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An Eye Tracking Study of Sentence Reading in Aphasia: Influences of Frequency and Context

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Declaration

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Abstract

Mild reading difficulties are a pervasive symptom in aphasia, but are little researched. Eye tracking research with neurologically healthy participants has demonstrated that reading is influenced by a number of information sources that are related to our experience with language. Two of these sources of influence, frequency and context, demonstrate that more probable words and structures are processed more quickly than those that are less probable. However, not much is known about probabilistic influences on the reading of people with aphasia at the sentence level.

Two eye tracking experiments were conducted to establish whether or not frequency and context influence reading for people with aphasia in a way that is parallel to that of neurologically healthy participants. The first experiment examined the influence of word frequency and context on visual word recognition at the sentence level. The second experiment examined the influence of argument structure frequency on the reading of temporarily ambiguous sentences. Specifically, target sentences appeared after a context that cued a specific verb meaning and probabilistically associated argument structure. The target sentence was either consistent with or at odds with that context.

The analysis of eye movements from both experiments revealed that people with aphasia have prolonged fixation durations and an increased proportion of regressions (backward fixations), indicative of their reading difficulties. Results from the first experiment demonstrated large effects of word frequency and context on both first pass and second pass eye movement measures by both groups. This suggests that frequency and context are related to both early and late processing stages of reading. However, differences were found between groups in a later processing stage where the aphasia group relied more on the context (top-down processing support) than the control group. The second experiment revealed that participants from both groups were sensitive to argument structure frequency when they read sentences that were temporarily ambiguous. Context cues facilitated the access of verb meaning and probabilistically associated argument structure, even though the individuals with aphasia showed delayed reading patterns. The context effect was found for both first pass and second pass eye movement measures, and was particularly strong for total fixation durations, which indicate re-reading behaviour.

Overall, the outcome suggests the importance of considering multiple factors in sentence reading. Reading and sentence decoding by neurologically healthy individuals as well as individuals with aphasia are not only influenced by syntactic factors, but are also sensitive to factors relating to our language exposure. Results from the aphasia group are consistent with constraint-based theories of sentence comprehension and with slowed or reduced processing accounts.

Chapter 1. Introduction

The process of reading consists of a complex relationship between visual, lexical, semantic and syntactic skills. Reading is incremental (Rayner & Clifton, 2009), meaning that at each moment in time, multiple information sources are integrated rapidly to establish the fullest possible interpretation. Some of these sources are closely linked to language, and some relate to our experience with language, that is, how often words and constructions are used (frequency), and in what context they occur (context or "predictability"). Words and structures that are more likely to occur due to their higher frequency and due to their predictability are processed more quickly (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Rayner, Ashby, Pollatsek, & Reichle, 2004). Such effects are believed to arise through varying levels of activation thresholds that words have in the mental lexicon or in their representation in a lexical network. High frequency words are activated more effectively since they – through more exposure – have lower activation thresholds than low frequency words (Morton, 1969). Similarly, the presence of contextual information reduces the amount of sensory information that is normally needed to activate the word (Morton, 1969). These factors of language experience are relevant as they may lead to predictions and expectations in reading, which may make reading fast and efficient.

The influences of word frequency and context are linked to different processes of visual word recognition. It is generally assumed that two types of information processes accomplish the visual recognition of words: bottom-up and top-down mechanisms. Processing visual characteristics of a word such as its length or shape is described as bottom-up; processing influences from a higher level such as meaning or the sentence context are considered top-down. Hence, word frequency is a bottom-up factor of processing, and the sentence context is a top-down factor processing. Since both factors are known to be robust influences on healthy silent reading, they have been integrated into various models of visual word recognition and reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; McClelland & Rumelhart, 1981; Morton, 1969; Seidenberg & McClelland, 1989). Frequency and context may not only facilitate visual word recognition, but they may also influence the interpretation of syntactic structures. When it comes to structural decoding, verbs are of specific interest. A verb can occur in different argument structures (e.g. transitive or intransitive), but may occur in some syntactic structures more often than others. The frequency of a verb in a certain syntactic structure is referred to as "argument structure frequency". This is a probabilistic factor that can influence the way people interpret a structurally difficult sentence such as a garden path sentence. Some psycholinguistic studies have revealed that even more subtle information inherent in lexical items can function as probabilistic constraints in sentence reading. The argument structure frequency of a verb can differ with verb sense, and readers have been shown to be sensitive to these form-meaning correlations (Hare, McRae, & Elman, 2003).

Influences of frequency and context on silent reading have been thoroughly studied in healthy reading using eye tracking (Garnsey et al., 1997; Kennedy, Pynte, Murray, & Paul, 2013; Radach & Kennedy, 2013; Rayner et al., 2004; Rayner, 1998; Trueswell, Tanenhaus, & Kello, 1993). In this paradigm, a camera sitting below a computer monitor films the reader's eye gaze while reading. The camera can track both pupil and corneal reflection, and this is how the position of the eyes on the monitor can be calculated. With eye tracking, processing difficulties are detected by prolonged gaze durations or by a greater than usual number of regressions, fixations that return to earlier positions in the sentence. Eye tracking is based on the assumption that there is an association between eye movements and cognitive processing such that eye movements allow us to make inferences about cognitive processes during reading (Rayner, Pollatsek, Ashby, & Clifton, 2012).

Reading may become less efficient after brain damage. Aphasia[1], which is an acquired language impairment after focal brain lesion such as stroke, can lead to difficulties with reading aloud as well as silent reading. Since aphasia varies in severity and type, reading impairments can similarly vary and manifest as difficulties in the recognition of single words, the comprehension of sentences, or reading comprehension at text level (Webster et al., 2013). Based on the *Western Aphasia Battery - Revised*, a standard aphasia assessment, seven subtypes[2] of aphasia can be distinguished (Kertesz, 2007). The subtypes are classified according to varying patterns of language impairments. The language by individuals with Wernicke's aphasia, a fluent type, is associated with a semantic impairment. It contains word substitution errors (paraphasias) and neologisms, and can in severe forms lead to incomprehensible jargon. Broca's aphasia, a non-fluent type, is the type of aphasia that has received the most attention in linguistic research. It is characterised by slow and effortful non-fluent speech with relatively preserved comprehension of simple language but difficulties with sentences that are grammatically challenging. The impairment of grammatical structure in Broca's aphasia is referred to as agrammatism. However, subtypes of

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[1] For a comprehensive introduction to aphasia see (Papathanasiou, Coppens, & Potagas, 2013)

[2] For a detailed description of syndromes see (Benson & Ardila, 1996; Huber et al., 2002)

aphasia often do not conform to proposed patterns. Further, the classification of aphasia subtypes does not generally include reading impairment. Therefore, the prevalent classification is not useful for this thesis.

A substantial amount of research has described oral word-level reading in aphasia based on cognitive neuropsychological models (Cherney, 2004; Dickerson & Johnson, 2004; Patterson, 1994, 2000; Rapcsak et al., 2009; Warrington & Crutch, 2007), and has linked patterns of reading impairment to methods of treatment (Ablinger, von Heyden, et al., 2014; Beeson & Insalaco, 1998; Beeson, Rising, Kim, & Rapcsak, 2010; Cherney, 2004; A. W. Ellis & Young, 1996; Hillis, 2002; Ska, Garneau-Beaumont, Chesneau, & Damien, 2003). However, most of our everyday reading is silent reading – reading sentences and text for comprehension. Compared to a large evidence base on silent sentence reading in the healthy population, knowledge regarding silent reading in aphasia is very limited. It is essential to investigate silent reading in aphasia in more detail, because it is the natural way of reading, and is linked to independence, the use of modern technologies, and is often associated with work and employability (Meteyard, Bruce, Edmundson, & Oakhill, 2015; Webster et al., 2013). A reading impairment can lead to a decline in quality of life (Knollman-Porter, Wallace, Hux, Brown, & Long, 2015), and hence reading ability is essential to restore quality of life for people with aphasia (Lynch, Damico, Abendroth, & Nelson, 2013).

Many people with aphasia (PWA) have mild to moderate reading or sentence comprehension impairments (DeDe, 2012a; Sung et al., 2011). PWA may, for example, have relatively well preserved comprehension skills, but reading can be slow and effortful (Beeson & Insalaco, 1998; Coelho, 2005; J. B. Lee & Moore Sohlberg, 2013). This leads to the question how reading with aphasia is different from reading by neurologically healthy individuals (NHI). As mentioned in the beginning to this introduction, healthy reading is influenced by factors that determine the probability of a word or a syntactic structure, such as frequency or context. There is evidence that frequency plays a major role in aphasia (Kittredge, Dell, Verkuilen, & Schwartz, 2008; Levelt, Roelofs, & Meyer, 1999). High frequency words like *house* tend to be more successfully retrieved in naming and reading aloud than low frequency words like *hostel*. Further, studies revealed that a sentence context can facilitate word retrieval or sentence comprehension in aphasia (Germani & Pierce, 1992; Pashek & Tompkins, 2002). Additionally, some recent research has shown that probabilistic constraints such as argument structure frequency not only influence reading in the healthy population, but also influence sentence comprehension in aphasia (DeDe, 2008, 2012b, 2013a, 2013c; Gahl, 2002; Gahl et al., 2003). To date, however, the evidence base is very limited. We do not know whether experience with language and hence factors such as frequency and context influence silent reading in aphasia, or whether reading and the influence of frequency and context are fundamentally different between language processing with and without brain damage. Most studies have not focussed on silent reading, and further, were mainly restricted to offline tasks such as the accuracy of sentence picture matching. It could be the case that reading in aphasia is less efficient because these factors are not as facilitative as in healthy reading. One may also assume that frequency and context are functioning similarly to healthy reading but evolve in a different pattern. Additionally, reading with aphasia might be less incremental than healthy reading as has been argued in relation to auditory comprehension (Hanne, Burchert, De Bleser, & Vasishth, 2015).

This thesis draws on evidence from psycho- and neurolinguistic research in order to explore the influences of frequency and context in reading for people with aphasia. The goal is to examine whether frequency and context facilitate silent online reading in aphasia. The first experiment investigates the influence of word frequency and contextual predictability on word recognition at the sentence level. The question is whether these influences facilitate the process of visual word recognition, and how they relate to each other. Studying the influence of word frequency and context in silent reading may indicate patterns of bottom-up and top-down processes in aphasia, and may enhance our knowledge of lexical processing such as lexical access and lexical integration.

The second experiment examines the influence of a sense-contingent verb argument structure frequency on the reading of sentences containing a temporary ambiguity. The aim is to find out whether associations between verb sense (cued by a context sentence) and verb argument structure facilitate reading, and whether they can function as cues to ambiguity resolution. Results regarding the potential influences on the interpretation of garden path sentences may shed more light on the use of different information sources/cues that guide comprehension. In addition, the eye movement analysis may indicate differences between the groups with respect to the time course of processing. This will enhance our knowledge of sentence comprehension theories in aphasia. Hence the experiments focus on lexical and structural predictions and expectations, and whether these are part of silent reading in aphasia and neurologically healthy individuals.

The analysis of eye movements is employed in this research, because (1) it allows the investigation of the underlying cognitive processes of reading, and (2) it has proven a highly successful methodology to understand healthy reading. Whilst other approaches require the person to make a response, for example by reading material aloud or performing a comprehension task, eye tracking allows us to make inferences about reading comprehension without any needed response. This makes eye tracking a valuable method to study silent reading in aphasia. Participants of this study are individuals who have a mild or moderate aphasia of any type. The motivation for including a heterogeneous group was that reading difficulties may occur with any type of aphasia as has been observed in previous work (DeDe, 2012a; Sung et al., 2011). Also, research has indicated that dividing people with aphasia into syndromes can be problematic (Caramazza, 1984; Marshall, 2010). Thus, the experiments in this thesis are group studies, but subsequent analyses are employed to examine individual differences.

The underlying assumption in this thesis is that the language system is flexible, dynamic, and influenced by our experience with language. As argued in usage-based theories, language is shaped by its use (J. Bybee, 2010), and the process of language comprehension is influenced by probabilistic constraints (Seidenberg & MacDonald, 1999). Aphasia can lead to difficulties with different aspects of language processing, but the aim of the system is to be as efficient and quick as possible. Thus, it is assumed that some sources of information are weighted more to compensate for others.

Following this introduction, Chapters 2 to 5 will acquaint the reader with the theoretical and methodological background to this research, and will explain the rationale of the experiments. Chapters 6 to 10 describe the materials used in the experiments, the methods and the results, and finally, provide a general discussion relating to both experiments.

The theoretical background is divided into two chapters, mirroring the two experiments employed in this thesis. **Chapter 2** introduces the process of visual word recognition, and explains how reading can be impaired after brain damage. The chapter summarises research on reading comprehension in aphasia at the text level, and describes how word frequency and context are factors that relate to bottom-up and top-down processing respectively. **Chapter 3** illustrates the study of sentences that are temporarily ambiguous. It provides an overview of the main approaches to sentence comprehension in the healthy population and in aphasia. Next to traditional approaches, the chapter also introduces a theory of sentence comprehension in aphasia that is usage-based. In **Chapter 4,** the method of eye tracking is presented in more detail. The first subsections of this chapter summarise what is known from eye movement research in healthy reading. Following this, research in aphasia that used eye tracking will be summarised, both for listening as well as for reading studies.

Chapter 5 explains the rationale of the two reading experiments. It summarises the research presented in the background chapters, and pinpoints the gaps in the literature. The chapter then explains how the experiments in this thesis will fill these gaps, and explains what this new research may contribute to the current stage of research.

Both Chapters 6 and 7 present Experiment 1 on the influence of word frequency and context in the reading of simple sentences. **Chapter 6** illustrates the development of the materials of the study, and explains how they were derived from several norming experiments. **Chapter 7** introduces the methods and presents the results, as well as a discussion of the findings. **Chapters 8 and 9** are devoted to Experiment 2 on the influence of sense-based verb argument structure frequency on ambiguity resolution in reading in aphasia. The materials and background norming studies are described in **Chapter 8**. Subsequently, **Chapter 9** describes the methods, results and the discussion of Experiment 2. **Chapter 10** ends the thesis with a general discussion that relates to the results from both experiments. It reflects on the implications of findings for theories of sentence processing in aphasia, while acknowledging some limitations of these experiments. Recommendations for future research are made, including suggestions relating to clinical practice.

Chapter 2. From visual word recognition to text reading

Reading is a highly complex process that involves the integration of visual, linguistic and cognitive skills. At the sentence or the text level, reading is influenced by attention skills and working memory (Chesneau & Ska, 2015; Coelho, 2005; Meteyard et al., 2015). Reading has been studied in various disciplines such as psycholinguistics, neurolinguistics, experimental psychology, computational neuroscience, and education (Purcell, Schubert, & Hillis, 2015; Riley & Kendall, 2013). This body of research led to an understanding of required subcomponents of reading that are conceptualised in a number of different reading models. Further, it has established some knowledge of different types of reading impairment in aphasia (Ablinger, von Heyden, et al., 2014; Damico & Nelson, 2010; DeDe, 2012a; Lynch et al., 2013; Mayer & Murray, 2002; Meteyard et al., 2015; Purcell et al., 2015; Riley & Kendall, 2013; Schattka, Radach, & Huber, 2010; Sung et al., 2011). Mild sentence and text level reading impairments in particular are common in aphasia (Coelho, 2005; Knollman-Porter et al., 2015; Meteyard et al., 2015), and a reduction of reading efficiency may even be a symptom that is present to some degree in nearly all people with aphasia.

This chapter provides the background to visual word recognition and reading in the healthy population as well as in aphasia, and focuses on semantic and lexical influences on sentence reading. If people with aphasia have compromised lexical-semantic skills, these may lead to slower word recognition, and might also affect sentence reading overall. The chapter begins with an overview of the process of visual word recognition, and describes cognitive neuropsychological models of reading, and how these have been utilised to classify different types of acquired dyslexia (2.1). The second subsection summarises the literature on reading comprehension in aphasia at the text level, including evidence on cognitive abilities that are important to reading (2.2). The third subsection first summarises lexical-semantic impairments in aphasia, and subsequently illustrates how word frequency and context relate to bottom-up and top-down processes of reading (2.3). An overview of word frequency and context effects in the healthy population as well as in aphasia will be provided. Overall, the overview of research in this chapter suggests that word frequency and context are factors that play a large role in aphasia. Hence, these factors may also influence the rate and efficiency of reading in aphasia. The final subsection summarises this chapter (2.4).

2.1. Visual word recognition and acquired dyslexia

Visual recognition and the comprehension of words is an essential part of text comprehension (Seidenberg & McClelland, 1989). Our understanding of how this complex process of word reading and comprehension unfolds has largely benefited from the study of reading impairments after focal brain damage, and has allowed a description of the cognitive processes underlying reading (Purcell et al., 2015). This description further contributed to the development of cognitive reading models (Purcell et al., 2015). This subsection describes the functional architecture of reading models, and summarises the subcomponents that are necessary for successful reading. It further provides a description of reading impairments after brain damage with a focus on types of dyslexia that are associated with aphasia.

2.1.1. Models of visual word recognition and reading

During language processing, the brain effectively moves from perception to meaning (Federmeier, 2007). In order to understand a written word, it has to be analysed visually, the stimulus has to be mapped with information that is stored in long-term memory, and finally, the meaning has to be derived (Federmeier, 2007). In reading aloud, phonological information has to be accessed and translated into phonemes. A number of visual word recognition models have been proposed to delineate the process of reading, referring to both reading aloud as well as silent reading. Examples of these are the *logogen model* (Morton, 1964, 1969), the *autonomous search model* (Forster, 1976, 1981), the *interactive activation model* (McClelland & Rumelhart, 1981), its successor the *dual-route cascaded model* (DRC, Coltheart et al., 2001), and the family of *connectionist models* (Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Most of these models divide the reading process into a number of required subcomponents or knowledge systems (Coltheart et al., 2001; Forster, 1976, 1981; Morton, 1964, 1969; Seidenberg & McClelland, 1989) which can again be part of at least two stages: the *pre-lexical* and the *lexical* processing stage (e.g. Purcell, Schubert, & Hillis, 2015). Some additionally refer to a *post-lexical stage*, which occurs after lexical activation, and involves the integration of the word into the sentence for text comprehension (Forster, 1981; Seidenberg, Waters, Sanders, & Langer, 1984).

The pre-lexical stage involves the computation of visual, i.e. orthographic information. Here, visual features are analysed, and become activated if they contain letters (Coltheart et al., 2001). Additionally, the letter, its position in the word, and the grapheme in the word are identified (Riley & Kendall, 2013). A grapheme consists of the letter(s) that represent a phoneme. For instance, *house* has five letters (h-o-u-s-e) and three graphemes (h-ou-se). In the DRC model, these processes are described as visual feature analysis and letter analysis (Coltheart et al., 2001). There is evidence that the representations at the letter level are abstract letter identities, meaning that they are independent of their visual form such as case, font or size (Purcell et al., 2015; Rastle, 2007).

During the lexical stage, a series of graphemes is mapped onto an orthographic representation, the word meaning is decoded, and potentially, its phonological information is accessed in the phonological lexicon. Models such as the logogen model and the DRC model propose that the lexical stage includes a lexicon referred to as "logogen system" (Morton, 1969) or the "orthographic input lexicon" (Coltheart et al., 2001) that incorporate word entries. In the logogen model, a word becomes activated if the visual information corresponds to the orthographic, phonological, semantic and syntactic information in the lexical entry, that is, if it reaches the needed activation threshold. The orthographic input lexicon in the DRC model contains all words that a reader is familiar with. The input lexicon allows the recognition of letter strings as known words that are stored in long-term memory (Purcell et al., 2015). For instance, *house* would be recognised and activated whereas the nonword *touse* would not. The DRC model additionally postulates a phonological output lexicon, which specifies the pronunciation of words (Coltheart et al., 2001). Like the input lexicon, this level contains the phonological forms of the words a reader is familiar with but not those of nonwords (Riley & Kendall, 2013). Further, the DRC model incorporates the semantic system where the meaning of the written word is accessed. For example, it would be determined that *house* refers to a place where people live in.

Next to these lexical components, some models of reading consist of additional levels specifying the output for reading aloud. After the activation in the logogen system, the word is sent to the output buffer for the articulatory response (Morton, 1969). Similarly to the output buffer in the logogen system, the DRC model incorporates a phoneme system in which the correct phonemes are activated to name the word out loud. The word *house* (or rather its activated phonological form), for instance, would activate the phoneme for /h/ in the first set, /aʊ/ in the second set, and /s/ in the third phoneme set.

Having laid out the functional architecture of some reading models, it becomes evident that there are different pathways to accomplish word reading. Since the DRC model and its variants are often referred to in the description of reading impairments after brain damage (Cherney, 2004; Purcell et al., 2015; Riley & Kendall, 2013), the three reading routes suggested by this model are summarised here (Coltheart et al., 2001). First of all, the model assumes a lexical semantic route. This proceeds from the visual analyses level to the orthographic input lexicon, via the semantic system, to the phonological output lexicon, and potentially, to the phoneme output. However, the information flow can also bypass the semantic system to directly move to the phonological output lexicon, this is referred to as lexical nonsemantic route (Coltheart et al., 2001). Both of these lexical reading routes can be employed to read familiar (both regular and exception) words that are stored in long-term memory (Purcell et al., 2015). However, only the lexical semantic route is used for reading comprehension. Importantly, the model also suggests a third route which is the grapheme to phoneme conversion route (Coltheart et al., 2001). This non-lexical route is used to read nonwords (Coltheart & Curtis, 1993) or unfamiliar regular real words (Schattka et al., 2010). During this route, a string of letters is converted to a string of phonemes and hence reading bypasses both the orthographic input lexicon as well as the semantic system. Hence, this route can only be used for oral reading but not for reading comprehension which would require meaning access (Riley & Kendall, 2013). This route is also referred to as sub-lexical (Purcell et al., 2015) or segmental reading route (Schattka et al., 2010). Healthy readers are able to switch between these routes dynamically.

However, not all models assert that orthographic knowledge is represented locally, with one unit representing one word (Rastle, 2007). Further, not all models assume that reading involves different reading routes. The family of connectionist models rejects the idea of a lexicon and proposes that knowledge representations are distributed in a lexical network (Plaut et al., 1996; Plaut, 1999; Seidenberg & McClelland, 1989). In connectionist models, reading of words involves the computation of orthographic, phonological and semantic codes (Seidenberg & McClelland, 1989). Each of these codes corresponds to a pattern of activation that is distributed over various units that interact with each other. Hence, these models do not refer to separate reading routes but assume that regular words, exception words and nonwords can be successfully activated by the network (Plaut et al., 1996). The system incorporates knowledge of correspondences between spelling-sound correspondences, and this knowledge is employed to read any letter string. The difference between words and nonwords is that the orthographic, phonological and semantic units interact differently for each of them (Plaut et al., 1996). The lexical network is not idiosyncratic to reading but is used for other aspects of language processing such as naming and lexical decision (Seidenberg & McClelland, 1989).

2.1.2. The mechanism of word recognition: serial vs. interactive models

The section above provided information about the functional architecture of reading models, and illustrated the different reading pathways that can be adopted, depending on whether the visual stimulus is a regular word, an exception word or a nonword. There are also other psycholinguistic variables, which can influence word reading performance that will be referred to in Section 2.3. In this section, the mechanism of word recognition will be briefly described, that is, how the information is transmitted through the different levels of representations (Rastle, 2007).

The process of word recognition can either be a search or it can be an activation process (Forster, 1989). The difference between these mechanisms lies in how the visual stimulus is compared to the lexical representations. Search models usually implement a serial comparison, whereas activation models typically implement parallel comparisons (Forster, 1989). In serial models such as the autonomous search model (Forster, 1976, 1981), visual word recognition involves a search or a verification process through a list of lexical entries, being complete once the representation of the word matches the word specification in the lexical entry (Forster, 1981). The search depends on the properties of the stimulus, and is independent of the context that the word occurs in even though the context can have a post-lexical influence on word recognition (Forster, 1981). Serial models do not implement interaction between levels of processing but are regarded as being modular.

Examples of interactive models are the interactive activation model by McClelland and Rumelhart (McClelland & Rumelhart, 1981), the dual-route cascaded model (DRC) (Coltheart et al., 2001), and the family of connectionist models (Plaut, 1999; Seidenberg & McClelland, 1989). Interactive models differ from modular models by assuming that instead of a search mechanism, words or units become activated at different levels of reading, and this can be in parallel, i.e. at the same time. The DRC model is a cascaded model of reading. It assumes that each reading route consists of interacting units. If any unit or subcomponent gets activated the information flows on to other subcomponents (Coltheart et al., 2001). This is also referred to as excitation, and is conceptualised in the model by bidirectional arrows between the subcomponents representing semantic, phonological and orthographic information. Hence, the activation in the orthographic input lexicon can be influenced by phonological and semantic information (Rastle, 2007). Also, knowledge from a higher-level unit such as a word can facilitate the recognition of a letter at a lower-level unit (Rastle, 2007). Interestingly, the activation of a word can be influenced by semantic knowledge even though it is not dependent on it; this is consistent with data from reading impairments showing that a word can be recognised even if semantics and phonology are severely impaired (Rastle, 2007). The layers of the model further interact through inhibition which means that if one unit is activated, the activation of other units is inhibited (Coltheart et al., 2001).

The connectionist models postulate even more interaction. None of the orthographic, semantic, and phonological units are considered independent, and can interact during all phases of word recognition (Seidenberg & McClelland, 1989). If a representation is built at one level, it influences the construction of a representation of another level and vice versa (Seidenberg & McClelland, 1989). In these models, the mechanism of word recognition is a comparison between the visual input and the information that has been acquired previously (Riley & Kendall, 2013). Further, reading is influenced by contextual factors that can arise from syntactic, semantic and pragmatic constraints (Seidenberg & McClelland, 1989). The activation of words is gradual, and the units interact via weighted connections (Plaut et al., 1996). How much values the weights carry is dependent on the system's experience with written words and their meanings (Plaut et al., 1996).

2.1.3. Acquired dyslexia

Reading models have also added to our understanding of how word reading can be impaired after brain damage, and have enabled us to distinguish different types of acquired dyslexia. Acquired dyslexias are associated with difficulties reading words out loud and/or comprehending them. Models of visual word recognition and reading such as the DRC model (Coltheart et al., 2001) have been very important in aphasia research as they can account for observed reading characteristics. The performance of readers is analysed against the model in order to make inferences regarding which routes in the model might be affected, leading to the reliance on a different route to complete the task (Patterson, 1994). The syndrome classifications of acquired dyslexia are traditionally made on the basis of error types as well as observation of accuracy on reading tasks such as reading words and nonwords (Greenwald, 2001). More recent research has also benefited from using eye movements to analyse acquired dyslexias (Ablinger, Huber, Schattka, & Radach, 2013; Leff et al., 2000; McDonald, Spitsyna, Shillcock, Wise, & Leff, 2006; Schattka et al., 2010; Schuett, Heywood, Kentridge, & Zihl, 2008). There is evidence for reading impairments at different levels and impairments in different reading routes that have been proposed by models (Purcell et al., 2015). A major distinction is made between peripheral and central types of dyslexia. The next two subsections provide an overview over each type of word reading impairment.

2.1.3.1 Peripheral dyslexia

The peripheral dyslexias can result from impaired visual processing or from impairments in the connections between visual processes and linguistic processes (Schattka et al., 2010). These are reading impairments that are not related to aphasia even though they may co-occur in principle (Riley and Kendall, 2013). Examples are *neglect dyslexia*, *hemianopic dyslexia* or *letter-by-letter reading* (Ablinger et al., 2013; Leff et al., 2000; McDonald et al., 2006; Primativo, Arduino, De Luca, Daini, & Martelli, 2013; Rayner & Johnson, 2005; Schuett et al., 2008; Schuett, Kentridge, Zihl, & Heywood, 2009b; Vallar, Burani, & Arduino, 2010). Neglect dyslexia is associated with a unilateral spatial neglect that leads to a difficulty in detecting and identifying objects in the space contralateral to the lesion (Primativo et al., 2013). In reading tasks this implies that parts of the word cannot be identified, resulting in omission and substitution errors in the reading of words, sentences and text (Vallar et al., 2010).

Hemianopic dyslexia is a reading difficulty that occurs if a unilateral homonymous hemianopia, a visual field impairment on one side, affects parafoveal and/or foveal vision to the extent that it hinders word identification (Schuett et al., 2009b). According to Schuett and colleagues (2008), hemianopic dyslexia is amongst the most common forms of peripheral dyslexia with a prevalence of about 15% of neurological rehabilitation inpatients. The reading impairment is associated with slow and inefficient reading as well as disrupted preparation of reading saccades[3] (Leff et al., 2000; McDonald et al., 2006; Schuett, Kentridge, Zihl, & Heywood, 2009a).

Lastly, *letter-by-letter reading* or *pure alexia* is associated with the effortful encoding of letters in a serial fashion, leading to a word length effect in reading (Ablinger et al., 2013; Rayner & Johnson, 2005). Letter-by-letter readers make more fixations and smaller saccades compared to average readers (Rayner & Johnson, 2005). Even though letter-by-letter reading is here and elsewhere identified as a peripheral type of dyslexia (Huber, Poeck, & Weniger, 2002), its impairment level is the connection between the letter and the grapheme level which corresponds to the pre-lexical stage. It could hence also be classified as a type of central dyslexia (Meteyard et al., 2015).

2.1.3.2 Central dyslexia

Central dyslexias are higher-level reading impairments that are directly related to aphasia (Schuett et al., 2008). They originate from an impairment in linguistic

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[3] A saccade is the rapid forward movement of the eyes during reading or during any other type of visual process. Saccades link fixations, which are resting moments of the eyes during which information is accessed. A more detailed description of eye movements is provided in Chapter 4.

processing, and tend to result from left-hemisphere damage (Cherney, 2004). Central acquired dyslexias can be associated with difficulties in the pre-lexical stage involving letters or graphemes, or with the lexical level involving word recognition difficulties (Purcell et al., 2015). All three reading routes suggested by the DRC model (Coltheart et al., 2001) can be disrupted. Depending on the different symptoms and proposed source(s) of the reading errors, the traditional syndrome classification of acquired dyslexia distinguishes three types: *deep*, *phonological* and *surface dyslexia*.

Deep dyslexia is associated with a disruption of the grapheme to phoneme conversion route, i.e. the sub-lexical or segmental reading route (Cherney, 2004; A. W. Ellis & Young, 1996; Warrington & Crutch, 2007). If this route is impaired, the reader will have difficulties reading nonwords and unfamiliar words (A. W. Ellis & Young, 1996). A difficulty with reading nonwords can be minor, or it can lead to the complete inability to do it. Dickerson and Johnson describe a case study of JAH who attempted to read nonwords, but was unable to read any of the 24 items she was given (Dickerson & Johnson, 2004). However, the error pattern of patients with deep dyslexia suggests that not only the segmental reading route, but also both lexical reading routes are impaired (Riley & Kendall, 2013). The hallmark of deep dyslexia is the frequent production of semantic errors next to visual errors and morphological errors (Cherney, 2004; Dickerson & Johnson, 2004; A. W. Ellis & Young, 1996; Plaut & Shallice, 1993; Riley & Thompson, 2010; Warrington & Crutch, 2007). JAH, for instance, read 'shut' for *door* (semantic error), 'bell' for *belt* (visual error), and 'thriller' for *thrill* (morphological error) (Dickerson & Johnson, 2004). Further, many patients with deep dyslexia show better reading of concrete and imageable words than abstract words (A. W. Ellis & Young, 1996; Riley & Thompson, 2010).

The non-lexical reading route is also disrupted in phonological dyslexia, and reading is mainly dependent on the use of the direct lexical route (Cherney, 2004). Due to the disrupted non-lexical reading route people with phonological dyslexia can not read nonwords or unfamiliar words, but can read familiar words well (Cherney, 2004; A. W. Ellis & Young, 1996; Patterson & Lambon Ralph, 1999; Rapcsak et al., 2009). The comprehension of written words is preserved, but readers often make visual errors (Cherney, 2004; A. W. Ellis & Young, 1996; Hillis, 2002). Since the lexicon is affected, frequency and lexicality effects can occur (Cherney, 2004; A. W. Ellis & Young, 1996; Hillis, 2002; Rapcsak et al., 2009; Riley & Kendall, 2013). For instance, lexicalisation errors such as reading "soot" for *soof* can occur when people with phonological dyslexia attempt to read nonwords (A. W. Ellis & Young, 1996). These lexical as well as visual errors are regarded as evidence for an over reliance on the lexical reading route (Riley

& Kendall, 2013). Due to a symptom overlap between phonological and deep dyslexia syndromes, some regard deep dyslexia as a severe form of phonological dyslexia, assigning both reading impairments along a continuum (Crisp & Lambon Ralph, 2006; Glosser & Friedman, 1990).

Finally, it is assumed that surface dyslexia results from a difficulty accessing the lexical reading route so that readers rely too heavily on the non-lexical route (Cherney, 2004; A. W. Ellis & Young, 1996; Hillis, 2002). Difficulties in employing the lexical reading routes can be due to impairments in the phonological output lexicon, the orthographic input lexicon and/or in the connection between the input lexicon to the phonological output lexicon, either via semantics or via the direct route (A. W. Ellis & Young, 1996). Being constrained to the intact non-lexical route means that there is an advantage in reading nonwords and words with regular pronunciations, but words with irregular spellings might be regularised (Hillis, 2002; Plaut et al., 1996). For instance, words such as *pint* may be read to rhyme with "hint" (A. W. Ellis & Young, 1996). If people with surface dyslexia have access to semantics, they may understand a read word based on the activated phonological representation (Purcell et al., 2015).

The description of patients with deficits in these three reading routes supports the assumption that there are separate cognitive processes for reading different types of stimuli. However, it should be noted that different types of acquired dyslexia can equally be accounted for by using connectionist models. Deep dyslexia can be seen as revealing weakened connections between semantic and phonological information, and phonological dyslexia can be interpreted as reflecting weakened phonological processing (Riley & Kendall, 2013). According to Plaut and colleagues (1996), surface dyslexia is associated with using the phonological pathway that relies on support from the semantic pathway, which is however impaired due to brain damage. More on connectionist accounts of acquired dyslexia can be found in Plaut and colleagues (1996), Crisp and Lambon Ralph (2006) as well as Patterson and Lambon Ralph (1999).

