Review paper: aphasia and acquired reading impairments. What are the high-tech alternatives to compensate for reading deficits?

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Abstract

Background: People with aphasia frequently present impairments in reading comprehension. Such impairments can be particularly debilitating due to the limitations and constraints they impose on everyday life. Recent technological advancements in the field of information and communication technologies offer many compensative tools for people with aphasia. However, most technological tools are designed for patients with *speech production* impairments. Instruments addressing *reading* impairments associated with aphasia remain scarce and underrepresented in the scientific literature.

Aim: This paper aims to conduct a state-of-the-art review of the technologies currently available to people with aphasia (PWA) and acquired reading impairments. In particular, this review covers a) research on technologies explicitly developed to compensate for reading difficulties associated with aphasia, and b) research into which accessibility features included in mainstream high-tech systems are helpful for people with aphasia when trying to access written material.

Methods: Following the PRISMA international standard, the authors conducted a systematic review from 2009 to 2019. The databases inspected were: Scopus, Web of Science, PubMed, the Cochrane collection, IEEE Xplore, ScienceDirect and SpringerLink. Other research papers were included after checking the references of the selected papers.

Main contribution: The review reveals that research on compensative devices for reading impairments largely neglects tools for individuals with aphasia and acquired reading

difficulties. Most of the studies in this field are qualitative investigations of how patients with literacy difficulties tackle everyday tasks with the help of mainstream technology (e.g. smartphone applications). Therefore, this paper highlights the scarce high-tech alternatives that support text comprehension in people with aphasia and acquired reading impairments, and suggests further work on the development of customised software for smartphones and personal computers.

Conclusions: High-tech reading tools may help people with aphasia to regain reading autonomy.. However, the supports currently available are not yet flexible and accurate enough to answer their day-to-day needs. Thus, further work is necessary to enhance the compensative devices available to them. For instance, existing new technologies in the area of natural language processing (such as automatic text simplification) could potentially be used in compensative devices.

What this paper adds

Most research on high-tech compensative reading tools is focused on investigating how patients with aphasia and acquired reading impairments cope with their reading difficulties in everyday life by resorting to different types of technology. Yet, we still lack specific research on compensative reading technology for PWA.

This review paper shows that PWA with acquired reading impairments are offered limited options for accessing written content easily and autonomously – and those few resources that are available are not specifically designed for PWA.

Both aphasia and acquired reading impairments can vary in terms of both their severity and the associated typology of cognitive impairments. Therefore, it might be interesting to investigate flexible and highly adaptable reading support designed for them – and innovations in the field of information and communication technology might prove particularly fruitful.

1. Introduction

Reading is fundamental to every aspect of life: socialising, family, leisure and work (Lynch *et al.*, 2013; Knollman-Porter *et al.*, 2015; Kjellén *et al.*, 2017). Arguably, its importance has only increased due to the growing prevalence of online textual information (Dietz *et al.*, 2011). Reading impairments are often associated with aphasia, and vary in degree and severity. Difficulties in decoding and comprehending written material can occur at every level: single words, sentences, paragraphs and the text as a whole (Dede, 2012, 2013; Webster *et al.*, 2018; Knollam-Porter *et al.,* 2015). Reading impairments following a stroke have been extensively investigated, and although reading impairments and aphasia are often associated, there is no direct and predictable relationship between types of acquired dyslexia (e.g. surface, deep, semantic) and aphasia syndromes (Cherney *et al.*, 2004). Difficulties at single-word level could reflect problems in word recognition (Patterson and Kay, 1982) or visual-attention deficits (e.g. Schuett *et al.*, 2008), as well as difficulties in grapheme-phoneme conversion (Tree, 2008). Single-word reading impairments are one of the causes of reading impairments at sentence and text level; however, impairments in sentence and text comprehension can occur even when single words can be read (Coelho, 2005). In 2015, Meteyard *et al.* gathered literature on reading ability in healthy adults summarising the primary cognitive skills underlying reading. Their survey found that the same skills can be variously disrupted in aphasia, ultimately causing the reading impairments that are often observable in this population. The cognitive skills identified included reading speed, language skills (single-word meaning and syntax), representation of the text base, inferencing, working memory and meta-cognitive skills (the ability to monitor text comprehension and use strategies to achieve it). Indeed, Reading is a complex interaction between strictly linguistic processes, cognitive skills such as attention, resource allocation, working memory and processing speed (Hula and McNeil, 2008; NcNeil *et al.*, 1991; Neto and Santos, 2012; Mayer and Murray, 2012) and, to some extent, motor abilities (Szabo and

Dittelman, 2014). Therefore, impairments in one or more of these areas could cause or exacerbate reading impairments.

From qualitative studies, it has emerged that PWA with acquired reading impairments desire and seek out effective methods and supports for decoding written text – not only in rehabilitation settings, but especially in everyday situations (e.g. work, leisure and personal healthcare) (Parr, 1995; Kjellén *et al*., 2017). According to Knollman-Porter *et al*. (2015), these patients desire to read even if they were not avid readers before their stroke. They want to gather information about the community, connect with friends and family through social media and practice communication skills (Knollman-Porter *et al.,* 2015). Reading comprehension deficits often impose restrictions on daily life tasks and engagement in pre-aphasia activities and roles, causing lower self-esteem, reduced cognitive stimulation and frustration (Knollman-Porter *et al*., 2015, 2019; Brown *et al*., 2019). Ultimately, such restrictions might reduce the individual's quality of life (Rose *et al*., 2011; Knollman-Porter *et al*., 2019; Parr 1995) and cause depression and anxiety. Indeed, in 2017, Døli *et al*. investigated self-reported symptoms of anxiety and depression in people with chronic stroke, both with and without aphasia. One of the main results of this study was that language processing difficulties involving reading comprehension, repetition and reading out loud was associated with more self-reported depression symptoms in patients with mild aphasia, with the repetition also being linked with a higher level of anxiety. As the authors point out, more severe aphasia might also result in more symptoms of depression related to additional language impairments.

