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< Scanning mechanisms in people with homonymous hemianopia whilst reading from left to right: a systematic review>

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Abstract

Aim: Providing a systematic overview of the scanning mechanisms uniquely employed by people with left and right homonymous hemianopia, whilst reading from left to right.

Methods: A qualitative synthesis of the literature was undertaken by two independent researchers utilising PsycINFO, Web of Science, Medline, and reference lists of relevant articles. Articles using eye-tracking in adult homonymous hemianopia patients and control groups, whilst reading, were included. All articles underwent a risk of bias and quality assessment.

Results: This systematic review includes ten studies. Overall, people with RHH used more fixations of longer duration than those with normal vision. They also refixated more frequently and made more saccades in either direction. Additionally, the progressive saccades were smaller than those of the controls. This pattern was less pronounced in people with LHH, who only differed from controls regarding the increase of regressive saccades, refixations, and slightly increased reading time. In general, the reading pattern of people with RHH proved to be rather ineffective and more time consuming than that of controls.

Conclusion: Scanning mechanisms of people with RHH whilst reading were found to be ineffective, maladaptive, and differ significantly from people with normal vision. While people with LHH were significantly less impaired, they still employed ineffective reading strategies compared to people with normal vision. Due to the severe nature of the reading impairments, the inclusion of reading in the rehabilitation of people with HH is suggested to be important.

Keywords: hemianopia, reading, scanning strategies

Introduction

Homonymous hemianopia (HH) is a visual field impairment in one half of the visual field of both eyes and is one of the most common visual field disorders (Zihl, 2000). It occurs after damage to the postchiasmatic visual pathways (Schuett et al., 2008). Such damage is often caused by brain damage resulting from a stroke, traumatic brain injury, or tumour. Strokes account for 52-70% of HH impairments and are therefore the most common cause (Zhang et al., 2006). Spontaneous recovery of HH can occur after one month and has been reported for approximately half of the people with HH (Zhang et al., 2006; Ali et al., 2012; Pambakian & Kennard, 1997). It is, however, permanent in approximately 8-10% of the people with HH (Goodwin, 2014).

This sudden loss of vision can have a great impact on daily life and adjusting to HH can be very challenging (Ali et al., 2012). It influences the autonomous performance of various activities of daily living, such as reading, which is impaired in approximately 80% of people with HH (Zihl 2000; Schuett, et al., 2008). Hence difficulties with reading are one of the main complaints (Trauzettel-Klosinski & Reinhard, 1998), and improving reading skills is one of the most prominent rehabilitation goals amongst people with hemianopic visual field loss (Trauzettel-Klosinski & Brendler, 1998).

Difficulties with reading with HH are often connected to processes such as planning and perception (Schuett et al., 2008). The problem with HH is that people are not able to detect the next word or line in their peripheral vision. Due to this lack of perceived information, it is difficult to accurately plan the eye movement to the next word or line (Leff et al., 2000). Since these processes are impaired in people with HH, they often struggle with slowness of reading, visual omission, and guessing errors (Schuett et al., 2008). Additionally, it has been found that people with right HH (RHH) show more severe problems during reading than those with left HH (LHH; Trauzettel-Klosinski and Brendler, 1998).

There is a lot of controversy in the literature and therefore no current consensus regarding the best rehabilitation and intervention strategies for people with HH (Liu et al., 2019). It is thus relevant to understand the scanning strategies employed by people with HH and the unique challenges they face. This knowledge can help to gain insight into the difficulties people with HH face and whether or not reading impairments should be included in common rehabilitation interventions.

This review aims to examine the literature regarding the scanning mechanisms employed by people with HH whilst reading and consider their implications for rehabilitation. To identify scanning mechanisms unique to people with HH, attention was paid to different clinical parameters, namely the side of HH, the time since onset of the visual field defect, potential comorbidity of pure alexia, and differences to people with left visuospatial neglect and neglect dyslexia. It is predicted that the included literature shows a pattern of impaired reading due to ineffective scanning mechanisms in people with RHH, while people with LHH will likely read slower than those with normal vision (NV) but show an intact scanning pattern. A better understanding of scanning mechanisms can be used for the assessment of effective compensatory scanning strategies, that can be employed by people with HH to use their remaining vision more efficiently (Goodwin, 2014).

Methods

The PRISMA checklist was used as a guideline to ensure best practices while conducting this systematic review (Moher et al., 2009).

Eligibility criteria

Letters, editorials, reviews, case studies, study protocols, and dissertations were excluded as well as articles that were not peer-reviewed. The eligible articles had to be published between 1960 and the present day in either English, Dutch, or German.

Furthermore, they had to include a group of adult participants with homonymous hemianopia, including quadrantanopia and peripheral scotomas, and a control group of people with normal vision. Transient field defects, as for example in migraine, epilepsy, or hyperglycaemia, were not included. The visual field defects had to be objectively measured by using an eye-tracker and/or head motion tracker system, which was not used during diagnostic and/or perimetry assessment. Only articles that specifically reported scanning behaviour as an outcome variable were included.

Search strategy

The literature search was conducted by using the electronic databases PsycINFO, Web of Science, Medline, and manually searching the reference lists of relevant articles. Search terms are listed in Appendix A.

Selection process:

The literature for this systematic review was gathered during a literature search for an extended systematic review that reports scanning behaviour in HH not only whilst reading, but also during mobility and search tasks. The literature searches and checks were therefore conducted for the extended systematic review, but only the articles regarding the topic of scanning mechanisms whilst reading were included in the current review. Reading tasks were defined as reading a short text or a word.

During the literature search, the articles were first submitted to an abstract and title check and afterwards, if eligible, a whole text check. These checks were performed by two independent researchers.

Data items, collection, and synthesis:

All included studies underwent a quality assessment which was performed with the Joanna Briggs Institute critical appraisal tools for case control studies (Joanna Briggs Institute, 2020) and quasi-experimental studies (Joanna Briggs Institute, 2017).