The classification system of acquired dyslexia has been adopted widely and is the basis for many reading assessments and treatments (Cherney, 2004). However, it also has some limitations. Inferences regarding the reading route are mostly based on the observed error types (Schattka et al., 2010). For example, segmental errors may signal an over dependency on the non-lexical route, and lexical and/or semantic errors may indicate that the reader relies on the lexical reading route (Ablinger, Huber, & Radach, 2014; Schattka et al., 2010). Further, since the classification system is based on inferences, it is hypothetical. Even though certain errors may suggest the use of certain reading routes, we don't know whether the hypothetical correspondence is correct. A method that might provide additional insight is eye tracking (Ablinger, Huber, et al., 2014; Schattka et al., 2010). Schattka and colleagues illustrated that eye tracking can support the characterisation of acquired dyslexia, and can distinguish between the pathologically preferred reading routes. They compared the eye movement patterns of six people with dyslexia to a group of seventeen control participants. Schattka and colleagues used a list of words that were of medium length (7–8 letters) or were long (11–12 letters), and that was controlled for various linguistic variables. Participants read words aloud whilst their eyes were tracked. Analysing the spatial saccadic pattern (i.e. the movement of the eyes progressing through the text), Schattka and colleagues found that three of the patients had landing positions of initial saccades that were mostly between letter position 2 and 4. This is similar to the pattern of the control participants and corresponds to the "optimal viewing position", indicative of a lexical reading route. The other three patients showed saccade peaks that were shifted to the extreme left of the word, with initial saccades landing on the first letter or just before it. According to the authors, this pattern suggests a more dominant use of the non-lexical segmental reading route. These two different patterns of spatial parameters coincide with two distinct reading routes described in the reading models. For four of the patients, the reading route suggested by the eye movements was consistent with their classification as deep dyslexia or surface dyslexia. Hence the use of the lexical or non-lexical use was supported by their linguistic error pattern as well as by the eye movements. For the other two patients this comparison between the error pattern and the eye movements could not be made, as they made few reading errors. However, even with these two readers, eye movements were suggestive of the underlying reading strategy. Hence, spatial eye movement parameters could distinguish between reading routes that are suggested by reading models, even if patients made few overt errors.

Additionally, Ablinger and colleagues revealed that particular types of errors are not necessarily associated with certain reading routes (Ablinger et al., 2014). One of the participants from their study (SW) showed saccade landing positions at the centre of the word, at two separate testing points. This indicates the use of a lexical, holistic reading strategy, as argued by Schattka and colleagues (2010). However, the majority of his errors were phonological errors, which would, if eye movements were not considered, be taken as evidence for a non-lexical segmental reading route. It was not evident what the source of the phonological errors where. Ablinger and colleagues argue that eye movements are more reliable in reflecting the underlying reading routes that people with acquired dyslexia were using, and can also reveal the reading route used during the recovery process (Ablinger et al., 2014). Both studies advanced reading research in acquired dyslexia with the use of eye tracking. However, they had a small number of participants, and more research is needed using eye tracking to understand reading in aphasia.

In summary, models of visual word recognition describe the subcomponents of reading such as visual, pre-lexical and lexical processing stages. Reading models can be utilised to identify reading impairments after brain damage, particularly to classify types of acquired dyslexia since they show that reading impairments reflect the loss of hypothesised processing routes, and overdependence on others. Reading patterns in aphasia have also, in turn, validated the models of reading. Further, some recent research has provided additional insights on acquired dyslexias through the use of eye tracking. However, a limitation of the models is that they are based on single-word, decontextualised reading (Lynch, Damico, Damico, Tetnowski, & Tetnowski, 2009; Mayer & Murray, 2002). In contrast, most everyday reading involves the reading of text. The reading models are hence not sufficient to explain the whole story of reading (Lynch et al., 2009; Mayer & Murray, 2002), and lack the consideration of other areas that are important to reading: the integration of world knowledge and cognitive factors (Mayer & Murray, 2002). As a result of these limitations, research conducted particularly in the last years made an attempt to improve this lack of knowledge by providing studies on sentence and text level reading comprehension. These will be the subject of the next subsection.

2.2. Reading comprehension in aphasia at the text level

Reading research in aphasia has primarily targeted word level reading in acquired dyslexia (Meteyard et al., 2015). However, the core of reading is the silent reading and comprehension of text. Text reading involves both written sentence comprehension and the comprehension of larger written texts. This research can be broadly divided into three areas: studies that illuminate the process of written sentence comprehension and compare it to auditory comprehension, work that focuses on cognitive skills that are required for successful reading at the sentence and the text level, and research that explores types of reading support that can facilitate reading comprehension in aphasia. This subsection will describe each of these areas briefly.

2.2.1. Aspects of written comprehension

The research on sentence comprehension has for a long time been dominated by focusing on the auditory modality so that research on written sentence comprehension is scarce (DeDe, 2013b). Nevertheless, studies have demonstrated that many individuals with aphasia have less efficient reading skills than healthy readers, even in structurally simple sentences (DeDe, 2012a, 2013c; Sung et al., 2011). A group study by Sung and colleagues (2011), for example, showed that people with aphasia have greater difficulties in processing or integrating linguistic written information than healthy participants. Thirty participants with aphasia and thirty neurologically healthy individuals took part in the study. Sung and colleagues used the self-paced reading version[4] of the *Computerized Revised Token Test-Reading-Word Fade, (CRTT-R*-WF, McNeil et al, 2008). Sentences from this test are controlled for word frequency and word length across the stimuli sentences. The sentences varied by the number of adjectives before the nouns (e.g. *Touch the green square and the black square* vs. *Touch the big green square and the little black square*). The aim of the study was to investigate whether the number of adjectives ("adjective padding") influenced reading times on the noun, which is where the linguistic integration occurs. These reading times were compared to the time required to read a determiner, which functioned as a baseline condition. For both groups, results showed longer reading times on the nouns than on the determiner as well as on the noun occurring after two adjectives compared to just one. Interestingly, this result is inconsistent with a previous study (Berndt, Mitchum, & Wayland, 1997). Berndt et al. did not find an influence of adjective padding (*stubborn, friendly*) on the processing times by people with aphasia. They did, however, find increased errors in a sentence-picture matching task when adding prepositional phrases (e.g. *with the black umbrella*). Sung and colleagues speculate that the different result might be due to the different methods used, i.e. using online reading measures might be more sensitive towards these differences than offline tasks such as sentence-picture matching. Further, Sung and colleagues' results showed that the people with aphasia had longer reading times than the healthy control participants overall, particularly for the noun region. With results from a large aphasia group, this study provides at least some evidence that reading in aphasia is sensitive to processing costs, and is less efficient as compared to healthy readers.

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[4] In the self-paced listening and the self-paced reading paradigm, sentences are divided into segments. The participants listen to or read these segments at their own speed, pressing a button when they finished one segment and would like to proceed to the following one. Listening and reading times are analysed for segments of the sentence, and these are interpreted as reflecting processing demand.

Two recent studies examined modality effects in sentence comprehension using self-paced reading and listening tasks (DeDe, 2012a, 2013b). DeDe (2012a) investigated effects of both word frequency and modality on sentence comprehension impairments in people with aphasia. For auditory comprehension, frequency effects were greater for PWA compared to controls. However, in reading comprehension there was much variability with some PWA showing exaggerated word frequency effects and others showing reverse effects. The findings suggest that lexical access is less stable in written comprehension than auditory sentence comprehension (DeDe, 2013b). In contrast, in a study on the influence of syntactic complexity on auditory and written sentence comprehension (DeDe, 2013b), results were not modality-specific for PWA. This indicates that modality differences are more likely to occur in lexical processing (as measured by word frequency effects in the study above) than in syntactic processing (as measured on long distance dependencies such as object relative sentences). According to DeDe (2013b), both word-level and sentence-level processing draw on a combination of bottom-up and top-down influences. However, lexical access is predominantly dependent on the bottom-up information; the auditory or visual information is accessed first, then the top-down information from the context plays a role. Thus word-level processing may reveal differences in how semantics is accessed from the perceptual signal. The auditory and visual signal can be selectively impaired, and this can lead to modality-specific effects. Alternatively, in syntactic parsing, the top-down influences include syntactic and semantic expectations generated from the sentence context. These are then validated by the bottom-up information coming from the lexical item. Thus the syntactic processer does not directly draw on the bottom-up information, and sentence comprehension is less likely to differ between modalities. Further, another area of reading research has focused on authentic reading in naturalist settings (Lynch et al., 2013, 2009). This has exemplified a meaning-based approach to reading that takes the context, the reader's background knowledge and their use of inferences and predictions into consideration. By context, Lynch et al. refer to reading data from multiple sources that are both authentic and elicited. For instance, they collected data from lunch dates, museum visits, and clinical settings, and filmed reading from authentic texts and reading tests. Essentially, the reader uses his/her own strategies to construct meaning from the text. However, strategy use and inference building is assumed to reside at a subconscious level so that the reader can focus on comprehension. Lynch and colleagues (2013) argue for the importance of using different contexts in authentic reading to analyse performance. Meaning-based approaches may be better than single word processing models to describe the complex process of reading that involves not only linguistic and cognitive but social aspects as well.

2.2.2. Cognitive contributors to reading

Another area of research focuses on cognitive skills that are required for the successful reading of sentences (Caspari, Parkinson, LaPointe, & Katz, 1998; Sung et al., 2009) and of texts (Chesneau & Ska, 2015; Coelho, 2005; Mayer & Murray, 2002; Meteyard et al., 2015; Sinotte & Coelho, 2007; Webster et al., 2013). These studies illustrate that attention, working memory, as well as executive functions, are cognitive processes involved in the reading process. Sung and colleagues (2009) for instance examined the relationship between verbal working memory and sentence-level reading in aphasia (Sung et al., 2009). They compared verbal working memory capacity (as measured in a listening sentence span task), aphasia severity, and overall severity of the reading impairment. The *Computerised Revised Token Test* (McNeil et al., 2008) for reading (CRTT-R) and listening (CRTT-auditory) was used as it uses decontextualised linguistic material such as shapes and colours, but at the same time changes the processing load by adding extra linguistic material such as padding adjectives. The CRTT-R, as mentioned earlier in Section 2.2.1, consists of commands such as *Touch the big green circle*. These commands get systematically more difficult with the most complex being *Touch the big black square unless you have touched the little red circle*. Three versions of the written CRTT-R were used: full-sentence condition, self-paced word-by-word reading with the words staying on the screen once revealed, and self-paced word-by-word reading with the disappearance of words when they were read. Results confirmed the hypothesis that working memory influences sentence comprehension. The results from the working memory span task significantly predicted the overall performance on the reading version of the CRTT, but only in the condition that presented sentences word by word that then faded out. The authors suggest that this condition was correlated to memory span because linguistic information was shown over a limited time course, leading to greater working memory demands. Further, the group with lower working memory capacity showed more difficulties than the higher working memory group with more complex subtests of the CRTT, which employ prepositional phrases and/or adverbial phrases. Results are consistent with another study that demonstrated a positive correlation between working memory capacity and reading comprehension (Caspari et al., 1998). The correlation result was obtained after measuring working memory in aphasia with an adapted version of Daneman and Carpenter's reading span task (Daneman & Carpenter, 1980).

Even though reading at the sentence level requires cognitive skills in addition to linguistic skills, cognitive skills are particularly needed to understand texts (Chesneau & Ska, 2015; Meteyard et al., 2015; Webster et al., 2013). A study by Meteyard and colleagues (2015) focused on text comprehension in aphasia in order to elucidate component processes of text reading, and to identify what type of underlying linguistic and cognitive impairments have an impact on text reading. The investigation involving four people with chronic aphasia (time post-stroke was between 3 and 5 years at the time of testing) revealed a mixed picture of text reading profiles. One participant showed difficulties with inferencing. Another participant had persistent comprehension impairments at the word level with difficulties in lexical-semantic access. Further, he had a mild impairment of working memory that also affected his inferencing abilities. The other two participants with aphasia were slow readers and had difficulties reading aloud. Additionally, they were impaired in sentence comprehension and showed a reduction of working memory skills. They were however better in reading at the text level, possibly as the context allows a gradual build up of information over time (Meteyard et al., 2015). In summary, the study suggested that text level reading comprehension can result from semantic-lexical access impairments as well as from reduced working memory skills associated with the ability to make inferences whilst reading.

Finally, Chesneau and Ska investigated text comprehension and cognitive function in a group of five people with ‘residual’ aphasia, which refers to a level of language skills that falls between mild aphasia and non-impaired language, and can often not be determined by clinical assessments (Chesneau & Ska, 2015; Jaecks, Hielscher-Fastabend, & Stenneken, 2012). The participants had no persisting linguistic impairment, but complained about comprehension difficulties at discourse level. The investigation showed that each PWA had deficits in text comprehension. First, all had difficulties recalling the microstructure of the text: they could not recall the details of the semantic content of the text. Second, two PWA also had difficulties with the recall of the macrostructure, i.e. referring to the main ideas of the text. Third, three PWA showed a deficit in episodic memory, and all five had a reduced digit span evident of reduced working memory capacity. These results indicate that text comprehension is dependent on different types of memory. Lastly, several PWA also had difficulties in executive functioning. Altogether, this study indicates that difficulties in text comprehension can be due to a combination of reduced cognitive skills.

2.2.3. Reading support in aphasia

Additionally, some research exhibited a number of reading strategies that can help the reader with aphasia to understand written text (Cocks, Pritchard, Cornish, Johnson, & Cruice, 2013; Knollman-Porter et al., 2015; Lynch et al., 2013). Cocks et al. revealed that a strategy-based treatment results in positive gains in reading rate, accuracy, comprehension and confidence. They focused on a single-case reading therapy with a client who had mild reading difficulties in addition to a cognitive impairment. The treatment incorporated strategies around highlighting, summarising (e.g. after each paragraph) and making mind-maps (e.g. tracking core aspects of the text such as who, where and what). Lynch and colleagues (2013) conducted a study with three people with chronic aphasia to examine what types of strategies people with aphasia use in reading. Employing a qualitative research design, reading performance was videotaped, ethnographic interviews conducted, and participant observations were made in daily settings. Outcomes revealed the use of at least 28 different strategies. Some of these were: sampling (only parts of the text are read), prediction (made on the basis of background information), experiential appropriation (context use), or pacing (reducing the reading rate). Knollman-Porter et al. (2015) carried out a phenomenological study to gain information about the individual feelings and preferences of people with aphasia regarding various types of reading support and strategies. They found that all six individuals that took part in the study had individual preferences of reading support and reading strategies. This support assisted their reading comprehension even though none of the participants re-gained the reading level that they had before the onset of their aphasia.

Lastly, some researchers manipulated the reading environment, endeavouring to reduce linguistic, visual and possibly cognitive demands involved in reading to benefit the people with aphasia. Some of these studies, for example, explored the benefits of reading support through the use of aphasia-friendly material (Brennan, Worrall, & McKenna, 2005; Rose, Worrall, Hickson, & Hoffmann, 2011; Rose, Worrall, & McKenna, 2003), by using pictures to support comprehension (Dietz, Hux, McKelvey, Beukelman, & Weissling, 2009) or by examining the support of technology (Dietz, Ball, & Griffith, 2011).

On the whole, the section above illustrated that recent research on text reading comprehension has widened our knowledge of reading difficulties in aphasia. This research shows that sentence and text reading is less efficient than healthy reading, and is particularly slowed if processing costs are increased. Further, a study comparing written to auditory sentence comprehension suggested that modality effects may occur when lexical access is measured: as lexical processing is largely dependent on bottom-up processes, which can be selectively impaired in the different modalities. Finally, text level studies of reading have identified cognitive processing components that are likely to influence reading comprehension. Whilst attention, working memory and executive function may all impact reading comprehension, most studies exhibited that verbal working memory in particular can be reduced in aphasia, with a negative influence on reading comprehension. This research supports studies in healthy reading that have indicated the role of working memory (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Daneman & Carpenter, 1980; Just & Carpenter, 1992), as well as non-reading studies in aphasia that have studied the contribution of working memory skills to language processing (Christensen & Wright, 2010; Friedmann & Gvion, 2003; Haarmann, Just, & Carpenter, 1997; N. Martin & Reilly, 2012; Miyake, Carpenter, & Just, 1994; Wright, Downey, Gravier, Love, & Shapiro, 2007; Wright & Shisler, 2005). One other interesting aspect revealed by the text level research was that text level reading comprehension difficulties can be affected by lexical-semantic access impairments. This is not surprising as semantic-lexical impairments hamper visual word recognition, which is the basis of text comprehension (Seidenberg & McClelland, 1989). However, not much is known about the impact of lexical-semantic impairments on sentence or text reading in aphasia. This is in contrast to reading research in psycholinguistics where lexical and semantic influences on reading have been at the centre of reading research (Calvo & Meseguer, 2002; Dambacher, Kliegl, Hofmann, & Jacobs, 2006; Juhasz & Rayner, 2006; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner et al., 2004; Rayner, Slattery, Drieghe, & Liversedge, 2011; Traxler & Tooley, 2007). The next and final subsection of this chapter will summarise lexical-semantic impairments in aphasia, and describe how these may be related to bottom-up and top-down processes of word recognition.

2.3. Bottom-up and top-down influences on reading

Silent sentence reading has been subject to thorough investigation in healthy reading using the analysis of eye movements (Radach & Kennedy, 2004, 2013). This research has demonstrated that reading consists of both bottom-up as well as top-down processes (Dambacher, 2009). Bottom-up processing starts with the visual analysis of the word and then proceeds to higher order processing. Top-down processing allows the early integration of higher order influences that come from the lexicon, the context, or world knowledge for example. These processes are often studied by examining two factors that represent these processes: word frequency and context (Dambacher, 2009). Word frequency relates to bottom-up processing since it characterises the visual form of the word, and context relates to top-down processing since it presents a higher order influence. Word frequency is often regarded as an index of the ease of lexical access whereas word predictability is often thought to be an index of the ease of lexical integration or semantic processing in general (Dambacher et al., 2006). These lexical-semantic factors are amongst the strongest ones to influence reading (Dambacher et al., 2006). They relate to our experience with language, and determine how likely words are to occur in English overall, and within a sentence.

The following subsection will summarise lexical-semantic impairments in aphasia. If a reader presents with lexical-semantic impairments, it can be expected that this leads to differences in bottom-up and top-down processing as compared to a reader who has unimpaired lexical-semantic processing. Since reading comprehension is dependent on lexical and semantic access, deficits in lexical access are likely to influence reading comprehension, even if such impairments are mild. An interaction between reading skill and the effects of word frequency and predictability has already been shown in an eye tracking study in healthy reading (Ashby, Rayner, & Clifton, 2005). This made evident that even very mild differences in the underlying cognitive processes for lexical access and integration can be revealed by an analysis of eye movements (Ashby et al., 2005).

Subsequently, three subsections will serve to explain the influences of word frequency and context in more detail, and to discuss their time course of processing. Each subsection will first refer to evidence from psycholinguistics, and then summarise the research from neurolinguistics. Findings will be reported from a variety of tasks such as naming and auditory comprehension. These are relevant and informative since on the one hand, lexical and in particular semantic impairments are not modality-specific, and on the other hand research on written language is limited. Drawing on evidence from psycholinguistic research, this subsection will also discuss issues of timing, or when factors may potentially exert an influence on reading. Finally, the following section will consider whether these factors work independently or whether they may interact.

2.3.1. Lexical-semantic impairments

There is evidence that many people with aphasia have lexical and/or semantic impairments, so differ from controls in the time taken to process lexical knowledge (Ferrill, Love, Walenski, & Shapiro, 2012; Grindrod & Baum, 2003; Laurinavichyute, Ulicheva, Ivanova, Kuptsova, & Dragoy, 2014; Love, Swinney, Walenski, & Zurif, 2008; Mack, Ji, & Thompson, 2013; Myers & Blumstein, 2005; Prather, Zurif, Love, & Brownell, 1997; Thompson & Choy, 2009; Utman, Blumstein, & Sullivan, 2001; Yee, Blumstein, & Sedivy, 2008). In reading aloud, the impact of lexical-semantic impairments is evident in the reading patterns of people with deep dyslexia. As described in Section 2.1, people with deep dyslexia over rely on the lexical-semantic reading route that is disrupted. This results in the production of semantically related errors (Hillis, 2002). Successful reading comprehension is dependent on the lexical and semantic access of words and their integration into a sentence context. Hence, difficulties in lexical-semantic processing or the timeline of their activation can have an impact on reading comprehension.

A number of priming studies have investigated lexical access in aphasia (Ferrill et al., 2012; Love et al., 2008; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995; Milberg & Blumstein, 1981; Prather et al., 1997; Prather, Zurif, Stern, & Rosen, 1992; Utman et al., 2001). In a lexical decision paradigm, a priming effect occurs when the reaction time to the lexical decision task is faster if the target word was immediately preceded by a semantically similar word (the prime) than when it was preceded by an unrelated prime (Prather et al., 1997). A priming effect is taken as evidence that the prime word facilitated word recognition of the target word (Prather et al., 1997). This means that lexical priming can reflect the strengths of connections between lexical-semantic associations in the mental lexicon (Prather et al., 1997). A number of studies have found that people with Broca's aphasia show either reduced or slowed effects of automatic priming (Milberg et al., 1995; Prather et al., 1992; Utman et al., 2001) whereas those with Wernicke's aphasia show priming effects at a normal activation time course (Milberg et al., 1995; Milberg & Blumstein, 1981). Delayed priming effects for people with Broca's aphasia are consistent with the slowed lexical activation hypothesis according to which people with Broca's aphasia are delayed in the time course of lexical activation (Ferrill et al., 2012; Love et al., 2008; Prather et al., 1997).

However, other studies revealed that both non-fluent and fluent types of aphasia are associated with impaired lexical activation patterns (Prather et al., 1997; Yee et al., 2008). Prather and colleagues (1997) compared lexical priming in one person with Broca's aphasia and one with Wernicke's aphasia. In order to understand the time course of lexical activation, they used the list priming paradigm. In this paradigm, a sequence of words and nonwords are visually presented continuously without pauses in between. The lists are interspersed with target words that are semantically related (e.g. *cabbage-lettuce*). The task was to decide as quickly as possible whether the letter string is a word or a nonword (lexical decision task). The interstimulus interval (ISI) was varied to find out at what ISI automatic priming occurs. Both participants completed the task with six different ISIs. Priming for the participant with Broca's aphasia was significant at the 1500ms ISI. This supports the slowed lexical activation hypothesis as studies with healthy elderly participants show a priming effect at an ISI of 500ms, with a subsequent decline. Priming for the participant with Wernicke's aphasia was significant at all ISIs between 300 and 1100ms. The early priming effect is consistent with the priming effects of healthy adults, but the persistent activation is different to the decline that would normally be observed. According to Prather and colleagues the difficulty in reducing the activation may suggest that Wernicke's aphasia is associated with an impairment of inhibition processes, which can impact comprehension processes, as too much but no specific information is available.

Further evidence for the finding that aphasia is associated with the dynamics of lexical activation is provided by eye tracking studies. Yee and colleagues investigated lexical-semantic processing impairments by people with Broca's and Wernicke's aphasia (Yee et al., 2008). In a series of three eye tracking experiments, participants heard a word and were asked to select this word from a screen showing the target word, a related distractor and a non-related distractor. In the first experiment, the distractor was a semantically related word (e.g. *banana*) next to a target word (e.g. *cherry*). The second experiment included a phonological onset competitor (e.g. *tulip*) next to a target (e.g. *tuba*). In the third experiment, Yee and colleagues examined the lexical access of a target word (*hammock*) next to a semantic onset competitor (*nail,* via *hammer*). First of all, both the control participants and the PWA showed more fixations on the semantically related word than the nonrelated distractor. This suggests that they were able to map a heard word to its lexical-semantic network. However, the other two experiments revealed that both aphasia groups differed from the control group in their pattern of lexical activation. The people with Broca's aphasia did not fixate more on the phonological onset competitor or on the semantic onset competitor than the unrelated picture even though the control participants did. Hence the PWA showed reduced competitor effects compared to the controls. The people with Wernicke's aphasia on the other hand were more likely to fixate the two distractors than the control participants. According to Yee and colleagues these results indicate that both aphasia groups show deficits in lexical access if they are faced with a situation of lexical competition. However, the people with Broca's aphasia show reduced levels of activation and those with Wernicke's aphasia exhibit increased levels of activation. Regarding the people with Broca's aphasia, the results do not support the hypothesis of delayed lexical access as there were no competitor effects, not even at a later time point. The results from the people with Wernicke's aphasia could be due to a difficulty in suppressing lexical activation as proposed by Prather et al. (1997), but could equally be explained by delayed deactivation.

The results shown by the people with Broca's aphasia as summarised above are also congruent with an auditory semantic priming study using a lexical decision task (Utman et al., 2001). Here, target words and nonwords (e.g. *dog*) were preceded by a semantically related prime (e.g. *cat*), a semantically unrelated prime (e.g. *ring*), or a semantically related prime in which one acoustic feature was altered to be more difficult to access. The ISI was either 50 or 250ms. The control group showed a small and short-lasting reduction in semantic priming if presented with the acoustically manipulated prime at the 50ms ISI. This was independent of the locus of the acoustic distortion in the word, and independent of whether a lexical competitor was present (e.g. *pill > bill*), or not (e.g. *peace > /biys/)*. The participants with Broca's aphasia however showed a large and a long-lasting reduction in priming if the acoustic distortion was word-initial. Further, semantic priming was influenced by the locus of the acoustic distortion and the presence of a lexical competitor. The priming effect was reduced if the altered prime had no lexical competitor (e.g. *peace* > /biys/). If the altered prime had a lexical competitor (e.g. *pill* > *bill*), priming was completely eliminated. This suggests that, if activation levels are reduced in aphasia, the bottom-up levels of activation for words with word-initial acoustic alteration may not be sufficient to overcome lexical competition (Utman et al., 2001). This would mean that the target word as well as the lexical competitor becomes activated, hence the lexical processing system has difficulties with settling on the lexical target. Semantically related words may thus not lead to a priming effect. However, if the prime has no lexical competitor that inhibits the activation of the target word, it can still be activated even if the input is distorted (Utman et al., 2001).

While the studies summarised above examined the process of lexical access in aphasia, other research has indicated that lexical processing impairments result from difficulties in lexical selection or integration (Dickey, Choy, & Thompson, 2007; Grindrod & Baum, 2003; Laurinavichyute et al., 2014; Swaab, Brown, & Hagoort, 1998; Thompson & Choy, 2009). This type of lexical impairment is located at a later point in processing, that is, after lexical access (Laurinavichyute et al., 2014). Two studies investigated the time course of processing a lexical ambiguity (Grindrod & Baum, 2003; Swaab et al., 1998). In an experimental study using event-related potentials, Swaab and colleagues demonstrated that people with Broca's aphasia have intact and fast lexical access, but are delayed in integrating lexical context information in a timely manner. People with aphasia and healthy controls listened to sentences containing a lexically ambiguous word in a sentence final position, followed by a target word (e.g. *river*). In order to examine whether context influences processing of a target word, ambiguous words (e.g. *bank*) appeared in three different contexts (concordant: *The man planted a tree on the bank*, discordant: *The man made a phone call to the bank*, unrelated condition: *The boy petted the dog on its head*). People with aphasia could successfully activate both meanings of the ambiguous word when the ISI was short and when the context was concordant (100ms), but unlike controls, they could not select the contextually concordant meaning. Evidence for lexical access was shown by a significant N400 amplitude reduction in the concordant as compared to the unrelated and discordant condition. Evidence for inability in lexical selection/integration was the finding that people with aphasia showed a significant difference in the N400 amplitude between unrelated and discordant conditions, suggesting that both meanings were still activated. In contrast, the controls were able to suppress the contextually inappropriate meaning. At the long ISI (1250ms), the people with aphasia were able to perform the contextual selection process successfully just like the control participants. According to the authors this result suggests that Broca's aphasia is associated with a delay in integration of lexical information.

Additionally, Laurinavichyute and colleagues (2014) investigated the time course of lexical processing as well as the influences of contextual bias in Russian, using an eye tracking whilst listening paradigm. As will be described in more detail in Chapter 4, eye movements can be recorded whilst people look at an array of pictures on the screen, and whilst they listen to linguistic stimuli. The proportion of looks on pictures can be informative with regard to comprehension and processing load. Laurinavichyute and colleagues compared people with fluent aphasia, non-fluent aphasia, and controls. Stimuli sentences contained lexically ambiguous words in a sentence context. The context biased the interpretation of the ambiguous word towards one or the other meaning (target or competitor). Half of the experimental sentences initially biased only one meaning, and ambiguity was resolved in a later disambiguation region. This enabled an investigation of both the process of ambiguity resolution as well as reanalysis. First of all, under a slowed speech rate, all participants showed an influence of the context bias by fixating the target picture more than a competitor when the context promoted the target meaning of the ambiguous word. This result suggests that people with non-fluent and fluent types of aphasia were able to perform successful lexical access and selection, in contrast to the finding reported by Swaab et al. (1998).

An explanation of the difference in finding may be that non-fluent participants in the study by Swaab and colleagues had a more severe type of aphasia than the participants in the study by Laurinavichyute and colleagues. Results did suggest, however, that people with non-fluent aphasia had reduced levels of lexical activation as was argued by Utman and colleagues (2001). This was evident as the non-fluent participants showed slower activation of the meanings of the ambiguous word, particularly with regard to the competitor. The people with fluent aphasia showed some underactivation of the target meaning in all analysis regions, reflecting difficulties in the inhibition processes. This suggests that there was lexical interference among activated meanings. The people with non-fluent aphasia further had an impairment in the reanalysis process, wherein they showed decreased comprehension as well as lower target advantage scores in the disambiguation region. These results indicate that non-fluent aphasia is associated with an impairment of activating multiple interpretations in a later processing stage. The lexical impairment in fluent aphasia is mainly increased activation levels but difficulties in suppressing non-relevant lexical information.

In summary, online studies using lexical and semantic priming tasks as well as event-related potentials and eye tracking revealed that lexical activation and/or lexical integration patterns[5] in aphasia can either be reduced, delayed or can reflect difficulties in the inhibition of information once activated. Even though there is no consensus about the exact nature of the lexical processing impairment, at this point it is an important observation that there are differences in the time course of lexical-semantic activation in aphasia as compared to healthy controls. The next subsection will provide an overview on the influences of word frequency and context in the healthy population as well as in aphasia.

2.3.2. Word frequency

As described in the beginning of Section 2.3, reading consists of both bottom-up as well as top-down processes. Bottom-up processing starts with the visual analysis of the word. One of the strongest types of bottom-up influences on reading is the frequency of a word (Dambacher et al., 2006). Written word frequencies can be obtained from corpora or databases containing written words, such as the CELEX lexical database (Baayen, Piepenbrock, & Gulikers, 1995) or the SUBTLEX database (Brysbaert & New,

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[5] It has further been argued that there is a connection between the speed of lexical activation and successful syntactic processing (Burkhardt et al., 2003; Ferrill et al., 2012; Love et al., 2008). According to Love et al. (2008), particularly people with Broca's aphasia are delayed in lexical processing, as evidenced by better auditory comprehension results when the input is presented at a slower-than-normal rate of speech (Love et al., 2008). The influence of lexical-semantic impairments on sentence parsing will be described in more detail in Chapter 3.

2009). The CELEX database comprises 17.9 million tokens, and consists of sources such as books or newspapers. The SUBTLEX database is based on 40-50 million words based on film subtitles. These list the word frequencies as occurrences per million. A word frequency effect occurs when high frequency words, i.e. words of common occurrence, exhibit a processing advantage over low frequency words, which we are less exposed to. The effect was first described more than sixty years ago by showing that the time needed to visually recognise a word depends on its relative frequency (Howes & Solomon, 1951). In this experiment, words were briefly flashed in front of the participant's eyes. The duration of flashes (and of word exposure) was slowly increased, and participants were asked to state which word they saw after each flash. The high frequency words required shorter exposure durations for correct naming as compared to the low frequency words. The facilitative effect of word frequency has now long been recognised and integrated in models of word recognition, speech production and comprehension (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt et al., 1999; Morton, 1969). It is widely accepted that a word is recognised after it has reached a certain threshold of activation. High frequency words have a lower baseline activation level compared to low frequency words, because threshold levels are reduced with frequency of exposure to a word (Morton, 1969). This means that the access to entries of high frequency words is faster than that of low frequency words (Coltheart, 2005; Jescheniak & Levelt, 1994). The same principle underlies connectionist models even though the wording is different. According to connectionist models, high frequency words are advantaged in recognition as the pathway between corresponding units are strengthened every time they are activated together (Whitney, 1998).

In the healthy population, word frequency effects have been described in naming, repetition, lexical decision, and spoken word recognition (Dahan, Magnuson, & Tanenhaus, 2001; Jescheniak & Levelt, 1994; Monsell, Doyle, & Haggard, 1989; Yap, Tse, & Balota, 2009). Word frequency is also a robust and reliable factor influencing eye movements. High frequency words attract shorter fixation durations and are more likely to be skipped in reading than low frequency words (Altarriba, Kroll, Sholl, & Rayner, 1996; Calvo & Meseguer, 2002; Inhoff & Rayner, 1986; Juhasz, Liversedge, White, & Rayner, 2006; Juhasz & Rayner, 2003, 2006; Just & Carpenter, 1980; Kennedy et al., 2013; Pollatsek, Juhasz, Reichle, Machacek, & Rayner, 2008; Rayner et al., 2004; Rayner, Binder, Ashby, & Pollatsek, 2001; Rayner & Duffy, 1986; Rayner & Raney, 1996; Reingold, Yang, & Rayner, 2010; White, 2008). As will be explained in more detail in Chapter 4, shorter fixation durations reflect decreases in processing load whereas longer fixation durations reflect increases in load respectively. Most of these reading studies find that word frequency has an influence on early processing stages as reflected by early eye movement measures (e.g. gaze duration) even though effects can spill over onto the next word (Rayner & Duffy, 1986), and are not always restricted to early measurements (Reingold et al., 2010). These findings indicate that reading in the healthy population is highly sensitive to the characteristics of visual input. The written word form entails information that is related to its probability of occurrence. The more often a word occurs in the language the more likely it is to be encountered, and the easier it is to process the word.

Word frequency effects in aphasia

In comparison to the healthy population, frequency effects can be exaggerated in aphasia (DeDe, 2012a; N. Martin, 2013), because aphasia and lexical impairments can lead to words having weaker lexical representations. This implies that words generally need more activation in order to be accessed. Activation may suffice for high frequency words that have lower activation thresholds but may not be strong enough to access low frequency words.

Much evidence for word frequency effects in aphasia stems from production tasks at the word level – from naming, repetition, and word reading (Bose, Lieshout, & Square, 2007; Bub, Cancelliere, & Kertesz, 1985; Cherney, 2004; A. W. Ellis & Young, 1996; Goodlass, Hyde, & Blumstein, 1969; Kittredge et al., 2008; Nozari & Dell, 2009; Schattka et al., 2010; Whitworth, Webster, & Howard, 2005; Zingeser & Berndt, 1988) as well from visual word recognition tasks such as lexical decision (Gerratt & Jones, 1987). These studies show robust effects of word frequency. High frequency words are produced with more accuracy or with faster reaction times than low frequency words. Low frequency words also lead to more semantic and phonological errors, for example in naming (Kittredge et al., 2008). This may be because words with low frequency are more likely to have semantically related words that are of higher frequency which are accessed instead (Nickels & Howard, 1994). There is also some evidence for word frequency effects in aphasia from online measurements that are not susceptible to meta strategies (Schattka et al., 2010). Schattka and colleagues investigated the influence of word familiarity/word frequency[6] on reading aloud in acquired dyslexia using eye tracking. The study involved six readers who either used a lexical or a non-lexical reading route. Word frequency/familiarity influenced first gaze durations in the lexical

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[6] The authors argue that both word familiarity and frequency have a very similar influence on reading as shown in previous the eye tracking literature (Rayner et al., 2004).

readers but not in the segmental readers. Lexical readers showed more fixations, longer mean fixation durations, and longer re-fixation times on low familiarity words compared to high familiarity words.