In the last decade, information and communication technologies have developed dramatically, leading to a critical enhancement in high-tech communication supports for PWA. The majority of mobile apps and computer software have been designed to compensate for *speech* difficulties (e.g. C-Speak, Proloquo2Go or Dynavox) (Nicholas *et al*., 2011; Beukelman *et al*., 2015), while

the range of compensative tools for the *reading* difficulties in PWA with acquired dyslexia is narrower. This is surprising, considering the number of studies showing the correlation between reading comprehension impairments and reduced quality of life (Rose *et al*., 2011; Knollman-Porter *et al*., 2019; Parr 1995; Døli *et al*., 2017), which would suggest that a compensatory reading tool for this population might be needed.

While there are a handful of studies on compensative tools for PWA and acquired dyslexia, other areas (e.g. developmental dyslexia, autism and cognitive disabilities) have attracted a great deal of research on compensative tools. Specifically, in the field of natural language processing (NLP), a branch of information and communication technology, tools have been designed that can simplify a text and make it more accessible, in consideration of the target population's difficulties. For instance, the Simplext project (Saggion *et al*., 2015) developed simplification technologies for people with intellectual disabilities; the FIRST project (Martin-Valdivia *et al*., 2014) developed a semi-automatic text adaptation tools for English, Spanish and Bulgarian to improve the accessibility of written text to people with autism; also, Rello *et al*., (2014) and Bingel *et al*., (2018) developed a lexical simplification system to support reading for people with developmental dyslexia in Spanish and Danish respectively: DysWebxia and Lexi (http://www.readwithlexi.net/). The system developed by Bingel *et al*., (2018) is a web extension that can adapt itself to each user by learning their lexical difficulties while they use it.

Similar systems have also been proposed for PWA with acquired reading impairment. Carroll *et al*. (1998) and Devlin and Unthank (2006) published their pipeline for developing a text simplification system for PWA. The researchers planned to develop a system (Practical Simplification of English Texts, or PSET) and a web extension (Help Aphasic People Process Information, or HAPPI) that together simplify online English-language newspapers for people

with aphasia. However, to the best of our knowledge, these systems have not yet been applied into an interface, unlike the other systems described.

The current research on reading difficulties and aphasia has two main lines of research. The first focuses on finding the most appropriate modality in which to deliver a text. It examines the impact of combined modality presentation on text comprehension – for instance, written and audio compared with audio-only and written-only, at sentence and paragraph level (Dietz *et al*., 2009; Brown *et al*., 2019; Wallace *et al*., 2019; Knollman-Porter *et al*., 2019). This line of research leans on the general principle of multimodal content presentation (Knollman-Porter *et al*., 2016; Wallace *et al.,* 2012). According to McNeil *et al*. (2004), the reading difficulties experienced by PWA are caused by impairments in resource allocation. For some PWA, accessing written information only in one modality represents an excessive cognitive load, while presenting information in two or more modalities appears to be less cognitively demanding (McNeil *et al*., 2004; Murray *et al.,* 1997). In this line of research, the high-tech components are limited to text-to-speech systems embedded in computers, the possibility to modify the text layout (e.g. larger font size and increased white space between lines and paragraphs) (Brennan *et al*., 2005; Rose *et al*., 2003) or the presence of images supporting the meaning of the written content (e.g. Beukelman *et al*., 2015; Dietz *et al*., 2014).

The second branch of research is interested in qualitative investigations of the strategies PWA with acquired reading difficulties resort to in their daily lives in order to understand texts of interest (Dietz *et al*., 2011; Lynch *et al*., 2013; Knollman-Porter *et al.,* 2015; Kjellén *et al*., 2017). From these studies, it emerged that PWA independently employ high-tech instruments such as audiobooks, e-readers with text-to-speech systems and compensative reading programmes aimed at other populations with special needs (e.g. individuals with dyslexia).

The current review paper aims to give a state-of-the-art literature review of the technologies currently available to PWA with reading impairments, investigating the following questions: a) Are there existing instruments explicitly designed to compensate for the reading difficulties associated with aphasia? b) What are the accessibility features of mainstream high-tech tools that are helpful for PWA when trying to access written material? The methodology used to answer these questions is a systematic review of the literature on studies investigating reading difficulties in PWA and high-tech compensative supports.

2. Methodology

The guideline for conducting this review was the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions (Moher *et al.*, 2009). The PRISMA statement consists of a 27-item checklist and a four-phase flow diagram aiming at improving how systematic reviews and meta-analyses are conducted. Figure 1 shows a four-phase diagram illustrating the steps used to select the studies to include in this review. The paper selection process started with 613 results. The final papers included in the review number 13: six drawn from the original 613, six selected from the reference lists of those first six papers and one paper added from another source.

The review team was composed by the three authors of the article. The team did not include a librarian. The review of the literature was carried out solely by the first author of the review who is a PhD student, as part of a research project. For this reason, the greater part of the literature review process was carried out by the first author. However, doubts and requests of advice on the procedure were shared with the other two authors of the manuscript.

