Questionnaire (NEI-VFQ), and Impairment of Vision Profile (IVI) have been extracted by examining tables and summarized findings in-text. These findings were only extracted if composite scores for subscales or items related to reading were reported. These measures have been chosen as they are commonly reported standardized indicators of visual functioning and independent functioning. Additionally, spontaneous complaints and observations from interviews have been extracted where reported. Some studies report correlations of quantifiable subjective measures, such as NEI-VFQ scores with objective measures such as reading speed and fixation accuracy. If reported, these have been extracted by examining tables and in-text results, to aid a comparative analysis.

Results

Literature Search

As mentioned earlier, twenty-one studies were included in this review. All studies passed the quality assessment process. Results of the Critical Appraisal Process (Munn et al., 2020) can be found in Appendices 1-4.

Table 1 provides a brief overview of all the studies included in the systematic review. Fifteen studies focused exclusively on reporting objective reading difficulties. Subjective difficulties were less commonly reported, in six studies. Some studies reported both and investigated possible correlations between these measures. The most commonly reported difficulty measure was reading speed, followed by saccadic amplitude, number of saccades, number of fixations, and fixation duration.

Fifteen studies reported time-since-onset of CVAs. However, only two studies used this data to draw conclusions about HH phenomenology. Most studies used tasks asking individuals to read text aloud, one investigation asked them to read the text silently. Two studies investigated the impact of text rotation on reading speed. Seven studies used standardized tests of reading ability (Radner reading charts, International Reading Speed texts, Visual Skills for Reading test). The rest of the studies used non-standard reading tasks, which involved asking participants to read an article or story off a computer screen. Further details about the reading tasks and oculomotor tracking equipment used can be found in Appendix 5.

Table 1

Studies included in the review

First author, Year	Sample size and type	Age (Mean, SD, Range)	Time since onset (Mean, SD)	Objective Measures Extracted	Subjective Measures Extracted	Notes:
Trauzettel-Klosinski & Brendler, 1998	40, 21 Healthy, 19 with HH	NR	NR	Reading Speed, Number of Saccades	NR	-
Trauzettel-Klosinski & Reinhard, 1998	8HH, RHH:3; LHH:5	52.9, NR, 27-74	NR	Reading Speed, Number of Fixations, Return Sweeps, Number of Saccades	NR	-
de Jong et al., 2016	13HH: RHH:6; LHH:7, 13 Age-matched controls	RHH: 57.5, NR, NR LHH: 62.6, NR, NR	NR	Saccades, Reading Accuracy	NR	-
Zihl, 1995	50HH: RHH:25; LHH: 25, 25 Healthy	LHH: 43, NR, 21-64 RHH: 38, NR,18,56 Healthy: 38, NR, 19-57	3-12 weeks	Reading Speed, Reading Accuracy, Number of Fixations, Sweep Patterns, Saccade Amplitude	NR	-
McDonald et al., 2006	RHH: 18, Healthy:18	57(median, Range:	27months	Reading Accuracy, Initial Landing Position, Progressive Saccade Amplitude, Regressive Saccade Amplitude,	NR	for 15/18 subjects stroke was the cause of HH

				Number of Fixations, Refixation Rates		
Schoepf and Zangemeister, 1993	HH: 8	Range: 24-73	NR	Reading Speed	NR	-
Gall et al., 2010a	HH: 43	54.8, NR, NR	NR	NR	NEI-VFQ item scores	-
Warren, 2009	HH:46	Over 18	NR	Reading Speed, Reading Accuracy	Spontaneous Reporting, Non-standard interview	-
Bormann et al., 2014	HH: 4, Healthy: 9 (simulated scotoma/hemianopia)	Range: 62-71	Range: 9-47 months Mean:22.5	Reading Speed, Number of Fixations, Saccadic Amplitude	NR	Participants were college educated
Schuett et al., 2008	HH:40, RHH:24; LHH:16	58.8, NR, 23-83	NR	Reading Speed, progressive Saccades, Number of Fixations	NR	Majority of participants had HH due to CVA
Hepworth et al., 2019	HH:7, RHH:2; LHH:5	73.1, NR, NR	Mean: 61.5 Weeks, Range: 3-291 weeks	Reading Speed (Horizontal and Vertical)	NR	-
Kuester-Gruber et al., 2021	HH: 21	>18	>6 months	Reading Speed	IVI item scores	-
de Haan et al., 2016	HH: 45, Healthy: 25	HH: 55, 10.9, NR Healthy: 53, 13.5, NR	>5 months	Reading Speed	NR	-
Zihl et al., 2021	HH: 97, RHH:44; LHH:53	Range: 21-84	>4 weeks	Reading Speed, Reading Accuracy	NR	-
Passamonti et al., 2009	HH: 12, RHH: 6; LHH:6 Healthy: 12	Mean:40	5-360 months	Reading Speed, Reading Accuracy, Progressive Saccades, Regressive Saccades, Return Sweeps, Fixation	NR	Participants were educated for 13 years. 7 suffered stroke, 4 suffered

				Duration, Saccade Amplitude		TBI, 1 suffered AVM
Keller & Lefin-Rank, 2010	HH: 20	Range: 16-85	3-24 months	Reading Speed	NR	-
Pflugshaupt et al., 2009	HH: 6, PA: 6	Ranges: HH: 35-78, PA: 18-64	In weeks: Mean:14; SD: 32; Range: 1-90.	Reading Speed, Reading Accuracy	NR	5 / 6 participants with HH suffered an ischemic stroke
Papageorgiou et al., 2007	HH: 33, RHH: 16; LHH: 17	51.4, 15.8, 21-74	Mean: 2.7 years Range: 6 months to 16 years	Reading Speed.	NR	-
de Haan et al., 2015	HH: 43, RHH: 17 LHH:37	56, NR, 27-75	Mean: 20 months	NR	Spontaneous Reporting, Non-standard survey	11 participants had QDA
Poggel et al., 2010	HH: 19	Range: 18-75	>6months	NR	Non-standard interview, Spontaneously reported Difficulties	-
Gall et al., 2010b	HH: 177	57.4, NR, 21-83	In Months: Mean: 30.69; Range:6-277	NR	Composite NEI-VFQ scores	-

NR: Not Reported; HH: homonymous hemianopia, LHH: Left Homonymous Hemianopia, RHH: Right Homonymous Hemianopia, QDA: Quadrantanopia, AVM: Arterio-Venous Malformation, CVA: Cerebro-Vascular Accidents; NEI-VFQ: National Eye Institute Visual Functioning Questionnaire; IVI: Impact of Visual Impairment Profile; - : none;

Objective Difficulties

Reading Capabilities

A full tally of the results extracted for reading capabilities can be found in Table 2.

Table 2

Summary of results from reading capabilities

First Author, Year	Reading Speed (Text)	Reading Speed (single word)	Reading Errors

Trauzettel-Klosinski & Brendler, 1998	HH<N LHH>RHH n.s.	NR	NR
Trauzettel-Klosinski & Reinhard, 1998	LHH = RHH	NR	NR
de Jong et al., 2016	At 0, 90, 270 degrees = HH< N *** At 180 degrees = HH = N n.a.	NR	Interaction with Speed* RHH>LHH>N in all rotations
Zihl, 1995	N>LHH>RHH***	NR	RHH>LHH*** Errors were mostly omissions when reading longer words/numbers
McDonald et al., 2006	NR	NR	Skipping Rate: N>HH Both groups are less likely to skip words as WL increases. Effect bottoms out at 5 letters for HH
Schoepf and Zangemeister, 1993	Average reading speed: RHH<LHH < N Maximum Reading Speed: RHH<LHH<N n.s	NR	NR
Gall et al., 2010a	Radner Reading: Sentence 3-7: RHH<LHH<N n.a Radner Reading: All sentence: RHH=LHH<N n.a	NR	NR
Warren, 2009	HH<N n.s.	NR	Reading accuracy ranged from 52-100%, median 92% n.s.
Bormann et al., 2014	NR	Response Time: 4 letters: HH>sVFD>BS** 6 letters: HH>sRHH>N** Difference in HH is higher	NR
Schuett et al., 2008	HH<N***	NR	NR
Hepworth et al., 2019	Horizontal: RHH<LHH RHH experience a steeper decline in clockwise rotation LHH experience a steeper decline in Anti-clockwise rotation n.a.	NR	NR

Kuester-Gruber et al., 2021	Horizontal: LHH>RHH (p=0.07 sign.) Vertical LHH>RHH n.a. Reading Speed at home < Reading speed during investigation	NR	NR
de Haan et al., 2016	Radner Reading Speed: Mean: 151.4, SD: 32.56 n.s.	NR	Text Correct answers: Mean:1.51, SD:0.59
Zihl et al., 2021	RHH<LHH<N n.a.	NR	NR
Passamonti et al., 2009	RHH<LHH<N ***	NR	RHH>LHH>N ***
Keller & Lefin-Rank, 2010	HH<N n.s.	NR	NR
Pflugshaupt et al., 2009	N > HH *** WLE in HH, n.s.	NR	NR
Papageorgiou et al., 2007	LHH>RHH n.s. In RHH, reading speed much slower if macular sparing less than 5 degrees	NR	NR

***** = p< 0.001**
**** = P<0.01**
*** = P<0.05**
n.s = not significant
n.a. = significance not available

Reading speed

Sixteen studies reported text reading speed measured in words per minute (wpm), one study reported single word reading speed using a response time task (Bormann et al., 2014).

Individuals with HH were universally found to have slower reading speed than individuals with normal vision. Five articles reported statistically and clinically significant differences in reading speed between individuals with HH and participants with normal vision (de Jong et al., 2016; Zihl, 1995; Schuett et al. 2008; Passamonti et al., 2009; Pflugshaupt et al., 2009). Six more articles also found evidence for slower reading speeds in individuals with HH that did not reach statistical significance (Trauzettel-Klosinski & Brendler, 1998; Schoepf & Zangemeister, 1993; Warren, 2009; Papageorgiou et al., 2007; de Haan et al., 2016; Keller & Lefin-Rank, 2010). Three more studies found evidence for decreased reading speed in individuals with HH but did not report the significance of their findings (Gall et al., 2010a; Hepworth et al., 2019; Zihl et al., 2021). De Haan et al. (2016) reported that the reading speed of individuals with HH was significantly lower than the accepted mean values for healthy individuals on Radner Reading Charts.