Importantly, word frequency effects are not limited to the word-level. There is some evidence that word frequency also influences sentence comprehension in aphasia (DeDe, 2012a). Eight individuals with aphasia (fluent and non-fluent) and eight control participants took part in a study using self-paced listening and self-paced reading. This allowed an analysis of the online process of sentence comprehension. Stimuli sentences (taken from Juhasz, Liversedge, White, & Rayner, 2006) were simple and contained target words varying in frequency. Results indicate that response times in both modalities were sensitive to the manipulation of word frequency. In listening, the PWA showed a larger word frequency effect than NHI, and in reading, word frequency was an overall trend effect. The effect of word frequency on reading may have been less strong than in listening, because the PWA showed more variability in reading than in listening. Some participants showed strong word frequency effects and others showed a reverse frequency effect. Consistent with other research arguing for a lexical origin for comprehension impairments in aphasia (e.g. Love et al., 2008; Thompson & Choy, 2009), DeDe concluded that the word frequency effects point to weakened lexical representations, which may affect the speed of lexical access and lexical integration, contributing to sentence comprehension impairments. The above study revealed that (1) low frequency words exacerbate comprehension difficulties and can impair the comprehension even of syntactically simple sentences, (2) word frequency manifests in both auditory and written tasks, (3) online processing measures are more sensitive to effects of word frequency than offline measures such as accuracy, and (4) the influence of lexical deficits on sentence comprehension can occur in both fluent and non-fluent aphasia.

Even though word frequency effects are an established phenomenon in aphasia, they are not observed in every study and for every individual. As already mentioned above, some individuals with aphasia show a reversed frequency effect (Almaghyuli, Thompson, Lambon Ralph, & Jefferies, 2012; DeDe, 2012; Marshall, Pring, Chiat, & Robson, 2001), and some studies found no word frequency effect (Jefferies & Lambon Ralph, 2006; Nickels & Howard, 1994). These studies are interesting, because they indicate that the word frequency effect may interact with other factors and aspects of language. A reverse frequency effect might be linked to a semantic impairment (Marshall et al., 2001). Marshall et al. observed an inverse effect of word frequency for an individual with a semantic impairment and jargon aphasia. The effect was evident in both naming and sentence completion. The participant also employed low frequency words in spontaneous speech, for example saying *Daimler* for *car* (p. 36). The authors suggest that trying to produce a high frequency word might lead to the activation of several competitors that block access to the target. Low frequency words on the other hand are highly distinctive and do not share many semantic features with other words. They therefore stimulate fewer competitors and are easier to name. Almaghyuli and colleagues (2012) also suggest a semantic explanation for a reverse frequency effect. They observed a reverse frequency effect in someone with aphasia and an associated multimodal semantic impairment. The reverse frequency effect appeared in a synonym judgment task for items with high imageability but not for medium and low imageability items. The authors argue that high frequency items occur in more variable contexts and thus need more executive control to make semantic decisions. Low frequency words on the other hand occur in less variable contexts and it therefore takes less executive control to access their semantics.

In summary, there is evidence that word frequency plays a major role in aphasia, and some limited evidence shows that word frequency may influence the reading speed and the comprehension of simple sentences. However, frequency effects are not universal or unidirectional. This further implies that word frequency is not an isolated factor, but may relate to other aspects of language such as semantic processing. One example of a semantic variable is the sentence context. The influence of context in aphasia will be described in the following section.

2.3.3. Context

The context of a word in a sentence exerts a top-down influence on its recognition. A context effect occurs in reading when words that are predictable within a sentence context exhibit shorter processing times than words that are unpredictable in a sentence context. The predictability of a word can be ascertained by closure tasks in which participants are given a sentence fragment. Participants are asked to complete the fragment, and the proportion of times a word is used as a completion conforms to its predictability rating. If visual word recognition was a process that is strictly bottom-up, then an influence from context would not be expected (Whitney, 1998). In fact, the influence of a context on word recognition might seem counterintuitive. As Whitney puts it, if the goal of word recognition is to access meaning, then how can the meaning of a word – the end product – influence the early stage of lexical access?

However, many studies using semantic priming and eye tracking have shown that the context as a top-down factor does influence word recognition (Becker, 1980;

Neely, 1991; Rayner et al., 2004, 2011). As argued by Swinney and colleagues, by now, no one would question the fact that context has an influence on lexical processing, but the question is *when* and *how* such effects arise (Swinney, Prather, & Love, 2000): a point that will be taken up in the following subsection on the time course of processing.

Most reading models have routes or connections that are bi-directional in order to account not only for bottom-up but also for top-down influences (A. Ellis, 1993). In the logogen model, the influence of context is embedded similarly to word frequency. Context can increase the activation of a lexical entry (Morton, 1964). Hence words that are predictable in a given context receive a high level of activation and are accessed at a faster speed than words that are not predictable in the context. However, as mentioned above, context has no influence on the visual word form, meaning that the earliest stage in visual word recognition is only a bottom-up process. Connectionist models assign top-down processes much greater relevance. They argue that both bottom-up and top-down processes influence word recognition, and both processes are connected. In connectionist models, context refers to semantic, pragmatic and syntactic constraints (Seidenberg & McClelland, 1989). These can influence the construction of representations at the semantic level. Since the semantic level is linked to all others, context effects can be pervasive throughout the model.

Similarly to word frequency effects, many eye tracking studies revealed strong effects of a context (or predictability) on the length of fixation durations in reading, and on whether a word is fixated or skipped. Words that are highly predictable receive shorter fixation durations than those that are unpredictable (Altarriba et al., 1996; Calvo & Meseguer, 2002; Ehrlich & Rayner, 1981; Kennedy et al., 2013; Rayner et al., 2004, 2001, 2011; Rayner & Well, 1996; Zola, 1984). Since words that are highly predictable can be anticipated, readers skip them more often than unpredictable words (Kliegl et al., 2004; Rayner et al., 2001). These studies show that readers are sensitive to the context words appear in, and they can predict upcoming words if the sentence context is constraining (for auditory processing see also (Altmann & Kamide, 1999)).

Another source of context effect can stem from associations between a noun and a verb and vice versa (Ferretti, McRae, & Hatherell, 2001; McRae, Hare, Elman, & Ferretti, 2005). It is argued that verbs encode information about possible and prototypical thematic roles, and so generate expectations regarding nouns in sentence comprehension (Ferretti et al., 2001). However, as pointed out by McRae and colleagues (2005), a verb is not the only constraint on expectations in sentence comprehension. The knowledge of the roles of verbs is acquired through event knowledge (for example we know that the verb *accuse* takes an agent because we have experienced that people accuse others), and nouns that designate salient participants should then activate event knowledge as well, resulting in the ability to predict a corresponding verb (McRae et al., 2005). McRae and colleagues conducted a priming study to investigate whether a noun can prime information of a class of events. They primed verbs with either typical (e.g. *nun-praying*) or atypical thematic roles (e.g. *sniper-praying*). Participants were presented with word lists, and for each trial, they read the first presented word silently (prime), and read the second word aloud. The naming latencies and mispronunciations of the second word in each trial were analysed. Results showed that verbs that were preceded by related primes were named more quickly than when verbs were preceded by an unrelated noun. This was the case for each of the thematic roles. Hence, noun verb priming showed that event knowledge leads to a reader's expectation of upcoming concepts.

Another study by Edmonds and Mizrahi (2001) examined whether noun verb priming effects are maintained in older typical adults. They focussed on word priming of verbs (with agents and patients primes), and the word priming of agents and patients (with verb primes). Instead of oral word reading, Edmonds and Mizrahi used a lexical decision task, as they planned to replicate the study with people with aphasia who may have difficulties reading aloud. For the young group, results revealed that reaction times were significantly faster for related pairs than for unrelated pairs, regardless of whether nouns or verbs were primed. Priming effects were also evident for the older group, although not for all pairings. The older participants showed significant priming effects when a patient primed a verb as well as when a verb primed a patient. However, these effects did not occur for agent prime pairings. Nevertheless, these findings are relevant here as they provide more explanation regarding the nature of context effects. They show that verb information generates expectations regarding nouns (through encoded information about prototypical thematic roles), and nouns can generate expectations regarding verbs (through the activation of event knowledge that is linked to particular verbs). In the two studies summarised here, these noun-verb links were due to event knowledge that the reader has accumulated through the learning of verb-noun associations.

Context effects in aphasia

As with word frequency effects, context effects can be magnified for individuals with aphasia. However, the 'context effect' is derived from multiple factors. It can stem from world knowledge (e.g. as semantic plausibility), syntactic cues, phonological cues, or semantically related words in a sentence. In this thesis, the focus is on meaning from a sentence context. A sentence context may increase the activation of words that are predictable within that context compared to those that are unpredictable.

In aphasia, context effects have been mainly described in relation to word retrieval. For some individuals who present with word finding difficulties it is easier to produce a word if a relevant sentence frame is given, or if word retrieval is linked to connected speech rather than to confrontation naming (Mayer & Murray, 2003; Pashek & Tompkins, 2002; Pierce & Wagner, 1985; Pierce, 1991; Zingeser & Berndt, 1988). Twenty individuals with various types of aphasia as well as ten control participants took part in the study by Pashek and Tompkins (2002). All completed an object naming and an action naming task as well as a video narration task. Responses were analysed for accuracy, word class and mean proportion of word finding difficulty. The control participants and thirteen individuals with aphasia showed an advantage in connected speech over confrontation naming. They showed fewer word finding difficulties in connected speech. In the study of Pashek and Tompkins the benefits of context were not tied to specific types of aphasia. Other studies have produced different findings. In one study, for example, a word production advantage in connected speech over confrontational naming was only observed for people with Wernicke's aphasia (Williams & Canter, 1982).

Different explanations for the observed context effects have been proposed in the literature. Zingeser and Berndt propose that production of words in sentences may have been improved through multiple semantic cues. These could derive from semantically related nouns in the sentence, the larger (non-)linguistic context as well as the syntactic context. Similarly, Pashek and Tompkins (2002) suggest that the context effect accrues from the facilitation of semantic, phonological and syntactic factors as well as the probabilistic co-occurrence of words (Pashek & Tompkins, 2002). The way that lexical items are associated with each other may have an effect on production. Hence, probabilistic constraints may have facilitated the word choices in the video narrations (Pashek & Tomkins, 2002). However, reduced word finding difficulties in connected speech could also be explained by the fact that connected speech has more options of word choice. Therefore, PWA may have produced alternative words whereas in confrontation naming a specific target has to be elicited.

Context effects have also been described in oral reading. Mitchum et al. compared the oral reading of words in sentences with list reading in four individuals with fluent aphasia and phonological dyslexia (Mitchum, Haendiges, & Berndt, 2005). Two of the four participants with aphasia read significantly more words correctly in sentences as compared to lists. In order to account for this difference in performance, Mitchum and colleagues carried out additional analyses and came to the conclusion that the advantage of the reading-words-in-sentence-condition arose because the context provided information about the word's grammatical class. Both patients who revealed a context effect also showed a grammatical class effect: in list reading, fewer errors matched the grammatical class of the target words, but in sentence reading, many errors matched the target word class.

Further studies report context effects in sentence comprehension tasks (Hough, Pierce, & Cannito, 1989; Pierce & Wagner, 1985; Pierce, 1988, 1991). It has long been known that individuals with aphasia who have difficulties understanding sentences often rely on context (Marshall, 2002). The context can not only facilitate word recognition, but can provide semantic and pragmatic cues to help understanding sentences that are syntactically challenging, such as for example passive sentences. When these cues are not useful as in semantically reversible sentences (e.g. *The cat is chased by the dog*), sentence comprehension often breaks down (semantic constraint hypothesis, Caramazza & Zurif, 1976). However, if such semantically reversible passive sentences are presented after a semantically supportive sentence context, comprehension can be augmented (Pierce & Wagner, 1985). Pierce and Wagner compared the facilitation of a sentence context (semantically supportive and non-supportive) on the auditory comprehension of reversible active and passive sentences. An example of a semantically supportive context is: *The man tries to avoid a wild pitch*, with the reversible passive target sentence: *The man is hit by the ball* (question: *Which one was hit?*). An example of the semantically non-supportive sentence is: *The boy and the man are playing checkers*. Here, the target reversible passive sentence was: *The man is beaten by the boy* (question: *Who was beaten*?). Results showed that the semantically supportive context sentences influenced the comprehension of the reversible passive sentences but not the active sentences. In contrast, the non-supportive sentences did not significantly enhance comprehension. The semantically supportive context provided enough semantic constraints to determine which noun phrase is the agent and which is the object. Hence, a context sentence provided prior to a challenging target sentence can augment the comprehension of the latter. However, this facilitation effect was only observed for those participants with aphasia whose comprehension of reversible passive sentences was poor. According to the authors, this suggests that people whose comprehension skills are near ceiling or mildly impaired do not need the context sentence to support the interpretation process, but those with poor comprehension skills do. Note that this does not necessarily mean that people with good comprehension skills are not affected by a context at all. In the healthy population the context has been shown to influence the speed of comprehension but not the offline result. Hence, it is possible that people with aphasia with good comprehension skills are affected by a context, but that it only influences the speed of processing as might be shown in more sensitive measures such as eye tracking.

Interestingly, the influence of a context has been shown to differ, depending on whether it comprises a single sentence or a narrative. Whereas in the study summarised above, the sentence context had to be semantically supportive to increase accuracy, a narrative can be facilitative even if it is not predictive (Germani & Pierce, 1992; Hough et al., 1989). The facilitative effect of a narrative has been shown on the comprehension of reversible passive sentences both for auditory processing (Hough et al., 1989) as well as for reading comprehension (Germani & Pierce, 1992). Germani and Pierce compared the written comprehension of reversible passive sentences in three different conditions: a) presented in isolation, b) preceded by predictive narratives, and c) preceded by non-predictive narratives. The predictive narratives included some semantic cues as to who might be the agent or object in the reversible sentence, whereas the non-predictive narratives only introduced the characters. Participants answered more questions correctly in both narrative conditions as compared to when the target sentence was presented in isolation. This result is different to the findings by Pierce and Wagner (1985), who found that the semantically supportive sentence context increased comprehension, but the non-supportive, i.e. non-predictive one did not. According to Pierce (1991), this may be because the context acquaints the listener with some of the target nouns and creates expectations towards actions. Hence, people with aphasia can allocate more processing resources to the syntactic decoding when they hear the passive construction. A single context sentence, however, has to be predictive in order to be facilitative, presumably because a single sentence does not provide enough topic information to reduce processing costs (Pierce, 1991).

A recent study examined the facilitative effect of a semantic context on eye movements in reading by a group of ten people with aphasia and eight control participants (Kim & Bolger, 2012). They used sentences with target words varying in predictability. A facilitative context effect for the aphasia group was evidenced by shorter fixation durations and also by a smaller number of regressions on predictable context words. The aphasia group had more reading difficulties with words in the unpredictable contexts than the predictable contexts. In contrast, there was no context effect on the reading by the control group. Kim and Bolger conclude that the top-down processing from predictable contexts supports reading in the group with aphasia.

Even though there is much evidence for context effects in aphasia, there may also be reasons why context effects on visual word recognition do not occur. Several studies have indicated that limitations in working memory can contribute to sentence comprehension impairments in aphasia (Caspari et al., 1998; Friedmann & Gvion, 2003; Haarmann et al., 1997; Sung et al., 2009; Wright & Shisler, 2005). Using information from a context sentence poses demands on working memory. The preceding context has to be held in short-term memory whilst new information is being processed. If information is lost during the on-going comprehension process, it cannot be facilitative. Hence, impairments in working memory may hinder any context facilitation.

In summary, context is a robust variable in aphasia, and has been shown both in production as well as in comprehension tasks. The reported evidence suggests that a context effect arises for a range of reasons. With respect to reading, a context may provide probabilistic constraints that increase the activation level of the target word(s) while reducing the activation level of other unrelated words and meanings. The presented research outcome is not limited to offline results, but some research shows a context effect on processing durations. This is particularly relevant to reading studies as less efficient reading is shown by a slower process but not necessarily by reading errors. One study reported the facilitating influence of a context on fixation duration in a group of participants with aphasia using eye tracking. More studies using eye tracking are needed, because they shed more light on the process itself and are not influenced by meta-strategies. However, research also suggests that an utilisation of a context is also dependent on other factors, and not all individuals with aphasia show context effects. Even though not empirically investigated, it has been suggested that stronger context constraints may decrease the importance of lexical factors such as word frequency (Pashek & Tompkins, 2002). It could be that word frequency and context are interactive factors since people with aphasia may seek to compensate for weakened connections within the language system (e.g. frequency effects). There may also be individual differences regarding context effects. Both context and frequency effects relate to language skills and non-language skills such as working memory. The possible interaction of factors, and the time course of processing are discussed in more detail in the next section.

2.3.4. The time course of word frequency and context effects

While the influences of word frequency and predictability on reading in the healthy population are unchallenged, there is more controversy regarding their time course of processing, i.e. what processing stages these factors affect, and whether these are necessarily distinct (Dambacher et al., 2006). In fact, the question of whether bottom-up and top-down processes are separate or interactive is one of the oldest debates in cognitive science (Carreiras, Armstrong, Perea, & Frost, 2014) and is on-going (Federmeier, 2007; C.-Y. Lee, Liu, & Tsai, 2012). Mostly debated is the time point that the context exerts an influence. The discussion is relevant because information from a sentence context that is used early may be used in a predictive manner (Federmeier, 2007; C.-Y. Lee et al., 2012). However, if the influence from a sentence context is used after lexical access has taken place, it would suggest that lexical access is a form-driven and autonomous process (Swinney et al., 2000).

In modular or serial approaches (Forster, 1976, 1981), there is no interaction between bottom-up and top-down processing at the lexical level. Forster (1981) argues that the lexical system is autonomous, and cannot benefit from any influences from higher levels of processing, neither syntactic nor semantic. However, Forster claims that this does not rule out a context effect in other situations. For example, context may exert an influence on post-lexical processing. It may assist with disambiguation when the lexical processor has selected several potential analyses, and the one that fits into the given context is selected. Models that do not allow the influence of top-down factors until a later stage adopt an integrative view of sentence comprehension (C.-Y. Lee et al., 2012). This implies that there is no interaction between lexical and post-lexical processing (Federmeier, 2007; C.-Y. Lee et al., 2012).

Fully interactive accounts (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Seidenberg & McClelland, 1989) on the other hand allow top-down influences like sentence context to interact with other types of information simultaneously, and at an early stage of processing. Neither bottom-up nor top-down influences are assigned priority, and both are connected. Hence, the context can be used in a predictive or anticipatory manner (Federmeier, 2007; C.-Y. Lee et al., 2012). If both word frequency and context influence the early stage of word recognition, they could also be interactive. Connectionist models for example (Plaut, 1999; Seidenberg & McClelland, 1989) incorporate both word frequency and context in very similar ways. Pathways between different units get strengthened the more they are activated together (Whitney, 1998). This is how words with a higher frequency are recognised faster than words with lower frequency. The influence of a context is considered as so important that the models represents it as one of the “units” that connect with the other ones in the lexical network (Seidenberg & McClelland, 1989). The context unit has a bidirectional link to the meaning unit, which is again bidirectionally connected with the phonology and the orthography level. This is how context can influence each level in the network.

The theory-based controversy of the timing of the effects is reflected in the eye tracking literature. Inferences about the time course of processing are usually made by distinguishing between measures that are thought to reflect early processing (first pass reading), and those that are thought to reflect later processing (second pass reading measures)[7]. For example, the former would include the duration of a first fixation on a word (*first fixation duration* or *gaze duration*), while the latter would take account of all fixations that occur on a word including those that occurred after regressions were made to earlier parts of the text (*total duration*). Word frequency is generally seen to affect early word recognition, that is, lexical access. This is shown by effects on early measurements such as first fixation or gaze duration (Calvo & Meseguer, 2002; Juhasz & Rayner, 2006; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006). However, some studies have shown that word frequency not only influences first pass reading but also second pass reading measures (Juhasz & Rayner, 2003; Rayner et al., 2004). Hence, it has been argued that word frequency affects processing at all levels (Juhasz & Rayner, 2003).

There is more controversy regarding context effects and whether they influence lexical access or post-lexical integration or semantic integration (Dambacher et al., 2006). Context effects are often revealed by later eye movement measurements which show re-reading patterns (Calvo & Meseguer, 2002; Juhasz & Rayner, 2006; Kliegl et al., 2004; Rayner et al., 2011). Hence it is argued that top-down processes like a predictable context do not exert an influence on lexical processing, but on the integration of an item into the semantic context of the sentence. This would be consistent with modular approaches that argue against any interaction between bottom-up and top-down processing at the lexical level. However, other eye tracking studies reveal effects of predictability on both early and late measurements (Altarriba et al., 1996; Balota, Pollatsek, & Rayner, 1985; Inhoff, 1984; Kliegl et al., 2004; Rayner et al., 2004, 2006). This would suggest that context effects are not restricted to post-lexical stages but influence lexical processing as well. These findings are consistent with interactive accounts.

One eye movement reading study (Rayner et al., 2004) tackled the question of whether word frequency and predictability yielded *independent* effects or whether they were *interactive*. If they are interactive, one factor is dependent on the other factor,

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[7] A more detailed description of eye movements is provided in Chapter 4.

indicating they may work at the same level of processing. Fifty-four undergraduate students completed an eye tracking reading study. Half of the target words were high frequency words with a frequency of 150 per million, and the other half were low frequency words with 5 occurrences per million. Further, half of the target words were predictable from the sentence context, and the other half were unpredictable in the given sentence context. In order to rate predictability of the constructed sentences, two norming studies were carried out with additional participants. In one norming task, twenty participants indicated how well a word fit into the sentence context, using a scale between 1-7. In the other norming task, twenty other participants were given the target sentence up to but not including the target word and were asked to complete the sentence. Participants were asked to read the sentences for comprehension and they were given a comprehension question after each sentence. Investigating both fixation durations on target words and the probability of skipping the target word, Rayner et al. found a weakly interactive pattern. There was a non-significant interaction of word frequency and predictability for both first fixation and gaze duration. The word frequency effect was more pronounced for unpredictable than predictable items. However, no such interactive pattern was found for total durations. Results revealed a significant interaction with respect to the probability of a fixation. The readers were more likely to skip a target word if it was both predictable from the context and a high frequency word. This interaction was of a different kind compared to the weak interaction in the fixation durations where the word frequency effect was stronger for unpredictable words as compared to predictable words. Studies finding interactive patterns between word frequency and predictability support models that do not see the processing stages as completely distinct, such as interactive activation models (Morton, 1964, 1969; Rumelhart & McClelland, 1982; Seidenberg & McClelland, 1989).

Time course of processing, interaction and compensation of factors in aphasia

As summarised above, there is evidence that word frequency and context effects are prevalent in aphasia in a number of tasks including reading. Another question regarding these effects – one that is debated in healthy processing – is at what time course such effects may arise. Regarding aphasia, there is no knowledge as to whether word frequency and context are factors that influence early or late stages of visual word recognition. According to some accounts of language comprehension in aphasia, we might expect people with aphasia to show effects that are delayed in comparison to neurologically healthy individuals. According to the slowed activation hypothesis people with Broca's aphasia have a delayed process of lexical access (Love et al., 2008).

This account would predict that effects like word frequency are revealed in later measurements as compared to NHI.

There are several indicators for the assumption that processing may be interactive for people with aphasia. First, some studies have shown individual differences in terms of the influence of word frequency and context. As described in the sections above, some people with aphasia show no influences of word frequency or reverse ones, and some people show no effects of context. This might be linked to individual differences in language impairments. If different areas of the language system are impaired, then different sources of information may be used for compensation. For example, if lexical access is impaired, influences from the context may support lexical processing from an early stage on, and interact with word frequency. The context effect may be stronger for words with low frequency words, because some PWA may experience difficulties with these in particular, hence relying more on a supportive context.

There is further reason to assume that people with aphasia generally rely more on context than controls. Studies of healthy readers have shown that the magnitude of contextual facilitation is dependent on the reading skill, particularly with respect to word recognition (Ashby et al., 2005). These findings have been explained in the framework of interactive compensatory processing (Ashby et al., 2005; Stanovich, 1986, 1988). If bottom-up processing is deficient, the processing system compensates and relies more on other sources of knowledge such as context (Stanovich, 1986). Since good readers are efficient processors, they need less cognitive resources to process the visual information, and hence do not need extra input. Pierce comments that in many studies investigating the influence of context in aphasia, the effect was only demonstrated with poor comprehenders (Pierce 1991). This may be because better comprehenders do not need the extra support of a semantic context whereas the people with more severe aphasia may use the linguistic and extra-linguistic environment to facilitate the comprehension of specific semantic and syntactic information.

These arguments rest on a more general assumption that PWA are able to compensate for weakened areas of processing. It was found in a different study that PWA had some preserved syntactic skills, but if they were faced with a syntactically complex sentence, they used semantic strategies to interpret them successfully (Sherman & Schweickert, 1989). This argument is consistent with other studies claiming that the use of semantic or pragmatic skills in syntactically difficult sentences is a compensation mechanism in aphasia. Further, it emphasises that syntactic and semantic processes are not dissociated but work interactively. It should be noted, however, that Sherman and Schweickert showed compensation in offline measurements (sentence-picture matching task), and the strategy to use semantic or pragmatics may have been applied consciously. In this thesis it is expected that compensation mechanisms may be shown in an automatic manner, reflected by online measurements and hence speed.

2.4. Summary

The first part of this chapter provided an introduction to the process of visual word recognition, and summarised the basic assumptions of current reading models. It also provided an overview of types of acquired dyslexia that are classified on the basis of observed error patterns in reading single words aloud. The second part reviewed the evidence on reading difficulties at the sentence and text level. Even though this research substantially increased our knowledge regarding reading in aphasia, it was also illustrated that a lack of research surrounds aspects of lexical-semantic influences on reading in aphasia at the sentence level. The third part of this chapter started by describing bottom-up and top-down processes in reading. It introduced two factors (frequency and context) that are thought to facilitate word recognition and comprehension, and which are prototypical of bottom-up and top-down processing. After an overview of lexical-semantic processing impairments in aphasia, the last subsections provided evidence of word frequency and context effects in the healthy population and in aphasia. A large body of evidence shows that both factors play a role in aphasia. Given that strong effects of word frequency and context are associated with compromised lexical-semantic processing, there is reason to believe that these factors also influence visual word recognition and contribute to silent reading difficulties in aphasia. However, it is not known whether these factors influence reading in real time, and at what time course they exert an influence. The influence may be strong during lexical access, or may be more dominant during the process of semantic integration. The factors may work independently or in an interactive and predictive manner. There might be some differences in terms of how these factors influence people with aphasia as compared to healthy readers. Since PWA may have compromised lexical-semantic processing and/or limited processing resources, they may show a delay in effects. Or, it may be that difficulties in reading lead to a more interactive reading pattern in comparison to the control group. Further, no studies in aphasia have yet investigated what kind of underlying language impairment may relate to influences of word frequency and context.

The gaps in the evidence outlined above are examined in the first experiment of this thesis. The method will be an eye tracking whilst reading paradigm as this enables an investigation of the time course of processing. The next chapter will start with an introduction to the phenomenon of sentences with a temporary ambiguity, as these will be studied in Experiment 2. Approaches to sentence comprehension will be discussed for both the healthy population as well as for people with aphasia, however, the main focus will be on the latter.

Chapter 3. Sentence comprehension and ambiguous sentences

For people without aphasia or other types of language difficulty, the process of sentence interpretation is usually effortless and rapid. Language processing involves the integration of a variety of information sources at different levels, sometimes referred to as cues (MacDonald, Pearlmutter, & Seidenberg, 1994; MacWhinney & Bates, 1989; Spivey-Knowlton & Sedivy, 1995). These are integrated in an incremental manner, meaning that each word enters the processing system as soon as it is encountered, and is analysed in light of the information that is available at that point in the sentence (Marslen-Wilson, 1975). Reading studies using eye tracking support the assumption that different information sources are processed incrementally. Readers aim to interpret each word at the moment it is encountered, even if a first interpretation might be wrong and has to be reinterpreted (Just & Carpenter, 1980). Evidence for this is provided by the investigation of sentences that are temporarily ambiguous, in which readers misinterpret the structure at the point of the ambiguity, and show longer eye movements during the disambiguation region (van Gompel & Pickering, 2007). If readers waited until the end of the sentence before beginning their syntactic analysis, they would not experience the misinterpretation as they could use later sentence content to unravel the ambiguity. Further, it is assumed that processing is not just based on the information encountered, but that processing may additionally be based on predictions, expectations, and anticipations (Altmann & Kamide, 1999; Hare, Elman, Tabaczynski, & McRae, 2009; Hare et al., 2003; Hare, McRae, & Elman, 2004; Kamide, 2008).

For many people with aphasia on the other hand, the process of sentence comprehension is slow and effortful, and much less efficient than in healthy processing. Sentence comprehension impairments in aphasia are common. They vary with respect to their severity and type, and have stimulated a range of different explanations. They may be due to disruptions of grammatical knowledge for example, or due to impairments in other areas of language such as lexical or semantic processing. Further, sentence comprehension may be less efficient if the ability to form predictions and expectations is compromised.

Chapter 2 summarised evidence that leads us to expect that word frequency and context may influence word recognition during the reading of sentences in aphasia. This will be investigated in the first experiment of this thesis. Chapter 3 introduces sentences that contain a temporary ambiguity, sometimes termed ‘garden path’, which will be investigated in the second experiment of this thesis. Sentences that are temporarily ambiguous have been the focus of investigations in psycholinguistics, and have recently sparked interest within the research of sentence comprehension in aphasia. The chapter starts with an introduction of some garden path sentences, and summarises two theories of sentence processing in the healthy population that differ in how they explain the resolution of sentence ambiguities (3.1). The following section focuses on theories of sentence comprehension in aphasia and illustrates a recent approach that can account for the processing of ambiguous sentences (3.2). Subsequently, factors that influence the comprehension of sentences that contain a temporary ambiguity are introduced (3.3). The focus will be on the influence of frequency at a structural level, and how this influence is related to contextual priming. These factors are under investigation in the second experiment of this thesis. Lastly, the final subsection will provide a summary of the chapter (3.4).

3.1. Approaches to sentence comprehension in the healthy population

In healthy processing in particular, sentence comprehension theories are often informed by the study of sentences with a temporal ambiguity. These can reveal the influence of different sentence cues since different structural interpretations are temporarily available. Sentence comprehension accounts that explain the phenomenon of garden path sentences can be divided into modular and interactive theories (van Gompel & Pickering, 2007). This mirrors the categorisation of visual word recognition and reading models that were introduced in the first part of Chapter 2. Anticipating the following two sections, two common theories are the modular *garden path model* (Frazier, 1987a) and the interactive *constraint-based approach* (e.g. MacDonald et al., 1994). In this thesis, the framework of constraint-based theories is adopted. This framework has recently also been applied to study sentence comprehension difficulties in aphasia (as will be summarised in Section 3.2.3.). In order to understand the merits of this theory, and to embed the research of this thesis into the current research themes, both the garden path model and the constraint-based theories will be introduced in this chapter.

3.1.1. Sentences with a temporary ambiguity

In the healthy population, the process of sentence comprehension is usually effortless and rapid. Yet this is less so when sentences contain a temporal ambiguity. Structurally ambiguous sentences contain a region that could be part of two different syntactic structures. That region can be a verb as in the following example, but it can also be a phrase. Since reading is incremental, an interpretation has to be chosen at the ambiguous region even if it might not be the correct one (Traxler, 2012). As a consequence, the interpretation can often be incorrect as there is more than one interpretation possibility. Here is a well-cited example (Bever, 1970):

(1) The horse <u>raced</u> past the barn fell.

In this sentence, *raced* is a region that is temporarily ambiguous. When this sentence is read, people experience a garden path, i.e. they misinterpret *raced* as the main verb of *the horse* as in: *The horse raced past the barn*. When they encounter the word *fell,* they become aware of their misanalysis. The correct interpretation is that *raced* is not the main verb in past tense, but the past participle introducing a reduced relative clause. This garden path leads to slowed processing: that is, such sentences are read less rapidly than non-ambiguous sentences.

In this thesis, the focus is on the direct object/sentence complement ambiguity (DO/SC ambiguity). Verbs like *see* can occur in both a direct object (DO) and in a sentence complement (SC) sentence frame. Consider the following example:

(2) The driver **saw** <u>the traffic lights</u> and stopped=> direct object frame (DO)
(3) The driver **saw** (that) <u>the traffic lights</u> had been broken for weeks
=> sentence complement (SC)

In (2), *the traffic lights* is the direct object of saw, and in the (3), *the traffic lights* is the subject of a new sentence complement clause. If the complementiser *that* is left out in the second sentence, it is unclear how the structure continues, leading to a temporary ambiguity at the noun phrase <u>the traffic lights</u>. It is only at the disambiguation area *had been broken for years* that the structure unfolds fully. Figure 3.1 shows a way of depicting the structures for sentence (2) and (3), and schematically presents the temporal ambiguity. This ambiguity arises since English allows for the SC construction to occur either with or without the complementiser *that*. If the sentence contains the complementiser as in *The driver saw* ***that*** *<u>the traffic lights</u> had been broken for weeks*, the sentence is not ambiguous since *that* is a strong structural cue for a sentential clause. Trying to interpret sentences like these, a reader is influenced by whether *that* is present (non-ambiguous situation) or omitted (ambiguous situation).

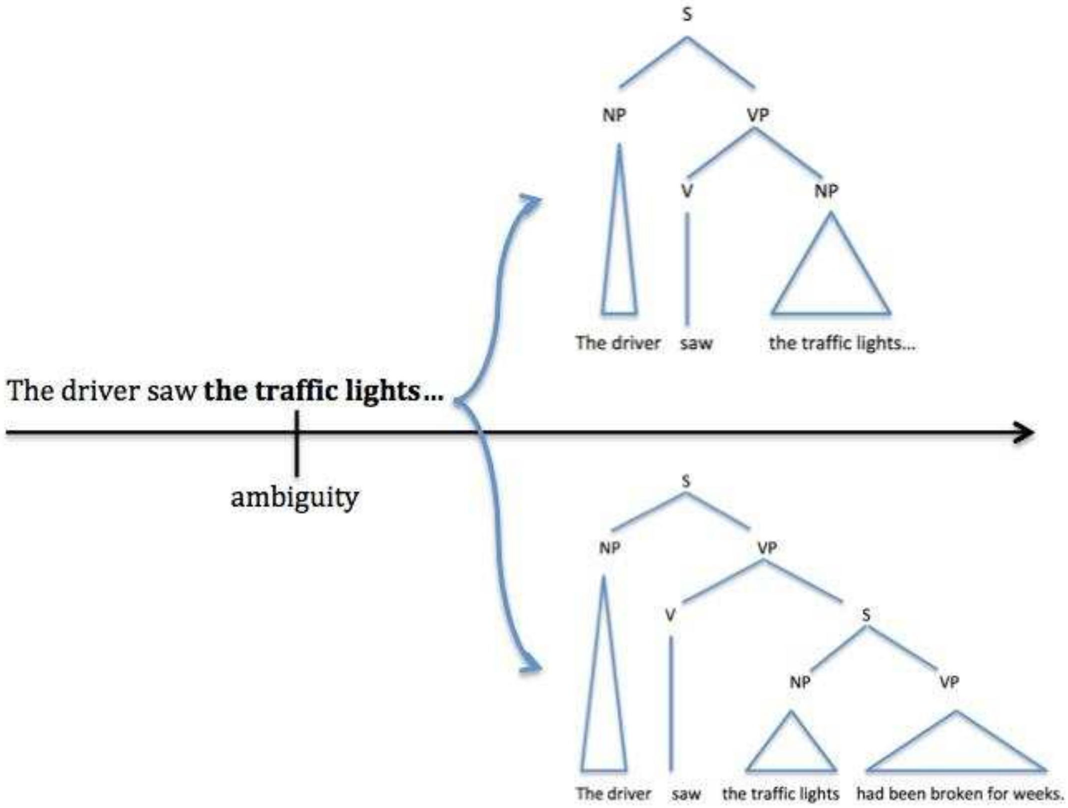

Figure 3.1 Schematisation of the direct object/sentence complement (DO/SC) ambiguity, inspired by (Wiechmann, 2006).