2.1 Eligibility criteria

The publication period was limited to the last 10 years, from 2009 to 2019, since this is a state-of-the-art review, concerned with the most recent research on the topic. The studies considered are peer-reviewed scientific articles or reviews in the English language. The target population for this review are patients with aphasia secondary to traumatic brain injury or stroke who experience acquired dyslexia. On the technological side, only studies involving high-tech compensative tools were included. Within the term "high-tech support" are included all the platforms that provide assistance through computing devices or electronic equipment. For instance, mobile technology (Apple iPads or other tablets) and applications; and programmes offering programmable vocabulary, dynamic storage and speech output – such as, for instance, Proloquo2Go (an augmentative and alternative communication programme for iPad or other tablets that compensate for speech-production deficits). The high-tech tools considered in the review are those focused on improving sentence-level, paragraph-level and text-level accessibility and comprehension, because sentence and paragraph are typically more meaningful than single words and the majority of written content is expressed in sentences (e.g. text messages, newspapers, emails and novels). PWA are equally dependant on being able to comprehend written content even though their comprehension is limited on single words reading. Nonetheless, the authors of this review paper are interested in devices that give the possibility to make the reading experience as much close as possible to the way it was before the vascular event , for instance, amplifying the word-level comprehension of some PWA to a sentence-level. For this reason, in the present paper, word-level reading supports are not included).

2.2 Exclusion criteria

We excluded those studies with a target population different from PWA with acquired dyslexia (e.g. people with developmental dyslexia or primary progressive aphasia). Studies on the efficacy of reading treatments, new rehabilitative protocols and therapy programmes and

applications were also excluded, since the focus of the review is on compensative, not rehabilitative, tools. Studies on neuropsychological theories on acquired dyslexia, developmental dyslexia or, more generally, linguistic abilities were also excluded, as were neurophysiological and neurobiological studies on reading ability. Finally, case studies investigating reading mechanisms were also excluded.

2.3 Search method

Seven databases were searched: SCOPUS, Web of Science, ScienceDirect, PubMed, the Cochrane collection, IEEE Xplore and SpringerLink. The databases were searched in October 2019. The multidisciplinary nature of the study justifies the broad selection of databases.

In this review paper, the central theme is the reading comprehension problems associated with aphasia. The development of reading impairments after a brain injury, especially when they exceed auditory comprehension, is also known as acquired dyslexia or alexia. Despite the existence of this specific terminology, in the literature review results, the authors mainly use the more general terms "reading impairments" or "reading difficulties". Therefore, besides the keywords "acquired dyslexia" and "alexia", the literature search was carried out also using "reading impairments" and "reading difficulties". Throughout the current review paper, we will use the term "acquired reading impairments". For the technology element, we used more general terms to keep the results as broad as possible and maximise the chance of obtaining results. We used a truncated search for the word "technology". The exact words used for the search are displayed in Table 1.

Insert Table 1 about here

For all the databases except ScienceDirect, an example of the search string is: *aphasia AND ("acquired dyslexia" OR alexia OR "reading impairment" OR "reading difficulties") AND ("reading support" OR "digital technolog*" OR "technolog* support" OR "augmentative and alternative communication system" OR "reading technolog*" OR "assistive device").*

ScienceDirect returned more hits than the other databases, possibly due to its extensive content and search modality that aims to provide a wide range of results (Tober, 2011). Since an accurate search in this database requires more parameters compared to the others, the search was narrowed using commands excluding all articles about treatment, primary progressive aphasia, dyslexic children and aphasia secondary to dementia. This was achieved by using the same search string specified above, with the addition of *(-treatment -primary -children -dementia).*
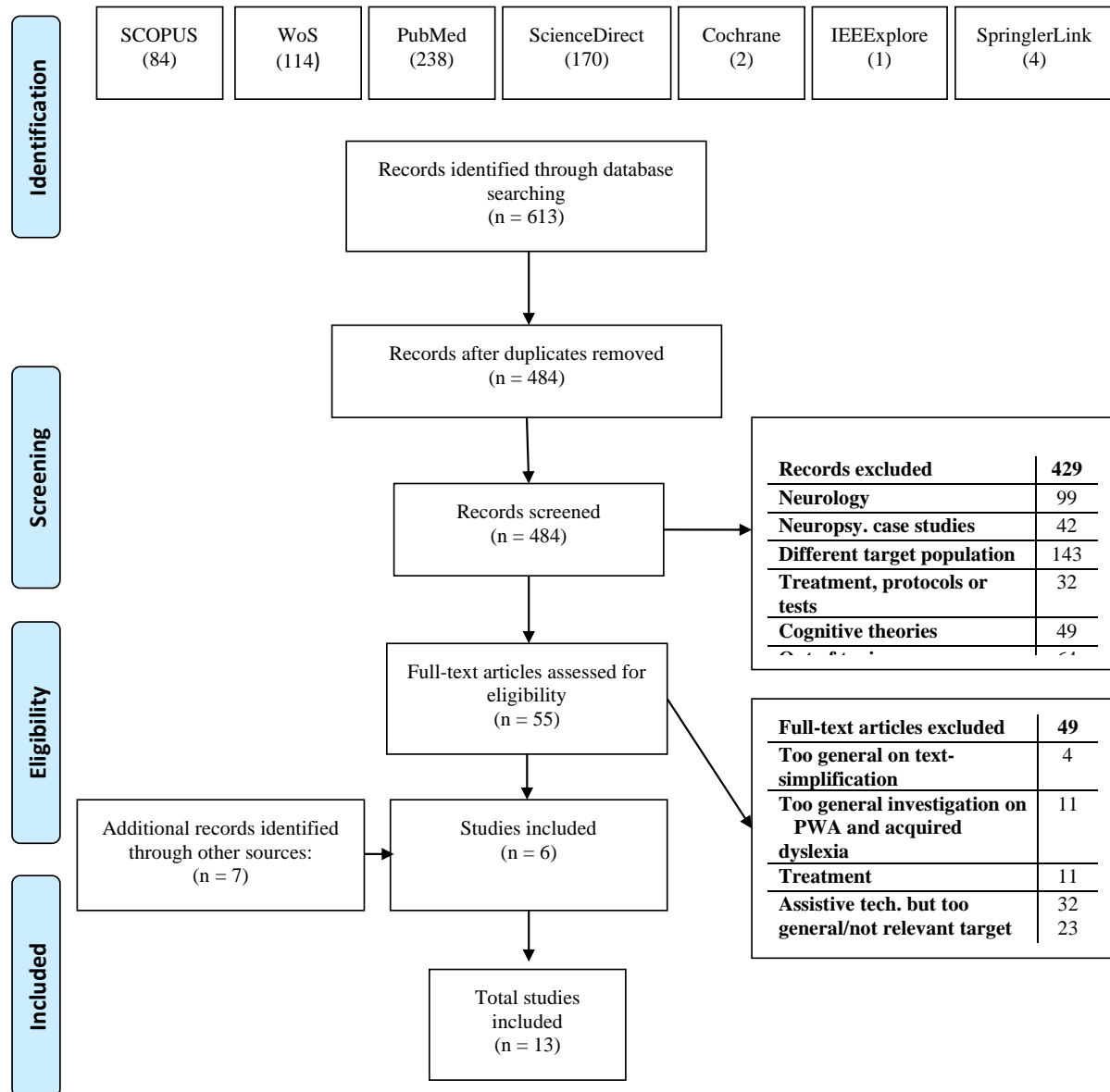
2.3 Study selection