Extraction of the characteristics of the participants of each included study was performed with a predesigned excel table. This table included participant groups, number of participants per group, sex, age, education, type of visual field defect, and side of visual field defect. Right and left homonymous hemianopias were analysed as separate groups to identify potential differences. Additionally, brands of the eye- and head-movement-tracking devices were listed, as well as a description of the performed experimental reading tasks.

Outcome variables and results for each of the articles were listed in the excel table. Results were then grouped into similar outcome variables to give a more concise overview and facilitate comparisons between articles. The outcome variables are reading performance, including reading time and errors, number of fixations, fixation duration, refixation rate, number of progressive and regressive saccades, and amplitude of progressive and regressive saccades.

Results

The results of the literature search are outlined in Figure 1. The quality assessment of the included case control studies can be found in Appendix B (Table B1) as well as the quality assessment of the quasi-experimental studies (Table B2). None of the studies reported inconsistent results. The characteristics of the participants from each article are presented in Table 1 and information regarding measurements and reading tasks of each article are given in Table 2.

PRISMA 2009 Flow Diagram

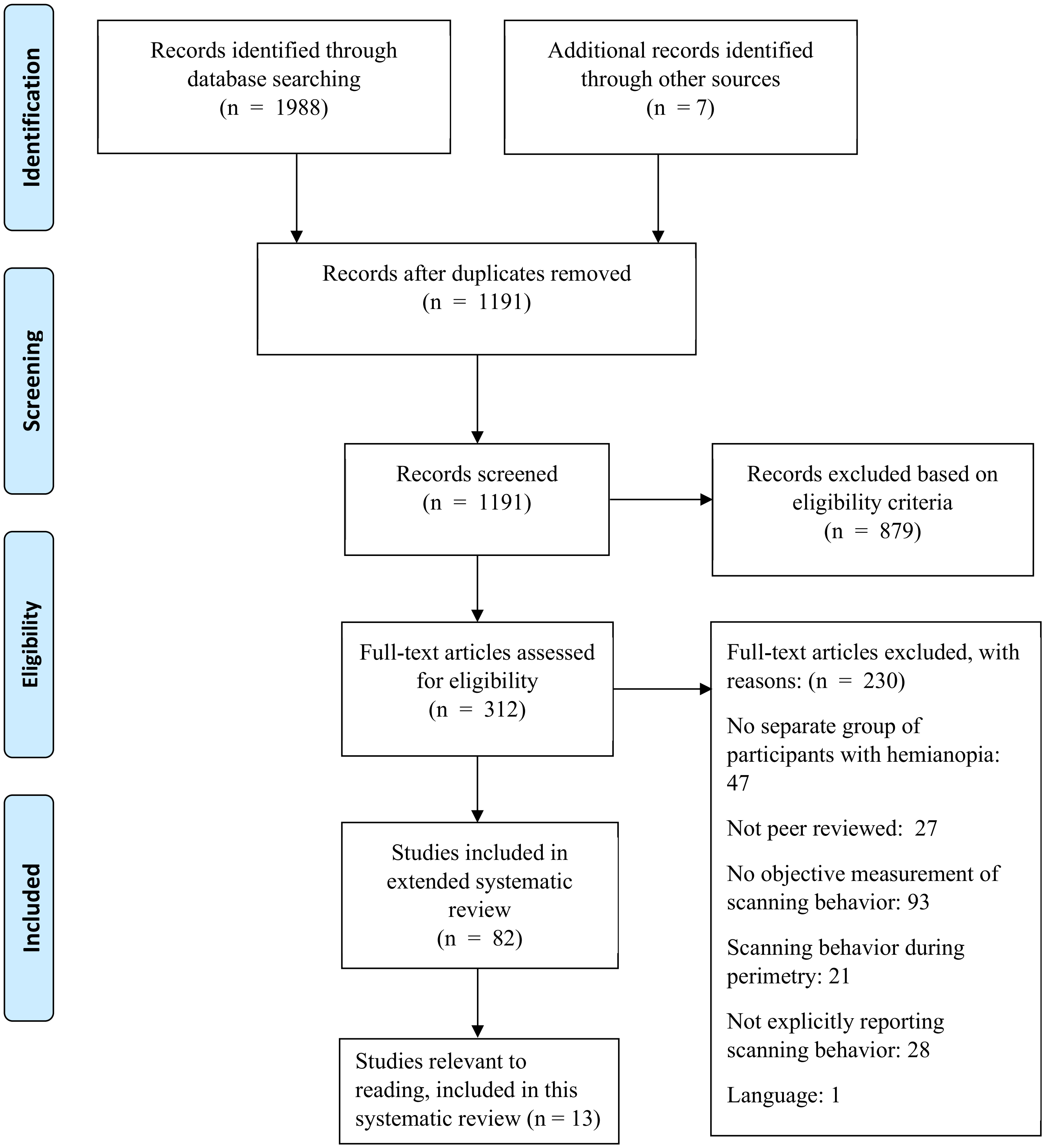

Fig. 1. PRISMA flow diagram (Moher et al. 2009) of the article search from the systematic review process. (1) Identification of articles after searching the databases; (2) Screening of the articles; (3) testing Eligibility of the articles according to pre-defined criteria; (4) Inclusion of eligible articles and data synthesis.