Overall, individuals with left-HH had a lower reading speed than participants with no visual impairments, but performed better than individuals with right-HH (Trauzettel-Klosinski & Brendler, 1998; Zihl, 1995; Schoepf and Zangmeister, 1993; Gall et al., 2010a; Hepworth et al., 2019; Kuester-Grueber et al., 2021; Zihl et al., 2021; Passamonti et al., 2009, Papageorgiou et al., 2007). Gall et al. (2010a) found that reading speed did not differ between right-HH and left-HH individuals if findings from all the sentences in Radner Reading Chart (Radner et al., 1998) were averaged. The significance of these findings were not reported, Trauzettel-Klosinski & Reinhard (1998) also found no significant difference in reading speed between the 2 groups.

Studies investigating vertical and rotated reading also reported similar findings. De Jong et al. (2016) report that individuals with HH have significantly lower reading speeds when compared to healthy controls at 0, 90, and 270 degrees. However, the difference in reading speed is not statistically significant at 180 degrees (upside-down). Kuester-Gruber et al., 2021 found that individuals with left-HH read faster than individuals with right-HH during vertical reading tasks. Hepworth et al. (2019) report that while individuals with right-HH experience a steeper decline in reading speed with clockwise rotations (90-degrees), individuals with left-HH experience a steeper decline with anti-clockwise (270-degree) rotation. However, Hepworth et al. (2019) do not report the significance of these findings.

Bormann et al. (2014) use a single-word reading task to demonstrate that individuals with HH perform worse than healthy controls and participants with simulated VFDs (sVFDs). Bormann et al. (2014) also report an increased word-length effect in individuals with HH, compared to healthy controls and participants with sVFDs. Pflugshaupt et al. (2009), also found evidence for an increased word-length effect in individuals with HH when compared to healthy controls, but these findings did not reach significance.

Reading Errors

Six studies reported on reading errors made by participants during reading tasks (de Jong et al., 2016; Zihl, 1995; McDonald et al., 2006; Warren, 2009; de Haan et al., 2016; Passamonti et al., 2009.) Passamonti et al. (2009) report increased errors in individuals with HH, with individuals with right-HH making more errors while reading aloud than individuals with left-HH. Zihl (1995) found that individuals with HH mostly erred by omitting letters/digits in longer words/numbers. Warren (2009) reported that reading accuracy in the HH group ranged from 52-100%, with a median of 92%.

De Jong et al. (2016) report that there was an interaction between reading speed and reading errors at all rotation angles (0, 90, 180, 270 degrees). Individuals with right-HH made the most errors, followed by individuals with left-HH and healthy controls respectively. McDonald et al. (2006) reported that the skipping rate (words that are not fixated on) reduced as word-length increased. While this effect was constant for healthy controls, it bottoms out at 5 letters for individuals with HH.

Summary of Reading Capabilities

Individuals with HH tend to have slower reading speed and make more errors when reading compared to healthy controls and participants with sVFDs. Individuals with left-HH perform better than individuals with right-HH, but this can depend on the rotation of the text and the reading task used. Differences in reading speed are constant across different rotations, except at 180 degrees where individuals do not differ from controls with regards to reading speed. A more pronounced word-length effect exists in individuals with HH when compared to healthy controls.

Oculomotor Measures

Saccade Characteristics

Seven studies reported on saccade characteristics. Table 3 shows a summary of the data extracted from each study.

Table 3

Summary of data extracted regarding saccadic characteristics

First Author, Year	Return Sweep Saccades	Number of Saccades	Saccade Amplitude	Saccade Pattern
Trauzettel-Klosinski & Brendler, 1998	Normal<HH, LHH<RHH n.a.	Regressions: Normal<HH LHH<RHH 0-6months > 24 months Number of Saccades Normal < HH Time of onset dependent in RHH, not in LHH n.a.	NR	NR
Zihl, 1995	NR	RHH show increase movements when saccade amplitude increases***	Right to Left: Normal>RHH>LHH*** Left to Right: Normal>LHH>RHH ***	"Normal subjects showed the typical regular staircase pattern of eye movements: fixations were followed by saccadic jumps, with incidental regressive saccades to the right or left. In contrast, patients with left-sided field loss showed eye movement patterns which were mainly characterized by the interruption of the saccadic jumps from the end of a line to the beginning of the next line, i.e., from right to left. patients worse than controls, the RH-group appearing worst of all. These patients required nearly threefold greater reading times".
McDonald et al., 2006	NR	NR	Progressive Saccade Amplitude: Normal>HH Regressive Saccade Amplitude: Normal > HH n.s.	NR
Warren, 2009	HH showed line	NR	NR	NR

	skipping			
Bormann et al., 2014	NR	NR	sVFD>HH**	NR
Schuett et al., 2008	NR	HH > Normals n.a.	Normals > HH n.a.	NR
Passamonti et al., 2009	Return Sweeps: N<RHH<LHH n.s.	Progressive Saccades: N<LHH<RHH *** Regressive Saccades: N<LHH<RHH ***	N>LHH>RHH ***	NR

***** = p< 0.001**
**** = P<0.01**
*** = P<0.05**
n.s = not significant
n.a. = significance not available

Saccade Frequency

Four studies reported the number of saccades made by participants during reading tasks and reported that individuals with HH made more saccades than healthy controls (Trauzettel-Klosinski & Brendler, 1998; Zihl, 1995; Schuett et al., 2008; Passamonti et al., 2009). Only one set of findings failed to reach statistical significance (Schuett et al., 2008).

Passamonti et al. (2009) observed that individuals with HH tend to make more progressive(left-to-right) and regressive(right-to-left) saccades when compared to controls, with individuals with right-HH making more than individuals with left-HH. Trauzettel-Klosinski & Brendler (1998) reported similar results, and observed that an increase in the number of saccades was correlated with time since onset in the right-HH group, but not in the left-HH group. However, these findings did not reach significance. Zihl (1995) reported that individuals with right-HH tend to perform more saccades as the amplitude of the saccade increases.

Saccade Amplitude

Five studies reported that individuals with HH tend to have lower saccadic amplitude than healthy controls (Zihl, 1995; McDonald et al., 2006; Bormann et al., 2014; Schuett et al., 2008; Passamonti et al., 2009). This means that individuals with HH make eye movements covering a smaller proportion of the visual field. Two of these did not reach statistical significance (McDonald et al., 2006; Schuett et al., 2008). Bormann et al. (2014) report that individuals with HH have smaller saccadic amplitude than participants with sVFDs.

Passamonti et al. (2009) also report that individuals with left-HH have larger amplitudes than those with right-HH. Zihl (1995) reports similar findings, but also reports that while individuals with left-HH have larger amplitudes than those right-HH when making left-to-right saccades, individuals with right-HH have larger amplitudes when making right-to-left saccades. McDonald et al. (2006) report that individuals with HH have lower amplitude than healthy controls when making progressive and regressive saccades, but these findings did not reach significance.

Return Sweeps

Three studies observed return-sweep saccades, but only 2 compared different HH groups and healthy controls (Trauzettel-Klosinski & Brendler, 1998; Passamonti et al., 2009). Both studies report that individuals HH make more return sweep saccades than healthy controls, and that individuals right-HH perform more return sweeps than those with left-HH. However, one set of findings did not reach significance (Passamonti et al., 2009) and the significance of the other was not reported (Trauzettel-Klosinski & Brendler, 1998). Warren et al. (2009) observed that individuals with HH showed incidences of line skipping when making return sweeps.

Saccade Patterns

Zihl (1995) reported that while healthy controls show a typical ‘staircase’ pattern while reading and switching lines, individuals with HH show many inconsistencies and interruptions in this pattern. Individuals with right-HH showed more interruptions when switching lines than individuals with left-HH, which translated to threefold increases in reading times

Fixations

Five studies reported on fixation characteristics. Table 4 shows a summary of the data extracted from these investigations.

Table 4

Data extracted on fixation characteristics

First Author, Year	Number of Fixations	Fixation Duration	Refixations
McDonald et al., 2006	HH > N ***	HH > N ***	HH > N, increases with word length ***
Zihl, 1995	NR	HH > N *** Magnified by increased saccadic amplitude	RHH > LHH ***
Bormann et al., 2014	4 letter words: wVFD<sVFD<HA * 6 letter words: wVFD<sVFD<HA* Difference stronger between HH and sVFD in 6-word condition	NR	NR
Schuett et al., 2008	HH > N **	HH> N n.s	HH > n.s
Passamonti et al., 2009	NR	N<LHH<RHH ***	NR

***** = p< 0.001**
**** = P<0.01**
*** = P<0.05**
n.s = not significant
n.a. = significance not available

Number of Fixations

Three studies reported on the number of fixations and observed that individuals with HH make more fixations than healthy controls while reading (McDonald et al., 2006; Bormann et al., 2014; Schuett et al., 2008). All findings achieved significance. Bormann et al. (2014) also observed that individuals with hemianopic alexia make more fixations than healthy controls with sVFDs. They also report a more pronounced word-length effect on HA (Hemianopic Alexia), where the increase in the number of fixations while reading a four-letter word versus a six-letter word is higher than the increase in participants with sVFDs and healthy controls.

Fixation Duration

Four studies reported on fixation duration and reported that individuals with HH fixate on words for longer while reading, when compared to healthy controls (McDonald et al., 2006; Schuett et al., 2008; Zihl, 1995; Passamonti et al., 2009). One of these findings failed to reach significance (Schuett et al.). Passamonti et al. (2009) report that individuals with right-HH fixate for longer than individuals with left-HH, who fixate longer than healthy control. Zihl (1995) observed a relationship between saccadic amplitude and fixation duration, suggesting that an increase in fixation durations in HH is amplified when the saccadic amplitude is increased.