Even though sentences with a temporary ambiguity have been subject of many studies (mainly in healthy processing), there is still controversy about what kind of information sources readers (or listeners) use in order to resolve the ambiguity as quickly as possible. These information sources could be syntactic, semantic, pragmatic, probabilistic etc. The main question is whether readers use only syntactic information in their first analysis, or whether individuals integrate a number of different information sources immediately, and in a parallel manner. The next two sections will explain this in more detail, and will provide separate accounts of the DO/SC ambiguity as introduced above.

3.1.2. Garden path model

One type of parsing models are serial, modular models (Forster, 1976, 1981; Frazier & Rayner, 1982; Frazier, 1987a). According to van Gompel and Pickering (2007) the most influential modular account of syntactic ambiguity resolution is the garden path model (Frazier & Rayner, 1982; Frazier, 1987a). As noted by Rayner and colleagues (2012), the model was introduced in the same paper that motivated the use of eye tracking to analyse syntactic processing. This model is based on the assumption that language processing is accomplished by separate modules. It is argued that syntactic information is the strongest cue or module in the comprehension of (temporarily) ambiguous sentences. When people process sentences, they build a syntactic tree by the use of implicit rule knowledge (Rayner et al., 2012). One of the major claims in the garden path theory is that the parsing system initially only pursues one single structure (Frazier & Rayner, 1982). If this analysis turns out to be incorrect, the parser is led down a garden path (Frazier & Rayner, 1982). Given the importance of syntactic structure in this theory, the initial process of sentence processing employs information about the syntactic structure, leading to a single analysis. Only if this first analysis appears to be inconsistent with the sentence as it unfolds, non-structural information sources can be employed in the re-analysis stage (e.g. semantics, context, discourse, frequency). Since processing consists of a first analysis stage and a re-analysis stage, the garden path model is also referred to as two-stage model (Traxler, 2012). It is also serial, because the stages occur subsequently.

The initial interpretation is guided by two parsing strategies: *minimal attachment* and *late closure* (Frazier & Rayner, 1982). Minimal attachment means that the processor attaches incoming lexical information using the fewest number of nodes. This corresponds to the simplest possible structure (Rayner et al., 2012). According to the principle of late closure, the incoming lexical items should be attached to the phrase that is currently processed (Frazier & Rayner, 1982). The most recent phrase is the easiest one to remember (Rayner et al., 2012).

Let's come back to the example of the DO/SC ambiguity presented in the last section, here reprinted as (4) and (5):

(4) The driver **saw** <u>the traffic lights</u> and stopped=> direct object frame (DO)
(5) The driver **saw** (that) <u>the traffic lights</u> had been broken for weeks
=> sentence complement (SC)

The ambiguous region is *the traffic lights*. The noun phrase could either be the direct object of *saw*, or it could be the sentence complement. According to the garden path theory, (4) is easier to process than (5), because in (4) the ambiguous noun phrase *the traffic lights* is attached to the verb phrase, and this uses the fewest number of nodes (see Figure 3.1). This would be consistent with the principle of minimal attachment. In (5), employing the principle of minimal attachment leads the reader astray. Here, the ambiguous noun phrase cannot be attached to *saw*, because this would be inconsistent with the syntactic information that occurs at a later stage of processing. If the initial analysis turns out to be incorrect, as would be predicted for (5), the sentence has to be reanalysed (van Gompel & Pickering, 2007).

But whereas the immediate interpretation is only guided by syntactic principles, there is empirical evidence showing that the re-analysis stage is sensitive to different factors, which determine the processing costs of the reanalysis (van Gompel & Pickering, 2007). A study by Stuart and colleagues (1999, cited in van Gompel & Pickering, 2007) focussed on the direct object/sentence complement ambiguity as exemplified above, here presented in (6), compared to the direct object/null complement ambiguity, shown in (7). Consider the following sentences:

Direct object/sentence complement ambiguity :
(6) The Australian woman **saw** the famous doctor had been drinking quite a lot.

Direct object/null complement ambiguity:
(7) Before the woman **visited** the famous doctor had been drinking quite a lot.

In these sentences, the processing difficulty is larger in (7) compared to (6). One of many different proposed explanations of this difference is that in (7) *the famous doctor* leaves the thematic domain of the verb *visited* whereas in (6), *the famous doctor* remains in the thematic domain of *saw* (Pritchett, 1992, cited in van Gompel & Pickering, 2007). Another explanation, one that would be preferred in constraint-based theories could be that the verb *visit* has a very strong preference to occur as a transitive verb, with a count of 87 according to a corpus-based subcategorisation count by Gahl (Gahl, Jurafsky, & Roland, 2004a, 2004b). In contrast, the count of *visit* in the null attachment structure is only 9. Hence the ratio of transitive to intransitive uses is 87:9 (0.97). The verb *see* also prefers a direct object construction (transitive use), with a count of 69. The count of *see* in the sentence complement structure is 10; the ratio of the transitive to the sentence complement structure is thus 69:10 (0.69). This means that the probability that a reader encounters (7) in the correct null attachment interpretation is lower than the probability that a reader encounters (6) as a sentence complement. This explanation can equally account for a higher processing cost in (7) compared to (6). This viewpoint will be described in more detail in the next subsection.

3.1.3. Constraint-based approach

The constraint-based approach is a parallel and interactive model of sentence processing (MacDonald et al., 1994; MacWhinney & Bates, 1989; McRae, Spivey-

Knowlton, & Tanenhaus, 1998; Seidenberg & MacDonald, 1999; Spivey-Knowlton & Sedivy, 1995; Trueswell et al., 1993; Trueswell, 1996). Even though this approach has in particular been used to refer to ambiguity resolution (like the garden path model), it can also account for sentence comprehension in general. The approach is based on usage-based theories (J. Bybee & Hopper, 2001; J. Bybee, 2010) and on exemplar-based models (Bod, 2006, 2009). In usage-based models of language, language knowledge is based on the "accumulated experience with language across the totality of usage events" (Tomasello, 2000, p. 61). Linguistic experience becomes entrenched through exposure, and becomes abstracted as expressions vary across events of usage.

According to constraint-based approaches, sentence processing is influenced by multiple sources of information. These can be lexical, (Spivey-Knowlton & Sedivy, 1995), semantic or pragmatic knowledge (Garnsey et al., 1997), context (Altmann & Steedman, 1988), world knowledge such as thematic fit (McRae et al., 1998), discourse (Altmann & Steedman, 1988), prosody (DeDe, 2010), or animacy (Trueswell, Tanenhaus, & Garnsey, 1994). Rather than focussing on syntactic processes in sentence comprehension, constraint-based approaches emphasise lexical and probabilistic factors. Probabilistic factors are for example aspects such as frequency which describe how often particular words or structures occur in language. But essentially, all information sources mentioned above can act as probabilistic constraints, because they can define the probability of a word or structure in a sentence. Information sources are referred to as 'cues' or 'constraints' as these sources are cueing or constraining the structural interpretation of the (ambiguous) sentence. This is in sharp contrast to the garden path model, which prioritises the use of syntactic rules. In the constraint-based approach, the focus is on statistical regularities of language (Rayner et al., 2012).

Another difference between serial and interactive models is the time point at which factors influence the interpretation process. In serial models of parsing, the influence of non-syntactic factors such as lexical and semantic factors occurs during the second stage of processing, during the revision process. In interactive models such as the constraint-based theories, the influence of all cues or constraints is immediate and simultaneous, and the model predicts interaction between constraints, for example between syntactic and lexical or contextual influences (MacDonald et al., 1994). Hence the constraint-based approach is also referred to as a one-stage model. Constraints can also produce competition among different interpretations, and the analysis achieving most support from the constraints receives the highest level of activation (van Gompel & Pickering, 2007). This does not rule out that syntactic influences play a role in structural processing, but they are not the most predominant ones. Sentence processing is simple if there is a constraint with a much higher activation than another constraint, but if constraints lead to equal activation, competition leads to processing difficulty (van Gompel & Pickering, 2007).

One of the first models which allowed a focus on multiple cues and competition amongst these (Elman, Hare, & McRae, 2005), was the *competition model* (Bates et al., 1987a; Bates, Friederici, & Wulfeck, 1987b; MacWhinney & Bates, 1989; Macwhinney, 2004). The model attempts to account for cross-linguistic differences in sentence processing. It is argued that grammatical, phonological, or lexical cues to sentence meaning have varying cue validity, i.e. different information values. In English, a language with a very restricted word order, word order has high cue validity; while, in German and Italian, morphology has high cue validity, because morphology is rich. According to Bates and colleagues, much of what we know about grammar use is entailed in relations between form and meaning which have probabilistic weights. The form function mappings vary in strength – determined by "relative frequency, informativeness, and processing costs" (Bates et al., 1987a, p. 28). Performance in language tasks thus depends on statistical differences between languages.

Argument structure frequency

One of the main tenets of constraint-based approaches is that sentence comprehension difficulty may not only be defined by syntactic complexity, but may also depend on the frequency of words or structures in a language. As mentioned in Chapter 2, word frequency is a factor that can influence the speed of lexical access. However, frequency can also function at a structural level. One type of frequency that has been analysed within interactive models is the frequency of a verb in a certain argument structure. As illustrated in the context of the DO/SC ambiguity, a verb such as *see* can occur both as a direct object (e.g. (4) *The driver* ***saw*** *<u>the traffic lights</u>*) as well as in a complement structure (e.g. (5) *The driver* ***saw*** *<u>the traffic lights</u> had been broken for weeks*). The most frequent argument structure of *see* is the direct object frame, and hence the verb is biased towards that structure. The argument structure frequency (or verb bias) describes the likelihood that a verb will occur in a particular type of syntactic structure (Gahl, 2002). This factor can also explain how people interpret the DO/SC ambiguity. Note that the garden path theory predicted that when *that* is omitted, (5) is more difficult to process than (4) as the principle of minimal attachment leads to the incorrect interpretation, and reanalysis occurs. Constraint-based theories also predict that (5) should be more difficult than (4), but the reason is different (Traxler, 2012). Sentence (4) is easier because the sentence structure is consistent with the argument structure frequency of *see*. In contrast, in (5) *see* occurs in an argument structure that is less frequent.

Lexical bias or argument structure frequency has a central role in constraint-based theories. It is seen as a lexical constraint as this information is included in the lexical entry of each verb (MacDonald et al., 1994). But since it is based on our exposure of this structure in English, it is also a probabilistic factor. Argument structures specify the grammatical categories of the phrase as well as the thematic roles that are assigned to that phrase (MacDonald et al., 1994). Its influence on sentence comprehension in healthy processing has been thoroughly studied (Ferreira & Henderson, 1990; Garnsey et al., 1997; Trueswell et al., 1993), and is generally acknowledged, even in studies that adopt more serial approaches to parsing (Ferreira & Henderson, 1990).

The role of lexical information and the link between form and meaning

It is argued in modular models that syntactic structures are constructed by grammatical rules whereas in constraint based theories it is assumed that syntactic structures are stored in memory, and are often word-specific (as shown by the example *see*). The lexicon encodes not only phonological and semantic information, but also structural information such as the frequency of occurrence of items or structures and the statistical properties of combinations between elements (Seidenberg & MacDonald, 1999). Hence a large part of processing is mediated lexically (MacDonald et al., 1994).

In constraint-based theories, constraints are integral to the language system and are responsible for language comprehension (Seidenberg & MacDonald, 1999). They are learnt during language acquisition, as children gain knowledge about the statistical and probabilistic aspects of language (Seidenberg & MacDonald, 1999). When children acquire verbs, they learn about the meaning of verbs as well as in what type of structures verbs occur in. A theory that accounts for this, and which is coherent with the constraint-based approach is the *bootstrapping theory* (Gleitman, 1990; Pinker, 1984). According to the bootstrapping theory there are tight links between syntax and semantics, correspondences that can be employed by the child. The number of arguments that are taken by a verb are not arbitrary, but depend on how many participants or locations are required by the predicate, for example *laugh* vs. *put* (Gleitman, 1990). The arguments that appear with the verb also carry meaning. The subject noun phrase is often the experiencer or the agent as in *Arnold laughs* or *Gloria puts Arnold in his place*, respectively (Gleitman, 1990, p. 28). Children observe the meaning of verbs, and can then project the structures from knowing the *linking rules* between semantic and syntactic structures.

This also works the other way around; children can use the structure that verbs occur in, and deduce the meaning of these verbs. For example, verbs of perception and cognition are correlated with different types of constructions. Verbs that describe perception, frequently occur with direct objects whereas verbs that describe mental states frequently occur with sentence complements (Gleitman, 1990). There are also verbs that can be used to convey both a perception/concrete meaning as well as a more abstract mental meaning, such as *see* (Hare et al., 2003). The reason for this polysemy may be a metaphorical meaning extension from the concrete to the abstract domain (Hare et al., 2003). If *see* means to 'perceive visually' it usually occurs with a noun phrase object as in *She saw the picture.* If *see* means 'to perceive mentally', however, *see* tends to occur with sentence complements as in *She saw his argument was right*. A language user chooses a type of structure if it suits the meaning of the verb (Gleitman, 1990). As a consequence, the structure carries information for the language learner that can be used as a cue to verb meaning. Taken together, there are links between the meaning of verbs and their syntactic structures, and children learn this 'probabilistic information' (Seidenberg & MacDonald, 1999) during language acquisition.

These arguments further coincide with usage-based approaches to language acquisition (Tomasello, 2000, 2003, 2009), in which it is assumed that children start developing language by learning verb-based utterance schemas such as *I wanna X*, *X gone* etc. (Tomasello, 2000). Syntactic knowledge in these item-based constructions is verb-specific. Various linguistic items that the child is learning then replace the X. Further down the acquisition process, children start using patterns of token and type frequency, understanding more patterns of language use. At the age of about three, children can transfer the item-based knowledge to new items (Tomasello, 2009).

Goldberg describes how children learn argument structure constructions, which are pairings between form and meaning (Goldberg, 2006). These are, as above, often referred to as linking rules. Goldberg disputes the view that associations between form and meaning are innate, and suggests that children can induce these associations by applying general categorisation principles. The first and the most frequent verbs learnt are general purpose verbs such as *put*, *go*, *do* and *make*. Constructions also have meanings, for example the intransitive motion construction means 'X moves Y', and the caused motion construction means 'X causes Y to move Z'. Interestingly, the meanings of the general purpose verbs are very similar to the meanings of these constructions. *Go*, for instance, corresponds to the intransitive motion construction, and *put* corresponds to the caused motion construction. It is assumed that these verbs help the children in generalizing meaning from these verbs to constructions, that is, children learn the meaning of syntactic patterns by overgeneralizing over specific times (Goldberg, 2006). Hence, children learn a correlation between the meaning of a verb in a construction and the construction itself, forming a tight link between meaning and structure. The finding that children are able to understand and use tight links between meaning and structure suggests that these links are an essential aspect of language. This again may suggest that sentence comprehension is sensitive to such links between meaning and form. The second experiment of this thesis will investigate whether these correspondences are so entrenched in the language system that they can be accessed when people with aphasia read sentences.

Criticism of the constraint-based approach

Returning to the overview of constraint-based theories, it should be noted that the theory also has some limitations. One of the main criticisms is that the tenets by these theories are difficult or may even be impossible to falsify (see for example Rayner et al., 2012). Claiming that processing is interactive and influenced by various constraints does not predict which constraints are most relevant, and how and when they influence processing (Rayner et al., 2012).

Additionally, results from some empirical studies support the claims by the constraint-based theory whereas others do not. An eye tracking study of the DO/SC ambiguity (for example: *Bill hoped/wrote (that) Jill arrived safely today*) revealed that argument structure frequency did not influence initial parsing decisions in the disambiguation; there was an effect of ambiguity on first pass eye movements, but no effect of argument structure frequency (Ferreira & Henderson, 1990). However, for second pass eye movements, a non-significant effect of argument structure frequency was observed for the disambiguation region, and a significant effect of argument structure frequency (at least by participants) for the post-disambiguation region. Hence, the initial structural analysis was dependent on the ambiguity, showing a preference for a minimal attachment analysis. The verb information showed a small influence on later measurements, suggesting that it may have been used for re-analysis of a falsely parsed sentence (Ferreira & Henderson, 1990). This result supports the claims by the garden path model. However, results from a study by Trueswell and colleagues (1993), who studied the same ambiguity, revealed an immediate effect of argument structure frequency in both a self-paced reading and an eye tracking reading experiment. For the ambiguous sentences, first pass eye movements were longer (but not significant) in the disambiguation region if the verb was biased to occur with a direct object as compared to when it was biased to occur with a sentence complement (the sentences occurred with sentence complement). The authors interpret this result as an early syntactic misinterpretation due to the misleading frequency information – even though the interaction between ambiguity and verb bias was not significant. This lack of interaction was likely to be due to a small ambiguity effect that was present in reading times for SC-biased verbs. This however could also be due to an observed complementiser preference effect. If ambiguous sentences contain SC-biased verbs that prefer to occur with *that,* an elevation of reading times can be due to the omission of *that*. This was in fact evidenced by a positive correlation between the degree of *that*-preference and first-pass reading times in the noun phrase region and the disambiguation region. The different results found in the study by Ferreira and Henderson compared to Trueswell and colleagues can be explained by slightly varying stimuli sets. Trueswell and colleagues point out that the verb-bias manipulation used by Ferreira and Henderson was not very strong. Second, they suggest that the earlier study was confounded by plausibility; potentially ambiguous noun phrases were often implausible as direct objects. In the study by Trueswell et al. the verb biases were stronger, and the (ambiguous) noun phrases were plausible direct objects of the DO-biased verbs.

3.2. Approaches to sentence comprehension in aphasia

The aim of this section is to provide an overview of approaches to sentence comprehension in aphasia. The main focus has traditionally been on syntactic impairments in aphasia, described in structural accounts. This approach is a rule-based approach to sentence comprehension, and holds that the presence of a structural impairment leads to difficulties in understanding sentences whenever syntactic structure has to be analysed. The following section further summarises processing accounts that assume that difficulties with linguistic rule applications are the result of limited processing capacities affecting systems beyond syntax. Limited processing capacities can, for example, be due to a delay in the activation of syntactic material or due to a decay of information that occurs before the information can be processed adequately. Processing limitations may also occur due to reduced working memory capacity or due to lexical processing impairments. The last subsection describes how the constraint-based approach has been used to account for some sentence processing difficulties in aphasia. According to this approach, language processing does not proceed through the application of linguistic rules, but draws on exemplars of encountered linguistic tokens in memory. Exemplars are representations that can be lexical items or form-meaning pairings. This framework is adopted in this thesis. It is assumed that language use, the frequency with which we encounter linguistic items and structures, and in what context words occur, influences language in healthy processing, and potentially, also in aphasia.

3.2.1. Structural accounts

Structural accounts attribute aphasic sentence disorders to an impairment of a syntactic function or its rule application. They are based on the observation that individuals with Broca's aphasia and associated agrammatism have particular difficulties with the interpretation of sentences that are dependent on syntactic analysis (Caramazza & Berndt, 1982; Caramazza & Zurif, 1976). The term agrammatism refers to a disruption of grammatical structure (Benson & Ardila, 1996) which leads to a specific difficulty with non-canonical sentences, while leaving canonical sentences relatively intact. Canonical sentences follow the subject, verb, object word order (S, V, O) whereas non-canonical sentences involve syntactic movement as in passives or object relative clauses. In a study by Caramazza and Zurif (1976) five individuals with Broca's aphasia and five individuals with Wernicke's aphasia were presented with different sentences that they had to match with a picture, with options showing the target, a lexical distractor, and a syntactic distractor. The non-fluent participants performed well on the control sentences and those sentences with strong semantic constraints (e.g. *The book that the girl is reading is yellow*, 1976, p. 575). However, they scored at chance on semantically reversible sentences (e.g. *The cat that the dog is biting is black*, 1976, p. 576). Thus, they had difficulties understanding sentences that required syntactic processing and that could not be interpreted on the basis of semantic and pragmatic cues alone. These findings suggested that Broca's patients with impairment in the anterior brain region have a selective impairment of grammar (Caramazza & Berndt, 1982; Caramazza & Zurif, 1976; Obler & Gjerlow, 1999) as shown in both production and comprehension. It was claimed that individuals with Wernicke's aphasia, with impairment in the posterior brain region, have a selective impairment of semantics (resulting in comprehension breakdown and word-finding deficits) accompanied with a selective sparing of grammar (evidenced by the patients' fluent speech). Thus, the apparent dissociability of grammar and semantics and the mapping of these domains onto separate and domain-specific neural systems were taken as evidence for a faculty or module dedicated exclusively to the representation/processing of syntax (Caramazza & Berndt, 1982; Grodzinsky, 2000).

Caramazza and Berndt (1982) write that Broca's aphasia represents an example of a disruption of a language system component, syntax, as the result of brain damage.

3.2.1.1 Trace deletion hypothesis

Grodzinsky generalised the observed grammatical deficits in Broca's aphasia and developed the *trace deletion hypothesis (TDH)* (Yosef Grodzinsky, 1986, 1990, 2000), which is one of the most well known hypotheses within the structural account. Grodzinsky claims that agrammatism affects the syntactic tree structure, and specifically traces. Traces arise from phrase movement. When a canonical sentence such as *The boy pushes the girl* is tranformed into the non-canonical sentence *The girl was pushed * by the boy* (Grodzinsky, 1990, p. 84), the phrase *[the girl]* has moved, and the * indicates the trace. A co-index relation is developed between the trace site and the element that was moved, i.e. between [the girl] and its original post-verbal position. Hence traces are left in the mental representation of a sentence to mark the original location of the moved element. According to the trace deletion hypothesis, the syntactic representation is impaired in agrammatism, because traces are deleted. If the co-index relation is impaired, the thematic relations of the sentence cannot be interpreted. The trace deletion hypothesis predicts that individuals with agrammatism should perform at chance level with sentences like the above, because traces are deleted as a result of the brain damage. It is argued that individuals with agrammatism use a compensatory mechanism. This is a general decision making strategy, or heuristic, that assigns the first noun phrase [the girl] to agent. As a result, two phrases compete for the role of agent, leading to a chance interpretation of the sentence. The non-grammatical heuristic, described above, is only used when the semantic role cannot be derived from the grammatically assigned theta-role, i.e. only to noun phrases in non-thematic positions. Evidence for this proposal is, for example, the finding that there is a difference in processing adjectival passives such as *John was interested in Mary* and verbal passives such as *John was kicked by Mary* (Grodzinsky 1990). The former is derived by lexical rules, and the latter is derived by transformation, i.e. by changing the active sentence *Mary kicked John* into the passive sentence *John was kicked by Mary*. Two individuals with Broca's aphasia were presented with different sentence types and both performed above chance level on the adjectival passives but at chance level with sentences such as *John was kicked by Mary*. These results support the trace deletion hypothesis as it argues that adjectival passives that do not involve transformations or traces should be processed accurately in Broca's aphasia whereas verbal passive sentences involving transformations should be more difficult.

3.2.1.2 Some problems with the structural account

The structural account has helped to characterise the sentence comprehension deficits of aphasia. However, whilst there is evidence for specific syntactic deficits, there are also a number of challenges relating to the proposed agrammatic profile as well as to the methodology used.

First, agrammatic comprehension also occurs in other types of aphasia (Bates et al., 1987a). This cannot be explained by a proposal that is specific to the symptoms of Broca's aphasia, such as the trace deletion hypothesis. Second, the specific deficit account has difficulties explaining the described cases of Broca's aphasia that do not show the postulated deficits (Caplan, 2006). Third, individuals with Broca's aphasia are also impaired in the processing of structures that do not involve movement, for example, pronominal structures as *The soldier told the farmer with glasses to shave him in the bathroom* (Thompson & Choy, 2009). These results will be discussed further in the next subsection. Whilst pronominal structures are complex, some individuals with Broca's aphasia also exhibit comprehension impairments that affect the ability to comprehend simple canonical sentences. In a study by Friedmann and Shapiro (Friedmann & Shapiro, 2003), two out of seven individuals with agrammatism scored 80% on sentences following the S, V, O pattern (whereas the other five scored higher). This result is significantly above chance, but is at the same time clearly compromised compared to the comprehension skills of control participants on these structures. It shows that there are some individuals with agrammatism whose comprehension impairment is not limited to structural complex sentences.

Also some of the used methodologies are subject to critique. Many studies postulating the structural account only used offline measures such as sentence picture matching or grammaticality judgments. More recent studies using online methods such as eye tracking suggest that individuals with aphasia can successfully build syntactic structure even though their offline-results are compromised (Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009). At least initially, eye movements are surprisingly similar to controls even though the comprehension results are so different (Dickey & Thompson, 2009; Thompson & Choy, 2009). Dickey and colleagues (Dickey et al., 2007) conducted an eye tracking while listening study to investigate real-time comprehension of wh-movement structures (object wh-question, yes-no question, object cleft). Participants with aphasia as well as control participants were listening to stories and looked at visual displays presenting words from the stories whilst their eyes were tracked. The displays included the subject, the object (target), the location and a distractor. The structures of interest appeared after listening to the short story. Offline accuracy of tested non-canonical sentences was significantly impaired. However, if the PWA understood the non-canonical sentences correctly, their eye movements showed similar patterns to those of the control group, at least sentence initially. In wh-questions (e.g. *Who did the boy kiss that day at school*?), both groups showed a preference to look at the object when they heard the verb. This was interpreted as evidence that a moved wh-element was rapidly associated with a verb. Differences between the groups appeared most strongly later in the sentence where the people with Broca's aphasia showed competition between the object and the animate subject competitor. The next subsection will explain this in more detail.

3.2.2. Processing accounts

According to processing accounts of sentence comprehension impairments in aphasia, syntactic rules and operations are not lost, but they are dependent on other processing capacities, and these are limited for some individuals with brain damage. This account is interesting since it represents a shift from a focus on syntactic skills to a variety of other language-specific or language-general skills that may influence the application of linguistic rules. There are many different explanations as to what these resource limitations capacities could be. Generally, evidence for resource reduction accounts comes from findings that both the complexity of the structure and the severity of the individual's aphasia are the main contributors to language processing deficits (Caplan, Baker, Dehaut, 1985).

Caplan and colleagues (2007) argue that several features contribute to the complexity of sentence interpretation, for example canonicity, verb argument structure, and the number of verbs per sentence. Since sentences with these features need more computational resources, they are more difficult to process. In a study of forty-two individuals with aphasia and twenty-five healthy controls, Caplan and colleagues (Caplan, Waters, DeDe, Michaud, & Reddy, 2007) investigated performance on three types of structural contrasts (active versus passive sentences, sentences with subject- and object-relative clauses, and sentences with and without reflexive pronouns). Since many previous studies concentrated on performance in just one task, they envisaged investigating whether performance is consistent across three tasks: enactment, sentence-picture matching, and grammaticality judgments. Results showed that there was only one participant with difficulties affecting both passives and object-relativised structures; and none who showed difficulties with sentences containing reflexives. This finding challenged the claim that individuals with aphasia have an impairment in one type of syntactic operation such as the processing of traces. A factor analysis showed that sentence comprehension was determined by factors that affect many sentence types, and the authors conclude that these factors reflected the varying processing resources available to the participants. Further, they compared accuracy, reaction times and data from on-line self-listening data. These data confirmed that the demands imposed by object relative sentences are higher than the demands of subject relative sentences, and demands by passive sentences are higher than by active sentences. For example, listening times on the verb are longer in passive sentences than in active sentences, suggesting an increased load. Online measurements showed further that even PWA with low accuracy showed normal processing patterns in sentences that were comprehended correctly. This suggests that the parsing mechanism is not always deficient; it is successful in some cases, but not others. Whether structure and meaning were correctly computed or not was dependent on processing load and the availability of processing resources. Processing resources are considered to be an aspect of mental functioning that influence cognitive operations. There may be a specialised pool of resources that facilitates the access of meaning, and a more general pool of resources that facilitates the use of a sentence meaning to perform a certain task successfully. According to Caplan and colleagues, PWA have limitations in both of these pools of resources. Consistent with the processing account, Caplan and colleagues conclude that the PWA have intermittent reductions in the resources that are needed to assign and interpret syntactic structure. Such resource limitations vary in severity and frequency of occurrence across patients.

3.2.2.1 Temporal accounts

Some processing accounts emphasise temporal patterns of processing. According to Haarmann and Kolk and other colleagues, processing capacities can be reduced due to a delay in activation of syntactic material, or due to a rapid decay of lexical, semantic or syntactic information (Haarmann et al., 1997; Haarmann & Kolk, 1991, 1994). Haarmann and Kolk (1991) carried out a syntactic priming study in order to examine the reasons for resource reductions that may lead to syntactic comprehension difficulties in Broca's aphasia. They used sentence fragments consisting of two words, and presented letter strings for a lexical decision task. These were presented at different stimulus onset asynchronies (300, 700, 1100ms) as this allows for an investigation of the time course of syntactic activation. They analysed the time it took the people with aphasia to respond to the word targets of the lexical decision task – this is where neurologically healthy individuals have been shown to reveal priming effects.

The priming effect depends on a successful integration of the syntactic representation of the priming fragment with the target fragment. Half of the critical test items were grammatical prime-target combinations, and the other half were ungrammatical. Four different stimuli types were constructed. The prime was a passive auxiliary, perfect auxiliary, modal verb or a preposition. The target words (shown for lexical decision) were either grammatical (e.g. *Wij worden getest = We are being <u>tested</u>*) or ungrammatical (e.g. *Wij worden gelopen = We are being <u>walked</u>*). Three different stimulus onset asynchronies (SOA) were employed between showing the prime fragment and the target. In order to have a control condition all target words were also presented in isolation. Results showed significant priming for the control groups at all three different SOAs, and for all stimuli types except the perfect condition. For the individuals with Broca's aphasia, the priming effect was only significant in the slow SOA (1100ms), and there was no effect of the type of the prime. This supports the view that the activation of syntactic information is slowed in Broca's aphasia.

Even though this result was consistent with other studies, it was inconsistent with a finding that syntactic information is activated at a fast rate, but also decays rapidly (Haarmann & Kolk, 1994). Haarmann and Kolk (1994) used the word monitoring paradigm to scrutinise whether syntactic information decays, and further, to examine the impact of syntactic complexity on the sensitivity of people with Broca's aphasia to grammaticality violations. They created sentences with simple and complex constituent structure, and all the sentences had an ungrammatical counterpart (with subject-verb agreement violations). The sentences were split into a first long segment and a short segment consisting of the final noun phase with the noun being the target word (e.g. *The women carry the child and eat / ICE-CREAM*). For each trial, participants were first shown the target word on the monitor. Second, they were auditorily presented with the target sentence, in two segments. Third, they had to press a button as soon as they heard the target word that was presented at the beginning of the trial. In the first experiment two segments of the target sentence were presented immediately after each other. In the second experiment there was a 750ms separation between hearing the first segment and the second segment. Results from the first experiment revealed that the control participants showed agreement effects for both simple and complex sentences. The people with Broca's aphasia only showed this sensitivity in the simple sentences. Since here the noun phrase followed the first segment of the sentence almost immediately, the participants must have accomplished syntactic analysis rapidly. Results from the second experiment showed an effect of agreement for the control group. The individuals with Broca's aphasia were not sensitive to the agreement violations. Also the grammaticality effect for filler sentences that was apparent in the first experiment vanished. In summary, the results suggest that people with Broca's aphasia show a fast decay of syntactic information. The authors note that this is not consistent with their earlier study on the time course of activation where the syntactic priming effect was only found for a slow stimulus onset synchrony (Haarmann & Kolk, 1991). Haarmann and Kolk suggest that there is a trade-off between syntactic activation and decay: A "normal" time course of activation can lead to a rapid decay; while slowed activation may reduce decay.

3.2.2.2 Reduced working memory capacity

Another source for a processing deficit could be a reduced capacity in working memory (Caplan & Waters, 1999; Caspari et al., 1998; Christensen & Wright, 2010; Friedmann & Gvion, 2003; Haarmann et al., 1997; N. Martin & Reilly, 2012; Miyake et al., 1994; Sung et al., 2009; Wright et al., 2007; Wright & Shisler, 2005). This is based on the observation that there are differences in working memory capacity in the healthy population which seem linked to differences in reading abilities (Haarmann et al., 1997). Miyake and colleagues (1994) present a theory that explains how limitations in working memory can induce sentence-level comprehension impairments in aphasia. They use the term working memory to mean "a computational arena" (Miyake et al., 1994, p. 673), corresponding to what Baddeley would refer to as central executive. First of all it is assumed that people with aphasia have sufficient structural knowledge to perform syntactic analyses, even if they exhibit sentence comprehension difficulties. These difficulties are at least partly due to reductions in working memory. There are two main functions of working memory: computations and storage. In order to understand an object-relative clause like *The boy that the girl is chasing is tall*, the noun phrase *the boy* has to be maintained until *is tall* is encountered*.* The embedded clause has to be parsed at the same time. According to Miyake and colleagues, such aspects of storage and computation are mediated by working memory. If a sentence poses high demands on the resources, then the two functions of working memory compete with each other. When resources are limited as is the case in resource demanding sentences such as the object-relative clause, a trade-off occurs between computation and storage. This de-allocation of resources used can lead to linguistic material needed for comprehension to be forgotten, and hence elements critical for comprehending the sentence may not be computed. Further, the speed of processing can be reduced as a consequence of fewer resources being available. This theory can explain individual differences in the comprehension of complex sentences. People with severe impairments and limited working memory resources may have difficulties even with simple sentences if these pose high working memory demands. Miyake and colleagues conducted two simulation experiments to test whether strong temporal commands can induce sentence comprehension difficulties in people without aphasia. The results revealed that a fast presentation of sentences to people without language difficulties made sentence comprehension so difficult that patterns were in some parts similar to those observed in aphasia. Sung and colleagues (2009) provided more evidence on the relevance of working memory and written sentence comprehension in aphasia. As described in Chapter 2, they showed that verbal working memory capacity as measured in a sentence span task could successfully predict performance on that subtest of the Computerised Revised Token Test, which only showed the words to be read over a limited time course. This subtest was the condition that needs greater working memory demands.

3.2.2.3 Deficits in lexical access or integration

An additional approach that is situated within the processing account argues that difficulties in the comprehension of non-canonical structures are due to impairments in lexical processing (Choy, 2011; Love et al., 2008; Meyer, Mack, & Thompson, 2012; Thompson & Choy, 2009). Lexical processing impairments were already introduced in Chapter 2 (Section 2.3.1). It is argued that syntactic processing is intact, but is hampered by deficits in lexical access or lexical integration. Since one of the foci in this thesis is lexical influences on sentence processing, the theory on the contribution of lexical access/integration to sentence comprehension is explained in some detail in the following subsection.