Table 1

Participant characteristics by article, sample size, population, time since onset, sex, and age

Article	Sample size	Population	Time since onset	% male	Age mean
Behrmann et al., 2002	n = 22	Left visuospatial neglect: 4	4 - 23 months	20%	72.8 (67-76)
		Left neglect dyslexia: 5	0.25 - 24 months	75%	64.5 (57-78)
		Hemianopia: 4	11 - 22 months	75%	53.8 (28 - 66)
		NV: 9	n.a.	44%	59.2 (3.4)
Behrmann et al., 2001	n = 13	Letter-by-letter readers (RHH): 2		0%	58 & 40
		Left hemianopic group: 4	11 - 22 months	75%	54 (18)
		NV: 7		43%	59 (3)
De Luca et al., 1996	n = 10	RHH: 3	4 months – 3 years	66.7%	34 (17,35) [23-54]
		LHH: 1	1 month	0%	37
		Left inferior quadrantanopia: 1	12 years	100%	46
		NV: 5		20%	36,2 (14,6) [25-54]
Gassel & Williams, 1963	n = 60	LHH: 18	n.a.	n.a.	n.a.
		RHH: 17			
		NV: 25			
Leff et al., 2000	n = 9	RHH: 4		50%	40-70
		NV: 5		40%	40-62
McDonald et al., 2006	n = 28	RHH: 18	3 months – 14 years	66.7%	36-78
		NV: 10		60%	24-75
Passamonti et al., 2009	n = 24	LHH: 6	5 months - 30 years	50%	32-65
		RHH: 6	6 months – 16 years	100%	22-63
		NV: 12		42%	40
Pflugshaupt et al., 2009	n = 18	Pure alexia (RHH): 6	5 - 18 weeks	67%	44.33 (18-64)
		RHH: 6	1 – 90 weeks	67%	56 (35-78)
		NV: 6		67%	Median 56
Trauzettel-Klosinski & Brendler, 1998	n = 61	LHH: 21	0 - >24 months	47.62%	53 (22-88)
		RHH: 19		68.4%	50 (20-72)
		NV: 21		61.9%	45 (25-82)
Trauzettel-Klosinski & Reinhard, 1998	n = 28	RHH: 3	3 - 4 years	0%	27-51
		LHH: 5	6 months – 28 years	80%	54-74
		NV: 20		n.a.	44.9 (25-82)
Zihl, 1995	n = 85	RHH: 25	4 - 9 weeks	56%	38 (18-56)
		LHH: 25	3 - 12 weeks		43 (21-64)

	NV: 35	52%

Note. Range and standard deviation are given in brackets if available;

n.a. = not available; RHH = right homonymous hemianopia; LHH = left homonymous hemianopia; NV = participants with normal vision.

Table 2

Experimental information by description of reading tasks, outcome variables, and eye trackers

Author	Task	Eye tracker	Outcome variables
Behrmann et al., 2002	Word reading task: all participants read two sets of 15 words (5, each with 4, 5, and 6 letters). Omission of the most left letter gave rise to another English word.	magnetic search coil technique, CNC Engineering; HM	Number of fixations Fixation duration
Behrmann et al., 2001	The subject's head was supported by an occipital rest. All subjects read aloud two separate paragraphs. Paragraph 1 consisted of three full sentences and paragraph two consisted of six full sentences.	magnetic search coil technique, CNC Engineering; HM	Reading time Number of fixations Fixation duration Regressive saccades (per word) Word-length effect Lexical/semantic effects Effect of paragraph layout
De Luca et al., 1996	The participants' heads were kept in position with a head- and a chinrest. Four different texts were presented, one with high-frequency words, one with low-frequency words, a list of 80 meaningful words, and a list of 80 non-words.	Ober2 Uno-Parallel infra-red eye movement monitoring system Premorbil Meditech; HM	Reading speed Fixation duration Progressive saccades (per line) Amplitude of progressive saccades
Gassel & Williams, 1963	The reading matter was considered appropriate to the participants' educational level. It consisted of a simple paragraph, reading numerical charts (right-left, left-right), and Jaeger charts (different sizes). The contribution of head movements was checked by immobilising the head and then repeating the task with no limitation of the head.	Bitemporal electrodes, pair of electrodes, and common earth electrode.; HM	Errors Regressive saccades Amplitude of progressive saccades Return sweeps
Leff et al., 2000	Participants silently read 10 trials of single words, 10 trials of three-word arrays, 10 trials of 5 word-arrays	"Eye-link" infrared pupil-tracking system; R	Reading speed (Words per minute) Fixation/word ratio Fixation duration General amount of saccades

McDonald et al., 2006	Participants with RHH silently read 3 passages from newspaper articles (each around 50 words). Comprehension was tested by asking questions regarding the content after each passage. The people with NV underwent the same procedure, but they read 10 passages.	SR EyeLink II video-based head-mounted eye-tracking system; HM	Number of fixations Fixation duration (General, first fixation, sum of first-pass fixation, total) Refixation rates Amplitude of progressive saccades Amplitude of regressive saccades Normalised landing position
Passamonti et al., 2009	The reading matter consisted of four short stories, each had around 330 syllables. These were counterbalanced between subjects and testing sessions. Subjects were asked to read aloud to obtain both accuracy and reading time.	Pan/Tilt Optic eye-tracker (Eye-Track ASL-6000); HM	Reading speed (syllables per second) Errors Fixation duration Regressive saccades (per line) Progressive saccades (per line) General saccadic amplitude Return sweeps
Pflugshaupt et al., 2009	For the single-word reading task, the participants silently read 40 four-letter and 40 six-letter nouns from a computer screen. For the text-reading task, the participants silently read four articles from a German newspaper. They were between 43 and 52 words long, with 194 words overall.	infrared-based video tracking system (EyeLinkTM, SensoMotoric Instruments GmbH, Berlin, Germany); HM	Reading speed (words per minute) Fixation-to-character ratio Fixation duration Proportion of regressive saccades Amplitude of progressive saccades Amplitude of regressive saccades Return sweeps
Trauzettel-Klosinski & Brendler, 1998	Subjects silently read German short stories with simple vocabulary.	infrared reflection system, the Ober2 system; HM	Reading speed (characters per minute) General number of saccades (per line) Regressive saccades (per line) Return sweeps Additional effects (Time since onset, Age, Reading practice, localisation of lesion)
Trauzettel-KLosinski & Reinhard, 1998	Reading performance was assessed by recording eye movements while silently reading paragraphs of 6-9 lines.	scanning laser ophthalmoscope (SLO); infrared reflection system (Ober2; Permobil Meditech AB)	Reading speed (words per minute) General number of saccades (per line) Regressive saccades (per line) Return sweeps
Zihl, 1995	Participants were tested on horizontal and vertical numbers and word reading.	Infra-red eye movement recordings; R	RT Errors FixN (r with RT) FD (r with RT and FixN)

	Text reading was tested with 180 words that were arranged in 20 lines.		Refixation rates (r with RT) Regressive saccades (r with RT, FixN, and ARS) Progressive saccades (r with RT, FixN) Amplitude of progressive saccades (r with RT and Fix and FD) ARS (r with RT, Fix)

Notes. ARS = Amplitude of regressive saccades; FD = Fixation duration; FixN = Number of fixations; HM = head mounted; R = remote; RT = Reading time;

; r = Correlation.