Refixations

Three studies reported on refixations. Two reported comparisons between HH groups and healthy controls, finding that individuals with HH make more refixations (McDonald et al., 2006; Schuett et al., 2008). One of these findings failed to reach significance (Schuett et al., 2008). Zihl (1995) reported that individuals with right-HH make more refixations than individuals with left-HH. McDonald et al. (2006) reported that the rate of re-fixations increases with word-length in both HH and healthy subject groups.

Summary of Oculomotor Measures

Individuals with HH have smaller saccadic amplitudes and make more saccades and return sweeps than healthy controls and participants with sVFDs. They also make longer and more numerous fixations and refixations than healthy controls and participants with sVFDs. These effects are generally stronger in individuals with right-HH than in those with left-HH, but may depend on saccade direction and reading task.

Additional Reported Measures

Initial Landing Position

Initial landing position can be defined as the relative distance from the start of the word (left-to-right)), and is expressed as a numerical value between 0 and 1, with 0.5 being the center of the word.

McDonald et al. (2006) report that while healthy subjects fixated just left of center regardless of word length (0.48 for 3-letter and .45 for 7 letter words), individuals with HH showed a word-length effect and fixated near-center for shorter words (.49 for 3-letter) and far left of center as words got longer (.28 for 7 letter words). These differences were significant at $p<0.001$.

Character Span

Trauzettel-Klosinski & Brendler, (1998) define character span as “the average number of characters spanned in a saccade”. They report that healthy subjects make saccades that span 8.6 characters on average, whereas individuals with left-HH average at 6, and right-HH average 3.9.

Interactions between Saccades and Fixations

Zihl (1995) investigated if there was a statistically significant relationship between the characteristics of saccades and fixations when reading left to right. They investigated the possibility of a relationship between saccadic amplitude and fixation duration. An increase in saccadic amplitude was shown to have a statistically significant effect on increasing fixation duration. As the frequency of saccades increased, saccadic amplitude and fixation durations increased.

Reading Speed at Home

Keuster-Gruber et al. (2021) reported that reading speed at home was worse than reading speed measured during standardized testing. This was true for both individuals with left-HH and right-HH.

Subjective Difficulties

Six studies reported investigations into subjective reading difficulties. Half reported scores from standardized measures, and half reported narrative findings from non-standard questionnaires, interviews, and spontaneous complaints.

Standardized Measures

Three studies reported scores on standardized measures. One reported NEI-VFQ item scores (Gall et al., 2010a), another reported NEI-VFQ composite scores (Gall et al., 2010b), and the final study reported IVI profile item scores (Kuester-Gruber et al., 2016). These results can be found in Table 5.

Table. 5

Summary of Results extracted on standardized measures of subjective difficulties.

First Author, Year	NEI-VFQ	IVI
Gall et al., 2010a	RH > LH on subscales general health and social functioning *	NR
Gall et al., 2010b	HH < N NEIVFQ sub scale 2 (General vision, contains 2 questions on reading, item 5 and 8 (National Eye Institute, 2000) ***	NR
Keuster-Gruber et al., 2021	NR	Likert Scale 0-3. 0- not at all, 3-Very often For Reading specific Questions: HH: 1.5 RHH:1.75

***** = p<0.001**
*** = p<0.05**

NEI-VFQ scores

Gall et al. (2010b), reported that individuals with HH score lower than healthy controls on sub-scale 2 of the NEI-VFQ, labeled “General Vision”. This subscale contains two reading-specific questions, Item 5 “How much difficulty do you have reading ordinary print in newspapers?” and item 8 “How much difficulty do you have reading street signs or the names of stores” (National Eye Institute, 2000).

Gall et al. (2010a) found that individuals with left-HH tend to score lower than individuals with right-HH on the subscales of health and social functioning. These scales do not contain questions related to reading, but shed light on how visual field loss impacts the quality of life. Both groups scored below healthy controls on all subscales.

IVI profile

Keuster-Gruber et al. (2021) used a Likert scale of 0-3 to see how individuals with right-HH compared to HH in general on reading specific questions on the IVI. Participants were asked to rate the difficulties the frequency of troubles they had completed reading-based tasks (0 = Not at all, 3= Very Often). These included the following items:

25. Reading ordinary size print;

26. Reading large print;

27. Reading labels or instructions on medicines;

28. Reading a sign across the street

Individuals with HH had an average score of 1.5 for these items, whereas individuals with right-HH had an average score of 1.75, suggesting greater and more frequent troubles in completing reading-related tasks.

Summary of Standardized Measures

Individuals with HH report greater difficulties on measures of visual functioning than healthy controls. There is no consensus on whether individuals with left-HH or right-HH struggle more while performing activities of daily living due to reading difficulties.

Spontaneous Complaints, Interviews, and Surveys

Three studies reported on subjective difficulties using non-standardized narrative investigations. The results extracted can be found in Table 6.

Table 6
Summary of Spontaneous Complaints, Interviews, and Surveys extracted

First Author, Year	Spontaneous Complaints	Interviews and Surveys
de Haan et al., 2015	Reading problems include finding the beginning of the next line, limited endurance during reading.	Patients experience problems with reading. More light needed when reading. Problems occur concurrently with requiring greater light intensity. summary results of survey: at least 54% patients reported one reading item as being {problematic}.
Warren, 2009	They also reported difficulty in accurately reading labels, identifying food items, and paying for items by check or credit card. most challenging	Participants were specifically queried regarding difficulties with the performance skills of reading, writing, and mobility (Figure 2) because they are key components of many IADLs. Shopping, for example, requires all three performance skills; driving requires reading and mobility; and both financial management and meal preparation rely on reading and writing, with the latter also involving limited mobility (transporting meal preparation items). Whereas the context of the

	components of meal preparation included reading recipes accurately, measuring food items, locating items on shelves and in the refrigerator, and safely cutting and chopping items.	sentence immediately cues the person that a word was misread so that the mistake can be corrected, misreading numbers does not usually result in such quick feedback. For example, a person who misreads a telephone number may dial that number repeatedly, and if the phone is not answered, the mistake goes unrecognized. Participants who reported difficulty reading numbers stated that they often misidentified numbers with similar visual constructions; thus, an 8 was mistaken for a 3 or a 6 was mistaken for a 5. Some participants reported that fear of misreading a number on a financial statement caused them to relinquish bill paying to a family member or friend.
Poggel et al., 2010	Patients feeling embarrassed about reading problems, hide them. Avoid reading text out loud in front of others	26.3% say vision loss effects reading. 57.9% indicate vision loss on blind side. 31.6% have problems fining the beginning of the line. 36.8% loose line while reading. 36.8% experience reduced reading speed. Reading also spontaneously measured as a general problem.

Spontaneous Complaints

De Haan et al. (2016) report that individuals with HH often struggle to find the beginning of the next line while reading. Individuals with HH also complain about limited reading endurance.

Concerning activities of daily living (ADLs), Warren (2009) reported that individuals with HH complain about difficulties performing tasks that are heavily reliant on reading. These include reading labels, identifying items, and paying for items. Tasks involving reading as an auxiliary component such as preparing a meal using a pre-set recipe were also harder to perform for individuals with HH.

Participants also relayed how problems with reading can make it harder for them to perform in social situations. Poggel et al. (2010) report that individuals feel embarrassed about not being able to read in public and avoid doing so in the presence of others.

Interviews and Surveys

Warren (2009) asked participants questions regarding difficulties in performing everyday tasks due to difficulties in reading. Participants reported that tasks involving reading and processing numbers such as paying bills and dialing phone numbers had become increasingly difficult to complete, some even relegated these tasks to caregivers. Warren (2009) further reports that while sentence structures may help readers with HH identify misread words/letters; no such context-correction exists while reading numbers.

Using a more structured surveyal process, Poggel et al. (2010) report that 26.3% percent of individuals with HH said vision loss affects their reading abilities. 31.6% said they have trouble finding the beginning of a line, 36.8% cannot fixate on the line continuously while reading, and 36.8% report greatly reduced reading speeds.

Finally, in the survey conducted by de Haan et al. (2015), 54% of participants reported at least one item related to reading as being problematic. Participants also stated that they require more light while reading.

Summary for Subjective Measures

Individuals with HH spontaneously reported problems with finding the beginning of lines and completing tasks where reading is a key component. Inability to perform these tasks can also lead to embarrassment and avoidance behaviors.

Tailored interviews and surveys have revealed that the inability to perform tasks involving reading can force individuals to relinquish certain tasks, particularly those involving numbers. The majority of individuals with HH struggle with at least one reading-related task, and at least a third report multiple reading problems, such as the inability to fixate on the correct line and reduced reading speed.

Relationships between Objective and Subjective measures

Only one study investigated statistical relationships between objective and subjective difficulties, by examining correlations between standardized measures of visual functioning, and reported reading problems. Gall et al. (2010a) examined the relationship between Radner Reading scores and scores on reading-related items on the NEI-VFQ. The following correlations were reported:

"How much difficulty do you have reading ordinary print newspapers?": .43**

"How much difficulty do you have reading street signs or the names of stores?": 0.37*

"Wearing glasses, how much difficulty do you have reading the small print in a telephone": .33*

"Because of your eyesight, how much difficulty do you have figuring out whether bills you receive are accurate?": .43**

**** = p<0.01, * = p<0.05**

Discussion

The aim of this review was to examine the existing literature on difficulties in HH and provide an overview of the difficulties faced while reading. The literature examined included seven quasi-experimental studies, five case-control studies, eight cross-sectional studies, and one randomized controlled trial. By collating data from exploratory analysis and pre-intervention testing, examining reported variables such as oculomotor changes and spontaneously reported issues, a holistic and nuanced picture of the reading difficulties experienced by individuals with HH can be formulated.