Much evidence for this approach is provided by online methods that study sentence comprehension in real time. For example, cross-modal lexical priming studies suggest that individuals with aphasia are able to form syntactic dependencies, but that this process is slowed (Burkhardt, Mercedes Piñango, & Wong, 2003; Ferrill et al., 2012; Love et al., 2008). Love et al. (2008) argue that the online processing of gapped sentences with syntactic dependencies (such as object relative clauses) requires fast lexical activation. Since lexical activation is delayed as a result of left inferior frontal damage, individuals with Broca's aphasia experience syntactic comprehension difficulties. Love and colleagues perform cross modal lexical priming experiments and a sentence picture matching task to study the comprehension of non-canonical sentences for individuals with Broca's aphasia. In healthy processing, an object relative clause like *The boy*$_i$ *that the horse chased (t)*$_i$ *is tall*. (p. 205), leads to an activation of *boy* after the word was heard, and to a reactivation at the gap (t). The subscript *i* reflects the dependency relation between *the boy* and the trace position after *chased*. This syntactic dependency is formed in real time. The results from their experiments reveal that individuals with Broca's aphasia show delayed lexical activation as well as delayed reactivation of the constituent at its gap. However, when the sentences were spoken at a slower speed, there was reactivation at the gap and the accuracy in comprehending the sentences improved. The slowed lexical access account differs from the slowed syntax hypothesis (Haarmann & Kolk, 1991), which argues that *syntactic* processing is slow, but correct once it is formed. Love and colleagues argue that *lexical* activation is too slow. As a result the agent first heuristic is used, which results in misinterpretation.

Similarly to the priming studies above, eye tracking studies revealed that people with Broca's aphasia and associated agrammatism show automatic processing of non-canonical sentences (e.g. wh-structures, object cleft) even though offline accuracy of tested non-canonical sentences was significantly impaired (Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009). As mentioned earlier, automatic processing of wh-structures, for example, is evidenced by a preference to look at the correct object picture when hearing the verb which signals the gap (Dickey et al., 2007). As found in the study by Love (2008), some eye tracking studies suggest that comprehension difficulties arise through a delay in lexical processing (Hanne et al., 2011; Meyer et al., 2012). In a study by Meyer and colleagues (2012), participants with Broca's aphasia and controls listened to both active (e.g. *The man was shaving the boy*) and passive sentences (e.g. *The man was shaved by the boy*) and completed a sentence-picture matching task whilst their eye gaze was tracked. They were given two pictures: one picture showed an agent performing an action on a theme/patient, and the other picture showed the same action but reversed roles. For the active sentences, correct trials revealed that PWA showed a target advantage after hearing the second noun phrase in sentence-final position (e.g. *boy*). This was delayed in comparison to the NHI who fixated on the target picture when hearing the verb (e.g. *shaving*). For the incorrect trials, PWA showed a significant negative target advantage again in the sentence-final position where they indicated the incorrect picture. This suggests that they did not interpret the sentence before hearing the final word, but when they did, they were unable to integrate the noun into the sentence structure. For the passive sentences that were understood correctly, the people with Broca's aphasia showed a target preference, but again, this was evident only after hearing the sentence offset (e.g. *boy* as in *The man was shaved by the boy*). The NHI on the other hand showed the target advantage in the post-verbal region (e.g. *by the*). For the incorrect passive sentences, the people with Broca's aphasia revealed a negative target advantage at the same point as the NHI. According to Meyer and colleagues, these results are evident for a lexical and/or syntactic processing delay as the people with agrammatism did not settle for a picture until they heard the sentence offset, at least for correct trials.

While some studies found a lexical delay in the processing of people with aphasia, other research suggested that one of the core difficulties, particularly for people with agrammatism, is the integration of lexical item into a sentence context. This hypothesis is based on findings of competitor effects, i.e. fixating more on competitor pictures than the target picture (Dickey et al., 2007; Dickey & Thompson, 2009). Dickey and colleagues (2007) investigated real-time comprehension of wh-movement structures. Participants looked at picture panels with objects whilst listening to brief stories. They were given prompts such as "point to who the bride tickled in the mall". After sentence offset, the people with aphasia looked more to the subject distractor than to the target object (that corresponded to the moved element), compared to the neurologically healthy participants. The authors suggest that the increased competition from other interpretations is what leads to the comprehension failure.

Such competition effects were mainly present in incorrect trials and they were sometimes shown in parallel to delays and sometimes without delays (Dickey et al., 2007; Dickey & Thompson, 2009). Dickey and Thompson (2009) investigated object-relative and passive sentences in agrammatic aphasia. For object-relative clauses they found that PWA and controls' eye movements differed towards the end of the sentence. Particularly for incorrect sentences the aphasia group showed competition effects by increased gaze towards an incorrect distractor.

In summary, these online studies on the comprehension of non-canonical sentences in agrammatism indicate that syntactic processing itself can be successful, particularly in the initial phase of processing. Difficulties can occur towards the end of the sentence, due to slowed lexical access and/or lexical competition, and these problems may be compounded with limited processing resources.

3.2.3. Constraint-based approach

The last subsection described an approach to sentence comprehension in aphasia which holds that difficulties in lexical processing can lead to sentence comprehension impairments. Some other recent studies on sentence comprehension in aphasia have stressed the importance of lexical information for successful and efficient sentence comprehension, focussing on lexical factors that are based on language usage (DeDe, 2008, 2012b, 2013a, 2013c; Gahl, 2000, 2002; Gahl et al., 2003). The studies by DeDe, Gahl and colleagues have adopted the constraint-based approach to sentence comprehension, which was introduced in the section on healthy sentence comprehension (3.1.2). Even though this approach does not reject assumptions made by other theories of sentence comprehension in aphasia, it offers a very different perspective. It does not seek to explain which aspects of grammatical competence are impaired, but it emphasises the importance of language usage and our experience with words and structures. The constraint-based approach is valuable for sentence comprehension research in aphasia, as it can show whether individuals with aphasia and neurologically healthy individuals are sensitive to similar influences during sentence comprehension. Knowing about this may potentially enhance our knowledge on why sentence reading in aphasia is often inefficient (even though severe sentence comprehension difficulties are only present in some individuals with aphasia), and how reading can be facilitated.

The constraint-based model is further interesting with respect to the study of sentence processing in aphasia, because it predicts that a linguistic impairment will encourage the system to exploit more frequent and reliable cues (Caplan et al., 2007). Given that individuals with aphasia may have disrupted semantic or syntactic processing, probabilistic aspects and a supportive context may play an increasingly important role. If brain damage weakens one of the systems, the correct interpretation might still be derived depending on the strength of the output of the other systems (Martin & Miller, 2002), even though this may be at a delayed speed. This has traditionally been described as a compensation mechanism, i.e. the use of semantic cues like plausibility to compensate for impaired syntactic analysis (DeDe, 2008). Interestingly, this approach may theoretically be able to account for the observation that patterns of agrammatism can vary depending on sentence type. It might be due to other information sources that are supporting the correct syntactic analysis in some contexts, but not in others. In anticipation of the following paragraphs, the evidence base on constraint-based theories in aphasia is limited, and not all studies revealed results that are completely consistent with assumptions of the approach. Also, most studies focussed on auditory comprehension and research on reading comprehension with respect to constraint-based theories is limited to date.

As already mentioned in Section 3.1.2, one of the precursors to the constraint-based model was the competition model by Bates and colleagues (Bates et al., 1987a; Bates, Friederici, & Wulfeck, 1987b; MacWhinney & Bates, 1989; Macwhinney, 2004), which focused on cues in sentence comprehension as well as probabilistic aspects. This model was also applied to the study of sentence comprehension in aphasia. Bates and colleagues performed a sentence comprehension task to test how much semantic, lexical and syntactic cues contribute to sentence processing in aphasia. The task was enactment, and the sentences varied combinations of word order, subject-verb agreement, and animacy. Results revealed that the participants with Broca's aphasia retained patterns in the use of word order, agreement, and animacy information. This reflects information specific to their language. The result confirms that a probabilistic model can account for differences in grammatical processing. Other findings however did not directly support the competition model, for example, morphology was shown to be consistently impaired in all languages; and this was not dependent on cue validity. It should be noted though that morphological impairment was not restricted to individuals with Broca's aphasia, but also non-neurologically impaired control participants showed vulnerability to morphology compared to healthy young controls. The authors argue that morphology is a vulnerable domain for all the languages studied, and that many different factors (for example hearing the unstressed endings and remembering these suffixes) can contribute to the observed vulnerability in different participant groups.

One of the central principles of the constraint-based approach is that resolving syntactic ambiguities is guided by lexical knowledge, making it a word-level approach (MacDonald et al., 1994). A major focus is on verbs, whose representations contain information about their argument structures. According to the *lexical bias hypothesis* sentence comprehension in aphasia is influenced by argument structure frequencies that are inherent in verb representations, and this can account for at least some comprehension errors (Gahl, 2002). If a verb's argument structure bias is in conflict with the actual sentence structure (e.g. a verb biased towards the intransitive structure but occurring transitively), people with aphasia find the sentence more difficult to process. If sentence comprehension in aphasia were indeed influenced by lexical bias or other probabilistic factors, it would show that PWA remain sensitive to statistical regularities in their language, in line with findings from healthy readers (Ferreira & Henderson, 1990; Garnsey et al., 1997; Trueswell et al., 1993). The next paragraphs will summarise the studies on argument structure frequency in aphasia.

One of the first studies on this topic did not find any evidence that people with aphasia were sensitive to argument structure frequency (Russo et al., 1998). This study was motivated by findings of argument structure frequency effects in healthy processing, as well as findings from aphasia showing that people with Broca's aphasia are sensitive to the number of arguments in a sentence whereas people with fluent aphasia are not (Shapiro & Levine, 1990). The study employed a cross-model lexical decision task. People with fluent types of aphasia and control participants listened to sentences in transitive and intransitive structures. The sentences contained verbs that were biased towards either the transitive or intransitive sentence frame so that they occurred in a preferred or non-preferred sentence structure. During the unfolding of the sentences, a visual probe in the form of a letter sequence was presented on the monitor. Participants had to make a lexical decision on these probes. The probes were placed after the item that disambiguated the structure as being transitive or intransitive (e.g. *The ageing pianist taught his * solo with great dignity,* in the transitive frame, and *The ageing pianist taught with his * entire family*, in the intransitive frame). Reaction times to the lexical decision showed that neurologically healthy individuals responded significantly faster to probes presented in the context of preferred sentence structures compared to the non-preferred ones. This was not the case for the four individuals with aphasia. This was taken as evidence that people with aphasia cannot access information from the verb's argument structure to facilitate comprehension. However, it could also be possible that whether argument structure frequency effects arise in aphasia is dependent on the underlying language impairment as well as on working memory. If lexical structures are severely compromised, the argument structure may not be accessed at all. If lexical processing is not or only mildly impaired, limitations in working memory may also lead to difficulties. There may have also been an issue in that processing difficulties were only probed for at one point (DeDe, 2013a). If the participants were generally delayed in processing, they would have shown the effects at a later point.

Several other studies have shown that lexical information that is based on frequency relationships does influence sentence comprehension in aphasia (DeDe, 2008, 2012b, 2013a, 2013c; Gahl, 2000, 2002; Gahl et al., 2003). Two of these studies focussed on sentences that contain a temporal ambiguity (DeDe, 2012b, 2013a); the discussion of these will be deferred to the next section. Regarding simple sentence structures, Gahl and colleagues employed plausibility judgment tasks in the auditory modality to examine the effect of verb bias in aphasia (Gahl, 2000, 2002; Gahl et al., 2003). Gahl and colleagues (2002) compared the comprehension of transitive sentences (active and passive) with intransitive sentences. The experimental sentences were either consistent with the verb's argument structure frequency (match) or inconsistent (mismatch). Consider the following examples:

Match	Mismatch
(8) The teacher opened the box.	The children crumbled the crackers.
(9) The box was opened by the teacher.	The crackers were crumbled by the children.
(10) The crackers crumbled in our hands.	The box opened after a short while.

The sentences in the “match” column on the left contain the verb *open* that is biased to occur with a direct object (transitive sentence structure), and the verb *crumble* that prefers an intransitive structure. The verb biases match the target sentences. In the “mismatch” column, however, the same verbs occur in structures that are not consistent with their argument structure preference. The verb *crumble* occurs with a direct object, and the verb *open* is used intransitively. The study revealed that people with aphasia (as a group) made fewer errors on target sentences that matched the verb’s most frequent frame of occurrence, i.e. they were influenced by its lexical bias. But there were some group differences. The verb bias effect was significant for people with fluent aphasia but the effect did not reach significance for people with Broca’s aphasia (Gahl, 2002). However, the pattern of results was as predicted: they made more errors in mismatching than matching conditions, for two out of three sentence structures measured. Out of the fluent group, people with anomia showed a trend effect, but people with Wernicke’s aphasia and Conduction aphasia showed no effect. This is partly in line with the findings by Russo et al. (1998) who did not find an effect for individuals with a fluent type of aphasia either. Overall, these studies imply that not only syntactic factors, but also lexical factors, account for the comprehension difficulties in people with aphasia but that this may not be the case for every individual (Gahl, 2002).

Consistent with the studies above, the argument structure frequency effect was also found to influence online reading in aphasia. DeDe investigated the influence of verb bias on self-paced reading of structurally simple sentences (DeDe, 2013c). Verbs that were biased toward a transitive or intransitive structure were embedded into sentences using either a transitive or intransitive frame. Hence, the target sentences either matched or did not match the verb bias. For example, the verb *dance* is intransitively biased because it usually occurs without a direct object. In the study, the verb was presented in both an intransitive sentence frame (*The couple danced every Friday night last summer*) and in a transitive sentence frame (*The couple danced the tango every Friday last summer*). After reading each sentence segment by segment, participants had to answer a comprehension question. The dependent measures were the reading time for each of the sentence segments and comprehension accuracy. Results were consistent with the lexical bias hypothesis: people with aphasia showed an effect of verb mismatch in transitive sentences when answering the comprehension questions, and showed extended reading times for the post verb region (*every*) when verb bias conflicted with the given sentence structure in the intransitive sentences. Both fluent and non-fluent types of aphasia showed the effect, and the result was marginally greater for people with aphasia than for the control group.

Even though some of the research presented above indicates that PWA are sensitive to some lexical information that is inherent in the verb, there are also reasons why they may find this more challenging than NHI. As argued in Section 2.3.1, there is much evidence that people with aphasia show lexical processing impairments that can present as reduced activation levels of lexical access, a difficulty to inhibit activated material, or a difficulty in integrating accessed linguistic information into a sentence. There are studies that suggest that some types of aphasia have difficulties with complex argument structures (Shapiro & Levine, 1990; Thompson, Dickey, Cho, Lee, & Griffin, 2007). Shapiro and colleagues determine argument structure complexity by the number of arguments a verb takes: the more arguments a verb allows, the more complex is the verb. Control participants as well as participants with Broca's aphasia showed an effect of argument structure with better performance on verbs with two argument structures than verbs with four argument structures. This effect was not present for the group of people with fluent aphasia. According to Shapiro and colleagues (1990) this may indicate a lexical impairment in the Broca's group, but the sentence comprehension difficulties that are generally observed by people with fluent aphasia may rather be due to semantic processing impairments. If people with aphasia have difficulties in processing argument structure as indicated in the group with Broca's aphasia by Shapiro and colleagues, then this may indicate that they are not sensitive to influences of argument structure frequency.

In summary, recent studies on sentence comprehension in aphasia have adopted approaches from psycholinguistics, emphasizing probabilistic factors in sentence comprehension. Overall, the evidence base about constraint-based theories in aphasia is limited and there are inconsistencies in the findings. First, not all studies revealed an effect of argument structure frequency for all types of aphasia. Second, only one study investigated the written modality using self-paced reading. It also remains an open question as to whether the influence would be reflected in a more natural method such as eye tracking. Nevertheless, some of the studies indicate that not only syntactic factors, but also lexical factors account for the comprehension difficulties in PWA, and that comprehension in aphasia can be influenced by exposure-based factors (Gahl, 2002). The more often an argument structure is encountered, the more entrenched becomes the lexical representation of the verb. The observation that this knowledge can be accessed during sentence processing implies that information inherent in words can guide sentence processing. As argued by Hare and colleagues (2009), words are used like cues, they are used to access extra knowledge and this may guide expectations and processing.

3.3. Factors influencing the comprehension of sentences that contain a temporal ambiguity

This section describes how argument structure frequency and context may be cues that influence the comprehension of temporarily ambiguous sentences. As will be summarised, the influence of argument structure frequency in resolving ambiguous sentences has been shown for the healthy and to some extent the aphasia population. There is also evidence that argument structure frequency is linked to verb meaning, i.e. the argument structure frequency of a verb may depend on verb sense (Hare et al., 2003). However, this link between form and meaning has not yet been investigated in aphasia. The following subsections will review evidence about the role of argument structure frequency as a processing constraint. They will also consider how this interacts with other factors, and will discuss the time course of processing. The factors are introduced and discussed using the constraint-based approach that was summarised in Section 3.1.3. and 3.2.3.

3.3.1. Argument structure frequency

The influence of argument structure frequencies on resolving temporal ambiguities has been shown in several psycholinguistic studies (Ferreira & Henderson, 1990; Garnsey et al., 1997; Hare et al., 2003; Spivey-Knowlton & Sedivy, 1995; Trueswell et al., 1993), some of which used eye tracking (Ferreira & Henderson, 1990; Garnsey et al., 1997; Trueswell et al., 1993). Trueswell and colleagues (1993) studied the DO/SC ambiguity in both a self-paced reading experiment as well as an eye tracking experiment, finding the expected verb bias effect in both paradigms. In both experiments they found that whether or not a misanalysis occurred was influenced by the verb's argument structure frequency. For example, in the sentence *The student forgot the solution was in the back of the book* (p. 536), which contains a verb that is biased towards taking a direct object, the misanalysis was shown by slower reading times at the verb *was*. This was the first word indicating that the structure did not unfold in the expected way. In contrast, this misanalysis was not observed for sentences containing SC-biased verbs occurring in a SC-structure (e.g. *The student hoped the solution was in the back of the book*). Overall, eye tracking studies confirm that information that is inherent in verb representations and that can be described probabilistically, can influence sentence comprehension. Studies on syntactic ambiguities like these have shown that it may not be a linguistic syntactic parser that rules the reading of syntactically complex sentences. Rather, readers' expectations are influenced by how frequently lexical items occur in a given structure. Readers are sensitive to probabilistic relationships between verbs and their argument structure frequencies (Garnsey et al., 1997; MacDonald et al., 1994; Trueswell et al., 1993).

There is evidence from two studies suggesting that people with aphasia may also be sensitive to verb bias when they process temporarily ambiguous and non-ambiguous sentences (DeDe, 2012b, 2013a). One of these used a self-paced listening paradigm (DeDe, 2012b), and the other one employed self-paced reading (DeDe, 2013a).

In the self-paced listening study, DeDe (2012b) investigated whether lexical-semantic (verb bias and plausibility) and prosodic clues influence syntactic parsing in early closure ambiguities. In early closure sentences (e.g. *While the parents watch (,) the child sings a song with her grandmother*), the second noun phrase is the beginning of a new clause. In late closure sentences (e.g. *While the parents watch the child (,) she sings a song with her grandmother*), the second noun phrase is the object of the subordinate verb. These sentences contain a temporal ambiguity at the second noun phrase (*the child*) where it is not clear how the structure unfolds. In early closure sentences the disambiguation takes place at the main verb *sings* where it is clear that *the child* must be the subject for the verb *sings*. In the listening study by DeDe, all target sentences were early closure sentences, with the noun phrase (*the child*) being the subject. For example:

(11) While the parents / **watched** / <u>the child</u> / sang / a song / with her grandmother.

(12) While the parents / **danced** / <u>the child</u> / sang / a song / with her grandmother.

Some of the probabilistic cues were consistent with this interpretation, and others biased the reader towards the object interpretation of the ambiguous noun phrase. Verb bias and plausibility were combined. The object-bias condition consisted of a verb that is biased towards the transitive frame, followed by a plausible direct object (11). The subject-bias condition consisted of a verb that is biased towards the intransitive frame, followed by an implausible direct object (12). Verb bias and plausibility were then crossed with a prosody bias. The target sentence was either spoken with a contour that biased the listener towards the object-interpretation (no 'auditory comma'), or it biased the listener towards the subject-interpretation of the ambiguous noun phrase (with 'auditory comma'). Crossing lexical and prosody cues meant that there were four experimental conditions, two with consistent cues ('subject prosody-intransitive bias' and 'object prosody-transitive bias') and two with inconsistent cues ('subject prosody-transitive bias' and 'object prosody-intransitive bias').

Results from the mixed model Anovas showed that both NHI and PWA were sensitive to the lexical and prosodic cues, but the use of the cues was delayed for the PWA in comparison to the NHI. In the disambiguation region (the main verb: *sang*), both groups showed longer listening times in the object prosody-transitive bias condition than in the other conditions, indicating that a reanalysis occurred when all cues conflicted with the structure of the target sentence. However, since verb bias and plausibility were conflated, it was not possible to interpret results from the ambiguous noun phrase and the disambiguation region regarding the influence of argument structure frequency independently of semantic plausibility. An additional analysis of the subordinate verb region (*watched/danced*), where only the transitivity and prosody cues were available, demonstrated that the control group showed a transitivity bias whereas the people with aphasia did not. The PWA, in contrast, showed this sensitivity at the ambiguous noun phrase (*the child*), and hence at a later time point than the control group. This indicates that the PWA and the control group differ in the time course of processing. According to DeDe (2012b), this result is consistent with processing accounts that argue that resource limitations lead to a difficulty in applying structural knowledge.

In the self-paced reading study (DeDe, 2013a), DeDe examined the influence of argument structure frequency and ambiguity on the comprehension of sentences. Stimuli included the DO/SC ambiguity, as studied within this thesis. The verbs used in the study were either biased[8] to take a direct object (DO) or a sentence complement (SC), and were placed in sentence complement sentences. Half of the sentences occurred with the complementiser *that* and half without. Consider the following example sentences:

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[8] Verb biases were taken from norming studies carried out by Garnsey et al. (1997) who originally used the stimuli sentences to examine the influence of verb bias and plausibility on the comprehension of temporarily ambiguous sentences by healthy readers.

(13) Direct object-biased verb:

The talented photographer / **accepted** / (that) / the fire / could not / have been / prevented.

(14) Sentential complement-biased verb:

The ticket agent / **admitted** / (that) / the airplane / had been / late / taking off.

In this example, the verb *accept* is biased towards the direct object, and *admit* is biased to occur in a sentence complement frame. According to constraint-based theories, (14) should be easier to read than (13), because in (14) the verb occurs in its preferred frame. Ten participants with various types of aphasia and twenty neurologically healthy participants took part in this study. They read target sentences in segments, and answered a comprehension question after each sentence.

For the NHI, reading time results for the ambiguous noun phrase section showed an effect of ambiguity in that they had longer reading times in the ambiguous sentences than non-ambiguous sentences, irrespective of the verb bias. The PWA demonstrated an interaction between ambiguity and verb bias (significant by participants). Reading times were longer for the ambiguous than the non-ambiguous trials in the DO-biased condition. There was no ambiguity effect for the SC-biased condition.

At the disambiguation region, the results suggested that the PWA and NHI found different cues facilitatory. The PWA experienced processing difficulties mainly due to verb bias whereas the NHI were mostly sensitive to the presence of ambiguity. This result is not fully consistent with results from previous studies of the DO/SC ambiguity in healthy processing. Previous studies showed that NHI integrated the cues of argument structure frequency and ambiguity, showing the effect of verb bias only for ambiguous sentences (Garnsey et al., 1997). It is difficult to account for the difference in these results. Regarding the results from the PWA, DeDe, argues that the complementiser may have been the less reliable cue as closed-class words tend to be more difficult to access for PWA. This would be consistent with previous findings from a study on the online processing of open- and closed-class words by people with Broca's aphasia (ter Keurs, Brown, & Hagoort, 2002). In this study, NHI show different event-related brain potentials (ERPs) waveforms dependent on word class whereas the participants' with Broca's aphasia ERP data did not. This aligns with the results of three participants of DeDe's study who had symptoms of agrammatism, and had difficulties using *that*. There were, however, no consistent patterns regarding verb bias or ambiguity effects based on other aphasia types. Another study compared *that*-presence with *that*-absence in subordinate clauses in spontaneous speech of people with aphasia compared to neurologically healthy participants (e.g. *I think (that) the weather is changing*) (Llinàs-Grau & Martínez-Ferreiro, 2014). Results demonstrated that overall, the ratio of *that*-presence and *that*-absence was similar between both groups even though the non-fluent aphasia group produced subordinate clauses less frequently than both the fluent aphasia group and the control group. Whilst this illustrates the production of *that* may be preserved even if produced in fewer numbers, there is still not enough knowledge on the comprehension of *that* in all types of aphasia.

Taken together, two studies examined the influence of argument structure frequency on sentence comprehension in aphasia. One of these revealed that argument structure frequency influences reading in sentences involving the DO/SC ambiguity, which is the structural ambiguity being pursued in this thesis. Even though the evidence is not yet strong, it can be expected that frequency at this structural level does at least influence sentence comprehension in some individuals with aphasia. This assumption is supported by strong evidence of word frequency effects in aphasia. However, the argument structure information that is inherent in the lexical representations of verbs is a more complex type of information compared to word frequency. Hence, the influence of this constraint might not be apparent in all individuals with aphasia.

3.3.2. Argument structure frequency and context

Context, together with frequency, plays an important role in constraint-based theories. Altmann and Steedman investigated the influence of a referential context on the self-paced reading of ambiguous prepositional phrases (Altmann & Steedman, 1988). Prepositional phrases (PP) of the kind studied here are temporarily ambiguous in that they could either attach to the preceding noun phrase (e.g. *The burglar blew open* ***the safe*** *<u>with the new lock</u> and made off with the loot*) or to the preceding verb (*The burglar blew open* ***the safe*** *<u>with the dynamite</u> and made off with the loot*). Altmann and Steedman constructed sentence pairs consisting of either a prepositional phrase with NP-attachment or with VP-attachment. Generally, the NP-attachment leads to longer reading times than the VP-attachment as it is syntactically more complex. According to the garden path theory, the NP-attachment is more difficult, because using the principle of minimal attachment would lead to the wrong analysis, and the reader has to reanalyse, given the semantic cue. In contrast, the VP-attachment is consistent with the principle of minimal attachment, because it leads to the fewest nodes in the tree structure, and is consistent with semantics. Constraint-based theories on the other hand argue that information sources like a sentence context can encourage the processing of a sentence that is syntactically more difficult than its studied counterpart.

In line with constraint-base theories, the hypothesis by Altmann and Steedman was that introducing biasing context sentences might mitigate the difficulty of processing a NP-attachment. For each pair of target sentences, a pair of context sentences was constructed, to investigate whether the context influenced the comprehension of the target sentences. One context sentence introduced only one referent for the post-verbal noun phrase to support the VP-attachment in the target sentence (16). The other context sentence introduced two candidates to support the NP-attachment (15). Here the specification of a NP-attached PP would be useful in order to know which of the candidates is meant. The following is an example:

(15) NP-supporting context:
A burglar broke into a bank carrying some dynamite.
He planned to blow open a safe.
Once inside he saw that there was a safe, *which had a new lock* and a safe, *which had an old lock*.

(16) VP-supporting context:
A burglar broke into a bank carrying some dynamite.
He planned to blow open a safe.
Once inside he saw that there was a safe, *which had a new lock* and a strongbox, *which had an old lock*.

Target sentences:
(17) The burglar blew open **the safe** <u>with the new lock</u> and made off with the loot. (NP-attached target)
(18) The burglar blew open **the safe** <u>with the dynamite</u> and made off with the loot. (VP-attached target)

The task for the sixty-four university students was self-paced reading. Each sentence was presented one at a time, and participants pressed a button in order to read the next sentence. In order to encourage reading for comprehension, participants had to answer a *yes/no*-question after each sequence. The dependent measure was reading durations. The main result showed that the NP-attachment was facilitated when the context sentence introduced more than one candidate referent to the NP (as in (15)). Hence, the influence from the context could override the level of difficulty that would be expected based on syntactic complexity alone.

The influence of a context has also been investigated in relation to the factor of argument structure frequency. A context can create a semantic scenario, which leads to an expectation of verb meaning for polysemous verbs. According to Hare and colleagues (Hare et al., 2003, 2004), one factor that explains the argument structure biases can be the relation between verb meaning and structure. They observed that the argument structure preference of verbs can be sense-specific, i.e. the bias of a verb differs with its meaning. As argued in Section 3.1.2, the verb *to see* prefers a direct object (DO) if it is used in the sense of 'to perceive visually', and prefers a sentence complement (SC) if it is used in the sense of 'to perceive mentally'. Hare et al. performed a self-paced reading study including verbs that differ in argument structure preferences based on their two most dominant meanings. As in previous studies (e.g. Garnsey et al., 1997), the target sentences were in the sentence complement structure and were either ambiguous (omitting *that*) or non-ambiguous (including *that*). Target sentences followed a semantic-syntactic bias: a context sentence cueing the reader for either the verb's DO- or SC-biased sense, and hence cueing them for either the DO- or SC structure. For example:

(19) SC biasing context (sense: REALISED):

(i) The intro psychology students hated having to read the assigned text because it was so boring.
(ii) They **found** (that) <u>the book</u> was written poorly and difficult to understand.

(20) DO biasing context (sense: LOCATED):

(i) Allison and her friends had been searching for John Grisham's new novel for a week, but yesterday they were finally successful.
(ii) They **found** (that) <u>the book</u> was written poorly and were annoyed that they had spent so much time trying to get it.

Reading times were analysed for different regions of the sentence, with the disambiguation region being the critical area. The results show that the healthy readers were influenced by the ambiguity as well as the context manipulations. Reading durations were longer in the ambiguous than the non-ambiguous trials. Further, they were longer after the DO-biasing than the SC-biasing contexts. There was also an interaction between context and ambiguity: reading times in the critical area were longer for ambiguous target sentences following the DO-biasing context than those following the SC-biasing context. There were no increased reading durations in the non-ambiguous sentences, which included *that*. The structural expectations were contingent on verb sense - promoted by context. Hence, the tendency to garden path in an ambiguous target sentence was mitigated by a context that encouraged a SC reading of the verb. In summary, whereas Altmann and Steedman (1988) used the context to bias one sentence structure over another, Hare and colleagues used a context to bias specific verb meanings and their associated structures. Hence they investigated the effect of specific meaning-structure associations on reading.

The study by Hare and colleagues extends the work on how lexically specific constraints influence language processing. They revealed that verb sense can be one source of argument structure biases. Similarly to a hypothesised association between word frequency and context as discussed in Chapter 2, there may be a link between argument structure frequency and context, strengthening the assumption of interactive patterns in the language system. The meaning-structure relations are so entrenched that healthy readers can access them as a guide to disambiguating temporarily ambiguous sentences.

So far, there is no evidence that PWA are sensitive to context-cued argument structure frequencies. However, as argued in Chapter 2, there is reason to assume that people with aphasia can in fact rely on a context during the processing of syntactically challenging sentences. For example, a semantic constraint can be accessed to facilitate the reading of passive sentences (Germani & Pierce, 1992; Hough et al., 1989). Additionally, it was shown that another semantic factor, semantic plausibility, influences syntactic ambiguity resolution in aphasia at least in connection with verb bias (DeDe, 2012b). However, the question whether context-cued argument structure frequencies can be employed during sentence comprehension may also be dependent on other cognitive skills. According to Wright and Shisler (2005), preserved working memory capacities are essential for language processing, particularly for the interpretation of lexical as well as structural ambiguities. Studies in the healthy population have shown that readers with a large reading span can use probabilistic cues better than readers with low reading spans (MacDonald et al., 1994). MacDonald and colleagues assume that one of the reasons for the difference is that readers with a large reading span have been exposed more to reading than the readers with low spans. This may imply that they are superior in the use of constraints, because their representation of statistical information is better. Further, reduced working memory skills may make it harder to use semantic information from a context sentence as this implies holding the information in memory until approaching the ambiguous sentence region. Since some individuals with aphasia have compromised working memory as a result of brain damage (Caspari et al., 1998; Friedmann & Gvion, 2003; Haarmann et al., 1997; Sung et al., 2009; Wright & Shisler, 2005), it may indicate that there are individual differences with respect to effects of argument structure frequency.

3.3.3. Time course of processing, interaction and compensation of factors

Similarly to the effects of word frequency and context, there is also a controversy regarding the time course of argument structure frequency effects. In psycholinguistics, many studies support the view that a context and lexical-probabilistic factors can influence sentence comprehension. However, the question has become one of *how* and *when* effects arise. This question is tied to different theoretical accounts. According to the garden path model, non-syntactic factors such as probabilistic constraints can never influence syntactic parsing. They can only facilitate the re-analysis procedure if the syntactic analysis was not successful. In constraint-based theories on the other hand, it is assumed that many types of constraints can be employed in parallel and at an early stage of processing. Further, the constraints do not work as modular components, but they occur simultaneously and can interact. Eye tracking studies in psycholinguistics have found differences regarding the time point of this influence (Ferreira & Henderson, 1990; Garnsey et al., 1997; Trueswell et al., 1993). Ferreira and Henderson for example found that argument structure frequency does not influence initial parsing, but guides reanalysis. The effect of verb argument structure was found for *total reading times* (= total fixation durations, global or late measurement[9]) but not for *first fixation durations* (first pass measurement). On the other hand, Garnsey and colleagues (1997) as well as Trueswell and colleagues (1993) revealed that argument structure frequency influences parsing at an early stage. They found an effect of verb bias on ambiguous conditions on first pass eye movement measures. Regarding the context-cued argument structure frequency, Hare and colleagues (2003) also found an early effect, i.e. during the reading of the complementiser. The reading times on *that* were shorter in SC-biased contexts. However, since Hare and colleagues did not use eye-tracking, the time course could not be analysed in more detail.

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[9] More information on eye movement measurements will be provided in Chapter 4.

Time course of processing, interaction and compensation of factors in aphasia

In neurolinguistic studies, the most important question is whether probabilistic constraints influence sentence comprehension. So far there is some evidence that they do, but the evidence of these studies is very limited. The question regarding the time course of such effects, i.e. when they arise, has so far been of secondary interest. Implications are as follows: if effects of argument structure frequency/context-cued argument structure frequency arise at an early stage of processing, it indicates that frequency influences initial parsing decisions, and may reflect reading expectations. In the case of context-cued argument structure frequency this would mean that the reader can form expectations after accessing meaning-structure correlations that are entrenched in the language system. This would support constraint-based theories. If effects arise at a late stage of processing, the implications are more complex. It could support the garden path model, claiming that the context and the argument structure frequency have an influence on the reanalysis stage of reading. However, with respect to other sentence comprehension theories in aphasia, late effects might also indicate a delay in semantic-lexical processing as argued in processing accounts. Some accounts of sentence comprehension in aphasia argue that delayed activation of linguistic knowledge or a fast decay of these leads to difficulties in syntactic operations (Haarmann & Kolk, 1991, 1994). It is particularly a delay in lexical access that has been related to sentence comprehension impairments in aphasia (Love et al., 2008). If lexical access is delayed, then it would be expected that an influence of context-based argument structure frequency would show at a later stage compared to the healthy control participants. A late effect could also point to difficulties in the integration of different sources of information. One neurolinguistic study investigated verb bias, plausibility and prosodic clues as cues to syntactic parsing in a self-paced listening study (DeDe, 2012b). They found that the aphasia group showed a delay in the use of the cues (DeDe, 2012b). Compared to the control group, they showed the effect of cues at a later time point. Whereas the neurologically healthy individuals were sensitive to conflicting cues at the verb region, the people with aphasia only showed this at the ambiguous noun phrase that followed the verb.