Reading performance

Reading performance includes reading time and the number of errors made throughout the task (Table 3).

A significantly slower reading time for people with RHH when compared to people with NV and LHH was found by most articles (De Luca et al., 1996; Passamonti et al., 2009; Pflugshaupt et al., 2009; Trauzettel-Klosinski & Brendler, 1998; Trauzettel-Klosinski & Reinhard, 1998). Trauzettel-Klosinski & Reinhard (1998) reported a slowed reading speed in people with RHH, but a slow to normal reading speed in those with LHH.

Participants with LHH were also found to read significantly slower than people with NV, by the majority of articles (Passamonti et al., 2009; Trauzettel-Klosinski & Brendler, 1998; Trauzettel-Klosinski & Reinhard, 1998). Yet, De Luca et al. (1996) reported no difference to people with normal vision.

People with pure alexia were found to read slower than those with LHH and RHH (Behrmann et al., 2001; Pflugshaupt et al., 2009).

Two articles found errors, in particular omission errors, made throughout the reading tasks to be significantly increased in people with RHH as compared to people with normal vision (NV) and people with LHH (Passamonti et al., 2009; Zihl, 1995). De Luca et al. (1996), on the other hand, found no marked increase of errors for people with RHH when compared to people with NV. The participants with LHH did not differ significantly from people with NV (Passamonti et al., 2009). Behrmann et al. (2002) reported that as opposed to people with neglect dyslexia, those with HH, NV, and neglect without dyslexia made no errors whilst reading.

Table 3

Statistical data for reading performance measures including reading speed and errors

Author	Reading speed	Errors
Behrmann et al., 2002		Neglect dyslexia > Neglect without dyslexia, HH, NV: n.a.
Behrmann et al., 2001	Pure alexia > LHH***	
De Luca et al., 1996	Differences between High/Low frequency and words/non-words: n.a.	
Gassel & Williams, 1963		n.a.
Leff et al., 2000	Single-word and text reading: n.a.	
Passamonti et al., 2009	Improvement Session 2 to session 3 LHH**; RHH* Group x session: LHH***; RHH**; all*** RHH > NV and LHH after improvement*	RHH > LHH and NV*** RHH improvement S2 to S3*
Pflugshaupt et al., 2009	Pure alexia > RHH*** RHH > NV***	
Trauzettel-Klosinski & Brendler, 1998	n.a.	
Trauzettel-Klosinski & Reinhard, 1998	n.a.	
Zihl, 1995	NV < LHH* NV < RHH* LHH < RHH*	n.a.

Note. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$; n.a. = not available; n.s. = not significant;

LHH = left homonymous hemianopia; RHH = right homonymous hemianopia; NV = normal vision;

RT = Reading time;

r = Correlation;

Summary

Overall, people with HH seem to be significantly slower whilst reading. This difference is even more distinct in people with RHH as compared to people with LHH. In addition, differences are more pronounced in people with pure alexia than in those with HH without alexia. The evidence regarding the number of errors made by people with HH as compared to people with NV is inconclusive.

Fixations

Outcomes on fixation measures are presented in table 4.

Table 4

Statistical results of all fixation measures including number and duration of fixations and refixations

Author	Number of fixations	Fixation duration	Refixations
Behrmann et al., 2002	Fixations on left and right: HH, NV, N+D- n.s. Fixations left < right: N+D+ n.a.	Right > left N+D+* Right and left HH, NV, N+D-: n.s.	
Behrmann et al., 2001	Pure alexia > LHH*** LHH and NV: n.s.	Pure alexia > LHH* LHH and NV: n.s.	
De Luca et al., 1996		n.a.	
Leff et al., 2000	n.a.	n.a.	
McDonald et al., 2006	RHH > NV***	RHH > NV*** First fixation duration: - word length effect NV*** - word length effect HH +p < 0.10 - effect of fixation position: 4 letter words*; 5 letter words*	RHH > NV*** Word length effect*** Position of the first fixation: HH***; NV***
Passamonti et al., 2009		RHH > LHH and NV** RHH improvement between sessions 2 and 3*	
Pflugshaupt et al., 2009	Pure alexia > RHH** RHH > NV**	Pure alexia and RHH n.s. RHH > NV**	
Zihl, 1995	RHH: r with RT: r = 0.82* LHH: r with RT: r = 0.67* NV: r with RT: r = 0.63* NV < LHH* NV < RHH*	Univariate F for interaction with saccades to the right*** NV < RHH* LHH < RHH*	RHH: r with RT: r = 0.67* LHH: r with RT: r = 0.71* NV: r with RT: n.s. NV < LHH* NV < RHH*

Note. + p < 0.10; *p < .05; **p < 0.01; ***p < 0.001; n.a. = not available; n.s. = not significant;

LHH = left homonymous hemianopia; RHH = right homonymous hemianopia; NV = normal vision; N+D- = Neglect dyslexia; N+D- = Neglect without dyslexia;

RT = reading time;

r = Correlation.

Number of fixations

People with RHH were found to have an increased number of fixations as compared to people with NV and people with LHH (McDonald et al., 2006; Pflugshaupt et al., 2009).

The participants with LHH, on the other hand, did not show any significant differences from the people with NV regarding the number of fixations (Behrmann et al., 2001; McDonald et al., 2006).

More fixations were also recorded for people with pure alexia, as compared to people with LHH and RHH (Behrmann et al., 2001; Pflugshaupt et al., 2009).