Objective Reading Difficulties

Individuals with HH seem to perform worse on all commonly reported measures of objective reading difficulties. Individuals with HH tend to have significantly slower reading speeds than individuals without VFDs (de Jong et al., 2016; Zihl, 1995; Schuett et al., 2008; Passamonti et al., 2009; Pflugshaupt et al., 2009), with individuals with right-HH having worse reading speeds than individuals with left-HH (Trauzettel-Klosinski & Brendler, 1998; Zihl, 1995; Schoepf and Zangmeister, 1993; Gall et al., 2010a; Hepworth et al., 2019; Kuester-Grueber et al., 2021; Zihl et al., 2021; Passamonti et al., 2009, Papageorgiou et al., 2007). Interestingly, individuals with HH might not struggle significantly more than controls while performing abnormal reading tasks, such as reading texts rotated 180-degrees (De Jong et al., 2016). This could be due to different search and oculomotor strategies that are used when performing novel visual scanning tasks (Pelz & Canosa, 2001). Individuals with HH also tend to show a more pronounced word-length effect than those without VFDs, showing a steeper increase in reading times as words get longer. Individuals with HH also tended to make more errors while reading, most of which consisted of omissions of words and numbers.

To understand why individuals with HH have slower reading speeds while making more errors, we can look at explanatory variables such as oculomotor characteristics. Inefficient eye-movement strategies have been associated with slowed reading speed and reading errors in individuals with a variety of visual disorders (Griffin et al., 1974). Saccades are essential to any task that is heavily reliant on visual search and detection (McPeek et al., 2000). Reading is one such task (Bouma & De Voogd, 1974). Seven studies examined both reading performance and saccade patterns. Alongside slowed reading speed and reduced reading accuracy, these studies found that individuals with HH tend to make more saccades while reading than individuals without VFDs (Trauzettel-Klosinski & Brendler, 1998; Zihl, 1995; Schuett et al., 2008; Passamonti et al., 2009). This was true of both progressive (left-to-right) and regressive (right-to-left) saccades (Trauzettel-Klosinski & Brendler, 1998; Passamonti et al., 2009).

Saccades made by individuals with HH were also smaller than those made by individuals without VFDs. The increased frequency of shorter saccades could be interpreted as inefficient scanning of the text. This interpretation is consistent with findings reported by Zihl (1995), who observed that individuals with HH do not follow the typical "staircase" reading pattern used by individuals with normal vision while reading; these findings have been replicated in newer literature investigating contrast sensitivity during visual search tasks in individuals with HH, suggesting that alterations in scanning patterns may impact visual search in tasks beyond reading (Sahraie et al., 2008). Zihl (1995) also reported that individuals with left-HH tend to make shorter saccades when moving from right-to-left, whereas individuals with right-HH tend to make shorter saccades when moving from left-to-right. Though atypicality is not directly associated with lower reading performance, it seems that individuals with HH use a particularly ineffective series of saccades during reading.

Further evidence of ineffective oculomotor strategies can be found when comparing fixation patterns during reading. Individuals with HH tend to make longer fixations than individuals without VFDs, suggesting that it may take them longer to process textual and numeric information that appears in their visual field. Individuals with right-HH tend to fixate for longer than those with left-HH, suggesting that the lateralization of field loss can impact the reading strategies. Zihl (1995) reported that fixation duration increased with saccadic amplitude in individuals with HH. This suggests an additive effect, where the increase in fixation duration is amplified if fixation is preceded by longer saccades. Individuals with HH tend to make more fixations than individuals without VFDs. This is in line with the findings discussed above, as the number of saccades and number of fixations tends to be positively correlated in individuals with visual field loss (Zihl, 1995). Individuals with HH also make more re-fixations while reading, with individuals with right-HH making more re-fixations than those with left-HH.

Findings reported by Bormann et al. (2014) are of particular interest here, as they observe that individuals with HH tend to make more fixations than healthy controls with sVFDs. These findings may indicate that individuals with HH slowly adapt and learn inefficient reading strategies, such as increased fixation frequency, over time. However, this assumes that sVFDs in healthy controls accurately replicate the impairment experienced by individuals with HH. Other studies contradict these findings by showing that adaptations in healthy controls can occur rapidly during sVFD trials (Simpson et al., 2009). More research comparing samples of individuals with VFDs and healthy controls with sVFDs could help us understand how different reading strategies develop over time.

Multiple oculomotor variables could help explain the impact of VFDs on reading performance, and comparative analyses examining relationships between them are of particular interest. Zihl (1995) reported that fixation duration increased with saccadic amplitude in individuals with HH. This suggests that individuals with HH need to fixate longer on words that require them to make longer saccades, providing further evidence for a more pronounced word-length effect in individuals with HH. Despite promising preliminary findings such as those reported by Zihl (1995), there is a dearth of research that directly investigates the possible relationships that exist between these variables, and how these relationships are different between individuals with and without VFDs.

Additionally, less commonly reported objective reading difficulties can provide novel insight into reading strategies in individuals with HH. McDonald et al. (2006) reported that the initial landing position is closer to the start of the word in individuals with HH when compared to healthy controls who tend to fixate near the center of the word. This shift in initial landing position is amplified by an increase in word-length, which could also help explain the more pronounced word-length effect seen in individuals suffering from HH. Trauzettel-Klosinski & Brendler, (1998), report a reduced character span during saccades in individuals with HH, stating that their saccades cover fewer characters than those made by individuals without VFDs. This reduction in characters covered is in line with the increased number of saccades reported in the literature and is another possible explanation for increased reading times in individuals with HH. A lower character span in individuals with right-HH when compared to their left-HH counterparts was reported.

Furthermore, deficits reported may not accurately portray deficits experienced in real life. Keuster-Gruber et al. (2021) report that individuals with HH had a significantly lower reading speed at home when compared to standardized experimental environments. These findings suggest that the deficits experienced by individuals with HH could be more severe in real-world settings, which implies that findings reported in the existing literature may not accurately reflect this degree of impairment. Additionally, studies also tend to immobilize the head by asking participants to place their chin in a standardized groove, or by placing the entire head into a mount. Though this eliminates the effect of horizontal pivoting using the neck and allows us to isolate the impact of visual field loss, it does not represent how individuals read during Activities of Daily Living (ADLs).

To address these concerns, research must investigate changes in reading performance in multiple settings using different levels of head immobilization. Though this may require more resources and time, it will paint a more accurate picture of the degree of impairment experienced and the oculomotor and physiological strategies used to adapt to the visual field loss. Studying other factors such as the degree of visual field loss may also help shed light on how pathological factors impact reading ability. Research comparing individuals with HH with individuals with Quadrantanopia (QA), has shown that individuals with QA read significantly faster (Baylock et al., 2016). This suggests that the degree of visual field loss may govern the degree of deficit in reading performance. Non-text characters must also be included in tests of reading ability, as the differences in performance may be more severe than text-based tasks (Warren, 2009). Using rotated text and vertical text paradigms may also help detail how individuals use alternative reading strategies in tasks that require non-standard (not left-to-right text reading) reading skills (Hepworth et al., 2019). Given that the samples in all the studies included in the review use populations that read Latin/Germanic languages, which are written and read from right-to-left, it is not possible to ascertain if observed differences between individuals with left and right-HH would be reversed or different in any way if the reading direction was different (El Alaoui-Faris et al., 1994). Research into reading strategies in individuals with visual field loss in cultures that read from left-to-right or top-down could shed light on the relationship between reading direction and the side of visual field loss.

Subjective Reading Difficulties

While objective reading difficulties allow us to use standardized measures to quantify and explain performance deficits in reading, investigating subjective reading difficulties allows us to capture narrative data detailing how performance deficits translate to impairments in reading abilities. Results from standardized visual impact questionnaires have revealed that individuals report difficulty when trying to read the text in professional and personal settings. These include tasks such as reading newspaper articles, reading street signs, and reading medicine labels and instructions.

In addition to standardized tests, individuals also tend to spontaneously report complaints regarding factors that may not be covered by clinical interviews and test questions. Spontaneous complaints and unstructured interviews are an incredible resource, as they allow for dynamism in the investigative process, which can lead to the documentation of concerns that were not within the purview of the research (Hinchcliff et al., 2012). Indeed, narrative documentation and synthesis may be crucial components of investigating subjective difficulties. Individuals with HH have reported trouble finding the beginning of the line and trouble fixating on the correct line while reading text, which is consistent with observations that reported increased fixations in individuals with HH when compared to individuals without visual field loss. Investigations into subjective reading difficulties have revealed issues faced by individuals with HH such as difficulty reading numbers and requiring more light when reading, which are not commonly reported in the literature and hence are not investigated in a standardized manner.

Gall et al. (2010) conducted an additional investigation into the relationship between objective and subjective measures of reading difficulties, by comparing reading-related item scores on NEI-VFQ to scores on the Radner-reading charts. Moderate correlations were found between items involving ADLs and reading speed scores, suggesting a direct relationship between objective and subjective reading difficulties.

In general, there is a dearth of literature investigating and hence reporting on subjective aspects of reading difficulties. As reported above, only six out of twenty-one studies included in this investigation reported on subjective difficulties in reading that are experienced by individuals with HH. Of these six, only 3 reported scores from standardized questionnaires that contain items that directly measure the impact of reading ability on ADLs. Of those that did report standardized measures, none reported item scores. Additionally, there is little literature reporting on the possible relationships between certain subjective and objective reading difficulties, making it hard to theorize how certain etiologies may translate into disability in daily life. More literature comparing degrees of visual field loss (HH vs. QA for example) is needed to understand how subjective difficulties may differ depending on the severity of VFD.

The implications of these observations on reporting subjective difficulties are threefold. First, there is not nearly enough literature reporting on the subjective difficulties experienced by individuals with HH. Second, the studies that do report subjective difficulties do not follow a standard protocol for investigating or reporting these measures, making it difficult to compare and validate findings across different sources. Finally, the lack of standardization leads some researchers to develop their own measures, such as the interviews (Warren, 2009) and surveys (Poggel et al., 2010). Though these nonstandard measures allow for researchers to ask follow-up questions and incorporate spontaneous complaints, the lack of a basic framework makes it difficult to collate and quantify findings.