Eye tracking proves a good method for studying the effect of argument structure frequency/context-cued argument structure frequency on parsing as it provides a measure of the initial parsing processes (Ferreira & Henderson, 1990). As will be discussed in more detail in the chapter on eye movements (Chapter 4), several eye movement measures can be analysed, and these may relate to different stages of processing. The main distinction is drawn between first-pass measurements and second-pass measurements. First-pass measurements describe the gaze duration before the eyes move back to a previous area in the sentence. Second-pass measurements describe the total gaze including fixations that occur after the eyes had moved back to a previous area in the sentence. This allows for a comparison of first pass versus second pass reading (Trueswell et al., 1993). In self-paced reading on the other hand, reading durations always include the total reading time so that no distinction can be made between different processing stages.

Argument structure frequency and context-cued argument structure frequency are only two types of cues out of a number of information sources that can influence sentence processing. In order to understand the processes of sentence comprehension it is important to determine the types of sources that guide it, when they are available, and how they interact (DeDe, 2010). There are some indications from the studies reported above. First, there is evidence that PWA's processing is particularly disrupted when the cues investigated were at conflict with each other (DeDe, 2012b, 2013c). This may suggest that two conflicting cues lead to higher processing costs and hence to more disruptions. DeDe (2013a) compared verb bias and syntactic ambiguity (presence or omission of *that*) on self-paced reading. During the (ambiguous) noun phrase, there was an interaction between verb bias and ambiguity such that the ambiguity effect was significant for target sentences that were inconsistent with the verb bias, but not for target sentences that were consistent with the verb bias. However, the interaction was not present in the disambiguation region where only the main effect of verb bias remained. This could be because at this time point of processing, PWA relied more on the verb bias due to slowed processing of the complementiser. The complementiser *that* is a closed-class word and may pose more difficulty for PWA. In this case, the verb bias effect would indicate a type of compensatory mechanism, i.e. focussing on the cue that is more available. It has to be kept in mind that differences in the effect of cues are likely to vary individually, depending on underlying lexical semantic skill as well as working memory. Difficulties with the lexical access of closed-class words may hinder the access of a complementiser, and semantic skills can have a varying impact on influences of a context. Mildly reduced lexical-semantic skills that are nevertheless in a normal range have been shown to lead to greater syntactic processing disruptions by ambiguity manipulations (Traxler & Tooley, 2007).

In summary, many questions remain regarding whether probabilistic constraints influence processing in aphasia, and further, at what time course these may play a role. Using eye tracking will be particularly useful to examine the time course, and may illuminate the weight of different cues. Even though the goal of this experiment is not designed to differentiate between different models of sentence comprehension in aphasia, results from this work may contribute to the understanding of the time course of sentence processing.

3.4. Summary

The first goal of this chapter was to introduce the phenomenon of sentences with a temporal ambiguity, and to describe theories that explain how these ambiguities are processed in healthy reading. Another aim was to summarise approaches to understanding language comprehension impairments in aphasia. The theories about sentence processing in the healthy population make contrastive claims. The garden path theory gives priority to a syntactic parsing system that works autonomously. The constraint-based approach on the other hand puts an emphasis on statistical aspects of sentence comprehension. Information gathered from language exposure is argued to be ingrained in the lexical representations of words. However, although the underlying assumptions of the two theories differ, their processing predictions diverge mainly with respect to the time course of processing. The garden path model assumes that processing occurs in two stages. Frequency or information from a context can only be used in the second part of processing, and only if the initial syntactic analysis turned out to be incorrect. Constraint-based theories on the other hand posit that there is only one stage of processing. Any type of information or constraints can be employed immediately.

All processing theories that explain sentence comprehension impairments in aphasia have their benefits and limitations. The structural account emphasises syntactic rules and argues that people with Broca's aphasia have an impairment in building and interpreting syntactic tree structures. This account has been restricted to the patterns associated with Broca's aphasia and indeed cannot explain all the patterns observed. In processing accounts, the main contributors to comprehension difficulties are the complexity of the structure, the severity of the aphasia as well as associated impairments such as in working memory. The type of aphasia is not regarded as a critical factor. It is alleged that the application of syntactic analyses depends on other processing capacities, which can be reduced as a result of the aphasia. The main problem with processing accounts is that they are quite unspecific; they can provide an explanation for many different patterns, but struggle to explain some of the fine grained patterns of sentence level impairments, such as a superiority of *who*-questions like *Who did the girl push* versus a *which*-question like *Which boy did the girl push*?

(Balogh & Grodzinsky, 1996). The studies focussing on lexical processes and their influence on syntactic comprehension are important and relevant to this study. However, a shortcoming is again that most of these studies have focused on Broca's aphasia. Further, the account does not make any predictions regarding influences of argument structure frequency or meaning-structure relationships, which will be studied in the second experiment in this thesis. The final constraint-based approach introduces a perspective change from structural to word-level aspects. Rather than focussing on syntactic rules, this approach investigates aspects of sentence processing that are inherent in word presentations such as relations between meaning and form and the frequency with which certain structures combine with certain verbs. This framework will be adopted in this thesis. This has three main reasons: first, it allows for an investigation of the influences of frequency and context, both in the recognition of words in sentences as well as in influencing syntactic processing. Second, it does not locate such influences to be per se less influential than syntactic structure, and third, the account makes specific predictions regarding influences of meaning-structure relationships on sentence processing.

The second goal of this chapter was to discuss different influences that may facilitate the interpretation of temporarily ambiguous sentences. Studying temporal ambiguity has recently been used to analyse the effect of different cues in sentence comprehension in aphasia. The main benefit of this paradigm is that it allows for a comparison of different cues such as argument structure frequency and ambiguity. Based on the literature summarised in the second section of this chapter, there is reason to believe that at least some people with aphasia are sensitive to argument structure frequencies in the reading of temporarily ambiguous sentences. However, only two studies have examined this phenomenon in the written modality, and both used tasks that differ from normal reading. It is not yet known whether results would be the same if a more natural task were used, as is the case when eye tracking methodology is employed. It is also not known whether individuals with aphasia are, like neurologically healthy controls, sensitive to sense-based argument structure frequencies, and hence whether they are able to access these associations between form and meaning when they read. Since PWA are generally sensitive to semantic cues, there is reason to assume that they are able to access verb-specific meanings through a context bias. Another question is whether they are able to generate structural expectations from the context bias. If that were the case, it would show that form-meaning associations are very resilient in aphasia. The evidence base regarding both the time course of processing and whether there are interactive patterns in the aphasia group is at the moment very limited. It is hoped that the present study will help to fill that research gap. The rationale for the present work will be explained in more detail in Chapter 5. Before that, the next chapter will describe general features of the eye tracking methodology that is to be used in this study.

Chapter 4. The analysis of eye movements

This chapter provides an overview of the analysis of eye movements. The first section will summarise the characteristics of eye movements during reading, and will explain the relationship between eye movements and cognitive processing (4.1). An excellent and more detailed review of eye movements in reading can be found in a seminal paper by Rayner (1998), and more recently, by Radach and Kennedy (2004, 2013). The second section reports on studies that employed eye tracking to study sentence comprehension in aphasia (4.2).

4.1. Eye movements in reading and sentence comprehension

The analysis of eye movements has become one of the most dominant and successful methods in reading research (Radach & Kennedy, 2013). This subsection provides an overview of eye movements in reading and sentence comprehension in the healthy population, and the second subsection summarises the use of eye movements in the aphasia literature.

4.1.1. The characteristics of eye movements during reading

When we read a language like English, our eyes move in saccades, i.e. jumps or forward movements. Saccades are rapid and last about 20-35ms (Rayner et al., 2012). Saccades usually move about 7-9 character spaces forward (Rayner et al., 2012). About 10-15% of the saccades are regressive, that is, they move backwards in text (Rayner et al., 2012). No information is perceived during saccades, a phenomenon called saccadic suppression (Rayner, 1998). Our eyes rest in fixations of about 150-500ms in length (Rayner, Pollatsek, Ashby, & Clifton, 2012). It is during these fixations that information is extracted for linguistic processing. According to Rayner (1998), long regressions of about 10 characters backwards indicate that the reader has difficulties understanding the text. This is consistent with findings that average readers regress more than skilled readers (Ashby et al., 2005). It is important to note however that there is great between-reader variability in eye movements (Rayner, 1998).

When we read, we make sure that what we want to see is in the centre part of the visual field (Rayner, 1998). The visual field consists of the fovea, the parafovea and the periphery (ibid). The best acuity is in the fovea which corresponds to 2° of vision. This explains the function of the saccade: to bring a region of text into foveal vision. Many experiments in reading research have revealed that the region where useful information can be extracted is 3-4 letters to the left of the fixation of a letter, and 14-15 letters to the right of it, for languages that are read from left to right (Rayner, Slattery, & Bélanger, 2010). This is referred to as perceptual span. The size of the perceptual span differs according to reading skill (Traxler, 2012). It can be smaller in readers with selective attentional dyslexia (Rayner, Murphy, Henderson, & Pollatsek, 1989) and in older readers (Rayner, Castelhano, & Yang, 2009).

Usually, content words consisting of a minimum of 5 characters are fixated (Traxler, 2012). Very short function word like *the*, *a* or *of* are skipped more often than content words (Just & Carpenter, 1980). Not only do word length or word class determine whether words are fixated or skipped, but also lexical or semantic properties. Words that are highly predictable from the context are skipped more often than words that are not predictable in the sentence context (Balota, Pollatsek, & Rayner, 1985).

Whilst the focus in this thesis (and equally the majority of reading research in the healthy population) is on silent reading, it should be noted that eye movements can differ in oral reading. For example, average fixation durations are about 50ms longer in oral reading (Rayner et al., 2012). Also, reading aloud is associated with shorter saccades and more regressions (Rayner et al., 2012). These differences are likely to be related to the eye-voice span, which is the distance describing how far the eyes are ahead of the voice (Rayner et al., 2012). In other words, the eyes are faster than the voice and regressions are likely to allow the voice to catch up. Since this thesis is on silent reading, the remainder of this chapter will focus on the literature of silent reading.

4.1.2. Eye movement control and eye mind hypothesis

The above subsection highlighted some of the most important characteristics of eye movements in reading. It indicated that eye movements can vary individually and that they are dependent on what is read (e.g. short function word or long content word), whether the reader is a skilled or average reader, a younger, or an older reader. It is assumed that the reason for this variability is that the control of eye movements is linked to the time course of cognitive processing during reading (Rayner, 1998). This amounts to saying that eye movements are not random, but can be predicted from the text, which is read. This makes the analysis of eye movements a good method for making inferences about cognitive processes through reading. The hypothesis of a correlation between cognitive processing and eye movement behaviour is formulated in two assumptions made by Just and Carpenter (Just & Carpenter, 1980): first, the *immediacy assumption*, which posits that readers aim at interpreting each content word at the moment it is encountered, even if a first interpretation might be wrong and has to be reinterpreted. Interpretation here refers to the processing of several levels such as word recognition, meaning assignment, the assignment of a referent, and determining the status of a word in discourse. This assumption is consistent with seeing reading as an incremental process. The second assumption is the *eye–mind assumption.* This states that the eye rests on a word, i.e. fixates it, until the word is processed. Further the assumption posits that there is no appreciable lag between what is being fixated and what is being processed. Hence the gaze duration on a word corresponds to the processing time of a word. Even though the eye-mind assumption forms the basis of most eye tracking research in reading, recent assumptions are less strong. Kliegl et al. (2006) argue that readers do not process information from just one word at a time, but the mind can process several words in parallel (Kliegl, Nuthmann, & Engbert, 2006). Some information can also be absorbed through parafoveal view, known as preview benefit (Rayner, Castelhano, & Yang, 2010). When readers fixate a word, they obtain a preview benefit of upcoming words (n +1, with n = to the current word), and this results in less time fixating that word, when it is in foveal view (Rayner, Castelhano, & Yang, 2010). It is also debated to what extent the processing of some parafoveal information can influence fixations on the previous word (n -1), referred to parafoveal-on-foveal effects, even though this is more controversial (White, 2008). In the sentence *The girl threw the large ball to her friend*, a parafoveal-on-foveal effect would occur for example if the properties of the word *ball* (word length or frequency for instance) influenced the duration of the fixation prior to the one on *ball*, possibly, but not necessarily on the word *large*. Whereas some argue that only orthographic characteristics of the parafoveal word information can be used, others claim that there can be lexical parafoveal-on-foveal effects (White, 2008). These effects show that the mind is usually somewhat ahead of the eyes (Kliegl et al., 2006). Further, readers use the sentence context to generate predictions and expectations about words to come (Kliegl et al., 2006). In short, the relationship between the eye and the mind is more complex than originally stated (Rayner et al., 2012). Nevertheless the association between eye movements and processing – even in its lesser form – makes eye movements a good method for making inferences about cognitive processes through reading (Rayner et al., 2012).

4.1.3. Using eye tracking to study sentence comprehension

The analysis of eye movements is the best method to study moment-by-moment processing, and it has become the state of the art for investigating online behaviour in the healthy population (Boland, 2004). Eye tracking has several benefits in comparison to other methods, both offline and online. Offline (behavioural) measures such as testing the accuracy of lexical decision or sentence to picture matching tasks, are limited to examining whether the task was successful or not. What is more, behavioural measures add an extra level of difficulty by reading or listening to a stimulus and making a decision based on that. Measures such as reaction times to a task can investigate online sentence processing, but are subject to meta-strategies. Eye tracking in contrast allows for an investigation of sentence processing in real-time that is not influenced by strategies and is largely automatic.

It is important to differentiate eye tracking methods that investigate written and spoken modalities (Boland, 2004). In listening paradigms, people look at objects whilst listening to linguistic stimuli. Inferences about comprehension and processing load can be made by exploring whether the person looks at the object that corresponds to the linguistic target, and if so how quickly. Alternatively, in reading paradigms, local processing difficulty is measured by investigating the gaze durations or the likelihood of regression on a letter/word/text that a person is trying to comprehend (Boland, 2004). Eye tracking reading studies have investigated a number of different cognitive processing phenomena (for an overview see Rayner, 1998). To name only a few, fixation durations and/or the pattern of eye movements are influenced by word frequency and predictability (Calvo & Meseguer, 2002; Rayner, Ashby, Pollatsek, & Reichle, 2004), lexical ambiguity (Rayner & Duffy, 1986), and syntactic ambiguity (Garnsey et al., 1997; Trueswell et al., 1993).

To investigate reading and its underlying cognitive processes, a number of different eye movement measurements are conventionally used (for a more detailed overview see Liversedge et al., 1998; Rayner, 1998; Radach & Kennedy, 2004, 2013). Table 4.1 summarises the measures that are used in this thesis. Spatial parameters are not reported here since the thesis focuses on temporal measurements (for an overview of spatial parameters used to study acquired dyslexia see Schattka et al., 2010). The measures are separated into those referring to the average duration of fixations in a critical area, and those that are ratios, which refer to the proportion of a measurement. The only ratio measure that is used in this thesis is first-pass regression, which indicates whether the first fixation after the target was regressive relative to the target or not. The ratio indicates the proportion of regressive fixations out of all fixations.

Even though there is controversy about what processing aspect each measure reflects precisely, it is generally accepted that increases in processing load are shown by longer fixations and secondary fixations in difficult regions, and by regressions to regions earlier in the text (Boland, 2004).

Table 4.1. Eye movement measures used in this thesis

Measure	**Definition**[10]
Fixation duration measures	
First Fixation Duration	The duration of the first fixation on a target region, provided that the first fixation did not occur after fixations on words further along in the text.
Gaze Duration	The total duration of all fixations in a target region until the eyes fixated a region of text that was either progressive or regressive to the target region, provided that the first fixation on the target region does not occur after any fixations on words further along in the text.[11]
Total Duration	The total duration of all fixations in a target region.[12]
Fixation ratio measures	
First-Pass Regression	Whether the first fixation following fixation(s) on the target region was regressive relative to the target region or not, provided that 1) words further along in the text have not yet been fixated (i.e., the region was not skipped during first-pass reading) and that 2) the target region had not already been fixated and exited.

Measures can also be divided into first- and second-pass measures (Radach & Kennedy, 2004; Rayner, 1998). A first-pass measure (for example single fixation duration, first fixation duration, gaze duration, first pass regression) refers to the first encounter of a word or a region in the text whereas second-pass fixations (for example total fixation duration) refer to those that occur when a region is read more than once (Radach & Kennedy, 2004).

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[10] Measures and definitions are taken from the documentation of the "Get Reading Measures" tool, which computes common dependent measures for eye tracking reading studies from fixation reports that are created by eye tracking software (from manufacturer SR Research).

[11] In the classification presented here, gaze duration refers only to first pass fixations, and does not include re-reading fixations – these are entailed in total durations.

[12] This includes those following a regression.

The benefit of using a number of different measures is that it allows an analysis of slightly different stages in processing, and hence the time course of processing. First-pass measures are thought to reflect an early stage of language processing, that is, initial lexical processing (Rayner & Liversedge, 2011). These measures are often found to be sensitive to lexical access, and tend to be longer for low-frequency words than high-frequency words, (Joseph, Nation, & Liversedge, 2013; Juhasz & Rayner, 2006; Rayner et al., 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006). First-pass measures can however also show effects of predictability (Inhoff, 1984; Rayner et al., 2004). Effects of predictability are also linked to first-pass regressions (Rayner et al., 2004). Words that are unpredictable within a sentence context create a small-scale garden path effect which can initiate regressive eye movements (Kliegl et al., 2004). Finally, first-pass measures can also be affected by structural integration and garden path effects (Boland, 2004).

Second-pass measures such as total fixation duration reflect later processing stages (Rayner & Liversedge, 2011). Effects on total fixation durations have been shown to represent semantic influences or influences from discourse (Rayner & Liversedge, 2011), and are primarily linked to predictability (Calvo & Meseguer, 2002; Kliegl et al., 2004). This is assumingly because unpredictable words motivate the reader to regress and reanalyse the sentence (Kliegl et al., 2004; Rayner, 1998). However, effects on total fixation duration are also found for both word frequency and predictability (Joseph et al., 2013; Juhasz & Rayner, 2006; Kliegl et al., 2004; Rayner et al., 2004, 2011). Intriguingly, prolonged re-reading times (which are included in the measure of total fixation duration) are also associated with high demands in postlexical integration processes (Ashby et al., 2005). Finally, according to an eye movement analysis of acquired dyslexia, Schattka et al. (2011) suggest that prolonged re-reading times can reflect linguistic processing difficulties in general as well as self-monitoring.

It should be noted that even though eye movement measurements are generally divided into first and second-pass stages, there is no straightforward relationship between early eye movement measurements and initial phases of processing on the one hand, or between late eye movement measurements and later stages of processing on the other hand (Pickering, Frisson, McElree, & Traxler, 2004). As Rayner and Liversedge point out (2011), one effect, for example a garden path effect, can occur in early measures as well as in late measures. Analogies that are made on the relationship between measures and processing stages rest on theoretical assumptions that processing takes part in two steps, i.e. with initial analysis and reanalysis. It is not certain that specific measures truly reflect certain stages of processing (Pickering et al., 2004). However, for a working hypothesis that is based on previous findings summarised above, it is assumed in this thesis that first-pass eye movements are related to an early stage of processing involving lexical access, and that second-pass eye movements are additionally associated with a later processing stage involving the integration of lexical information into a sentence context, using semantic and discourse information.

4.2. Eye movements studies in reading and sentence comprehension in aphasia[13]

Whereas eye tracking has become a standard in studying online sentence comprehension in the healthy population, its use in aphasia research is not yet as widespread. The majority of studies using eye tracking in aphasia have employed the visual world paradigm, a paradigm investigating auditory processing. These studies will be summarised in the first subsection. Following, eye tracking reading studies will be discussed. In both sections in will be highlighted how eye tracking adds value to the research.

4.2.1. Eye tracking in listening

In aphasia research, a number of studies explored the potential of using eye-tracking while listening to reveal patterns of auditory comprehension (Bos, Hanne, Wartenburger, & Bastiaanse, 2014; Choy & Thompson, 2010; Choy, 2011; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2015, 2011; Laurinavichyute et al., 2014; Mack et al., 2013; Meyer et al., 2012; Schumacher et al., 2015; Sheppard, Walenski, Love, & Shapiro, 2015; Thompson & Choy, 2009). This is referred to as visual world paradigm[14]. Many of these studies were already mentioned in previous chapters, but some of them are summarised here to show how eye tracking methodology provides new insights into sentence comprehension research in aphasia.

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[13] This narrative literature review is based on a systematic search of the literature. The objective of this search was to provide an overview of research on reading and auditory/written sentence comprehension studies in aphasia employing eye tracking. The methods (inclusion criteria and keyword search) and results of this search are included in Appendix A.1. Additionally, this subsection refers to publications on peripheral dyslexia using eye tracking.

[14] The term "visual world paradigm" describes studies, in which people listen to linguistic stimuli whilst they observe visual scenes that include elements from the linguistic input. Researchers started using the term after an article published by Tanenhaus and colleagues (Tanenhaus, Spivey-Knowlton, Berhard, & Sediviy, 1995) in *Science*. This article illustrates how the analysis of eye movements can contribute to the study of syntactic processing by examining ambiguous language in different visual contexts.

First, the analysis of eye movements enables an investigation of the time course of processing and is not limited to the end result – whether a sentence was understood or not. This can potentially reveal whether comprehension difficulties are associated with certain stages of processing and/or whether processing evolves at an expected or at a delayed rate. Some eye tracking studies revealed that people with Broca's aphasia and associated agrammatism show automatic and hence normal processing of canonical (e.g. reflexive and pronoun constructions) and non-canonical sentences (e.g. wh-structures, object cleft) when they understand the sentence correctly (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009). Dickey and colleagues (Dickey et al., 2007), for example, investigated PWA's real-time comprehension of non-canonical wh-sentences. PWA and age-matched NHI listened to brief stories that embedded a transitive event (e.g. …*The girl was pretty, so the boy kissed the girl*…) followed by a wh-question (e.g. *Who did the boy kiss that day at school*?). Whilst listening, participants looked at visual displays of story elements, and their eye movements were recorded. The picture panels showed the subject (*boy*), the object/target (e.g. *girl*), the location (e.g. *school*), and an unrelated distractor (e.g. *door*). Interestingly, both participant groups fixated on the object/target picture (*girl*) that corresponded to the moved element, when they heard the verb in the question. This result indicates that PWA had automatic processing of wh-structures even though their offline comprehension scores of wh-questions were severely worse than that of the NHI. Thus eye movements show that even though offline accuracy of tested non-canonical sentences was significantly impaired, the processing was not always deficient.

However, many studies showed that the eye movements by the PWA and NHI are only initially similar, and differences arose towards the end of sentences where PWA show competition between the target and the competitor pictures. Such differences particularly arose when the sentences were misinterpreted (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009). This pattern suggests that difficulties in processing for the aphasia group occur in later stages of processing, and may point to problems in lexical integration. Other studies demonstrated that the people with aphasia mainly showed a delay in their eye movements and processing pattern – but no qualitative differences (Bos et al., 2014; Hanne et al., 2011; Meyer et al., 2012). Combining the visual world paradigm with a sentence-picture matching task, Hanne and colleagues (2011) investigated the time course of processing German OVS sentences. The participants – all with agrammatism – showed at chance levels of comprehension impairment for non-canonical sentence.

Reaction times were longer on non-canonical than canonical sentences, longer on incorrect as compared to correct sentences, and longer for the participants with aphasia than controls. The eye movement analysis showed a delay for correct canonical sentences but no qualitative difference. The eye movements by the PWA were similar to those of the control group but it took longer to rest on the picture. Results support the slowed processing account; the authors argue that there is interaction between processing time and response accuracy.

As summarised above, eye movements can show what goes right in sentence processing, and equally, they can show that is going wrong (Dickey et al., 2007; Dickey & Thompson, 2009). Being able to separate the analysis of correct from incorrect trials allows a closer picture on processing in unsuccessful attempts. This has demonstrated that eye movements tend to differ from those of neurologically healthy participants in the incorrect trials (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Meyer et al., 2012). In the study by Dickey and colleagues mentioned above, people with aphasia show competition effects toward the end of the sentence, but only in the incorrect trials. Participants looked at picture panels with objects whilst listening to brief stories. They were given prompts such as *Point to who the bride tickled in the mall*. After sentence offset, the people with aphasia looked more to the subject distractor than to the target object (that corresponded to the moved element), compared to the neurologically healthy participants. Hence the authors indicate that the increased competition from other interpretations is what leads to the comprehension failure.

Taken together, eye movement studies cast doubt on accounts of sentence processing that are based on pure results from offline studies. Many of these argued that people with aphasia are impaired in the processing of non-canonical sentences. The story emerging from eye tracking studies is more nuanced. First, they have shown that moved elements are processed at least some of the time, pointing to important residual competences in aphasia. Second, when difficulties do arise with non-canonical sentences the difficulties may not reflect syntactic problems per se. Rather, lexical processing may be delayed (Hanne et al., 2011; Meyer et al., 2012) or lexical competition arises (Choy, 2011; Dickey et al., 2007; Thompson & Choy, 2009).

One limitation of the eye tracking listening studies is that comprehension is not completely natural, because presented pictures always influence processing. Particularly the competition effects found might be increased through the experimental paradigm. Seeing an array of four pictures including a lexical competitor might create a competition that is stronger than it would be without the presence of pictures. By contrast, in eye tracking studies of reading comprehension we can explore how reading in a near natural situation unfolds in real time. An overview of the small number of eye tracking studies in reading in aphasia will be given in the next subsection.

4.2.2. Eye tracking in reading

The use of eye tracking to investigate reading in aphasia is very limited. The purpose of this section is to give an overview of how this method has contributed to the overall evidence so far, and to highlight the gaps in this area of research.

Some early studies investigated eye movements in aphasia and acquired dyslexia (Huber, Lüer, & Lass, 1983; Klingelhöfer & Conrad, 1984), but were limited to global parameters (such as saccade behaviour and the number of fixations) of eye movements and did not use temporal measures such as fixation durations. Nevertheless, this early work provided first evidence that the eye-mind hypothesis holds true for reading patterns for people with language difficulties. Klingelhöfer and Conrad (1984) carried out the first study to investigate eye movements during reading by people with aphasia. They employed electrooculography, a method that can record small eye movements by using electrodes that are placed near the eye. Their explorative study aimed to examine the saccadic pattern of people with different type of aphasia. Results revealed that saccadic strategies corresponded with individual speech difficulties. Participants with Wernicke's aphasia showed more and smaller saccades as well as a larger number of fixations compared to the control participants. This pattern was consistent with the observed comprehension difficulties of that group. The participants with Broca's aphasia showed longer reading durations particularly in oral reading. Thus their reading was hesitant and non-fluent like their speech. The individuals with anomia were the least hindered in reading by their aphasia, and showed only a small increase in the number of fixations and regressions as compared to the control group.

In recent work, researchers have been able to analyse more fine-grained aspects of eye movements, i.e. fixation patterns as well as fixation durations. Technological advances enabled the study of eye movements in relation to specific word boundaries, and hence much smaller areas than saccade behaviour on a sentence or text. The first of these more recent eye tracking studies on reading in the clinical population focussed on types of peripheral dyslexia that were introduced in Chapter 2 (Ablinger, Huber, Schattka, & Radach, 2013; Behrmann, Shomstein, Black, & Barton, 2001; Leff et al., 2000; McDonald, Spitsyna, Shillcock, Wise, & Leff, 2006; Rayner & Johnson, 2005; Schuett, Kentridge, Zihl, & Heywood, 2009). These studies enabled a more detailed view on peripheral dyslexia by demonstrating that many subtypes of peripheral dyslexia are associated with an increase in the number of fixations and regressions in the context of shortened saccades, and may further be related to a difficulty of programming saccade behaviour. These eye movement characteristics can provide evidence for hypothesised reading behaviours.

In contrast to peripheral dyslexia, central dyslexia is an acquired reading impairment that results from an impairment in linguistic processing, and tends to occur after left-hemisphere damage (Cherney, 2004). Acquired dyslexia is related to aphasia, and is hence of more interest in regard of this study. A small number of studies have started to use eye movement analysis to find out more about online word processing associated with central dyslexia (Ablinger et al., 2014; Ablinger, Huber, & Radach, 2014; Schattka et al., 2010). All of these studies investigated the process of reading words aloud. One study investigated the use of eye tracking to assess sentence reading pre- and post reading treatment in an individual with acquired dyslexia (Kim & Lemke, 2016). Interestingly, some of this research provides evidence for assumptions that were made based on previously proposed models. Based on the dual route cascaded model (Coltheart et al., 2001), Schattka and colleagues differentiated two reading pathways: the non-lexical (segmental) route which works via grapheme-to-phoneme conversion, and the lexical route via access to whole orthographic word representations that are mapped onto phonological representations (Schattka et al., 2010). This research revealed that the pattern of eye movements, particularly the spatial measurements, reflects the reading route that is used by the reader. The lexical readers had initial saccades that landed in the optimal viewing position, i.e. the centre between the beginning and the middle of the word. Lexical readers use a whole word reading strategy and hence try to fixate the whole word in order to access it in the mental lexicon. This mirrored the reading pattern of the control readers. The segmental readers on the other hand showed initial saccades in the beginning of words such as the first letter. Since segmental readers cannot access the word forms, they rely on sublexical processing, hence they have to land initial saccades on the beginning of words. Therefore, different routes of word processing (the lexical reading route through the lexicon, and the segmental route through grapheme to phoneme conversion) can determine the spatial parameters of eye movements. Generally, total fixation durations, the number of fixations and the re-reading times of the readers with acquired dyslexia were larger in nearly all instances than in the control group whereas most of the early processing measures such as first pass gazes did not differentiate the two groups. This reflected the linguistic processing difficulties of the PWA, and the likely need for increased monitoring. Interestingly, the treatment study by Kim and Lemke (2016) revealed that reading treatment facilitated the use of a lexical-semantic reading route, and that initial landing positions were shifted towards the optimal viewing position post treatment as well as during follow-up.

The analysis of eye movements in acquired dyslexia further revealed that other more traditional methods are not always sufficient in the diagnosis and classification of acquired dyslexia (Ablinger et al., 2014). The discrimination of different types of dyslexia such as deep dyslexia, phonological dyslexia and surface dyslexia is traditionally largely based on the analysis of errors. However, Ablinger and colleagues found that particular types of errors are not associated with certain reading routes. On the other hand, eye movements can reflect the underlying reading routes that people with acquired dyslexia were using, and can also reveal the reading strategy employed during the recovery process (Ablinger et al., 2014). The authors note that error analysis combined with the analysis from eye movements is valuable in the comprehensive diagnostics of acquired dyslexia.

Summarising the paragraphs above, most studies using eye tracking to investigate reading in aphasia focused on acquired dyslexia. As of today, there is limited published research on eye tracking studies for silent sentence reading in aphasia. Whereas most of the studies on sentence processing in the healthy population have been carried out in reading using eye tracking, sentence comprehension studies in aphasia have mostly been carried out in the auditory modality. However, some recent research indicates a growing interest in this area. To date, this has been reported in one publication (Knilans & DeDe, 2015), and in one conference presentation (Kim & Bolger, 2012). These studies are highly relevant to the present work from a methodological as well as from a theoretical viewpoint. First of all, Kim and Bolger examined the facilitative effect of a semantic context on the eye movements of a group of ten people with aphasia and eight control participants. They used plausible sentences with 40 target words varying in predictability. Even though most studies in healthy reading have shown an influence of context before, the study by Kim and Bolger did not find a context effect for healthy readers. The context effect only occurred for the participants with aphasia. The aphasia group had more difficulties with words in the unpredictable contexts than the predictable contexts. This was evidenced by longer total fixation durations and also by a larger number of regressions on low context words. Kim and Bolger conclude that the top-down processing from high cloze contexts supports reading in the group with aphasia. This is in line with interactive activation models as well as views of interactive compensatory processing.

The eye tracking reading study by Knilans and DeDe (2015) investigated whether the lexical bias hypothesis can be extended to include biases on structural frequency. To recap, the lexical bias hypothesis states that sentences with a mismatch between the verb bias and structure are more difficult to process than sentences with a match. Knilans and DeDe were interested in whether processing ease was similarly affected by structural frequencies. They compared the processing of object vs. subject cleft sentences using eye tracking. Subject relative sentences occur more frequently in English than object relative sentences (Roland, Dick, & Elman, 2007), and hence create a bias or an expectation for this structure. Recent studies in the healthy population showed that reading times for the verb in object relative sentences are slower than reading times at the verb in subject relative sentences (Staub, 2010). This suggests that readers are slowed down at the point when they notice that expectations for a subject relative clause are incorrect. Further to structural frequency, object cleft sentences are structurally more complex than subject cleft sentences. Nine people with aphasia and eight control participants read sentences including object (e.g. *It was the baby that the father entertained during the party last week*) or subject cleft sentences (*It was the father that entertained the baby during the party last week*) whilst their eyes were tracked. Critically, both the NHI as well as the PWA showed an influence of the frequency bias, and there was no difference in effect size. They both showed longer gaze durations on the second noun phrase in the object relative than the subject relative sentences, consistent with earlier studies of healthy reading. PWA were also affected by structural complexity as emerged in re-reading durations of critical regions.

With regard to eye movement behaviour, the results from both eye tracking studies showed that the people with aphasia differ from control participants in eye movements. Generally, people with aphasia read more slowly, show longer fixation durations, and make more regressions (Kim & Bolger, 2012; Knilans & DeDe, 2015). With regard to the theoretical research questions, these two recent eye tracking studies provide first evidence that eye movements in aphasia (1) are sensitive to semantic factors such as a sentence context, and (2) can show sensitivity to structural frequencies. This indicates that predictive processes and expectations of structures may be retained at least for some people with aphasia. However, more evidence is needed. This thesis will provide new evidence by investigating the influence of context and how it relates to word frequency. The aim is to understand more about the relation between bottom-up and top-down influences in aphasia. Moreover, this thesis will investigate whether people with aphasia are sensitive to associations between meaning and form, and whether meaning-structure associations facilitate the processing of one structure over another.

4.3. Summary

The analysis of eye movements is a valuable method to examine processing in real time. It is based on the assumption that eye movements reflect cognitive processing, even though this relationship is not as straightforward as previously thought. A number of different eye movement measurements can provide cues to different stages of processing. The biggest difference is between first- and second-pass eye movement measurements, reflecting early and later stages of processing. Eye movements show specific features but these vary individually, and are dependent on who is reading and what is being read. Readers with aphasia and acquired dyslexia exhibit longer re-reading times than neurologically healthy readers. This indicates that eye movements reflect linguistic processing difficulties by people with aphasia, as would be expected on the basis of the eye mind hypothesis.