Behrmann et al. (2002) investigated whether it made a difference if words were written on the left or the right side of the reader's visual field. They found that the number of fixations made by people with HH, neglect without dyslexia, and people with NV did not differ whether the words were written on the left or the right side of a display. People with left neglect dyslexia, on the other hand, made fewer fixations towards the contralesional left side (Behrmann et al., 2002).

Fixation Duration

The duration of fixations was reported to be higher in people with RHH than it was for people with NV (De Luca et al., 1996; McDonald et al., 2006; Passamonti et al., 2009; Pflugshaupt et al., 2009; Zihl, 1995) and in people with LHH (Passamonti et al., 2009; Zihl, 1995).

People with LHH, on the other hand, were not found to show significant differences from the control group regarding the duration of their fixations (Behrmann et al., 2002; Behrmann et al., 2001; De Luca et al., 1996; Zihl, 1995).

People with pure alexia did not make longer fixations than people with RHH (Pflugshaupt et al., 2009), but did make longer fixations than those with LHH (Behrmann et al., 2001).

When comparing text written on the left and the right side, people with HH did not differ in their fixation duration to either side, as well as people with NV and neglect without dyslexia. People with neglect dyslexia made much shorter fixations on the contralesional side (Behrmann et al. 2002).

Number of refixations

An increased number of refixations was found in people with RHH as compared to people with NV (McDonald et al., 2006).

Zihl (1995) reported an increase in refixations made by people with LHH when compared to people with NV. They did not find this difference between people with RHH and LHH. Additionally, significant correlations of reading time with the number of refixations was found for both groups.

Summary

Generally, fixations appear to be significantly more numerous and longer for people with RHH as compared to those with NV. These effects were not found for participants with LHH. People with RHH and LHH made fewer fixations than those with pure alexia. While fixation duration appeared to be similar for pure alexia and RHH, it was shorter in those with LHH than in people with pure alexia. When comparing text written on the left versus the right side of a display no differences were found in the number or duration of fixations made by people with HH, as opposed to people with neglect dyslexia who made fewer and shorter fixations on their contralesional left side. Refixations did not differ between people with RHH and LHH but were more numerous in both groups than they were in people with NV. Moreover, refixations were significantly related to the reading time in both HH groups.

Saccadic measures

Outcomes for all saccadic measures can be found in table 5 and table 6.

Table 5

Statistical results of each article for the number of progressive and regressive saccades

Author	General number of saccades	Number of regressive saccades	Number of progressive saccades
Behrmann et al., 2001		Pure alexia > LHH** LHH and NV: n.s.	
De Luca et al., 1996			n.a.
Gassel & Williams, 1963		n.a.	
Leff et al., 2000	n.a.		
Passamonti et al., 2009		RHH > LHH and NV** RHH improvements from session 2 to session 3* During return sweeps: - LHH > RHH and NV** - LHH improvements from session 2 to session 3*	RHH > LHH and NV** RHH improvements from session 2 to session 3*
Pflugshaupt et al., 2009		RHH and NV: n.s. Pure alexia and RHH: n.s.	
Trauzettel-Klosinski & Brendler, 1998	n.a.	n.a.	
Trauzettel-Klosinski & Reinhard, 1998	n.a.	n.a.	
Zihl, 1995		Number of saccades to the left: - RHH: r with RT: n.s.; r with FixN: $r = 0.69$* - LHH: r with RT: n.s.; r with FixN: $r = 0.79$*; r with ARS: $r = -0.77$* - NV: n.s. - NV < LHH* - LHH < RHH* Repetition of regressive saccades: - RHH: RT: n.s.; FixN: $r = 0.90$* - LHH: RT: $r = 0.60$*; FixN: $r = 0.69$* - NV: RT: $r = 0.60$*; FixN: $r = 0.82$* - NV < RHH*	Number of progressive saccades: - RHH: r with RT: n.s.; r with FixN: $r = 0.66$*; - LHH: r with RT: $r = 0.64$*.; r with FixN: $r = 0.81$* - NV: n.s. - Group x duration effect: $p < 0.0001$ - LHH < RHH* Repetition of progressive saccades: - RHH: r with RT: n.s.; r with FixN: $r = 0.86$* - LHH: r with RT: n.s.; r with FixN: n.s.

		- LHH < RHH*	- NV: r with RT: n.s.; r with FixN: r = 0.61* - NV < RHH* - LHH < RHH*

Note. *$p < .05$; **$p < .01$; ***$p < .001$; n.a. = not available; n.s. = not significant;

LHH = left homonymous hemianopia; RHH = right homonymous hemianopia.; NV = normal vision;

ARS = Amplitude of regressive saccades; FixN = Number of fixations; RT = Reading time;

r = Correlation.

Table 6
Statistical results for each article regarding progressive and regressive saccadic amplitude

Author	General amplitude of saccades	Amplitude of progressive saccades	Amplitude of regressive saccades
De Luca et al., 1996		RHH < LHH and NV: a factor slightly less than two	
Gassel & Williams, 1963		n.a.	
McDonald et al., 2006		RHH < NV***	RHH < NV*
Passamonti et al., 2009	RHH < LHH and NV*** RHH improvements from session 2 to session 3*		
Pflugshaupt et al., 2009		Pure alexia < RHH: n.s. RHH < NV*	Pure alexia < RHH: n.s. RHH < NV: n.s.
Zihl, 1995		RHH: r with RT: r = -0.64*; r with FixN: r = -0.53; r with FD: r = -0.58* LHH: r with RT: n.s.; r with FixN: n.s. NV: n.s. NV > RHH* LHH > RHH*	RHH: r with RT: n.s.; r with FixN: r = -0.6; FD: r = -0.58* LHH: r with RT: r = -0.52*.; r with Fn: r = -0.51* NV: n.s. NV > LHH* LHH > RHH*

Note. *$p < .05$; **$p < .01$; ***$p < .001$; n.a. = not available; n.s. = not significant;

LHH = left homonymous hemianopia; RHH = right homonymous hemianopia.; NV = normal vision;

FD = Fixation duration; FixN = Number of fixations; FixR = Refixation; RT = Reading time;

r = Correlation.