The first search yielded 613 results. These results were first filtered for duplicates, resulting in 484 papers. Afterwards, the titles and abstracts of the 484 papers were reviewed against inclusion and exclusion criteria. Specifically: 99 articles were excluded because they focused on the neurophysiology or neurology of reading in people with reading difficulties (e.g. investigating neural pathways through fMRI or EEG); 42 articles were excluded because they were case studies investigating the neuropsychological mechanisms behind reading impairments; 143 articles were excluded as the target population was different from the one under study (e.g. developmental dyslexia, primary progressive aphasia or dementia), 32 were excluded because they concerned treatments or rehabilitative protocols, or new assessments for reading impairments; 49 papers were excluded because they were about cognitive theories on reading and related linguistics abilities; 64 papers were excluded because they were completely off-topic (e.g. studies on schizophrenia). The full texts of the remaining 55 articles were

retrieved and reviewed; 49 articles were excluded because they did not meet the inclusion criteria. Among these 49 papers, four were excluded because they investigated text simplification with a general focus on people with reading difficulties rather than PWA; 11 papers were interesting investigations on aphasia and acquired dyslexia, but without any mention of compensative methods of any kind; another 11 papers were concerned with treatments for PWA and reading impairments; 23 papers were excluded as the content was on assistive reading devices, but was either too general or related to a target population other than PWA. This second step in the studies' selection left a total of six articles for this review. While reviewing these six articles, six more articles of interest were found in the references list of the first six papers, and one relevant paper was added during the review process from the journal. This last study was published in December 2019, while the literature review was conducted in October 2019. The addition of these seven papers brought the total number of papers used for this review to 13. The pipeline followed to select the final papers is represented in Figure 1.

PRISMA 2009 Flow Diagram

SCOPUS (84)	WoS (114)	PubMed (238)	ScienceDirect (170)	Cochrane (2)	IEEExplore (1)	SpringlerLink (4)

Identification

Records identified through database searching
(n = 613)

Records after duplicates removed
(n = 484)

Screening

Records screened
(n = 484)

Records excluded	**429**
Neurology	99
Neuropsy. case studies	42
Different target population	143
Treatment, protocols or tests	32
Cognitive theories	49

Eligibility

Full-text articles assessed for eligibility
(n = 55)

Full-text articles excluded	**49**
Too general on text-simplification	4
Too general investigation on PWA and acquired dyslexia	11
Treatment	11
Assistive tech. but too general/not relevant target	32
	23

Additional records identified through other sources:
(n = 7)

Studies included
(n = 6)

Included

Total studies included
(n = 13)

3. Results

The results of the literature review highlight the lack of devices, software or applications designed for PWA with acquired reading impairments. The review highlighted two ways in which PWA compensate for their reading problems: a) using technology designed for a different target population (for instance, people with dyslexia), and b) adapting the technology

embedded in mainstream devices (e.g. iPad accessibility features and e-readers) to their own needs. Table 2 summarises the main information about the 13 papers, and also differentiates between qualitative and quantitative studies. Qualitative studies are defined as those that do not involve any kind of measurements (e.g., comprehension accuracy scales) but rely solely on interviews and experiences reported by participants. Conversely, quantitative studies measure a specific skill, such as comprehension rate, with dedicated tests and scales.

Table 2: summary of the 13 papers selected for the review (alphabetically ordered)