Subjective reading difficulties must form a standard component of investigations into reading difficulties caused by visual field loss. Standardized measures focusing on reading difficulties experienced must be developed and used with different samples, so we can contrast how different etiologies may translate to different impairments in ADLs. For existing standardized measures such as the NEI-VFQ and the IVI profile, item scores must be reported for reading-related items, as reporting composite scores do not allow us to isolate the impact on reading. A standard measure for narrative investigations such as an interview should also be developed, consisting of an adaptable question set and an established framework for thematic analysis, which would allow for results to be quantified and reported in a standardized manner. The availability of such tools would make it easier for researchers to investigate subjective difficulties and compare findings across existing literature.

Impact on Activities of Daily Living

Detailing reading difficulties helps us measure and quantify the differences in reading performance that may arise due to VFDs. However, it is important to note that objective differences may not present an accurate picture of the impairment experienced by an individual. Performance on these tests may be impacted by comorbidities and differences in acquired abilities (Merten et al., 2007). A lawyer used to reading several hundred words per minute may appear unimpaired on objective measures of reading performance, but may be unable to return to work due to inability to function at an above-average level. Similarly, tests may reveal that a painter experiences an objective deficit in reading performance, but this individual may not report a significant reduction in daily functioning if reading is not essential to their job performance or their lifestyle. Therefore, it is important to study deficits in the context of where they occur and what activities they impact.

De Haan et al. (2016) report that individuals with HH complain about limited endurance while reading text. This can make tasks that require prolonged reading such as catching up with the news or reading contracts difficult, severely reducing independence and hence the individual's quality of life (Balazs et al., 2016). Problems associated with limited endurance form only the tip of the iceberg when it comes to reading-related impairments in activities of daily living. Warren (2009) has reported that some individuals experience such significant difficulty reading numbers that they have had to relinquish tasks such as dialing phone numbers, managing receipts, and paying bills to caregivers or peers, thus further reducing their ability to independently complete essential tasks. These could include tasks such as using the correct email address or interpreting a series of commonly used abbreviations and symbols. However, disparities in reading numbers and non-text characters are not frequently reported in the literature, making it difficult to draw conclusions regarding the degree of difficulty experienced by individuals with HH.

Being unable to read even large print text has the potential to impair mobility and healthcare routines. Reading signs and other large text is a key component of mobility during tasks such as biking and driving (Tejero et al., 2019). Hence, reduced ability to quickly read passing text could significantly reduce an individual's ability to independently get from A to B. Being unable to read medium size text such as labels and medical descriptions could create a need for additional assistance, as individuals with HH may be unable to care for themselves and stick to pharmaceutical routines. Other reported problems include difficulties performing self-care tasks such as preparing meals using recipes, buying groceries, and identifying items on shelves. Increased dependence and inability to complete reading-related tasks may also have an adverse effect on the social lives of individuals with HH.

Poggel et al. (2010) report that individuals may feel embarrassed about engaging in tasks reliant on reading in front of peers or other social situations. Embarrassment due to the inability to complete a task can lead to social isolation and reduced social functioning. This pattern is also noticeable in other populations with acquired brain injury (Singleton et al., 2017; Wolfenden & Grace, 2009). The degree of reading disability can determine the reduction in social functioning. Gall et al. (2010a) confirm these implications by reporting that individuals with right-HH, who tend to experience a greater reduction in reading performance, tend to have lower scores on NEI-VFQ subscales of general health and social functioning. It is important to keep in mind that the implications discussed above are based on a small sample of studies, making it harder to validate the findings and assess their reliability.

Implications

Ascertaining the difficulties experienced by individuals that suffer a deficit is the first step in formulating effective interventions. The next step is to determine why those deficits occur, and what factors must be changed or controlled in order to manage and reduce their impact on the individual's functioning. Given the wide range of difficulties in reading experienced by individuals with HH and the various etiologies that may lead to them, there are many ways to translate the findings presented above into actionable points for documenting the impairments, guiding research, and governing treatment.

A decrease in reading performance can be an expression of symptoms that arise from visual field loss. The research on oculomotor disparities presented above showcases how disparities in reading performance can arise, possibly due to adaptations in eye movement strategies. Research has shown that visual field loss can cause individuals to develop ineffective visual search strategies with a much broader impact on vision (Gall et al., 2009). To this end, it may be more beneficial to view the decrease in reading performance as an expression of inefficient visual search strategies that develop over time in individuals with visual field loss.

Insights from investigating subjective reading difficulties have shown us that individuals can experience a wide range of non-standard difficulties in performing activities of daily living due to an inability to complete tasks that have a significant reading component. These subjective complaints must be incorporated into the conceptualization of the reading deficit, as they allow us to understand how a deficit translates into a disability over time.

Treatment

The aim of any study investigating deficits or disorders is to aid the development and implementation of effective interventions. Naturally, findings with varied results and wide broad conclusions will have varied and broad implications for treatment. Based on the literature included in this investigation, it would not be wise to suggest a specific treatment course for reading deficits in HH. The conclusions drawn in this review are primarily descriptive, and an in-depth explanatory analysis is warranted when making recommendations for treatment based on etiological and population factors. However, certain general recommendations regarding treatment methods, disease factors, and outcome measures can be made.

That healthy controls with sVFDs can perform better than those with chronic HH suggests that inefficient eye movements used in HH can be learned over time (Schuett et al, 2009). Eight of twenty-one studies included in this review report oculomotor irregularities that co-occur with deficits in reading performance. It is therefore not unreasonable to purport that the decrease in reading performance is caused by the irregularities in eye movement. This highlights the need for early detection of visual field loss, and subsequent intervention using compensatory oculomotor training paradigms.

Individuals with right-HH experience more significant impairments in reading than individuals with left-HH. Upon detection of a stable VFD, right-HH individuals may require a more intense treatment regimen for reading disability. No information regarding the degree of visual field loss or brain regions impacted was extracted, therefore recommendations regarding transcranial direct cortical stimulation and restitution therapy cannot be made.

With regards to subjective difficulties, it could be argued that HH has the potential to severely impact domains that have little to do with reading, by reducing an individual's independence. Increased dependence can lead to reduced self-esteem (Chang & Mackenzie, 1998) and increase the risk for mood disorders (Serretti, 1999). Additionally, increased dependence can also increase the burden felt by caregivers, which can strain relationships and worsen psychosocial outcomes. Reported subjective difficulties such as inability to pay bills, mobility issues, and avoidance of reading in social situations must be addressed using specific skill-based intervention strategies, to reduce the risk of increased dependence. Mood assessment using standardized measures such as the Beck Depression Inventory (Beck et al, 1987) and Caregiver Burden Inventory must be administered (Marvardi et al., 2006), so that psychotherapeutic and family-based intervention can be provided where necessary.

Critical Appraisal

All studies included in the review passed the quality assessment process using tools developed by the Joanna Briggs Institute. These quality assessment tools were developed much later than most of the literature included in this review. This could be a possible explanation for why thirteen out of twenty-one studies do not clearly report on at least one criterion of the quality assessment process. Though this does not necessarily invalidate their findings or make them ineligible for inclusion, it is a factor that future researchers must keep in mind when reporting their methods, to make reviewing and critiquing easier.

Limitations

The existing review suffers from a small sample size due to the exclusion criteria that were defined in the methodology and a general dearth of literature on this topic. This problem is compounded in the case of subjective difficulties, as only a handful (six) of investigations report findings concerning them. Since comorbid conditions and HH due to non-CVA causes were excluded, many investigations providing broader insight into the reading difficulties experienced by individuals with HH were not considered. Though this allows for conclusive reviewing of difficulties in a specific population caused by a specific pathology, it does have the effect of excluding commonly occurring comorbidities such as macular degeneration, which occur in 50% of HH cases (Mostafa, 2016). Visual impairments in stroke individuals exist beyond the realm of visual field loss, and a broader, more comprehensive review may be able to marry disparate findings and provide a more holistic picture.

Upon filtering using the exclusion criteria, only studies including participants that read from left-to-right were included in this review. This restricted sample does not detail how participants with other natural reading directions such as right-to-left in Arabic or top-down in Japanese experience reading deficits due to visual field loss (Shibuki et al., 2021). Studies that reported objective reading difficulties used different measures of eye-tracking and reading performance, which may have impacted the data collected and hence the disparities detected. Different methods can have different sensitivities, which impact the degree of deficits detected. Furthermore, many studies did not specify whether comorbid conditions such as hemi-spatial neglect and other forms of visual impairment were controlled for, making it harder to isolate the impact of visual field loss on reading ability. Many studies did not make raw data such as reading speeds and test-item scores available, instead opting to report comparative statistics. This prevented a thorough review, as only pre-summarized data could be included from these investigations.

The review also only included studies that were published, included a documented measure of reading, and reported their findings in English. These criteria could introduce a selection bias. Information such as time since onset, recruitment procedure, and validity of reading tasks was not analyzed in this review. These are all possible explanatory variables that may impact the nature and degree of impairment reported.

Conclusion

Reading is an essential skill that is severely impacted by the onset of homonymous hemianopia. Individuals with HH read slower and make more mistakes. This can be likely explained by oculomotor factors such as increases in saccades, reduction in saccadic amplitude, increase in fixation duration, increase in fixation frequency, and shifted landing position. Deficits in reading performance are worse in individuals with right-HH when compared to left-HH. These deficits translate to significant disability through hampering the afflicted individual's ability to complete reading-related tasks, which can lead to reduced independence and increased stigmatization.

To provide the best possible care to individuals with reading impairments due to HH, we must go beyond just measures of performance. Objective measures help explain the physical causes of deficits but do not accurately represent the impairment experienced by sufferers in everyday life. Subjective difficulties have been neglected in the literature, but have the potential of highlighting how difficulties translate to disabilities.

Conducting holistic assessments that combine measures of speed, accuracy, eye movement, and subjective problems, so that we have a more complete picture of the impairment faced. This will require the development of standardized protocols in research and assessment, that will allow us to compare and collate data to identify patterns of impairments and moderating factors that can lead to them. The answer hasn't been spelled out for us, so we must keep reading between the lines.