The outcomes for the number of saccades made in either direction can be found in Table 5.

Generally, saccades were reported to be more numerous in people with HH than in people with NV (Leff et al., 2000; Trauzettel-Klosinski & Brendler; Trauzettel-Klosinski &

Reinhard, 1998) and even more so in those with RHH than in people with LHH (Trauzettel-Klosinski & Brendler, 1998).

Regressive saccades

Saccades towards the left visual field and repetitions of those saccades were found to be increased in people with RHH as compared to those with normal vision by the majority of articles (Passamonti et al., 2009; Zihl, 1995). This effect was not found by Pflugshaupt et al. (2009).

Most of the articles found that people with LHH made more regressive saccades than people with NV (Gassel & Williams, 1963; Passamonti et al., 2009; Trauzettel-Klosinski & Brendler, 1998; Trauzettel-Klosinski & Reinhard, 1998; Zihl, 1995). However, Behrmann et al. (2001) did not find this difference to be significant, but they did report a significant interaction of an increasing number of regressive saccades leading to shorter fixation durations.

Regarding the comparison between LHH and RHH, people with RHH were found to use more regressive saccades and repetitions than those with LHH (Passamonti et al., 2009; Trauzettel-Klosinski & Brendler, 1998; Trauzettel-Klosinski & Reinhard, 1998; Zihl, 1995). However, some articles also investigated the number of regressive saccades exclusively during return sweeps to find the beginning of a new line. They reported that while the general use of regressive saccades is smaller in people with LHH than in participants with RHH, the use of regressive saccades during return sweeps is significantly higher in people with LHH than in those with RHH (Gassel & Williams, 1963; Passamonti et al., 2009; Trauzettel-Klosinski & Brendler, 1998; Trauzettel-Klosinski & Reinhard, 1998).

People with RHH were not found to significantly differ from people with pure alexia (Pflugshaupt et al., 2009), while people with LHH made less regressive saccades than those with pure alexia (Behrmann et al., 2001).

Progressive saccades

People with RHH were reported to make more progressive saccades and repetitions than people with NV and people with LHH (De Luca et al., 1996; Passamonti et al., 2009; Zihl, 1995).

No significant differences were found between people with LHH and people with NV (Passamonti et al., 2009).

General saccadic amplitude

The outcomes for the amplitude of saccades in either direction can be found in Table 6.

Passamonti et al. (2009) found people with RHH to have a decreased general saccadic amplitude in comparison to people with NV and people with LHH.

Amplitude of progressive saccades

Participants with RHH were reported to have a shorter amplitude of progressive saccades when compared to people with NV (De Luca et al., 1996; Gassel & Williams, 1963; McDonald et al., 2006; Pflugshaupt et al., 2009; Zihl, 1995) and people with LHH (Zihl, 1995).

No significant difference was found between people with LHH and people with NV (Gassel & Williams, 1963; Zihl, 1995).

People with pure alexia and people with RHH did not differ (Pflugshaupt et al., 2009).

Amplitude of regressive saccades

McDonald et al. (2006) found that their participants with RHH had a significantly shorter amplitude of regressive saccades in comparison to people with NV, while Zihl (1995) and Pflugshaupt et al. (2009) did not find this difference.

People with LHH were found to make significantly smaller saccades when compared to healthy controls and people with RHH (Zihl, 1995).

No significant differences were found between people with pure alexia and RHH (Pflugshaupt et al., 2009).

Summary for saccadic measurements

People with RHH make significantly more and smaller progressive saccades than healthy controls and people with LHH, but the amplitude did not differ from those with pure alexia. Their regressive saccades were also found to be more numerous than those of people with NV by the majority of articles but were similar in amount to those with pure alexia. People with pure alexia made more regressive saccades than those with LHH. Regarding the regressive saccadic amplitude of people with RHH, results remain inconclusive when compared to NV, but show no significant difference to pure alexia. People with LHH, on the other hand, appear to make more regressive saccades than controls, based on most articles. They also make more regressive saccades than people with RHH, but solely during return sweeps.

Normalised landing position and additional effects

The statistical data of the articles assessing normalised landing position in people with HH and people with NV, the effect of word frequency and imageability of a word, and the effect of time since onset, are given in Table 7.

Normalised landing position

Normalised landing position while reading was assessed by McDonald et al. (2006), who reported people with NV fixating just to the right of the centre of each word, while people with RHH fixated to the left of the centre of the word. For the control group, the landing position was not significantly affected by word length, while the effect was more pronounced for participants with RHH for longer words.

Table 7

Statistical results for the normalised landing position, lexical/semantic effects, and time since onset

Author	Normalised landing position	Lexical/semantic effects	Time since onset
Behrmann et al., 2001		Word frequency: - Pure alexia** - Pure alexia > LHH vs NV* - Main effect length** Imageability: - Pure alexia > LHH vs NV*	
McDonald et al., 2006	Group effect 4 letter words or longer: $p < 0.001$ Group effect reliable difference for 4-7 letters: $p < 0.03$		
Trauzettel-Klosinski & Brendler, 1998			n.a.

Note. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$; n.a. = not available; n.s. = not significant.

Lexical/semantic effects

Behrmann et al. (2001) found that both lower word frequency and lower imageability of a word led to a significant increase of fixations for people with pure alexia. This effect was more pronounced for long words over short ones. They did not find a significant effect for people with LHH and people with NV.

Time since onset

Trauzettel-Klosinski & Brendler (1998) investigated the time since the onset of the visual field defect. This factor significantly affected reading for people with LHH and RHH. For participants with LHH increasing time after onset led to a decrease in return sweep saccades, and landing points in the middle of a word were occurring more often in the early stages of the visual field defect than in any people with RHH and NV. For people with RHH, reading time, saccades, and regressions per line decreased with increasing time since onset. These factors were not significantly influenced in participants with LHH.