Study	Type of study	Aims	Participants	Main Results
Brown *et al.*, 2019	Quantitative	To examine comprehension accuracy of single sentences when presented in auditory-only, written only and combined modality.	n:27	Combined modality can facilitate comprehension accuracy in people with aphasia and varying level of severity.
Caute *et al.*, 2016	Quantitative	To investigate if people with aphasia can learn to use e-readers following a brief period of training and if e-reader improves reading comprehension, participation and enjoyment of reading activities.	n:4	E-reader use improved enjoyment, participation and reading confidence in the participants. E-readers did not show to enhance reading comprehension compared to text on paper when the assistive functions were not utilised.
Caute and Woolf, 2016	Quantitative	To investigate the usefulness of a Voice Recognition Software (Dragon NaturallySpeaking^{RTM}) to assist writing and the use of Read+WriteGold^{RTM} to assist reading.	Single case	The combination of Voice Recognition Software and text-to-speech systems improve writing and reading independently (e.g. writing email and reading news) when using the computer.
Caute et al., 2019	Quantitative	To investigate a) if a technology-enhanced reading therapy improves reading comprehension, especially when reading is assisted by trained technology, and if this technology-enhanced reading therapy improves self-report gains in reading confidence, enjoyment, functional communication, mood and ultimately the quality of life.	n:21	The reading comprehension of the participants improved only when using the technology, indicating that the treatment trained for the use of a compensative tool rather than remediating for the impairments.
Dietz *et al.*, 2011	Qualitative	To give an overview of the existing reading and writing techniques for people with aphasia.	-	Web-based communication strategies (e.g. email and social network or text-to-speech features) must be considered more during the rehabilitation process. More research on integrating web-based technology with rehabilitation is warranted.
Hux *et al.*, 2017	Quantitative	To compare the preferences and the accuracy of auditory comprehension of sentences when listening to two different computer-generated speech, compared with a digitalised natural voice.	n:20	Participants ranked the digitalised natural speech as the preferred one. Better accuracy when listening to sentences spoken by the digitalised natural voice.
Kelly *et al.*, 2016	Qualitative	To examine the personal experience of the participants in using main programmes (e.g. email, audiobooks, navigating on the Internet) after a training course.	n:21	The experiences of these patients highlight the advantage of using technology to improves their way to communicate and to facilitate certain aspects of their day-to-day life.
Kjellén *et al.*, 2017	Qualitative	To describe how patients' experience literacy and what role it has in their everyday life.	n: 12	Participants in this study experienced literacy as playing an essential part in their lives. The findings imply that personal experiences are important in the design of reading and writing interventions.

Knollman-Porter et al., 2015	Qualitative	To depict pre- and post-aphasia reading experiences of PWA and acquired reading impairments and to understand the feeling and preferences of the participants about supports and reading strategies.	n:6	Reading impairments negatively impact on the individuals' lives. Consistent themes appeared across participants (e.g. the need to pursuit reading activities despite the challenges) and individualised preferences in strategies and supports emerged.
Knollman-Porter and Julian 2019	Qualitative	To describe the experiences, engagement, and reading supports used by people with aphasia participating for the 1st time in a book club	n:10	Participants report greater reading enjoyment, social engagement, and support following book club participation. Recognised a positive attitude towards more functional reading activities, such as book clubs.
Knollman-Porter et al., 2019	Quantitative	To examine comprehension accuracy, reviewing time, and modality preference of edited newspaper articles when presented in written-only, auditory-only, and combined modality.	n:28	Not a significant difference in comprehension between combined and written only modalities. The reviewing time was shorter when the material was presented in combined modality. Participants largely preferred combined modality.
Szabo and Dittelman, 2014	Qualitative	Discuss the mobile technology program at the Adler Aphasia Center. Such program has the goal to improve access to mobile technology for PWA. The main focus is on features and apps native to Apple's as well as other apps with widespread popularity.	-	Technology is a powerful tool that can help people with aphasia in their needs. In general PWA benefited the from the use of mobile technologies as iPad. Rapide development of websites and apps suggest that in the future the use of mobile technology will successfully assist PWA in their daily struggle. Participants overall had a positive experience even though experiences some difficulties.
Wallace et al., 2019	Quantitative	To examine the comprehension accuracy and reviewing time when processing short and paragraph-length passages across three conditions (auditory-only, written only and combined modality)	n:20	Presenting paragraph-length material in more than one modality support comprehension. However, the effect is not generalisable, and it need to be tested on patients with varying aphasia severity.

3.1 Technology used by PWA but designed for another target population

The literature review on compensative devices designed for PWA with acquired reading impairments revealed that there is no scientific literature investigating the use and the efficacy of tools designed for this target population. Scientific research on the topic takes into consideration the use of other tools that are not primarily designed for this target population, but with specific functionality (for instance, text-to-speech systems) that is also helpful for

PWA with acquired reading difficulties. One study that reports the successful use of a compensative reading tool by an individual with aphasia and acquired reading impairments is that by Caute *et al*. (2016). In their research, the authors investigated whether PWA with acquired reading impairments could learn to use the Amazon Kindle, an e-book reader produced by Amazon, and if using the device might improve reading comprehension, participation and enjoyment of reading for these patients. The study involved four participants; at the time of the study, one was already using another reading compensative tool, ClaroRead™. ClaroRead™ (developed by Claro Software Ltd) is a software application created for people with dyslexia. It is compatible with Windows, Google Chrome, Mac, iOS, Android and PDF files. It provides text-to-speech functionality with the option to adjust the speech rate and choose a male or female voice. The patient who was already proficient in using ClaroRead™ reported no benefits in using the Kindle: he found it difficult to navigate and strongly disliked the text-to-speech voice, which he described as too mechanical. Moreover, at the time of the study, the Kindle e-reader did not allow the reading speed to be altered – a feature that the participant considered a fundamental help. This patient was able to use ClaroRead™ successfully with the text-to-speech function to listen to online news, recipes and short stories. However, he only used this device once or twice a week for 10 minutes, due to the fatigue he experienced when reading – even when using ClaroRead™. This patient had mild dyslexia and good comprehension of single words and sentences, but impairments in reading paragraphs and texts, and mild working memory impairments. The other three participants had a positive experience with Amazon Kindle and reported having regained confidence and enjoyment in reading.