References

Balazs, J., Miklosi, M., Toro, K. T., & Nagy-Varga, D. (2016). Reading disability and quality of life based on both self-and parent-reports: importance of gender differences. Frontiers in Psychology, 7, 1942.

Blaylock, S. E., Warren, M., Yuen, H. K., & DeCarlo, D. K. (2016). Validation of a Reading Assessment for Persons With Homonymous Hemianopia or Quadrantanopia. *Archives of Physical Medicine and Rehabilitation*, *97*(9), 1515-1519.

Beck, A. T., Steer, R. A., & Brown, G. K. (1987). Beck depression inventory. New York:: Harcourt Brace Jovanovich.

Boland, T. (1993). The importance of being literate: Reading development in primary school and its consequences for the school career in secondary education. European Journal of Psychology of Education, 8(3), 289-305.

Bormann, T., Wolfer, S. A., Hachmann, W., Lagreze, W. A., & Konieczny, L. (2014). An eye movement study on the role of the visual field defect in pure alexia. Plos one, 9(7), e100898.

Bouma, H., & De Voogd, A. H. (1974). On the control of eye saccades in reading. Vision Research, 14(4), 273-284.

Bowers, A. R., Dickinson, C., & Peli, E. (2017). Comments about outcome measures for clinical trials of interventions for post-stroke patients with hemianopia. Acta Neurologica Scandinavica, 136(5), 548.

Brocke, J. V., Simons, A., Niehaves, B., Niehaves, B., Reimer, K., Plattfaut, R., & Cleven, A. (2009). Reconstructing the giant: On the importance of rigour in documenting the literature search process.

Chang, A. M., & Mackenzie, A. E. (1998). State self-esteem following stroke. Stroke, 29(11), 2325-2328.

Clay, M. M. (1969). Reading errors and self-correction behaviour. British Journal of Educational Psychology, 39(1), 47-56.

Code, C., & Herrmann, M. (2003). The relevance of emotional and psychosocial factors in aphasia to rehabilitation. Neuropsychological rehabilitation, 13(1-2), 109-132.

de Haan, G. A., Heutink, J., Melis-Dankers, B. J., Brouwer, W. H., & Tucha, O. (2015). Difficulties in daily life reported by patients with homonymous visual field defects. Journal of Neuro-Ophthalmology, 35(3), 259-264.

de Haan, G. A., Melis-Dankers, B. J., Brouwer, W. H., Tucha, O., & Heutink, J. (2016). The effects of compensatory scanning training on mobility in patients with homonymous visual field defects: further support, predictive variables and follow-up. PLoS One, 11(12), e0166310.

de Jong, D., Kaufmann-Ezra, S., Meichtry, J. R., von Arx, S., Cazzoli, D., Gutbrod, K., & Müri, R. M. (2016). The influence of reading direction on hemianopic reading disorders. Journal of clinical and experimental neuropsychology, 38(10), 1077-1083.

El Alaoui-Faris, M., Benbelaid, F., Alaoui, C., Tahiri, L., Jiddane, M., Amarti, A., & Chkili, T. (1994). Alexia without agraphia in the Arabic language. Neurolinguistic and and MRI study. Revue neurologique, 150(11), 771-775.

Epelbaum, S., Pinel, P., Gaillard, R., Delmaire, C., Perrin, M., Dupont, S., ... & Cohen, L. (2008). Pure alexia as a disconnection syndrome: new diffusion imaging evidence for an old concept. cortex, 44(8), 962-974.

Friedman, R. F., Ween, J. E., & Albert, M. L. (1993). Alexia.

Gall, C., Franke, G. H., & Sabel, B. A. (2010). Vision-related quality of life in first stroke patients with homonymous visual field defects. Health and Quality of Life Outcomes, 8(1), 1-14.

Gall, C., Lucklum, J., Sabel, B. A., & Franke, G. H. (2009). Vision-and health-related quality of life in patients with visual field loss after postchiasmatic lesions. Investigative ophthalmology & visual science, 50(6), 2765-2776.

Gall, C., Wagenbreth, C., Sgorzaly, S., Franke, G. H., & Sabel, B. A. (2010). Parafoveal vision impairments and their influence on reading performance and self-evaluated reading abilities. Graefe's Archive for Clinical and Experimental Ophthalmology, 248(6), 863-875.

Gallagher, D., Ni Mhaolain, A., Crosby, L., Ryan, D., Lacey, L., Coen, R. F., ... & Lawlor, B. A. (2011). Dependence and caregiver burden in Alzheimer’s disease and mild cognitive impairment. American Journal of Alzheimer's Disease & Other Dementias®, 26(2), 110-114.

Giorgi, R. G., Woods, R. L., & Peli, E. (2009). Clinical and laboratory evaluation of peripheral prism glasses for hemianopia. Optometry and vision science: official publication of the American Academy of Optometry, 86(5), 492.

Goodwin, D. (2014). Homonymous hemianopia: challenges and solutions. Clinical Ophthalmology (Auckland, NZ), 8, 1919.

Griffin, D. C., Walton, H. N., & Ives, V. (1974). Saccades as related to reading disorders. Journal of Learning Disabilities, 7(5), 310-316.

Grunda, T., Marsalek, P., & Sykorova, P. (2013). Homonymous hemianopia and related visual defects: Restoration of vision after a stroke. Acta neurobiologiae experimentalis, 73(2), 237-249.

Hassell, J. B., Weih, L. M., & PhD, J. K. (2000). A measure of handicap for low vision rehabilitation: the impact of vision impairment profile.

Hepworth, L., Rowe, F., & Waterman, H. (2019). VeRSE: vertical Reading strategy efficacy for homonymous hemianopia after stroke: a feasibility study. The British and Irish orthoptic journal, 15(1), 28.

Hinchcliff, R., Greenfield, D., Moldovan, M., Westbrook, J. I., Pawsey, M., Mumford, V., & Braithwaite, J. (2012). Narrative synthesis of health service accreditation literature. BMJ quality & safety, 21(12), 979-991.

Keller, I., & Lefin-Rank, G. (2010). Improvement of visual search after audiovisual exploration training in hemianopic patients. Neurorehabilitation and Neural Repair, 24(7), 666-673.

Kellermeyer, L., Harnke, B., & Knight, S. (2018). Covidence and rayyan. Journal of the Medical Library Association: JMLA, 106(4), 580.

Kim, E. S., Rising, K., Rapcsak, S. Z., & Beeson, P. M. (2015). Treatment for alexia with agraphia following left ventral occipito-temporal damage: Strengthening orthographic representations common to reading and spelling. Journal of Speech, Language, and Hearing Research, 58(5), 1521-1537.

Kiran, S. (2006). Pure Alexia: Causes, Characteristics, and Treatment. Perspectives on Neurophysiology and Neurogenic Speech and Language Disorders, 16(1), 16-21.

Kuester-Gruber, S., Kabisch, P., Cordey, A., Karnath, H. O., & Trauzettel-Klosinski, S. (2021). Training of vertical versus horizontal reading in patients with hemianopia–a randomized and controlled study. Graefe's Archive for Clinical and Experimental Ophthalmology, 259(3), 745-757.

Liu, K. P., Hanly, J., Fahey, P., Fong, S. S., & Bye, R. (2019). A systematic review and meta-analysis of rehabilitative interventions for unilateral spatial neglect and hemianopia poststroke from 2006 through 2016. Archives of physical medicine and rehabilitation, 100(5), 956-979.

Marvardi, M., Mattioli, P., Spazzafumo, L., Mastriforti, R., Rinaldi, P., Polidori, M. C., ... & Mecocci, P. (2005). The Caregiver Burden Inventory in evaluating the burden of caregivers of elderly demented patients: results from a multicenter study. Aging clinical and experimental research, 17(1), 46-53.

McDonald, S. A., Spitsyna, G., Shillcock, R. C., Wise, R. J., & Leff, A. P. (2006). Patients with hemianopic alexia adopt an inefficient eye movement strategy when reading text. Brain, 129(1), 158-167.

McPeek, R. M., Skavenski, A. A., & Nakayama, K. (2000). Concurrent processing of saccades in visual search. Vision research, 40(18), 2499-2516.

Meienberg, O., Harrer, M., & Wehren, C. (1986). Oculographic diagnosis of hemineglect in patients with homonymous hemianopia. Journal of neurology, 233(2), 97-101.

Merten, T., Bossink, L., & Schmand, B. (2007). On the limits of effort testing: Symptom validity tests and severity of neurocognitive symptoms in nonlitigant patients. Journal of Clinical and Experimental Neuropsychology, 29(3), 308-318.

Monteiro, M. L., Hokazono, K., Fernandes, D. B., Costa-Cunha, L. V., Sousa, R. M., Raza, A. S., ... & Hood, D. C. (2014). Evaluation of inner retinal layers in eyes with temporal hemianopic visual loss from chiasmal compression using optical coherence tomography. Investigative ophthalmology & visual science, 55(5), 3328-3336.

Mostafa, J., Wickum, S., Frishman, L. J., & Porter, J. (2016). Examining retinal structure and function in brain injury patients with homonymous hemianopia. Investigative Ophthalmology & Visual Science, 57(12), 5989-5989.

National Eye Institute. (2000, January). Visual Function Questionnaire 25. Retrieved February, 12, 2021 https://www.nei.nih.gov/learn-about-eye-health/resources-for-health-educators/outreach-materials/visual-function-questionnaire-25

National Institutes of Health (2013). "Age-related Macular Degeneration", National Eye Institute. 22 October 2013. Archived from the original on 2013-10-22. Retrieved 5 November 2018.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International Journal of Surgery, 88, 105906.

Papageorgiou, E., Hardiess, G., Schaeffel, F., Wiethoelter, H., Karnath, H. O., Mallot, H., ... & Schiefer, U. (2007). Assessment of vision-related quality of life in patients with homonymous visual field defects. Graefe's Archive for Clinical and Experimental Ophthalmology, 245(12), 1749-1758.

Passamonti, C., Bertini, C., & Làdavas, E. (2009). Audio-visual stimulation improves oculomotor patterns in patients with hemianopia. Neuropsychologia, 47(2), 546-555.