Discussion

This systematic review aimed to provide an overview of the scanning mechanisms employed by people with homonymous hemianopia whilst reading. In the following discussion, the scanning patterns that emerged from the literature will be discussed regarding the impact of clinical factors such as the side of the visual field defect, time since onset of the visual field defect, and potential comorbidity with pure alexia. Some differences to left visuospatial neglect and neglect dyslexia are also mentioned.

The results of this systematic review show a particularly ineffective scanning pattern for people with RHH whilst reading, yet people with LHH still appear to be impaired. Both groups benefitted from an increasing time since onset. Generally, people with RHH were found to have a worse reading performance, including both slower reading and more errors, they made more and longer fixations, and more and shorter progressive saccades than people with NV and people with LHH. They also fixated words further to the left than people with NV. The increased number of fixations, refixations, fixation duration, and the shorter amplitude of progressive saccades were all connected to the elongated reading times of people with RHH. Their regressive saccades were also found, by most of the articles, to be more numerous than those of people with NV and LHH when it comes to general text reading. Throughout return sweeps, however, people with LHH made more regressive saccades than people with RHH and NV. Results regarding regressive saccadic amplitude remained inconclusive for people with RHH, while people with LHH were found to not differ from people with NV. Furthermore, people with LHH did not differ from people with NV when it comes to the number of errors made, number and duration of fixations, and progressive saccades and their amplitude. They did however make more refixations and regressive saccades than people with NV. Regarding people with pure alexia, they were found to read slower, make more and longer fixations, and make more regressive saccades than those with LHH. They did not differ from people with RHH when it comes to fixation duration, regressive saccades and their amplitude, and progressive saccadic amplitude, but they did read slower and made more fixations than people with RHH. When looking at the fixation duration and number of fixations for texts being written on the right, versus the left, side of a display, there was no difference for people with HH, while people with left neglect dyslexia made shorter and fewer fixations on the left.

As predicted the results of this systematic review show a particular pattern of scanning mechanisms for people with RHH whilst reading, that differs greatly from that of participants with normal vision. Overall, people with RHH appear to show an ineffective scanning strategy, since their fixations and saccades both appear to lead to prolonged reading times. Additionally, the overall scanning and fixation pattern of people with LHH was reported to be much more intact than that of people with RHH, while still reading slightly slower than those with NV, according to the included articles. Nevertheless, the prediction of an intact scanning pattern for people with LHH as compared to people with NV was partly inaccurate, due to the fragmented and increased regressive saccades.

The reason that the maladaptive fixation strategies of people with RHH lead to ineffective reading is that fixation strategies were found to be utilised in reading for the execution and planning processes of following eye movements (Leff et al., 2000). McDonald et al. (2006) additionally connected this to the fact that people with RHH set their fixation point further to the left than people with NV. This results in more of the fixated word being covered by their right-sided visual field defect, which in turn leads to impaired eye movements whilst reading since unimpaired reading movements require visibility of at least 20 characters towards the right side when reading from left to right (Leff et al., 2000). Because of this lack of information towards the right side, people with RHH use a so-called bottom-up strategy, which manifests in the reported usage of smaller and more numerous progressive saccades to explore the following words to the right (De Luca et al., 1996). Trauzettel-Klosinski & Brendler (1998) compared this pattern of eye movements to spelling a word rather than reading it. Which is another reason why reading proved to be very time consuming and ineffective for people with RHH.

Taking all the results regarding the differences in scanning mechanisms between people with RHH and people with NV into account, it seems that it could be beneficial for people with RHH to fixate words further to the right than do people with NV. This would lead to more of the word being visible with one fixation, rather than having to fixate each letter to read the whole word. Hence it could result in a reduction in fixations as well as an increase in progressive saccades, which were both connected to the increased reading time.

Similarly, to people with RHH, the slowed reading time of people with LHH was connected to their increase in number and fragmentation of saccades to their blind hemifield (Gassel & Williams, 1963; Passamonti et al., 2009; Trauzettel-Klosinski & Brendler, 1998). The manifestation of the increased regressive saccades especially during return sweeps was explained by the difficulties of people with LHH to scan their left hemifield, which is required for return sweeps when searching for the beginning of a new text line in left to right reading (Zihl, 1995). Trauzettel-Klosinski & Brendler (1998) found that people with LHH adapted to this problem by fixating further towards the beginning of a word with increasing time since onset. This appeared to be a compensatory strategy since it also led to a decrease in regressive saccades. Based on the results of this systematic review, it can be suggested that further decreasing of regressive saccades during return sweeps could potentially be accomplished by training to make bigger return sweeps to find the beginning of the line with one rather than multiple sweeps. Otherwise facilitating the localisation of the beginning of the line or the left side of the paragraph, to prevent over or undershooting, could be beneficial.

Overall, the scanning mechanisms in people with RHH appear to be more generally impaired than those of people with LHH, as was predicted. This is connected to the fact that people with LHH can see the right side of their visual field, meaning they do not have the same difficulties in obtaining parafoveal information to plan and execute progressive saccades that people with RHH face (De Luca et al., 1996).

Looking at the results regarding pure alexia and visuospatial neglect dyslexia it can be concluded that pure alexia outweighs and differs from the scanning impairments in both LHH and RHH, but even more so from LHH (Behrmann et al., 2001; Pflusghaupt et al., 2009). Neglect dyslexia also appears to lead to a differing scanning pattern with more difficulties in the contralesional visual field (Behrmann et al., 2002). Considering this, it is important to differentiate neglect, pure alexia, and HH. It would therefore be beneficial to include eye movement analysis in assessments of patients with HH to determine a potential comorbidity of pure alexia and enable clinicians to tailor the rehabilitation accordingly (Pflugshaupt et al., 2009).