In 2019, Caute *et al*. conducted a quasirandomised wait-list controlled design study that extended the findings just described in Caute *et al*. (2016). In this study, the authors investigated the improvements following a six-week treatment that consisted in training the participant in using a high-tech support. The 21 participants were randomised to an immediate or a delayed

therapy group. The delayed group started the technology-enhanced therapy with six weeks' delay. The authors investigated improvements in a) reading comprehension (especially when assisted by the trained technology), b) reading confidence and enjoyment and c) functional communication, mood and quality of life. The reading supports considered were ClaroRead™ and Amazon's Fire 7 tablet. The choice between the two technologies depended on the severity of the participant's reading impairment: less impaired patients were trained in the Fire 7, whereas those with more pronounced difficulties were trained in ClaroRead™. Besides the technology training, another critical factor was the highly individualised goal setting. Every participant was trained with their specific reading goal in mind (e.g. reading a novel or sharing a book with a grandchild). The results of this study were quite positive and similar in both groups. The patients were able to use the two high-tech devices as a compensative tool consistently, for at least the six weeks' follow-up, and they also self-reported enjoyment and improved confidence in reading after the training treatment. Nonetheless, there was no wider change in mood, functional communication or quality of life. The results of this study are quite different from the results of Caute *et al*. (2016), which the authors speculated might be due to the extensive therapy training (14 hours twice a week) or the personalised reading goals associated with the technology training. Regardless of the differences between these two similar studies, the positive outcomes of Caute *et al*. (2019) encourage studies more oriented towards investigating individually tailored compensative supports.

In 2016, Caute and Woolf carried out a single case study on a patient with severe dysgraphia and acquired dyslexia, whose spoken language comprehension was moderately impaired. The authors wanted to investigate whether training the patient in using voice recognition software (VRS) and a reading support tool with a text-to-speech system could help him improve his participation in everyday activities. Specifically, the participant desired to go back to work or partially recover his role at work, which was not possible with his current writing and reading

difficulties. In the study, Dragon NaturallySpeakingᴿᵀᴹ (a voice recognition software application) was utilised to assist with writing, and Read&Write Goldᴿᵀᴹ (reading support for people with developmental dyslexia) to assist with reading. Initially, the patient was trained to use Dragon, and Read&Write Goldᴿᵀᴹ was only introduced in a second stage.

The reading support was introduced as the text-to-speech system incorporated into Dragon had a low-quality text-to-speech system that impeded the participant's already-compromised auditory comprehension. Moreover, the text-to-speech system embedded in Dragon could only read what was written in Dragon software. The patient found Read&Write Goldᴿᵀᴹ extremely useful; he slowed the inter-word pause and was able to follow the text through the highlight. With Read&Write Goldᴿᵀᴹ he was able to read the emails he received and to check possible errors in what he had written. In the months following therapy, the patient continued to use both devices to interact with colleagues and friends successfully. He used them for the majority of his communications, and reported a better quality of life. There was an increase in the number of people and activities he engaged with. He continued using Read&Write Goldᴿᵀᴹ to read emails and online news and purchase items online. He also added an e-book reader to his routine, to read books even if it was not part of the training.

3.2 Use of mainstream high-tech tools to access written text

The majority of the studies investigating the usefulness of mainstream technologies are qualitative investigations where the researchers collect information about personal experiences and preferences. Only the two studies by Caute *et al*. (2016, 2019) gathered data on text comprehension improvements associated with the use of a mainstream technology (e-book reader) for PWA with acquired reading impairments.

The two studies mentioned above are the ones discussed in section 3.1. In Caute *et al*. (2016), it was investigated whether the Amazon Kindle Keyboard 3G™ could aid text comprehension

in PWA with acquired reading impairments, and whether it might restore their confidence and enjoyment in reading. As already described, three of the four participants rated the Amazon Kindle positively, whereas the fourth preferred the reading support software he was already using (ClaroRead™). Interestingly, comprehension and reading rate did not improve using Amazon Kindle. Nonetheless, the three participants who rated the Kindle positively reported significant benefits in using it, despite the difficulties and barriers it posed. For instance, two participants experienced a wider benefit, as they felt more sociable and willing to engage in conversation. Two other participants reported improved confidence in reading and more positive emotions associated with it. The authors speculated that the enhanced confidence in reading, and the sense of enjoyment and achievement, were caused by being able to use a new technological device. The difficulties encountered by the participants were the text-to-speech feature (used only by one participant, due to the low quality of the system), and the number of steps and the level of fine motor skill required to activate the accessibility features. Similarly, in Caute *et al*. (2019), the use of Amazon's Fire 7 tablet was well accepted by the participants, as evidenced by the sharp disparity in reading material before and after the training and the use of the tablet. For instance, one participant read only the TV subtitles before the intervention, whereas during the intervention period, they were able to read the news on the BBC app, two short books and three full-length autobiographies.

Qualitative studies have investigated the experiences that PWA with acquired reading impairments have with devices such as e-readers (especially Amazon's Kindle) and audiobooks, and whether these tools are valuable compensative strategies for text comprehension (Knollman-Porter *et al*., 2015; Kelly *et al*., 2016; Kjellén *et al*., 2017). However, qualitative research does not provide data on possible comprehension improvements related to the use of audiobooks or e-readers. Nonetheless, the qualitative information from the

patients is encouraging, and also important to consider when thinking about supports for specific populations, since the end user must be engaged in using the tool in the first place.

Although these tools are not designed for PWA with acquired reading impairments, these patients do find benefits in some of their features. For instance, in 2017, Kjéllen *et al*. interviewed 12 patients with aphasia and literacy difficulties. The results of this study highlighted that each patient has their own preferences, and takes advantage of different features to support their writing or reading difficulties. For instance, some participants in this study have used, or are still using, supports such as text-to-speech software, audiobooks or electronic dictionaries when reading. In other studies, some participants report a rediscovered pleasure in reading novels when using the Amazon Kindle with text-to-speech (Knollman-Porter *et al*., 2015). Others are pleased that they can listen to long novels that they would not otherwise be able to read (Kjéllen *et al*., 2017; Kelly *et al*., 2016).