Pelak, V. S., Dubin, M., & Whitney, E. (2007). Homonymous hemianopia: a critical analysis of optical devices, compensatory training, and NovaVision. Current Treatment Options in Neurology, 9(1), 41-47.

Pelz, J. B., & Canosa, R. (2001). Oculomotor behavior and perceptual strategies in complex tasks. Vision research, 41(25-26), 3587-3596.

Petretto, D. R., & Masala, C. (2017). Dyslexia and specific learning disorders: new international diagnostic criteria.

Pflugshaupt, T., Gutbrod, K., Wurtz, P., von Wartburg, R., Nyffeler, T., de Haan, B., ... & Mueri, R. M. (2009). About the role of visual field defects in pure alexia. Brain, 132(7), 1907-1917.

Poggel, D. A., Mueller, I., Kasten, E., Bunzenthal, U., & Sabel, B. A. (2010). Subjective and objective outcome measures of computer-based vision restoration training. NeuroRehabilitation, 27(2), 173-187.

Radner, W., Willinger, U., Obermayer, W., Mudrich, C., Velikay-Parel, M., & Eisenwort, B. (1998). A new German Reading Chart for the simultaneous evaluation of reading acuity and reading speed. KLINISCHE MONATSBLATTER FUR AUGENHEILKUNDE, 213, 174-181.

Roth, T., Sokolov, A. N., Messias, A., Roth, P., Weller, M., & Trauzettel-Klosinski, S. (2009). Comparing explorative saccade and flicker training in hemianopia: a randomized controlled study. Neurology, 72(4), 324-331.

Rowe, F. J., Wright, D., Brand, D., Jackson, C., Harrison, S., Maan, T., ... & Freeman, C. (2013). A prospective profile of visual field loss following stroke: prevalence, type, rehabilitation, and outcome. BioMed research international, 2013.

Sahraie, A., Trevethan, C. T., & MacLeod, M. J. (2008). Temporal properties of spatial channel of processing in hemianopia. Neuropsychologia, 46(3), 879-885.

Schoepf, D., & Zangemeister, W. H. (1993). Correlation of ocular motor reading strategies to the status of adaptation in patients with hemianopic visual field defects. Annals of the New York Academy of Sciences, 682(1), 404-408.

Schuett, S. (2009). The rehabilitation of hemianopic dyslexia. Nature Reviews Neurology, 5(8), 427-437.

Schuett, S., Heywood, C. A., Kentridge, R. W., & Zihl, J. (2008). The significance of visual information processing in reading: Insights from hemianopic dyslexia. Neuropsychologia, 46(10), 2445-2462.

Serretti, A., Cavallini, M. C., Macciardi, F., Namia, C., Franchini, L., Souery, D., ... & Mendlewicz, J. (1999). Social adjustment and self-esteem in remitted patients with mood disorders. European Psychiatry, 14(3), 137-142.

Sharif, M. O., Janjua-Sharif, F. N., Ali, H., & Ahmed, F. (2013). Systematic reviews explained: AMSTAR-how to tell the good from the bad and the ugly. *Oral Health Dent Manag*, *12*(1), 9-16.

Sheldon, C. A., Abegg, M., Sekunova, A., & Barton, J. J. (2012). The word-length effect in acquired alexia, and real and virtual hemianopia. Neuropsychologia, 50(5), 841-851.

Shibuki, K., Yokota, T., Hirasawa, A., Tamura, D., Hasegawa, S., & Nakajima, T. (2021). Visual Field Test With Gaze Check Tasks: Application in a Homonymous Hemianopic Patient Unaware of the Visual Defects. Frontiers in Neurology, 12.

Simpson, S. A., Abegg, M., & Barton, J. J. (2011). Rapid adaptation of visual search in simulated hemianopia. Cerebral cortex, 21(7), 1593-1601.

Singleton, D., Mukadam, N., Livingston, G., & Sommerlad, A. (2017). How people with dementia and carers understand and react to social functioning changes in mild dementia: a UK-based qualitative study. BMJ open, 7(7), e016740.

Smythies, J. (1996). A Note on the Concept of the Visual Field in Neurology, Psychology, and Visual Neuroscience. Perception, 25(3), 369–371. https://doi.org/10.1068/p250369

Tejero, P., Insa, B., & Roca, J. (2019). Reading traffic signs while driving: Are linguistic word properties relevant in a complex, dynamic environment?. Journal of Applied Research in Memory and Cognition, 8(2), 202-213.

Trauzettel-Klosinski, S., & Brendler, K. (1998). Eye movements in reading with hemianopic field defects: the significance of clinical parameters. Graefe's archive for clinical and experimental ophthalmology, 236(2), 91-102.

Trauzettel-Klosinski, S., & Reinhard, J. (1998). The vertical field border in hemianopia and its significance for fixation and reading. Investigative Ophthalmology and Visual Science, 39, 2177-2185.

Vincenzi, H. (1987). Depression and reading ability in sixth-grade children. Journal of School Psychology, 25(2), 155-160.

Warren, M. (2009). Pilot study on activities of daily living limitations in adults with hemianopsia. The American Journal of Occupational Therapy, 63(5), 626-633.

Wolfenden, B., & Grace, M. (2009). Returning to work after stroke: a review. International Journal of rehabilitation research, 32(2), 93-97.

Young, M. S., & Stanton, N. A. (2002). Attention and automation: new perspectives on mental underload and performance. Theoretical issues in ergonomics science, 3(2), 178-194.

Zhang, X., Kedar, S., Lynn, M. J., Newman, N. J., & Biousse, V. (2006). Natural history of homonymous hemianopia. Neurology, 66(6), 901-905.

Zihl, J. (1995). Eye movement patterns in hemianopic dyslexia. Brain, 118(4), 891-912.

Zihl, J., Kentridge, R. W., Pargent, F., & Heywood, C. A. (2021). Aging and the rehabilitation of homonymous hemianopia: The efficacy of compensatory eye-movement training techniques and a five-year follow up. Aging Brain, 1, 100012

Appendices

Appendix 1

Joanna Briggs Critical Appraisal Form for Cross-Sectional Studies

First Author, Year	Trauzettel-Klosinski & Reinhard, 1998	Schoepf & Zangemeister	Gall et al., 2010 a	Warren, 2009	Pflugshaupt et al., 2009	Papageorgiou et al., 2007	de Haan et al., 2015	Gall et al., 2010 b
Were the criteria for inclusion in the sample clearly defined?	1	1	1	1	1	1	1	1
Was the exposure measured in a valid and reliable way?	1	1	1	1	1	1	1	1
Were objective, standard criteria used for measurement of the condition?	1	1	1	1	1	1	1	1
Were confounding factors identified?	1	1	1	0	1	1	1	1
Were strategies to deal with confounding factors stated?	1	1	1	0	1	1	1	1
Were the outcomes measured in a valid and reliable way?	1	1	1	1	1	1	U	1
Was appropriate statistical analysis used?	0	0	0	0	1	1	U	U
Criteria Passed (n)	6	6	6	4	7	7	5	6
Criteria Included in Appraisal (n)	7	7	7	7	7	7	5	6
Percentage Score	78%	78%	78%	78%	78%	78%	56%	67%

Appendix 2

Joanna Briggs Critical Appraisal Form for RCTs

First Author, Year	Kuester-Gruber et al., 2021

Was true randomization used for assignment of participants to treatment groups?	1
Was allocation to treatment groups concealed?	U
Were treatment groups similar at the baseline?	1
Were participants blind to treatment assignment?	1
Were those delivering treatment blind to treatment assignment?	U
Were outcomes assessors blind to treatment assignment?	U
Were treatment groups treated identically other than the intervention of interest?	1
Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	1
Were participants analyzed in the groups to which they were randomized?	U
Were outcomes measured in the same way for treatment groups?	1
Were outcomes measured in a reliable way?	1
Was appropriate statistical analysis used?	1
Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	1
Percentage Score	69%

Appendix 3

Joanna Briggs Critical Appraisal Form for Quasi-Experimental Studies

First author, Year	**Schuett et al., 2008**	**Hepworth et al., 2019**	**de Haan et al., 2016**	**Zihl et al., 2021**	**Passamonti et al., 2009**	**Keller & Lefin-Rank, 2010**	**Poggel et al., 2010**
Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?	1	1	1	1	1	1	1
Were the participants included in any comparisons similar?	1	0	1	1	1	1	1
Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	U	U	U	U	U	U	U
Was there a control group?	1	0	1	U	1	1	1
Were there multiple measurements of the outcome both pre and post the intervention/exposure?	1	0	1	1	1	1	0
Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	U	U	1	1	1	1	0

Were the outcomes of participants included in any comparisons measured in the same way?	1	1	1	0	1	1	1
Were outcomes measured in a reliable way?	1	1	1	1	1	1	1
Was appropriate statistical analysis used?	1	0	1	1	1	1	1
Criteria Passed (n)	7	3	8	6	8	8	6
Criteria Included in Appraisal (n)	7	7	8	7	8	8	8
Percentage Scores	100%	43/%	100%	86%	100%	100%	75%

Appendix 4

Joanna Briggs Critical Appraisal Form for Case-Control Studies

First Author, Year	**Trauzettel -Klosinski & Brendler, 1998**	**de Jong et al., 2016**	**Zihl, 1995**	**McDonald et al., 2006**	**Bormann et al., 2014**
Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	U	1	U	U	0
Were cases and controls matched appropriately?	U	1	U	U	1
Were the same criteria used for identification of cases and controls?	1	1	1	1	1
Was exposure measured in a standard, valid and reliable way?	1	1	1	1	1
Was exposure measured in the same way for cases and controls?	1	1	1	1	1
Were confounding factors identified?	1	1	1	1	1
Were strategies to deal with confounding factors stated?	1	1	1	1	1
Were outcomes assessed in a standard, valid and reliable way for cases and controls?	1	1	1	1	1
Was the exposure period of interest long enough to be meaningful?	NA	NA	NA	NA	NA
Was appropriate statistical analysis used?	0	1	1	1	1
Criteria Passed (n)	6	9	7	7	8
Criteria Included in Appraisal (n)	7	9	7	7	9
Percentage Scores	86%	100%	100%	100%	89%