Eye tracking methodology has several advantages for aphasia research. First, it sheds light on processing rather than comprehension accuracy. It can show whether the reading process differs from healthy readers, and if so, where the disruptions occur. Further, the analysis of the time course of eye movements can reveal whether the speed of processing differs from healthy readers. This is relevant as several accounts of sentence comprehension deficits in aphasia have argued that slowed lexical processing or weak syntax are the basis of sentence comprehension deficits.

Lastly, the eye tracking whilst reading paradigm provides a method to study ‘near natural’ reading without any distractors from pictures on a computer screen. From a theoretical point of view, further evidence is needed to establish whether the analysis of eye movements can be used to answer questions related to reading comprehension, influences on reading comprehension, and the time course of this process. This thesis will contribute to this evidence.

Chapter 5. Rationale for experiments and aims

The last three chapters provided an overview of the theoretical and methodological background to this study. They argued that successful reading comprehension relies on efficient visual word recognition. This is a complex process that consists of both bottom-up as well as top-down components. Further, the comprehension of sentences involves the integration of various sources of information (e.g. semantic, syntactic, pragmatic, probabilistic). In healthy reading, these processes are fast and incremental. In mild to moderate aphasia on the other hand, the process of visual word recognition is often more difficult, and may be more slowly integrated with other sources of information, leading to difficulties in sentence comprehension.

The first section of this chapter provides a brief summary of the current research evidence, and addresses the issues under investigation in this thesis (5.1). The second section discusses why the eye tracking whilst reading paradigm is an excellent method to answer the questions posed in this thesis (5.2). Finally, the third section summarises this chapter (5.3).

5.1. Summary of research and issues addressed in this thesis

The overall goal of this thesis is to investigate silent reading in aphasia in comparison to neurologically healthy individuals. This goal is divided into two parts, which will be addressed by two separate experiments respectively. The first part focuses on non-ambiguous sentences, allowing an investigation of bottom-up and top-down components of reading. The second part focuses on sentences that contain a structural ambiguity. Sentences of this type are suitable for an investigation of different kinds of information sources, which can bias the reader towards different structural interpretations. Both parts of this thesis are connected by a focus on factors that relate to our experience with language: the frequency of words and structures, and the contexts in which they appear.

5.1.1. Visual word recognition at the sentence level and Experiment 1

From a theoretical perspective, very little research exists on the process of visual word recognition and reading comprehension in aphasia. Much research has focused on word reading, describing and classifying people with acquired dyslexia. The focus in this thesis is on silent reading at the sentence level, because silent reading is what people engage in mostly in their everyday lives, and secondly, it is the modality that has been studied and hugely benefited from the availability of eye tracking in the healthy population. A number of recent studies have shed more light on the process of reading comprehension in aphasia. These suggest that many people with mild or residual aphasia exhibit reduced reading efficiency both at the sentence and text level. Additionally, this research added substantial knowledge regarding cognitive skills that are required for successful reading; working memory in particular. However, there is still a discrepancy between what is known from reading in the healthy population, and what is known about reading in aphasia.

One well-studied aspect in psycholinguistics is the influence of bottom-up and top-down processes on sentence reading. These component processes of reading are usually studied by focusing on the influences of word frequency and predictability which are thought to be representatives of bottom-up and top-down processes respectively (Dambacher, 2009). Some of these studies found that bottom-up and top down processes are generally separate processes (Ashby et al., 2005; Calvo & Meseguer, 2002; Rayner et al., 2001), but some have hinted that they may be more interactive than previously thought (Rayner et al., 2004).

Within the context of language impairments, word frequency and predictability/context have proven to be very robust factors (Bose et al., 2007; Bub et al., 1985; Kittredge et al., 2008; Nozari & Dell, 2009; Pashek & Tompkins, 2002; Pierce & Wagner, 1985; Zingeser & Berndt, 1988). However, much less is known about the influences of bottom-up and top-down processing (and their representatives word frequency and context) on silent sentence reading. Not much is known about the time course of these processes, for example, whether top-down information such as a sentence context influence early or later stages of visual word recognition. Another unsolved issue is how word frequency and context relate to each other, and hence, whether they can interact in aphasia. An interactive pattern would be expected as the impairment of some processes may lead to more input from other systems, as argued within the interactive compensatory processing approach (Stanovich, 1986, 1988). Finally, knowledge is needed regarding potential individual differences in the effects of word frequency and predictability. Given that some people with aphasia show no word frequency or context effects whilst others show reverse word frequency effects, it can be expected that such a heterogeneous pattern will also be found with silent reading.

Experiment 1

The first experiment in this thesis addresses the issues raised above. The experiment investigates the influences of word frequency and context on visual word recognition at the sentence level in aphasia compared to neurologically healthy controls, using eye tracking. It further investigates the time course, the relation between the two factors, and whether the people with aphasia show any individual differences. Knowing what factors influence reading in aphasia is a useful way of understanding the nature of the functional loss (Zingeser & Berndt, 1988). As noted by Pierce, knowing what kind of information is used and when it is integrated during language processing provides information on how language processing in aphasia can be facilitated (Pierce, 1991) .

The investigation of word frequency and context on reading in aphasia will enhance our knowledge of reading comprehension at the sentence level. This experiment will show whether lexical-semantic factors that facilitate reading in NHI are likewise available in the aphasia group. Further, comparing the effects of word frequency and context between both groups will indicate whether bottom-up and top-down processes are similar, or whether they differ between the groups. Reduced lexical and/or semantic skills may lead to a different weighing of bottom-up and top-down processes. If the aphasia group demonstrates a stronger word frequency effect compared to the control group, then this would indicate that lexical representations are weakened to the extent that mainly high frequency words can be accessed. If the aphasia group shows a stronger predictability effect compared to the control group, then this would suggest that they rely more on the context cues in comparison to neurologically healthy individuals. However, it could also be the case that the participants with a semantic impairment are less influenced by predictive contexts if they have difficulties in forming lexical expectations during reading.

Results on the time course of processing (i.e. when factors play a role) can indicate further whether factors are linked to certain processing stages. Magnified effects on early eye movement measures would signal difficulties or a delay with the stage of lexical access as this is the stage of processing that early eye movements mainly reflect. Magnified effects on later eye movement measures could point to difficulties or a delay with later processing stages that may relate to lexical integration and/or semantic processing as well as monitoring processes. It could be that reduced lexical and/or semantic skills lead to slower reading and hence delayed effects of the experimental manipulations. Results on the time course of processing will also have implications regarding models of visual word recognition. Evidence showing that high-level information (i.e. context) exerts an influence on early aspects of visual word recognition challenges modular models of reading in which lexical access is thought to be limited to bottom-up influences (Carreiras et al., 2014).

Examining the relation between word frequency and context will reveal whether bottom-up and top-down influences on reading are independent of each other, or whether they can interact. Finding out whether there is a relationship between frequency and predictability effects and certain language skills would enhance our understanding of what the essential language skills are in reading comprehension, and may point to strategies in reading intervention.

It is hoped that Experiment 1 also validates the eye tracking whilst reading methodology for individuals with aphasia. Word frequency effects are highly expected since frequency has been shown to be a robust effect in aphasia. If eye movements are susceptible to word frequency in reading sentence comprehension, then it is assumed that the methodology can also be used to explore further and subtler aspects of lexical representations, such as argument structure frequencies.

Results from the first experiment may also have implications for clinical settings. Knowing what kind of influences readers with aphasia are sensitive to, and how these interact would indicate whether bottom-up or top-down influences should be targeted in reading treatment. A large effect of word predictability would indicate that it is useful to focus on strategies such as using the sentence context to derive the meaning of more difficult words. If word frequency was a strong factor for a participant, it would suggest the importance of training lexical access of low frequency words, with the aid of sentence contexts.

5.1.2. Structurally ambiguous sentences and Experiment 2

A recent perspective on sentence comprehension in aphasia has focussed on probabilistic influences (DeDe, 2012b, 2013a; Gahl et al., 2003). Studies within the probabilistic constraints approach emphasise our experience with words and structures, and assume that this information is integrated into lexical representations. Probabilistic information such as argument structure frequency may influence sentence processing including the assignment of structure (eg. DeDe, 2013a). However, the effects were not always observed for all types of participants with aphasia. Further, the influence of argument structure frequency on sentence comprehension by people with aphasia has not been studied using eye tracking.

It is not clear where the argument structure frequency originates from, but one suggestion has been a link to verb meaning. Hare and colleagues demonstrated that argument structure frequencies can in some cases be determined on verb sense (Hare et al., 2003). If healthy participants are primed with a sentence context that biases them towards one verb sense more than the other (in polysemous verbs), then this also creates certain structural expectations. This means that healthy readers are influenced by correlations between meaning and structure. It is not yet known whether people with aphasia are sensitive to such more subtle information inherent in lexical representations.

Further, if effects of meaning-structure correlations do occur in aphasia, another question is when such effects would occur, i.e. whether they affect earlier or later stages of processing. Yet another issue is the question of how cues or factors of investigation relate to each other. One study on argument structure frequency in aphasia suggests that people with aphasia may be sensitive to different type of cues compared to neurologically healthy participants, i.e. the aphasia group was sensitive towards argument structure frequency but not the structural cue whereas the control group showed the opposite pattern (DeDe, 2013a).

Another gap in the research evidence relates to potential individual differences. Aphasia varies greatly among individuals and so factors that are found to play a role in some PWA might be irrelevant for others.

Experiment 2

The second experiment in this thesis aims to address the above limitations in our knowledge. The eye tracking experiment investigates the influence of a verb's sense congruent argument structure frequency (measured as context effect) and the influence of the presence or absence of the complementiser *that* (measured as ambiguity effect) on the reading of structural ambiguities. Further, it investigates the time course of processing, and whether the factors are independent or interactive. The second aim is to study whether the PWA show individual differences, and whether this is linked to their underlying language profiles.

If the reading by the individuals with aphasia shows to be influenced by context manipulations, it would show that they can access these probabilistic features of verb representations, and that they have access to higher order mappings between form and meaning. This would extend previous work around the lexical bias hypothesis in aphasia (Gahl, 2002; Gahl et al., 2003), it would also show similar processing to neurologically healthy readers (Hare et al., 2003). Finally it would support constraint-based theories in aphasia research (DeDe, 2013a; Gahl, 2002; Gahl et al., 2003).

5.2. The value of the eye tracking whilst reading paradigm

As summarised in Chapter 4, a small number of studies have investigated aspects of sentence reading in aphasia (Kim & Bolger, 2012; Knilans & DeDe, 2015). These suggest that eye tracking can be a valuable method to study silent reading. One major benefit of the eye tracking method is that through the analysis of eye movements, inferences can be made about reading comprehension without individuals making a response. This is particularly beneficial for studying reading comprehension by individuals who have difficulties with spoken output or with acquired dyslexia. For this group an analysis of reading out loud might not reflect their silent reading comprehension process. Additionally, readers are not distracted by having to focus on other experimental tasks such as lexical decision or sentence to picture matching. Other tasks require the allocation of resources and place higher demands on attention and executive functions. On the other hand, eye tracking allows an investigation of the automatic and less consciously manipulated aspects of processing.

In the healthy population, the eye tracking whilst reading paradigm has been used extensively throughout the last decades. One reason for its success may be that it allows an investigation of real time processing and hence the time course in which comprehension unfolds. Finding experimental effects on different eye movement measures reflecting early vs. late processing stages allows a closer investigation and comparison of bottom-up and top-down processes, as well as a comparison of syntactic guiding and re-reading processing stages. An analysis of the time course of reading in aphasia may inform theories of sentence comprehension which differ in their emphasis on a focus on syntactic impairments vs. limited resources.

With the technical gains throughout the last decade, eye tracking technology is advanced enough to be used involving people with language impairments following stroke. However, studying silent sentence reading in aphasia is not without challenges. Since language profiles in aphasia vary individually, it is likely that eye movement data will be less consistent than in a control group. Additionally, people with aphasia may have additional difficulties with cognitive abilities such as working memory which may influence eye tracking data. Further, understanding the individual's visual abilities is equally important as their linguistic resources. In order to guarantee that no such confounds resulting from visual difficulties are present, individuals with severe visual impairments are excluded from this study.

5.3. Summary

This chapter briefly explained the rationale and the aims of the two experiments in this thesis. The main motivation for both experiments is to investigate aspects of lexical and semantic influences on reading in both word recognition at the sentence level, and in the context of structurally complex sentences. Since both lexical and semantic influences may be present in all types of aphasia, participants with any aphasia syndrome are included in this thesis. Importantly, the lexical and semantic factors are linked to the frequencies of lexical items themselves, the frequencies of verbs in particular argument structures, as well as to the context they commonly occur in. Results from both experiments combined may show whether there are parallels in the influence of lexical-semantic processing on word recognition at the sentence level, and the success of using lexical information in the reading of structurally more complex sentences. One focus in aphasia research is often on impairments and not on cues or facilitators of sentence comprehension. The goal of this thesis is to extend the literature by understanding factors that may facilitate reading and sentence comprehension. It is hoped that the eye-tracking experiments shed more light on how these processes of reading sentence comprehension unveil in real time.

Chapter 6. Experiment 1. Materials and design

This chapter illustrates the construction of the experimental sentences that are used in Experiment 1. The first subsection describes how and with which criteria the target words were selected from corpora, and how the experimental sentences were developed (6.1). It also depicts two norming studies on the sentences. The second subsection presents the development of filler sentences as well as comprehension questions (6.2). A further norming study involving the comprehension questions is also described. The third subsection depicts the design of Experiment 1 (6.3), and the last subsection summarises this chapter (6.4).

6.1. Stimulus development - sentences

Twenty-eight sentences were developed that contained the target words in the critical region. Target words were fourteen high frequency nouns (*mean* frequency = 245.93; *range* = 95.00-645.00 occurrences/million) and fourteen low frequency nouns (*mean* frequency= 5.46[15]; range = 0-35.00 occurrences/million). Written word frequencies were obtained from = WebCelex (Max Planck Institute for Psycholinguistics, 2001, http://celex.mpi.nl/, downloaded on 23/12/2012). This database was used since it contains almost exclusively written text (16.6 million words are written, 1.3 million words are spoken), and most is British English[16]. Since the corpus was compiled in England the spelling has in most cases been changed into the British English standard. The English frequency data in the Celex are based on the COBUILD/Birmingham corpus, which comprises 17.9 million tokens.

In order to guarantee that the frequencies are as valid as possible, efforts were made to ensure that the target words were from the same frequency range (high: > 95 occurrences per million, low: < 35 occurrences per million) in both the Celex and the SUBTLEX database (Brysbaert & New, 2009, http://expsy.ugent.be/subtlexus/)[17]. The

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[15] The aim was to use words of very low frequencies such as < 2 occurrences/million. However, this was not realizable since the words had to appear in a predictable and unpredictable context whilst at the same time being semantically non-violating. It was impossible to create highly predictable sentence contexts for very low frequency items.

[16] Out of 284 written texts, 44 are American, thus 84.6% of the total written corpus is British English.

[17] Exceptions from the SUBTLEX are *student* (43.04 occurrences/million), *bank* (84.98 occurrences/million), *chapter* (11.84 occurrences/million), and *history* (83.92 occurrences/million), which have frequencies of < 95 occurrences/million in the Subtlex database but were included as high frequency items), and *safe* (143.0 occurrences/million), which has a frequency of > 35 occurrences/million in the Subtlex database but was included as low frequency item).

decision to use, and cross-reference two databases was made as several studies have questioned the validity of the Celex database as well as the old but widely used database by Francis and Kucera (Francis & Kucera, 1982) (Balota et al., 2004; Brysbaert & New, 2009; Burgess & Livesay, 1998; Zevin & Seidenberg, 2002). Whereas the Celex database consists of sources such as books or newspapers, which are often edited, which avoid word repetitions, and concern topics that may not be representative of individuals' lives or interests (Brysbaert & New, 2009), the SUBTLEX database is based on 40-50 million words from American English subtitles, and hence has a more natural and varied source of words. These frequency norms predict human processing latencies[18] much better than the existing norms so far (Brysbaert & New, 2009). The difference in mean frequency between the low and high frequency word group was significant in the Celex database ($t(26) = 4.92$, $p < .0001$) as well as in the SUBTLEX database ($t(26) = 4.82$, $p < .0001$).

Target words were between 4 and 8 letters long and word length was matched between the frequent and infrequent pair (+/- one letter[19]). The mean length was 6 letters, and there was only one word pair involving short words (*bank/safe*). Apart from this, short words ≤ 4 letters were avoided since words of this length and shorter are frequently skipped during reading as shown in eye tracking-reading studies (Rayner et al., 2011).

Two sentence frames were constructed for each word pair (example sentences are shown in Table 6.1). In one sentence frame the target word was predictable, in the other it was unpredictable. Thus there were four sentence conditions: 1) a high frequency word in a predictable context (HF P); 2) a low frequency word in an unpredictable context (LF U); 3) a low frequency word in an predictable context (LF P); and 4) a high frequency word in an unpredictable context (HF U). The sentence pairs were as similar as possible whilst creating either predictable or unpredictable contexts. None of the sentences made the target words implausible or anomalous. The sentences ended in a further clause in order to include a region subsequent to the critical word; a region in the end of a sentence may attract different eye movements than regions in the middle of the sentence.

In order to determine predictability ratings, two norming studies (a sentence completion and a rating study) with the healthy population were conducted. These are tasks that are conventionally used to assess predictability ratings for target words in

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[18] Naming and lexical decision latencies based on British English are available through the *British Lexicon Project* (Keuleers, Lacey, Rastle, & Brysbaert, 2012). 78 British participants responded to 28,700 monosyllabic and disyllabic words and the same number of nonwords.

[19] There was one exception: the word pair *doctor/explorer* differed in length by two letters.

sentences (Balota et al., 1985; Rayner et al., 2004). These will be described in the following two subsections.

Table 6.1. Experimental target words in a predictable and unpredictable sentence context

	Condition abbreviation	**Frequency**	**Context predictable/ unpredictable**	**Example sentence**
(1)	HF P	high frequency	predictable	Anna was able to get a reduced ticket for the show because she is a *student* working there.
(2)	LF U		unpredictable	Anna was able to get a reduced ticket for the show because she is a *florist* working there.
(3)	LF P	low frequency	predictable	Claire loves flowers and wants to be a *florist* learning how to make nice bouquets.
(4)	HF U		unpredictable	Claire loves flowers and wants to be a *student* learning how to make nice bouquets.

6.1.1. Norming study 1 - sentence completions

The first norming study was a sentence completion study. Participants were given the potential experimental sentences, up to, but not including the target word. They were asked to generate three different possible sentence endings. The goal was to examine whether the sentence fragments made the potential target words predictable or unpredictable.

Methods – Questionnaire one

Participants

Participants without brain damage (a different group to the one taking part in the eye tracking reading study) took part in the first norming study (N = 42). Most of them were university students; some were recruited via personal contacts of the author. The age range was 18-63 (M = 27.86), thirty-eight were female and four were male. Participants were entered into a lottery to win a £20 shopping voucher in each of the norming studies as incentive for participation.

Materials and procedure

Initially, all words from the selected frequency range that could be assembled into word pairs were placed into two sentence frames creating testable predictable or unpredictable contexts. These were 34 word pairs. Participants were given the sentences up to the target word, e.g. *There is only one way to solve the*.... (expected answer: problem). The sentences were uploaded onto an online survey tool called *Sosci Survey*[20]. The welcome text on the online platform asked individuals to only take part if they were a native speaker of British English or if they started speaking English at a very young age and speak it fluently. The participants were told that the study consists of a number of incomplete sentences and that they should make three suggestions as to how the sentences could end. They were asked to write down the first word(s) that came to their mind, and that it could be one word or more. An example was given. Sentences occurred in a different random order for each participant. This controlled for order effects that might arise from fatigue or fluctuations in attention. The study took approximately 20min.

Results and discussion

The number of times the target word was named first, second, third and overall was recorded. Target words were tallied if they were part of multiple word phrases (e.g. *school* in *after school club*). If the word was named first, it was not counted if it was named again in the second or third choice (sometimes the target word was used in different phrases). The criterion for a word to count as predictable was that at least 60% of the respondents offered it as a potential closure. A target word was counted unpredictable if 20% or fewer respondents used it as a potential closure. Often a semantically suitable, but pragmatically less predictable word was named second or third. Overall, six word pairs out of thirty-four achieved these criteria. For many word pairs, three conditions out of the four achieved the criteria, but one failed. For some word pairs only the one sentence frame achieved the criteria, but the other sentence frame did not. For example, the word pair *child/collie* achieved the criteria for all conditions except HF P, i.e. the predictable context for *child* only achieved a score of 26%. This reflects the difficulty of creating a sentence frame that allows both words to fit the sentence context semantically, but makes one word predictable and the other word unpredictable. In the next phase, sentence frames were improved and the norming study was carried out again with an updated questionnaire. For the word pairs that fulfilled the criteria in only one sentence frame, another sentence frame pair was created.

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[20] This survey tool allows creating questionnaires online. A maximum flexibility can be implemented by using PHP or HTML, and for academic purposes its use is free of charge.

Methods – Questionnaire two

Participants

Twenty-six participants completed the second questionnaire. These were recruited via personal contacts, and fellow students as well as via social networks. The whole dataset from one person was deleted since the answers were unconventional multi-word phrases. Data for twenty-five participants was included in analysis. The age range was 20-69 (M = 31.56), nineteen were female, and six were male.

Materials and procedure

The second questionnaire of the completion study included sentence frames for 27 word pairs. These sentence frames excluded the six word pairs that achieved the criteria in the first questionnaire, and consisted of improved sentences for the rest (one word pair was omitted as it was not possible to improve the sentence frames in a semantic plausible way). The sentences were developed to make the target words either predictable or unpredictable. Procedures were the same as used for questionnaire one.

Results and discussion

The second questionnaire identified five new word pairs that achieved the criteria. In addition, fourteen pairs from the previous questionnaire, but with revised contexts, also achieved the criteria. Together with the previously identified six word pairs this meant that 25 pairs could be entered into the second norming study.

6.1.2. Norming study 2 – ratings

The second norming study was a rating study. In the second norming study the 25 word pairs that fulfilled the criteria in the first norming study were rated for predictability given the sentence frames. The goal was to achieve predictability ratings for all target words.

Methods

Participants

Fifty participants completed the rating study, and were distinct from those taking part in the eye tracking study. The age range was 18-53 (M = 26.69), and 100% female. Most of them were speech and language therapy students. Forty-eight participants were native speakers of English, two were not.

Materials and procedure

Participants were given the stimuli sentences in a randomised order up to and including the predictable or unpredictable word. Sentences ended after the target word so that the tail of the sentence did not influence predictability of the target word. The questionnaire was again implemented via Sosci Survey. The sentences were divided in two datasets (list A and list B) since otherwise participants would have read each word and sentence frame twice, and rating one sentence could have influenced rating the other sentence. One dataset contained the word pair in the predictable condition, and the other dataset contained the word pair in an unpredictable condition. The two lists contained sentences, which alternated in predictability so that half of the high frequency and half of the low frequency were predictable (see Table 6.2). The lists were sent to different groups of individuals[21] (thirty rated list A, and twenty rated list B). Most of them were speech and language therapy students. Participants were asked to rate how well the word fits the context on a scale of 1-7 (1 = very low; 7 = very high). This was completed for all four conditions.

Table 6.2. Experimental sentences in two lists for the rating study.

List	**Sentence example**	**Condition**
A	After the accident they rushed to the *hospital*.	HF P
	The friends carry their tents to the *campsite.*	LF P
	Carla keeps her jewellery in a *bank.*	HF U
	John withdraws money from the *safe.*	LF U
B	The friends carry their tents to the *hospital.*	HF U
	After the accident they rushed to the *campsite.*	LF U
	John withdraws money from the *bank*.	HF P
	Carla keeps her jewellery in a *safe*.	LF P

Results and discussion

The criteria for target words were ratings ≥ 5 in the predictable condition, and ratings of ≤ 4.5 in the unpredictable condition. Fourteen word pairs that fulfilled the criteria in all conditions were selected as experimental target words. These were: *child/collie,*

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[21] The number of participants between the lists varied as the lists were constructed as separate studies on Sosci Survey, and the links were shared separately.

house/hostel, doctor/explorer, dinner/spinach, student/florist, bank/safe, water/whisky, story/email, office/casino, manual/chapter, history/geology, hospital/campsite, school/tailor, company/brewery. Table 6.3 shows the mean predictability ratings of the four conditions. There was no statistical difference between the HF P and LF P condition ($t(35) = .35$, p > .5), and the HF U and LF U condition ($t(26) = 1.40$, $p > .15$). There was a significant difference between HF P and HF U ($t(26) = 18.20$, $p < .0001$) condition, and between the LF P and LF U condition ($t(26) = 14.00$, $p < .0001$).

Table 6.3. Mean predictability ratings of the four conditions

Condition	**Mean predictability rating**
high frequent predictable	6.73
low frequent predictable	6.69
high frequent unpredictable	2.68
low frequent unpredictable	3.14

Note. The scale was 1-7, with 1 = very low; 7 = very high

6.2. Stimulus development – filler sentences and comprehension questions

After the target sentences had been tested, filler sentences and comprehension questions were then developed.

Filler sentences

Thirty-one filler sentences were developed to prevent participants from developing expectations about the nature of the task. The filler sentences comprised simple transitive and intransitive sentence structures as well as a range of different grammatical structures such as passives and comparative sentences. With all sentences randomised, it was unlikely that someone could guess the purpose of the study.

Comprehension questions

Yes/no-questions were developed for each experimental and filler sentence to monitor comprehension of the readers. These questions guaranteed that participants were paying attention to the sentences, and checked the accuracy of comprehension as an offline measurement. The questions were constructed to be presented both auditorily and visually. A female native speaker of British English who was blind to the answer of the questions read the questions with coherent question intonation but otherwise monotonously. Recordings were made in a soundproofed room with a standard voice recorder, and were tailored using Praat (Boersma & Weenink, 2013).

The questions were simple and queried either the comprehension of the context (Table 6.4 a-d) or the noun and thus the target word (Table 6.4 e-h). This guaranteed that the comprehension of the whole sentence was controlled, and participants would not get accustomed to focusing on the target noun for example. One question for each sentence context was constructed, and hence the question for the high frequency and low frequency word condition were the same (a and b/c and d). If the question queried the context, the answer was the same in all conditions (a-d). If the question queried the target noun, the answer was *yes* in one of the two sentences in one sentence context (f) and *no* in one of the two sentences in the other sentence context (g). There was a nearly equal number of *yes*- and *no*-responses. These question types were distributed as equally across the stimuli types as possible. There were 16 different variations (HF P noun yes, HP P noun no, LF P noun yes, LF P noun no etc.) and 56 stimuli sentences. Thus a completely even distribution was not possible to achieve. Further, after the question-norming study, a noun-question was changed into a context question leading to a small number advantage of context questions (16) over noun questions (12). There were 12 *yes*- and 16 *no*-questions. An equal distribution of *yes/no*-questions was developed for the filler sentences.

Table 6.4 Stimuli sentences and comprehension questions Experiment 1

	Condition	Example sentence	Question
(a)	HF U	The friends carry their tents to the *hospital* where they want to sleep.	Did the friends forget their tents? (context - no)
(b)	LF P	The friends carry their tents to the *campsite* where they want to sleep.	Did the friends forget their tents? (context - no)
(c)	LF U	After the accident they rushed to the *campsite* to get the injury cleaned.	Did they walk slowly? (context - no)
(d)	HF P	After the accident they rushed to the *hospital* to get the injury cleaned.	Did they walk slowly? (context - no)
(e)	HF U	The poor backpackers are staying in a *house* in New York.	Are the backpackers staying in a hostel? (noun-no)
(f)	LF P	The poor backpackers are staying in a *hostel* in New York.	Are the backpackers staying in a hostel? (noun-yes)
(g)	LF U	The young couple are saving to buy a *hostel* to refurbish.	Are the couple saving to buy a house? (noun-no)
(h)	HF P	The young couple are saving to buy a *house* to refurbish.	Are the couple saving to buy a house? (noun-yes)

6.2.1. Norming study 3 – comprehension questions

In the third norming study, comprehension questions were normed. This was to guarantee that the comprehension questions for the different conditions had the same level of difficulty.

Methods

Participants

A further group of healthy individuals completed the question norming study (*N* = 21). These were eleven females and ten males. The age range was 22-64 (*M* = 34.58). All participants were native speakers of British English. They were recruited via personal contacts and via social networks.

Materials and procedure

Participants were presented with the sentences, followed by simple *yes/no* comprehension questions. They had to read the sentences and to answer the comprehension questions, then rate the difficulty of the question on a scale of 1-7 (1 = easy; 7 = difficult). Again two lists, list A and list B were used so that participants did not read the same sentence context twice. Twelve completed list A, and nine individuals completed list B.

Results and discussion

The results were analysed for accuracy (correct/incorrect) and for the rating of difficulty (1-7). If the participants made more than two errors in one question, it was considered to be too difficult or ambiguous and was replaced with a new question. This was the case for three questions. The mean ratings for the different conditions are shown in Table 6.5. There was no significant difference between the difficulty of the HF P and HF U condition ($t(26) = 0.12$, $p > .5$), the LF P and LF U condition ($t(26) = 0.34$, $p > .5$), the HF P and LF P ($t(26) = 0.42$, $p > .5$), and the HF U and LF U condition ($t(26) = 0.30$, $p > .5$).

Table 6.5 Mean difficulty ratings of the four conditions

Condition	**Mean difficulty rating**
high frequency predictable	1.47
low frequency predictable	1.38
high frequency unpredictable	1.50
low frequency unpredictable	1.44

Note. The scale was 1-7, with 1=easy; 7=difficult

6.3. Design of Experiment 1

The stimuli set splits into four conditions with 14 target sentences each (14 high frequency and 14 low frequency words in the predictable/unpredictable context), thus there were 56 experimental sentences. The conditions were counterbalanced across two lists. One list comprised half of the items in a predictable context, and the other half in an unpredictable context. The other list was the same except that it included the reverse sentence contexts. The stimuli were mixed with 31 filler sentences in each list. Hence, each list was comprised of 59 sentences plus 5 practice trials that were shown at the start of each session. The whole study included 64 trials. Each of these trials consisted of a sentence to read, and a following *yes/no*-comprehension question. All participants read both lists, but in two separate sessions with a minimum of 7 days in between. Sentences were randomised for individual participants.

6.4. Summary

This chapter described how the materials for Experiment 1 were developed and controlled. High and low frequency target words were identified from two databases. One comprised mostly written text, and the other was drawn from film subtitles, hence offered a more natural and varied source of everyday language. Predictable and unpredictable contexts were developed for the target words, which were checked through a series of norming studies with healthy language users. These studies ensured that the predictable contexts elicited the target words significantly more often than the unpredictable contexts against stringent criteria, and that this was the case for both high and low frequency words. Ratings of predictability also confirmed the difference between the stimuli. Comprehension questions were also developed for the stimuli sentences to ensure that participants were attending fully, and to give an offline measure of understanding. In a third norming study, a group of healthy participants read the stimuli sentences, answered the questions, and rated their level of difficulty. There were no differences in mean difficulty between the four conditions. In summary, this chapter indicates a high quality of stimuli designed for Experiment 1. Stimuli sentences, comprehension questions and the design were thoroughly tested to guarantee that the experimental manipulation is sound. In Chapter 7 the methods and results of Experiment 1 will be described.

Chapter 7. Experiment 1. The influence of frequency and contextual predictability on sentence reading by people with aphasia

7.1. Introduction

This experiment investigates the influence of word frequency and contextual predictability on eye movements during the reading of sentences, comparing PWA with NHI. It is hoped that this will shed more light on the nature of visual word recognition in aphasia, and how it relates to silent reading of sentences. More specifically, the investigation of word frequency and context allows a closer examination of bottom-up and top-down processes in reading in aphasia. As outlined in Chapter 2, these influences are not only attributable to linguistic factors, but are probabilistic as they are shaped by language exposure. As it is known from healthy reading that words that are more likely to occur in a sentence are processed faster, it will be interesting to find out whether this pattern manifests in aphasia.

The remainder of this introduction will provide a short summary of the previous research on reading, and will present the aims and research questions of this experiment. The methods are described in Section 7.2. It provides an overview of the participants in this study, and explains the experimental procedures and the analyses. The results will be presented in Section 7.3. This will first consider global characteristics of the data, and will subsequently present the results form the eye movement analysis. Another two subsections address individual results and the relationship between language skills in the aphasia group and eye movement measurements. Finally, Section 7.4 discusses the results by a comparison to previous literature and theoretical accounts.

7.1.1. Summary of previous research

As outlined in previous chapters, the analysis of eye movements has become one of the most dominant and successful methods in reading research (Radach & Kennedy, 2013). An increasing number of studies involving healthy readers have examined the process of reading. These eye tracking studies have been able to demonstrate that reading is incremental and predictive. That is, people process each word as soon as they come to it, and they make predictions as to which word(s) come(s) next. Evidence for this is provided by shorter eye movements (and hence faster processing) on words that are likely to appear in a sentence context (e.g. high frequency or predictable words) than on words that are unlikely to occur in a sentence context (e.g. low frequency or unpredictable words). However, there is more controversy about when these factors exert an influence on reading, and whether they influence either bottom-up or top-down processes, or both.

Reading can be difficult for people with aphasia, and this might be related to inefficient bottom-up and top-down processes. However, little research has been devoted to the study of sentence reading in aphasia. There is however evidence that word frequency as well as context are factors that influence language in aphasia. Recently, the analysis of eye movements has also been applied to the diagnosis and treatment of reading impairment after brain damage, such as dyslexia (Ablinger, Huber, et al., 2014; Schattka et al., 2010). There is also an emerging interest in using eye tracking to examine silent reading of people with aphasia. Kim and Bolger (2012), for example, examined the facilitative effect of a semantic context on the eye movements by a group of ten people with aphasia and eight control participants. Their target sentences included words that were either predictable or unpredictable from the sentence context. Results showed that the PWA had more difficulties with words in the low context conditions than the high context condition, as evidenced by longer fixation durations and also by a larger number of regressions. Kim and Bolger conclude that the top-down processing from predictable contexts supports reading in the group with aphasia.

Based on this research it may be expected that people with aphasia and neurologically healthy individuals are both sensitive to effects of word frequency and contextual predictability in sentence reading analysed by eye movements. Differences can be expected in the magnitude of these factors, and how they relate to each other. On the basis of the compensatory processing theory (Stanovich, 1986), it can be expected that the processing system of PWA can compensate for difficulties in lexical access by depending more on a sentence context.

7.1.2. Aims of the experiment

This experiment uses eye tracking whilst reading to investigate the influence of word frequency and contextual predictability on sentence reading by people with aphasia. The study design, which has been used in the healthy population before, places high and low frequency words into a predictable or unpredictable sentence context (Rayner et al., 2004). Half of the target words are high frequency words, and the other half of target words are low frequency words. The words are placed into either a predictable or an unpredictable sentence context.

Research Questions

The first research question is whether NHI and PWA show an influence of word frequency and contextual predictability on visual word recognition when they read sentences, and whether these effects are equivalent. If effects arise, follow-up questions will be pursued concerning the time course of these effects, and whether factors are independent or interactive.