Other studies reported how patients favour the use of screen-reader applications (e.g. the iPad's Speak Selection) or computer-generated text-to-speech technology to independently access text they are interested in when using the device (Kelly *et al*., 2016; Knollman-Porter and Julian, 2019; Knollman-Porter *et al*., 2015). For instance, a participant in the study carried out by Knollman-Porter *et al*. (2015) reported using the iPad screen reader to make purchases online. For this patient, it has become very hard to navigate the Web, or to do any "reading", without a text-to-speech system.

Another study (Szabo and Dittelman, 2014) examining websites observed that participants particularly enjoyed their subscriptions to n2y (news-2-you; www.n2y.com). A subscription offers worksheets along with articles of different difficulty levels, and the facility to reproduce the content of the article out loud while the words are highlighted. A new article is uploaded

each week. In the case of the n2y website, the only information available is the degree of enjoyment of the patients; the authors provide no information on comprehension improvements.

Alongside the positive experiences, researchers also observed some difficulties associated with the use of high-tech mainstream tools. For instance, in Szabo and Dittelman's (2014) study, the authors investigated the use of embedded iPad features such as Reader (in Safari), Speak Selection and Siri, and everyday mobile applications used by PWA with acquired reading difficulties. The study focused on training patients on mobile apps and accessibility features in iPads, and investigating the satisfaction level and the real usefulness experienced by participants. Interestingly, the accessibility features embedded in the iPad were not easily accessible for people with aphasia (Szabo and Dittelman, 2014). For instance, the iPad provides Speaker Selection: an accessibility option that reads the text presented on the device's screen aloud. Although participants with reading difficulties reported a positive experience overall, they still encountered challenges in using this feature because it requires fine motor skills, which are often compromised in patients with aphasia (Szabo and Dittelman, 2014).

In Kjéllen *et al.*'s (2017) study, although the majority of the participants interviewed reported positive experiences in using, for instance, audiobooks or text-to-speech software, other participants reported difficulties in using high-tech reading or writing supports. In particular, one participant found the speech rate of audiobooks too fast.

4. Discussion

This paper aimed to review the literature on the technologies currently available to PWA with acquired reading impairments. In order to achieve this aim, we explored two research questions. The first of these focused on research into instruments explicitly designed to compensate for

reading difficulties associated with aphasia. The literature review revealed that research on technologies designed purposely for PWA with acquired reading impairments is lacking.

The second research question investigated the accessibility features of mainstream high-tech tools that are helpful for PWA when trying to access written material. This second question yielded more results than the first. Indeed, scholars have investigated how patients cope with their disability by adapting existing technology. Such research sheds light on how patients either resort to software designed for another population with special needs (e.g. ClaroRead™ for dyslexic individuals) or adapt existing mainstream technological features to their needs (e.g. text-to-speech systems embedded in iPads and smartphones). The accessibility features common to these devices that are most helpful for PWA when they try to access written material are a) the presence of text-to-speech system or a recorded voice, b) the option to see the text highlighted as it is read out loud by the device and c) the option to modify the text font and add blank space between lines and words to improve readability.

Combined modality – namely, the combination of speech and text – is a feature that reportedly helps PWA with acquired reading difficulties (Brown *et al*., 2019; Wallace *et al*., 2019). It seems to decrease the demands on working memory, thus promoting an improved performance in text comprehension as patients can focus their cognitive resources on understanding the content (McNeil *et al*., 1991; Murray *et al*., 1997; Wallace *et al*., 2019). The second recurring feature – that is, highlighting text as it is read aloud – is usually associated with text-to-speech systems, and is welcomed by patients with reading impairments as it allows them to follow the text easily. Despite the possibility that this feature can enhance comprehension, there still limited evidence for this as yet (Wallace *et al*., 2019). This last feature is one of the overt aphasia-friendly principles, together with simple sentence structure and vocabulary (Rose *et al*., 2003; Brennan *et al*., 2005; Worrall *et al*. 2005; Caute *et al*., 2016). Aphasia-friendly features help to reduce the visual and cognitive load (Caute *et al*., 2016). However, none of these tools

has been designed with this target population in mind. Therefore, in each of these tools, there is a particular aspect that does not conform to the needs of aphasic patients, thus causing them difficulties. For instance, the difficulties experienced by the patients in the studies considered in the review are a) the number of steps required to complete an action (e.g. from deciding to use an application to realising it successfully), b) the motor difficulties encountered in activating accessibility options (Szabo and Dittelman, 2014; Caute *et al.* 2016) and c) the length and complexity of the sentences that patients listen to, read or access in combined modality (Caute *et al.*, 2016; Knollman-Porter *et al.*, 2015).

Indeed, the literature review shows the variability in how PWA with acquired reading impairments benefit from assistive devices designed for another special-needs population – for instance, people with developmental dyslexia. Despite the undisputed help provided by these tools for some patients, they are not suitable for all PWA with acquired reading difficulties. Indeed, aphasia is a complex condition, with considerable variability in clinical pictures. It very often comes with auditory comprehension difficulties (Knollman-Porter and Julian, 2019) and with physical impairments that compromise fine motor skills (Szabo and Dittelman, 2014). Moreover, there might be underlying cognitive impairments, in areas such as attention, resource allocation, working memory and processing speed (Hula and McNeil, 2008; McNeil *et al.*, 1991; Neto and Santos, 2012; Mayer and Murray, 2012). These additional conditions could cause or exacerbate linguistic processing impairments. Besides, some external variables, as the quality of the artificial voice, can hinder auditory comprehension (Caute *et al.*, 2016; Hux *et al.*, 2017). Past research on aphasia and text-to-speech systems also considered the devices' speech rate as a variable that could compromise text comprehension (Kjéllen *et al.*, 2017). However, all current devices and accessibility features now provide the option to adjust the speech rate of the output voice.