Appendix 5

Reading tasks and Oculomotor tracking techniques used

First Author, Year	Reading Task	Reading Performance Measure	Oculomotor Tracking Details
Sheldon et al., 2012	4 tasks. German texts containing 129-132 words. Texts rotated by 90, 180 or 270 degrees. Words repeated, omitted or mispronounced counted.	Reading speed conceptualized as number of correct words per minute	-
Trauzettel-Klosinski & Brendler, 1998	The text, in German, was a short story with a simple vocabulary and it was easy to read. It was printed on eight separate transparent foils (3±7 lines each), which were viewed against a translucent background of about 320 cd/m2 . Reading distance was 25 cm. Contrast was 99% [Michaelson Contrast (LmaxLmin)/(Lmax+Lmin)100]. Script type was Times Roman; the height of the capital letters (e.g. at the beginning of nouns) was 3.1 mm (0.71), about 1.5 times higher than normal newspaper print. Average line length was 7 cm (15.7), average number of characters per line was 38.5 (7.2), and average number of words per line was 6.4, i.e. average number of characters per word was 6.02. Distance between lines: texts 1±6, 0.2 cm (0.46); texts 7±8, 0.7 cm (1.6). The texts were read with best corrected visual acuity and the age-related addition for presbyopia.	Reading speed was measured in characters per minute (char/min). For exact calculation of the amount of text in each line it was more convenient to determine char/line because of some especially long words in German and their not infrequent division at the line end. If necessary, the number of char/min can easily be converted into average words/min by dividing by 6.02	Eye movements were recorded with an infrared reflection system, the Ober2 system [for details see 21]. In this system, infrared diodes and sensors are placed in a pair of goggles and the angular size of each monocular field is 40 on the horizontal and a 30 on the vertical meridian. The spatial resolution was approximately 1, and, as we used a frequency of 100 Hz, the temporal resolution was 10 ms
Trauzettel-Klosinski & Reinhard, 1998	Paragraphs of six to nine lines were scanned onto the retina by the laser beam, and fixation behavior during reading was observed. . Paragraphs of printed text of six to nine lines were read silently	Reading speed in words per minute was determined	Eye movements were monitored by an infrared reflection system (Ober2; Permobil Meditech AB, Timre, Sweden
de Jong et al., 2016	Four German texts from the International Reading Speed Texts	Participants were instructed to read the text aoud as quickly as	-

	(IReST, Hahn et al., 2006; TrauzettelKlosinski, Dietz, & Group, 2012) were selected as stimuli. Each text consisted of 129 to 132 words. One text was presented in the standard reading direction, while the three other texts were rotated by 90°, 180°, and 270°, respectively.	possible. All readings were audio-recorded for offline analysis. Words that were repeated, omitted, or incorrectly read were counted. Reading time for each text was calculated. Reading speed was expressed as the number of correct words per minute (WPM)—that is, the total number of words minus the sum of repeated, omitted, and incorrectly read words. Furthermore, we calculated, for each participant and each rotation, the percentage of WPM in relation to the standard reading direction.	
Zihl, 1995	Horizontal + vertical number and word reading. Also horizontal text reading. text containing 180 words, 20 lines	Time taken to read text	Pupil-Corneal reflection method.
McDonald et al., 2006	10 short (50 words each) text passages extracted from newspaper journalism (see Appendix for example). Passages were displayed on a 22 in monitor, and each passage occupied at most nine lines of the display.	Single word reading speed (voice-activated keying), Text reading speeds	SR EyeLink 2 video based head mounted eye tracking system.
Schoepf and Zangemeister, 1993	NR	NR	NR
Gall et al., 2010	Radner Reading charts	Mean reading speed sentences 3-7, mean reading speed total. Max reading speed 3-7	-
Warren, 2009	Visual Skills for Reading Test (VSRT) developed by Watson, Baldasare, and Whittaker (1990). The VSRT evaluates reading accuracy and rate in people with central field involvement.	-	-
Bormann et al., 2014	Two lists were created of 110 words each. The words in the two lists were matched for CELEX word frequency], lexical orthographic neighbors, length, and concreteness.	Time between the word onset and beginning of the complete correct response was measured.	EyeLink 1000, tracking system with a head rest. It offers an accuracy of 0.25u to 0.5u of the visual field, and a temporal resolution of 1000 Hz. For DH, a head-mounted EyeLink II tracker was used. DH tended to squint his eyes

			during reading which affected the corneal reflection and led to track losses. Therefore, tracking was carried out based only on the position of the pupil. Accuracy was still around 0.5u of the visual field on average. The EyeLink II system has a temporal resolution of 500 Hz when tracking in pupil-only mode and corrects for the head position and rotation of the participant
Schuett et al., 2008	Text consisting of 200 words, double spaces, 14pt arial font, 20 lines. Short sentence. Read aloud, time and errors recorded. Performance	Correctly read words per minute.	Eye-movements were recorded using a video-based, infrared remote eye tracking system (iView X RED, SensoMotoric Instruments GmbH, Teltow, Germany). Viewing was binocular and the position of the dominant eye was sampled at 50 Hz, with a spatial resolution of 0.1°.
Hepworth et al., 2019	Radner Reading Chart	Mean reading speed sentences 3-7	-
Kuester-Gruber et al., 2021	International Reading Speed Texts, IReST (German Version), Reading speed at home measured using training computer used for interventions	Reading speed (RS) in words per minute (wpm) during reading standardized paragraphs of printed text aloud	-
de Haan et al., 2016	Radner reading chart and with a text of approximately 400 words (three standardized parallel versions).	Reading speed, minimal readable text size, and comprehension of the text	-
Zihl et al., 2021	Each of six versions of text consisted of 200 words (font: Arial, 14pt) arranged in 20 double-spaced, left-aligned lines printed on a white sheet of paper.	Patients asked to read text aloud as accurately and as quickly as possible.	-
Passamonti et al., 2009	short story (330 syllables). Four different stories were counterbalanced between subjects and testing sessions. The texts chosen were equivalent with	Subjects were asked to read aloud to obtain both accuracy and reading time.	Eye movements were recorded in a dimly lit room using a Pan/Tilt optic eye-tracker (Eye-Track ASL-6000) which registers real-

	respect to the graphical and lexical characteristics (font: Arial 40; 6–8 lines for each paragraph; 5–6 words per line; distance between lines: 1.5 cm) and were presented on a computer monitor (visual scene: 30° × 24°).		time gaze at 60 Hz. The recording was performed in a dimly lit room. The subject's dominant eye was illuminated by invisible infra-red light, and the reflections were recorded by a video-camera positioned 60 cm from the eye. During the tasks, the position of the subject's eye in the visual scene was monitored on-line by the experimenter.
Keller & Lefin-Rank, 2010	2 standardized reading tests were developed for the assessment of reading time. Each test consisted of 180 words arranged in 20 lines with regularly indented margins on the left side (Arial font, point size 12, double line spacing, printed on a 29.7 × 21 cm2 sheet of paper)	Patients were instructed to read the text aloud as accurately as possible without using their fingers. The time a patient needed to read the whole text was measured.	-
Pflugshaupt et al., 2009	Four articles taken from a local newspaper written in German were used as stimuli of the text reading task. They measured between 43 and 52 words in length, summing to 194 words overall. Each text was presented in seven left-justified lines. Before the presentation of each article, a ‘starting point’ was shown in the left upper screen corner to indicate the position of the first letter in the subsequently appearing text	Reading times were analyzed by calculating the mean increase in milliseconds per additional letter, which is the standard measure for the word-length effect	An infrared-based video tracking system (EyeLink™, SensoMotoric Instruments GmbH, Berlin, Germany) was used to measure eye movements at a sampling rate of 250 Hz and with a spatial resolution of 0.01°. Gaze-position accuracy relative to stimulus coordinates was 0.5–1.0°, depending on participants’ fixation accuracy during the calibration procedure. The latter was performed before each text presentation by means of a 9-point target grid.
Papageorgiou et al., 2007	The text was a short story with a simple vocabulary and was easy to read. It was printed on an A4 page in landscape format and was read with best corrected visual acuity and the age-related addition for presbyopia. Reading distance was 30 cm. The total number of letters was 1614, which was equivalent to 276 words.	Reading ability of patients was expressed as reading speed in letters/minute.	-

Thank You

I would like to take a few words and thank some of the people that helped me out when I was working on this thesis. I was not an easy year, and I could not have done it without them.

First and foremost, to my supervisor, Sarah Tol: Your patience and guidance have helped me learn and develop as a psychologist and researcher. Your words of kindness, your understanding nature and your unrelenting support have been a major driving force in the completion of this project. I could not have done this without you. Thank you, for choosing me, teaching me, and believing in me.

To my friends, Shail Bhatt, Parth Shukla, Kush Saluja, and Pooja Doctor: Thank you for reminding me of who I am and what I'm capable of. Your words of kindness got to me when I most needed them.

To my friends and fellow students Lea-Claire Tersou and Chiara Biserni: Thank you for helping me find my footing when I thought I couldn't do this anymore. You believed in my abilities even when I didn't.

To Mortiz de Wit and the rest of my housemates: Thank you for being there when I needed to disconnect and reprioritize. Being around you always helps me re-focus and see what's important in the long run.

To Fenne Eleah Bagust: Thank you for listening to me complain and for telling me it's going to be okay. I cannot stress how helpful that has been in helping me keep my head.

To Emma Pheulpin: Your calming presence helped me work consistently with resolve. Thank you for being there, and cheering me on through all of it.

To my sister, Tanya Gupta: Thank you for checking up on me at odd hours and reminding me that I need to sleep and take care of myself. You're still taking care of me, and I love you for it.

Finally, to my mother, Divya Gupta: I could never have done this without you. Your support and belief in me have brought me where I am, and I plan to spend the rest of my life working to deserve what you have given me. Thank you for everything.