Implications for the clinical context regarding HH

Improvements of reading appear to be possible even without specific training just due to passing time since onset and are more likely and more pronounced in those with RHH. Nevertheless, some people with RHH remain impaired even after the improvement (Trauzettel-Klosinski & Brendler, 1998). To an extent people were also found to benefit from more premorbid (Behrmann et al., 1998) as well as postmorbid reading practise (Passamonti et al., 2009). Nevertheless, training of visual capacities is most likely still necessary in rehabilitation to further improve scanning mechanisms whilst reading in people with HH who have had the impairment for more than 3-6 months. Sabel and Kasten (2000) have found that after this time further improvement and adaptation of the patient to the HH by themselves is unlikely.

While some authors suggested that the identified impairments do not relate to everyday functioning (Gassel & Williams, 1963), it was also pointed out that some people with homonymous hemianopia do not have an active impairment in reading, because they avoid it altogether by either looking for jobs that do not require reading or terminating their studies if it is required (De Luca et al., 1996). To support people in adapting to the new challenges of their everyday lives, it is suggested to include eye movements in assessments of people with HH to ensure detection of reading impairments early on (De Luca et al., 1996; Pflugshaupt et al., 2009) and enable the implementation of reading practise and tailored compensatory training, such as compensatory head posture or scanning strategies, in rehabilitation (Rowe et al., 2013; Howard & Rowe, 2018). As mentioned before, the results of this systematic review allow the conclusion that in rehabilitation for people with RHH it could be beneficial to teach them to fixate further to the right of a word than is usually seen in people with NV. Regarding rehabilitation for people with LHH the inclusion of strategies to facilitate the localisation of the beginning of a new line of text, or generally the left side of the paragraph, could be beneficial.

Limitations

As mentioned, the results of this systematic review are limited to scanning mechanisms employed by people with HH whilst reading from left to right only. The impairments are likely to differ when looking at reading from right to left. Furthermore, due to a lack of available literature, the number of articles and the number of participants overall included in this systematic review are rather limited. More research in this field is needed to give a more refined review of all factors that influence scanning mechanisms whilst reading in people with HH, and their potential role in rehabilitation.

Conclusion

The results show that people with RHH and LHH have impairments in reading from left to right. These impairments are more pronounced in people with RHH and arise due to the ineffective and fragmented scanning strategies that they employ whilst reading. The impairments differ from people with pure alexia, which is why eye movement assessments are important to distinguish the two. Including different compensatory strategies in the training for reading in the rehabilitation of people with RHH and LHH can help them adapt to the new challenges of everyday life and improve their quality of life. Nevertheless, future research in this field is needed to identify the exact nature of effective compensatory strategies for scanning mechanisms whilst reading. Investigating the exact degrees of the visual field defect might also give some additional information to further specify the rehabilitation needed for each individual patient.

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Appendix A

Search terms used throughout the literature search to find relevant articles

Table A1

Search strings

Hemianopia OR hemianopic OR hemianopsia OR hemiopia OR homonymous field defect* OR cerebral blindness OR cortical blindness OR visual field defect* OR visual field disorder*
AND
Scanning performance OR scanning behavior OR scanning behaviour OR saccadic behavior OR saccadic behaviour OR saccadic adaptation* OR saccades OR Visual scanning OR visual performance OR visual search OR visual exploration OR oculomotor compensation* OR oculomotor pattern* OR oculomotor response Or oculomotor adaptation* OR Ocular fixation OR fixation performance OR gaze OR gazing OR viewing behavior OR viewing behaviour OR viewing efficiency OR eye-fixation OR eye fixation OR visual fixation OR eye-tracking OR eye tracking OR eye movement* OR eye–movement* OR EOG OR electrooculography OR electro oculography OR scan path OR scanpath OR head movement* OR head-movement* OR eye-head coordination

Appendix B

Results of the Quality assessment according to the critical appraisal tools from the Joanna Briggs Institute (JBI; 2017; 2020)

Table B1

Quality assessment with the JBI critical appraisal tool for case control studies

Method	Behrmann et al., 2002	Behrmann et al., 2001	De Luca et al., 1996	Gassel & Williams, 1963	Leff et al., 2000	McDonald et al., 2006	Pflugshaupt et al., 2009	Trauzettel-Klosinski & Brendler, 1998	Trauzettel-Klosinski & Reinhard, 1998
Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	1	1	1	?	1	1	1	1	0
Were cases and controls matched appropriately?	1	0	1	?	1	1	1	1	?
Were the same criteria used for identification of cases and controls?	1	1	1	?	1	1	1	1	1
Was exposure measured in a standard, valid and reliable way?	1	?	1	1	?	0	1	0	0
Was exposure measured in the same way for cases and controls?	1	1	1	1	1	1	1	1	1
Were confounding factors identified?	1	1	1	1	1	1	1	1	1
Were strategies to deal with confounding factors stated?	1	1	1	1	1	1	1	1	?
Were outcomes assessed in a standard, valid and	1	1	1	1	1	1	1	1	1

reliable way for cases and controls?									
Was the exposure period of interest long enough to be meaningful?	0	0	1	0	0	1	1	?	0
Was appropriate statistical analysis used?	1	1	1	n.a.	1	1	1	n.a.	n.a.
Total percentage 1	90%	70%	100%	55.5%	80%	90%	100%	77.8%	44.4%

Note. Total percentage of 1 excludes n.a.;

1 = yes; 0 = no; ? = do not know; n.a. = not applicable.

Table B2

Quality assessment with the JBI critical appraisal tool for Quasi-experimental studies

Method	Passamonti et al., 2009	Zihl, 1995
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
Were the participants included in any comparisons similar?	1	1
Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	1	1
Was there a control group?	1	1
Were there multiple measurements of the outcome both pre and post the intervention/exposure?	1	1
Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?	1	1
Were the outcomes of participants included in any comparisons measured in the same way?	1	1
Were outcomes measured in a reliable way?	1	1
Was appropriate statistical analysis used?	1	1
Methods described enable to be replicated?	1	1
Results		
Total percentage 1	100%	100%

Note. 1 = yes; 0 = no; ? = do not know; n.a. = not applicable.