The great diversity in clinical pictures of aphasia seems to call for software with a high level of flexibility and personalisation. For instance, some patients can present a low level of reading impairment, where the combined modality (written and auditory input) or the font adjustment might be sufficient (as in the case of ClaroRead™ or tablets' and e-readers' accessibility features). Other patients, meanwhile, can present severe reading difficulties where none of these supports would help. Moreover, PWA often have difficulties in processing long and complex sentences or low-frequency words via the auditory channel. Indeed, in these cases, it would not be sufficient to convert the text on the screen into speech, or to provide the option to follow the text in combined modality, if the text on the screen is long and articulated. Alongside strictly linguistic impairments, PWA often also experience cognitive impairments such as working memory or executive-function deficits (e.g. task monitoring and planning and organising actions), as well as motor impairments. These impairments hinder not only reading ability itself, but also the movements and actions required to activate and use a reading-support programme.

Another aspect that emerged from the study by Caute *et al.* (2016) and the authors' speculation on the results, is the importance of taking a broader perspective on the importance of literacy. Participants in this study provided positive feedback, even though there was no improvement in their reading comprehension. According to the authors, using assistive technology might have a positive impact not just on reading comprehension itself, but also on other aspects associated with it – for instance, on the sense of achievement that flows from learning new skills using a new tool. Moreover, this kind of success could boost self-confidence, facilitating social interactions that, in turn, are likely to improve patients' general wellbeing. Therefore, assistive technologies could improve quality of life not only through the canonical means – namely, better text comprehension – but also through side avenues involving self-confidence and sociality. These results might also suggest that the importance of literacy in a person's life

is not based exclusively on their ability to read (or write) in itself, but must also be understood in relation to others.

Taken together, these studies confirm that research on reading compensative tools to help PWA with acquired reading impairments is narrow. Moreover, the studies do not provide enough quantitative data about improvements in content comprehension. Indeed, the only quantitative studies on mainstream technology and reading comprehension are those by Caute *et al.* (2016, 2019). The qualitative research shows that there is variation in people's preferences, and that their preferences do not necessarily mirror the best modality to allow text comprehension. However, patients' preference is an important factor to take into account when studying aids for patients, as the end user must be engaged in using the tool or they will simply stop using it (Wallace *et al.*, 2019; Brown *et al.*, 2019).

Overall, the results of the review show that while the aphasia-friendly text adaptation of adjusting font size and line spacing is integrated into every device as an essential accessibility tool, the same cannot be said for the facility to convert the text into a simpler version. Usually, it is a caregiver or the speech therapist who executes this operation manually, giving many patients a sense of dependence and frustration (Dalemans *et al.*, 2010; Knollman-Porter *et al.*, 2015).

Research on PWA with acquired reading difficulties has yet to investigate the possibility for patients to select and simplify a text passage autonomously. However, the capability to modify complex and lengthy texts into simpler, shorter versions has already been developed in the field of natural language processing (NLP). In this area, research on automatic text simplification for populations with special needs has been ongoing for two decades, and continues to make remarkable improvements.

The examples of NLP tools such as Dyswebxia (Rello *et al*., 2014), Lexi (Bingel *et al*., 2018) or Simplext (Saggion *et al*., 2015) suggest that although the fields of NLP and language rehabilitation are separate, they can be successfully combined to provide helpful compensative methods. Indeed, new NLP technologies could potentially be adapted and integrated with aphasia rehabilitation and play a critical support role in overcoming issues that have hardly been covered as yet, such as compensative tools for PWA with acquired reading impairments. Technological advancements in NLP are evolving towards more customisable software that can conveniently be merged with research in aphasia. Indeed, the possibility of personalised text adaptations would represent a relevant improvement for PWA, as the difficulties experienced when reading or comprehending auditory speech can vary substantially across individuals. Therefore, flexible tools such as those already developed for other populations, such as dyslexic individuals, could also be highly desirable and beneficial for PWA with acquired reading impairments.

5. Conclusions

The findings of the review show an important lack of research on compensative tools developed for the population of PWA with acquired reading impairments. Most of the studies in the field are qualitative investigations that pertain to how patients with literacy difficulties tackle everyday tasks with mainstream technology, whereas two other studies measure the reading comprehension improvements associated with the use of an external tool (ClaroRead[TM], Amazon Kindle Fire and Amazon's Fire 7 tablet).

Interestingly, the results from the studies considered in this review paint a fairly diverse picture. In general, literacy appears to be a crucial ability in the majority of study participants' lives. Participants employ a wide array of devices in order to overcome reading difficulties, which underlines the importance of reading in everyday life. Interestingly, in some patients, enjoyment

and reading confidence improved independently from successful reading comprehension. Indeed, some patients experienced enjoyment and confidence purely from the sense of achievement associated with being able to use a new technological tool.

High-tech features, such as text-to-speech systems and the option to change the text font size, are recurring preferences that seem to facilitate text access significantly for these patients. These features, along with syntactic and lexical simplification, are among the elements recognised as helping PWA with acquired reading impairments access texts. Due to the observable benefit that participants derived from these two features, and from the use of high-tech tools in general, it would also be interesting to investigate what benefit (if any) the provision of automatic text simplification might have on patients' reading ability.

The additional facility to simplify words, sentences or texts of interest automatically could also help to engage PWA with more severe difficulties. Indeed, the studies discussed in the review mostly consider PWA with mild reading and auditory comprehension problems and minor cognitive impairments. It would be interesting to investigate whether adding automatic text simplification would result in a more inclusive tool, and also whether it would further improve reading comprehension in those PWA who already benefit from mainstream technologies.

Acknowledgements

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