Based on previous findings in the healthy population, it is predicted that the NHI are sensitive to both word frequency (Juhasz & Rayner, 2006; Rayner et al., 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006) as well as contextual predictability (Balota et al., 1985; Rayner et al., 2004, 2011). This would show by shorter fixation durations on high frequency items compared to low frequency items, and by shorter fixation durations on predictable as compared to unpredictable items. Predictability effects should also manifest in first pass regression data, with more regressions on unpredictable than predictable items, as found previously (Rayner et al., 2004). The question of whether there is an interaction between word frequency and predictability is more explorative. No interaction between word frequency and context, i.e. independent effects of both factors, suggest that there is no interaction between bottom-up and top-down processes. Finding that word frequency influences an early processing stage associated with lexical access, and context exerts an influence on later processing stages that are post-lexical, would be consistent with modular models of visual word recognition. Interactive patterns would support interactive models. Rayner and colleagues found a mild but non-significant interaction between word frequency and predictability in reading by NHI (Rayner et al., 2004). Many other studies revealed that word frequency and predictability were independent factors on reading (Altarriba et al., 1996; Rayner et al., 2001). Based on this research, it is expected that the NHI show independent effects of word frequency and predictability. Hence word frequency and predictability should show no interaction. Predictions regarding the time course are that both factors show an influence on early as well as late eye movement measures (Altarriba et al., 1996; Balota et al., 1985; Inhoff, 1984; Kliegl et al., 2004; Rayner et al., 2004, 2006), but that the word frequency effect is stronger for the early stage of processing and predictability on the later stage of processing.

For the aphasia group, expectations are, in parallel to the NHI, that eye movements are sensitive to both word frequency and predictability. It is expected that both effects will be larger than for the NHI group, because PWA have shown strong effects of these variables in other offline (Kittredge et al., 2008; Pashek & Tompkins, 2002) and some online studies (DeDe, 2012a; Kim & Bolger, 2012). A processing advantage for high frequency and predictable words may be explained by the fact that these words have lower activation thresholds and are therefore easier to recognise than low frequency and unpredictable words. The effect of a context can be particularly robust for PWA who have profound difficulties in sentence comprehension (Pierce & Wagner, 1985). Hence larger word frequency and predictability effects are expected, as well as interaction between the factors. As claimed within the compensatory processing theory (Stanovich, 1986, 1988), it can be expected that the processing system by PWA needs to compensate for reductions in reading skills. A larger reliance on a context may compensate for poorer bottom-up processes (Kim & Bolger, 2012). The sentence context may have an effect of low frequency words in particular as low frequency words are more difficult to recognise. Finally, predictions regarding the time course are that the factors exert an influence at the same stages of word recognition as for the NHI. However, many studies of auditory comprehension in aphasia showed delays in processing compared to the NHI (Hanne et al., 2011; Love et al., 2008; Meyer et al., 2012). If reading comprehension is subject to a similar delay, word frequency and predictability effects in this study may occur later for the PWA than for the control group.

The second research question is to investigate whether PWA show any individual differences in the effects, and if so, whether this relates to their underlying language impairment. A follow-up question is to examine whether specific underlying language impairments are related to prolonged fixation durations and hence slower reading, as compared to the control group (independent of experimental manipulation).

For this analysis, test results from the background assessments are correlated with the effects of word frequency and predictability. It is expected that effects of frequency and predictability in PWA vary depending on their overall severity of aphasia, as well as the severity of their semantic and lexical impairments. Individuals with a moderately compromised lexical system might find high frequency words easier to access than low frequency words since the activation threshold of the frequent words is lower. This effect might be less strong for individuals with a very mild impairment in lexical processing. A moderate impairment of semantic processing may show a more robust predictability effect than an intact semantic system, because the reader relies more on the facilitation from the context to integrate the words into the sentence. On the other hand, it might also be the case that an impairment of the semantic system leads to a reduced predictability effect, because the reader finds it difficult to generate expectations from the sentence context. Finally, it is expected that there would be a relationship between working memory skills and the effect of a sentence context. This assumption is based on the research finding that limitations in working memory contribute to sentence comprehension impairments in aphasia (Caspari et al., 1998; Friedmann & Gvion, 2003; Haarmann et al., 1997; Sung et al., 2009; Wright & Shisler, 2005). This might be because using information from a context sentence poses demands on working memory.

Results from the background assessments will also be correlated with eye movements, independent of the experimental conditions. The goal is to investigate whether there are any underlying language impairments that can predict the length of eye movement durations. It is expected that reduced lexical and/or semantic skills correlate with longer fixation durations, particularly with total fixation durations, which is the global measure. However, this analysis is largely exploratory.

7.2. Methods

Ethical approval for this study was obtained from the School of Community and Health Sciences Research Ethics Committee, City University London. All participants gave informed consent before being involved in any of the study procedures. Chapter 6 described the development of the stimuli sentences through norming studies; hence, this chapter begins with an overview of the participants. After summarizing the results from various background assessments, the eye tracking procedure will be described, and an overview of the planned analyses will be provided. The analysis section will summarise the conditions of the experiments, the eye tracking measurements, and the statistical procedures.

7.2.1. Participants

The participants met the following inclusion criteria in order to take part in the project: 1) a single left hemisphere stroke at least six months prior to testing; 2) English as a first language, or English as their primary language since adulthood; 3) mild or moderate aphasia with some impairment of written word or sentence comprehension, and finally, 4) no developmental dyslexia or any evidence of visual (-spatial) impairment such as a cataract, glaucoma, visual neglect, or severe visual field impairment.

The participants with aphasia were recruited through the in-house Aphasia Research Clinic at City University, London and through community groups for individuals with aphasia in London. The recruitment was accomplished in a team of aphasia researchers. The group leads from the community groups were provided with information about all aphasia research projects and their inclusion criteria. Flyers with information about all aphasia research projects as well as flyers for individual projects were distributed in the groups and at aphasia events. Invitations to the groups were followed with accessible presentations of the research for the group members. Through individual conversations, individuals with aphasia could express their interest in one or many research projects. Individuals received an information sheet written in accessible language. The project was explained and all questions were answered before consent was elicited.

The screening and the background assessments were either carried out at City University London or at the participant's home. Four screening tests were administered to establish the participant's level of language comprehension and visual skills. Potential participants had to score at least 60% in the written word to picture matching tasks from the *Psycholinguistic Assessments of Language Processing in Aphasia* (Kay, Lesser, & Coltheart, 1997), and at least 40% in the PALPA written sentence to picture matching task. The line bisection task from the *Comprehensive Aphasia Test* (Swinburn, Porter, & Howard, 2004) and a letter cancellation task (Weintraub & Mesulam, 1985) screened for visual impairment. The letter cancellation screens visuo-spatial skills and can detect visual neglect (Ferber & Karnath, 2001; Hartje & Poeck, 2002). The line bisection task investigates the ability to see size relation within an object, and has been shown to be sensitive to hemianopia (Ferber & Karnath, 2001; Hartje & Poeck, 2002). If participants reported visual field impairments but were not in possession of the reports, or if there was any doubt about the screening results, additional perimetry testing (visual field test) was carried out. A perimeter is a machine that can systematically test the visual field. The reading impairment in hemianopia is dependent on the parafoveal visual field sparing. If the parafoveal visual field sparing is severe, that is under 4°, up to 92% of people with a right-sided hemianopia (as would be expected after a left-hemisphere stroke) show hemianopic dyslexia (Schuett et al., 2008). However, the literature reports rare impairment in reading when the parafoveal visual field sparing of 10° is not compromised (Schuett et al., 2008). In this study the visual angle of a letter was 0.3°, and with a perceptual letter span of 8-10 letters, this span should not be affected if the visual field was spared for 3°. In order to exclude hemianopic dyslexia, 10° was used as exclusion criteria in this study. The perimetry testing took place within the Optometry Department of City University London, and was carried out by the author by the use of an Octopus Perimetry, after training form a qualified staff member. This procedure screened out two potential participants.

Individuals with additional cognitive impairments such as dementia were excluded from the study.

Seventeen[22] people with aphasia (PWA) met the criteria and took part in the study (10 women and 7 men, *mean* age = 58.76 (*SD* = 14.96), *range*: 22-80). All participants were right-handed. Nine other individuals with aphasia were screened, but were not included because their aphasia was too severe, or because they had evidence of visual impairments. Table 7.1 presents an overview of the demographic information of the individuals with aphasia. This includes information about their aetiology, which is based on medical reports that most participants were able to provide. A description of their language impairments will be given in Section 7.2.2.

Twenty native speakers of English with no reported history of neurological impairment (neurologically healthy individual = NHI), speech/language disorder or reading difficulty such as developmental dyslexia took part as control participants (13 women and 7 men, *mean* age = 53.60 (*SD* = 14.54), *range* = 22-76). All NHI participants had cognitive functioning commensurate with their age at the time of testing. This was established by administering the *Mini-Mental State Examination*, 2nd Edition Standard Version (Folstein, Folstein, White, & Messer, 2010). The control participants were matched with the aphasia group on age and level of education. The level of education was identified by scoring the education level from 1 (no formal) to 7 (doctoral degree), and calculating the average. There were no statistical differences between the two groups in terms of age, $U = 132.00$, $z = -1.16$, $p = .25$, r = .19 or in terms of education, $U = 123.00$, $z = -1.46$, $p = .14$, r = .24. Some of the control participants were recruited through personal contacts and through the distribution of flyers at community centres, libraries and The University of the Third Age, London. Others were recruited through the subject pool of the University College London. The control participants came to City University London for two eye tracking sessions. They were provided with an information sheet and had time to answer questions before they gave consent. Table 7.1 presents an overview of demographic information of the controls. Their screening will be explained in Section 7.2.3. All NHI participants had normal or corrected-to-normal vision or hearing, and no visual (-spatial) impairments such as glaucoma, visual field impairment, or visual neglect. Some of the participants had their cataracts removed in the past; one participant had a cataract in one eye (but eye movements were recorded from the other eye). They were all right-handed.

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[22] Nineteen PWA took part in the study and completed the background assessments, but one participant's eye tracking file was corrupt, and another participant represented as an outlier in the eye tracking experiment. Hence, both participants were excluded from the whole dataset, and are not reported.

7.2.2. Background assessments PWA

The PWA were tested with a battery of language assessments. The purpose was to determine which areas of each individual's language were affected, and to see whether there is an association between certain language impairments and results of the reading eye tracking experiments. Different composite scores with a number of subtests were calculated. Composite scores were calculated by taking the straight average of scores from the subtests. For test results that could not be grouped together, no composite scores were derived (working memory). All composite scores as well as the working memory scores are the input for correlations with experimental effects and eye movement durations. All background test results are presented in Tables 7.2-7.5. Scores that were entered into the correlation analyses are shaded in grey.

In order to assess the type of aphasia as well as its severity *The Western Aphasia Battery-Revised* (WAB-R, Kertesz, 2007) was administered[23]. The severity of aphasia is expressed by the Aphasia Quotient (AQ), which is derived from summing up and weighing scores of the following subtests: spontaneous speech with a rating of fluency and content (40%), auditory verbal comprehension (20%), repetition (20%), and naming and word finding tasks (20%). By using a taxonomic table in which subtests scores are compared to those scores that are associated with each type of aphasia, the WAB-R allows a syndrome classification. The WAB-R was preferred to other tests such as the Comprehensive Aphasia Test (CAT, Swinburn et al., 2004), because it is more sensitive to individuals with mild aphasia, and can be completed in one test session. Moreover, the WAB-R is a widely used aphasia test so that results are comparable to other publications. Overall, thirteen participants presented with a mild, and four participants with a moderate aphasia. Types of aphasia were mixed with about half showing Anomic aphasia, none had Wernicke's aphasia. The individual results on the WAB-R including the **Aphasia Quotient** as a severity score are given in Table 7.2.

For a more thorough understanding of how the aphasia affects each participant's lexical-semantic processing system, different lexical/semantic tasks were carried out in comprehension and in production. An overall semantics score (referred to as "**semantics overall**" in Table 7.3) was derived from three subtests: the semantic memory test from the CAT (Swinburn et al., 2004), which assesses nonverbal semantics; the written synonym judgment task from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) as a demanding assessment of verbal

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[23] The WAB-R has a supplemental section with assessments on reading and writing as well as non-linguistic skills, but the supplemental tests were not administered here.

semantics (synonyms score); and the word-picture matching task from the PALPA (Kay et al., 1997).

A **lexical-semantics written comprehension** score was derived from the PALPA written word-picture matching and the PALPA visual lexical decision imageability & frequency test. The PALPA object naming (frequency) and the action naming test of the *Verb and Sentence Test* (VAST, Bastiaanse, Edwards, & Rispens, 2002) were administered to test lexical production skills. The lexical production score hence consists of both naming nouns and naming verbs. To gain a **lexical-semantics overall** composite score, the average outcome of the two naming tasks (nouns and verbs), the visual lexical decision task and the word to picture matching task was calculated.

Table 7.3 summarises the individual and mean scores on semantic and lexical processing. Overall, most participants achieved high scores in the semantic memory and the word to picture matching tests, but some show impairment in semantic processing as assessed in the written synonym judgment task, with scores between 72% and 98%. Some also had compromised naming (scores between 61% and 99%), and difficulties with the lexical decision task (68-100%). None of the participants had a severe impairment of semantic or lexical processing at the word level.

Written sentence comprehension was examined by the written PALPA sentence picture matching task and the VAST sentence comprehension test (Bastiaanse et al., 2002). The latter is a test on auditory processing, but was changed into a written version for the purpose of this study. Whereas the PALPA test investigates a range of sentence structures, the VAST focuses on two canonical and two non-canonical sentence structures. Participants differed significantly between the comprehension of canonical and non-canonical sentences ($z = -3.275$, $p =.001$). Superior performance in canonical over non-canonical sentences can be taken as evidence for grammatical impairments (DeDe, 2013c). The outcome suggests that fifteen out of the seventeen participants had grammatical difficulties. This is not consistent with the results from the WAB-R showing that most of the participants had Anomic aphasia and are generally not thought to have any grammatical difficulties. The **sentence overall** score comprised the mean of both tests, and can be used to explore associations between the offline understanding of sentences and eye movements. Table 7.4 presents results on sentence comprehension.

PALPA tests were utilised to achieve an acquired dyslexia profile. Five tests were selected to assess for surface, deep and phonological dyslexia. This was deemed as important background information as acquired dyslexia may influence eye movements in reading (Schattka et al., 2010). The overview of the acquired dyslexia profile of all participants can be found in Appendix B.1 as additional background information.

Further, individuals rated their own reading confidence and emotions on the *Reading Confidence and Emotions Questionnaire (RCEQ)* (Cocks et al., 2013). This has the potential to reveal whether a reading impairment that is assessed through the language tests or that becomes apparent in the eye tracking experiments also affects the individuals' self-perceived reading. The RCEQ assesses both premorbid and current reading with questions that refer to elements of the dimensions of the International Classification of Functioning, Disability and Health model (World Health Organization, 2001) (Cocks et al., 2013). For instance, questions on the individual's reading in the presence of others reflect the scale of action and participation. The questionnaire includes a 10-point rating scale from 1 to 10. Regarding the confidence questions, 1 means "not confident at all" and 10 means "completely confident". Regarding the questions about emotions, 1 refers to "none/not at all", and 10 refers to "a lot/extremely". The scores are presented in Table 7.5. The scores of the RCEQ are usually treated as individual items for the development of goals and treatment plans (see Cocks et al, 2013). For the purpose of this study, the scores represent the proportion of scores out of the maximum score as this made the scores comparative. The scores of main interest were the **reading confidence after stroke** score and the **reading pleasure after stroke** score.

Finally, working memory was assessed. This was to examine whether there was a relationship between working memory capacity and reading comprehension, and to find whether working memory capacity influences eye movement behaviour. Previous work has shown that deficits in working memory can contribute to language processing problems in aphasia (Caspari et al., 1998; Wright et al., 2007; Wright & Shisler, 2005). However, working memory tests are more challenging for individuals with aphasia than for healthy individuals since they require an understanding of the task as well as the use of expressive language (Ivanova, 2012). Hence, a low outcome in a working memory test can be due to poor language skills and not due to poor working memory capacity. It was decided to use two working memory tests for the purpose of this study. First, the forward and backward digit span from the *Wechsler Memory Scale* (Wechsler, 1997) was administered. According to Wright and Shisler (2005) this test has the benefit of testing both storage and manipulation of information, and it is standardised. Both the **working memory digit forward** and **working memory digit backward** scores were used as they measure different aspects of working memory. However, the response includes verbal recall, which makes it more challenging for use with PWA. Hence, a *reading span*[24] test designed for people with mild aphasia task was used additionally (Caspari et al., 1998). In this test, participants have to read sentences and retain the terminal word(s) that followed each sentence for later recognition. The outcome was the **working memory sentence span** score. Overall, there was variation between the participants, but no one showed a severe impairment of working memory. The group had more difficulty with the backward task than the forward task. The means of the **working memory digit forward** and the **working memory digit backward** were 5.06 and 3.47 respectively (forward norm[25]: M = 5.98, SD = 1.12; backward: M = 4.30, SD = 1.11).

Individuals with aphasia were not tested for the presence of dementia (as the controls, see following section). The reason is that the Mini Mental State Examination (MMSE-2) (Folstein et al., 2010) used for the control group is a test that requires a level of language ability that was not in place for all participants with aphasia. However, participants were seen over a long period of at least eight sessions (1-2 sessions per week), and no indications of dementia were observed.

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[24] The reading span task is described in more detail in Appendix B.2.

[25] Norms are from the manual of the Wechsler Memory Scale (Wechsler, 1997) and are based on a group of healthy participants (N = 46) within the age group of 40–49.

Table 7.1. Demographic information for participants

Group	**ID overall**	**ID (group)**	**Gender m/f**	**Age**	**Handedness left/right**	**Years.Months post Onset**	**Aetiology (all left hemisphere)**	**MMSE**[a]	**Education (Group)**[b]
NHI	1	1	f	71	right	n.a.	n.a.	29	Diploma (4)
NHI	2	2	m	44	right	n.a.	n.a.	30	Doctoral (7)
NHI	3	3	m	40	right	n.a.	n.a.	30	Bachelor's (5)
NHI	4	4	m	41	right	n.a.	n.a.	30	Bachelor's (5)
NHI	5	5	f	59	right	n.a.	n.a.	30	Master's (6)
NHI	6	6	f	53	right	n.a.	n.a.	27	GCSE (2)
NHI	7	7	f	53	right	n.a.	n.a.	30	Bachelor's (5)
NHI	8	8	f	22	right	n.a.	n.a.	30	Bachelor's (5)
NHI	9	9	f	50	right	n.a.	n.a.	30	Master's (6)
NHI	10	10	f	70	right	n.a.	n.a.	30	Master's (6)
NHI	11	11	f	69	right	n.a.	n.a.	28	Diploma (4)
NHI	12	12	m	38	right	n.a.	n.a.	28	Master's (6)
NHI	13	13	f	76	right	n.a.	n.a.	28	Bachelor's (5)
NHI	14	14	m	68	right	n.a.	n.a.	30	Bachelor's (5)
NHI	15	15	f	73	right	n.a.	n.a.	27	no formal (1)
NHI	16	16	f	51	right	n.a.	n.a.	29	Bachelor's (5)
NHI	17	17	f	54	right	n.a.	n.a.	30	Bachelor's (5)
NHI	18	18	m	51	right	n.a.	n.a.	30	A levels (3)
NHI	19	19	f	55	right	n.a.	n.a.	30	A levels (3)
NHI	20	20	m	34	right	n.a.	n.a.	30	Master's (6)
mean	n.a.	n.a.	n.a.	53.6	n.a.	n.a.	n.a.	29.3	4.7

PWA	21	1	f	75	right	11,6	CVA	n.a.	Bachelor's (5)
PWA	22	2	f	61	right	13,5	CVA, ischemic	n.a.	Master's (6)
PWA	23	3	f	46	right	1,4	CVA, MCA infarct	n.a.	PhD (7)
PWA	24	4	f	40	right	4	CVA, post central left parietal lobe	n.a.	GCSE + other (2)
PWA	25	5	f	54	right	4,3	CVA, large insular infarct with small area of haemorrhagic transformation	n.a.	Master's (6)
PWA	26	6	m	70	right	7,2	CVA	n.a.	Diploma (4)
PWA	27	7	m	74	right	8,6	CVA, MCA infarct, subdural haematoma	n.a.	Master's (6)
PWA	28	8	m	57	right	2,1	CVA, subarachonid haemorrhage and MCA infarct	n.a.	GCSE (2)
PWA	29	9	f	80	right	4,3	CVA, left posterior putamen, insular cortex & corona radiata	n.a.	Diploma (4)
PWA	30	10	m	65	right	4,8	CVA, MCA infarct with probable near occlusion of left ICA (pre and post central gyru middle and inferior frontal gyri, posterior insula and the underlying white matter of the centrum semiovale and corona radiata)	n.a.	No formal (1)
PWA	31	11	f	22	right	3,9	CVA, lesion anterior and temporo-parietal	n.a.	A levels (3)

PWA	32	12	f	53	right	15,4	CVA, MCA infarct, left carotid dissection leading to stroke	n.a.	Bachelor's (5)
PWA	33	13	m	46	right	8	CVA, secondary haemorrhage, left frontal parietal craniotomy performed	n.a.	Diploma (4)
PWA	34	14	m	68	right	1,1	CVA, ischaemic changes in the left MCA territory	n.a.	College (4)
PWA	35	15	m	73	right	2,6	CVA, MCA infarct, frontal lobe, thrombolysed. Developed left parietal bleed.	n.a.	Apprenticeship (3)
PWA	36	16	f	64	right	0,10	CVA, MCA infarct	n.a.	GCSE (2)
PWA	37	17	f	51	right	1,5	CVA, parietal infarct	n.a.	Apprenticeship (3)
mean	n.a.	n.a.	n.a.	58.8	n.a.	5.89	n.a.	n.a.	3.94

[a]MMSE=Mini-Mental-State Examination [b]Education groups: (1) no formal, (2) GCSE, (3) A levels/Apprenticeship, (4) Diploma/College Degree, (5) Bachelor’s Degree, (6) Master’s Degree, (7) Doctoral Degree

Table 7.2. Individual (and mean) scores on the Western Aphasia Battery - Revised

PWA ID	**Spontaneous Speech (max=20)**	**Auditory Compre-hension (max=10)**	**Repetition (max=10)**	**Naming (max= 10)**	**Aphasia Quotient (max= 100)**	**WAB-R Subtype**	**Aphasia Severity**
1	17	9.35	8.4	9.1	87.7	Anomic	mild
2	17	10	8.2	9.5	89.4	Anomic	mild
3	17	10	9.6	8.7	90.6	Anomic	mild
4	17	10	9.3	9.5	91.6	Anomic	mild
5	15	9.4	9.2	8.5	84.2	Anomic (Broca)[a]	mild
6	19	9.95	9.1	8.9	93.9	Anomic	mild
7	17	9.45	8.2	7	83.3	Anomic	mild
8	16	8.5	5.4	7.3	74.4	Conduction	moderate
9	18	9.3	9	7	86.6	Anomic	mild
10	12	8.65	9.1	7.5	74.5	Transcortical motor	moderate
11	13	9.35	3.4	6.3	64.1	Broca	moderate
12	14	8.7	6.4	9.2	76.6	Conduction (Broca)[b]	mild
13	17	9.9	9	9.1	90	Anomia	mild
14	15	9.95	8.7	8.2	83.7	Anomia	mild
15	13	9	8.2	8.1	76.6	Transcortical motor	mild
16	18	9.15	7.2	7.1	82.9	Anomia	mild
17	15	7.95	4.8	7	69.5	Conduction	moderate
Mean	15.88	9.33	7.84	8.12	82.33	n.a.	n.a.

[a/b] ID 5 and ID 12 were classified as Anomic/Conduction but presented the clinical picture of Broca's aphasia. This picture was supported by their comprehension advantage of canonical over non-canonical sentences as shown in Table 7.4.

Table 7.3. Individual (and mean) scores on semantic and lexical processing (all in proportions)

PWA ID	Nonverbal semantics (CAT)	Synonyms (PALPA)	Word - picture matching (PALPA)	Semantics overall	Visual lexical decision (PALPA)	Lexical-semantics written comprehension	Naming nouns (VAST)	Naming verbs (VAST)	Lexical production (VAST)	Lexical overall
1	0.90	0.97	1.00	0.96	1.00	1.00	0.93	0.91	0.92	0.96
2	1.00	0.98	1.00	0.99	1.00	1.00	0.95	0.79	0.87	0.93
3	1.00	0.92	0.98	0.97	0.94	0.96	0.95	0.80	0.88	0.92
4	1.00	0.90	0.98	0.96	0.89	0.94	1.00	0.98	0.99	0.96
5	1.00	0.87	0.93	0.93	0.74	0.84	0.85	0.71	0.78	0.81
6	1.00	0.92	0.93	0.95	0.99	0.96	0.93	0.80	0.87	0.91
7	1.00	0.77	0.98	0.92	0.82	0.90	0.90	0.63	0.76	0.83
8	0.90	0.97	0.98	0.95	0.99	0.99	0.90	0.80	0.85	0.92
9	1.00	0.98	1.00	0.99	0.98	0.99	0.95	0.78	0.86	0.93
10	1.00	0.72	0.98	0.90	0.81	0.90	0.77	0.70	0.73	0.81
11	1.00	0.88	1.00	0.96	0.97	0.99	0.78	0.43	0.61	0.80
12	1.00	0.83	1.00	0.94	1.00	1.00	0.95	0.65	0.80	0.90
13	1.00	0.88	1.00	0.96	0.93	0.97	1.00	0.91	0.95	0.96
14	1.00	0.97	1.00	0.99	0.99	1.00	0.90	0.68	0.79	0.89
15	0.80	0.90	0.95	0.88	0.68	0.82	0.82	0.78	0.80	0.81
16	1.00	0.85	0.98	0.94	0.87	0.93	0.92	0.65	0.78	0.85
17	1.00	0.97	0.95	0.97	0.93	0.94	0.83	0.68	0.76	0.85
Mean	0.98	0.90	0.98	0.95	0.91	0.95	0.90	0.74	0.82	0.88

Table 7.4. Individual scores on sentence comprehension (in proportion) and working memory (number score)

PWA ID	**Sentence-picture matching (PALPA)**	**Total canonical (VAST)**	**Total non-canonical (VAST)**	**Sentence comprehension overall**	**WM digit forward (Wechsler)**	**WM digit backward (Wechsler)**	**WM sentence span (after Caspari et al., 1998)**
1	0.90	1.00	0.95	0.94	6.00	3.00	4.50
2	0.88	1.00	0.65	0.85	5.00	5.00	4.00
3	0.97	1.00	0.90	0.96	7.00	4.00	4.50
4	0.98	0.95	0.85	0.94	5.00	3.00	6.00
5	0.83	0.95	0.35	0.74	8.00	3.00	2.50
6	0.87	1.00	0.70	0.86	7.00	5.00	5.00
7	0.87	1.00	0.95	0.92	5.00	3.00	3.50
8	0.88	0.95	0.70	0.85	5.00	4.00	5.50
9	0.90	0.90	1.00	0.93	6.00	4.00	6.00
10	0.72	0.80	0.25	0.62	5.00	3.00	2.50
11	0.78	0.90	0.70	0.79	4.00	3.00	6.00
12	0.77	0.95	0.75	0.81	4.00	3.00	4.00
13	0.95	1.00	0.90	0.95	4.00	3.00	4.50
14	0.90	0.95	1.00	0.94	5.00	4.00	2.50
15	0.67	0.95	0.50	0.70	4.00	3.00	1.50
16	0.75	0.90	0.40	0.70	4.00	3.00	2.50
17	0.85	0.85	0.65	0.80	2.00	3.00	5.50
Mean	0.85	0.94	0.72	0.84	5.06	3.47	4.15

Table 7.5. Reading Confidence and Emotions Questionnaire (RCEQ)

PWA ID	Reading confidence before stroke	Reading confidence after stroke	Reading pleasure before stroke	Reading pleasure after stroke	Reading negative emotions after stroke
1	0.90	0.78	1.00	0.90	na
2	1.00	0.33	1.00	0.40	0.92
3	1.00	0.32	1.00	0.30	0.57
4	0.65	0.33	1.00	0.40	0.28
5	1.00	0.49	1.00	0.50	0.41
6	1.00	0.80	1.00	1.00	0.17
7	1.00	0.49	1.00	0.30	0.25
8	0.65	0.59	0.60	0.30	0.77
9	1.00	0.63	1.00	0.90	0.73
10	0.90	0.45	1.00	0.10	0.83
11	1.00	0.23	1.00	0.20	0.70
12	1.00	0.33	1.00	0.20	0.68
13	0.90	0.78	0.90	0.70	0.38
14	0.85	0.83	1.00	0.80	0.23
15	0.75	0.12	1.00	0.10	0.53
16	0.65	0.47	0.60	0.20	0.80
17	0.80	0.28	0.80	0.40	0.40
Mean	0.89	0.49	0.94	0.45	0.54

Note. The scores relate to the proportion of scores on a scale between 1 (“not confident at all”) – 10 (“completely confident”) out of a maximum score.

7.2.3. Background assessments NHI

Control participants filled out a questionnaire, which elicited information about their age, handedness, language(s), education, and work. Further, they were asked whether they had a history of developmental dyslexia, speech- and language impairments, neurological impairment, or any visual impairment.

In order to screen for cognitive impairment, control participants were tested with the *Mini-Mental State Examination*, 2nd Edition Standard Version (MMSE-2, Folstein, Folstein, White, & Messer, 2010). The test includes questions regarding orientation to time, place, immediate and short-term recall, attention and calculation, naming, repetition, comprehension (the ability to follow verbal and written commands), writing and drawing. The maximum raw score is 30 points. The examination was normed and validated within a healthy population as well as in populations with dementias of different aetiologies.

Since the cognitive examination is potentially sensitive, the participants were introduced to it carefully (cf. manual, p. 3). After explaining the procedures of the research study, they were asked whether they agree with a short examination on their memory. The examination took place in a one to one setting, and during the test, a supportive attitude was maintained, but no reactions towards the correctness of the answers were given. Each answer was scored with 0 or 1. In order to take part in the experiment participants had to score within one standard deviation from the mean raw score of their age group and education level (in years). Results are presented in Table 7.1. There was no sign of cognitive impairment in any of the control participants (*M* = 29.3, *SD* = 1.08, *range* = 27-30).

7.2.4. Procedures

The materials for this experiment, and how sentences were derived from norming studies, were described in Chapter 6. An overview over the four conditions in this experiment, including example sentences, will be shown in Table 7.6 in the section on the analyses (7.2.5).

Apparatus and Set-up

An EyeLink 1000 video-based eye tracker (manufactured by SR Research) with low spatial and temporal noise was used to track eye gaze. Tracking was created via a pupil and corneal reflection, and was monocular at a sampling frequency of 1000 Hz. The average accuracy is 0.25 º - 0.5 º. The setup consisted of a Host PC for processing of the camera data (Eyelink computer), a laptop connected to a 24-inch widescreen monitor (display computer), a high-speed camera eye tracker, the desktop mount, a Microsoft sidewinder gamepad and the SR research chinrest. In order to facilitate the use of the gamepad, all non-meaningful buttons were covered with grey sugru, a self-setting rubber. For individuals with a right hemiparesis, the gamepad was turned upside down which made it easier to press the yes/no buttons with one hand. As recommended in the EyeLink 1000 Installation Guide (2005-2010), the Host and Display computers were arranged on tables in an L-shape (see Figure 7.1). The L-shape guaranteed that participants could not see the host monitor during the testing, which could be a distraction.

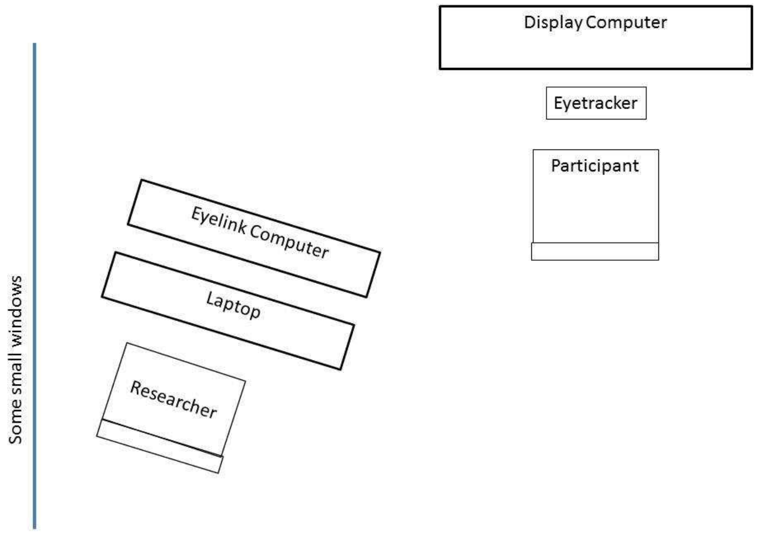

Figure 7.1. Set-up of the experiment

The test room had small windows and ceiling-mounted lights that did not induce reflections on the monitors. The chair was comfortable and adjustable in height.

The EyeLink 1000 desktop mount was used for tracking. The mount carried a 35mm lens and an IR illuminator. It sat in front of the display monitor and 52cm away from the participant's eyes. The display monitor sat 92cm away from the participant's eyes. The camera screw of the mount was adjusted with the middle of the display monitor, and the eye tracker was placed as high as possible without blocking the view on the monitor. This set-up was adjusted for each participant, and the monitor/eye tracker was elevated if necessary. The chinrest/forehead rest was mounted on the table. The stimuli sentences in lower and uppercase letters were displayed on a single line in the centre of the monitor. The sentences were written in black Arial 14p on a grey background, and the visual angle of a letter was 0.3°.

Procedure

Participants were tested twice with one list of sentences in each session. Both lists contained all target words. In one list words appeared in a predictable context, in the other list they were placed in an unpredictable context. Both lists had the same number of predictable or unpredictable words. The stimuli sentences were mixed with filler sentences of various structures, and the order of sentences was randomised. There were at least seven days between testing of the first and the second list. The presentation of the lists was counterbalanced across the participants.

The eye tracking studies took place at City University London. Each session started with an informal chat to make the participants feel comfortable in the room and with the setting.

In the first session, control participants read the information sheet about the study, gave consent and filled out a questionnaire. Following this, they were screened with the Mini-Mental State Examination. The participants with aphasia had already given consent at an earlier stage of the project, and the background assessments were administered in different sessions. Participants were placed in front of the monitor and eye tracker, with their chin on the chinrest, and leaning their head against the forehead rest. A 9 point grid calibration was used aiming at an average error of less than 0.5° and a maximum error of less than 1°. These numbers indicate accuracy, that is, the correspondence between the calculated fixation location and the actual fixation location (Raney, Campbell, & Bovee, 2014). In this experiment the visual angle of a letter was 0.3°. Hence, an error of 1° would mean that the fixations are shown about 3 letters away from their actual place. If this level of tracking accuracy was not successful, the set-up was changed slightly to improve calibration. The calibration procedure was repeated when necessary, as well as at least once halfway during the experiment.

The experiment started with a screen displaying the instructions, which were read out aloud by the experimenter. Participants were instructed to read the test sentences for comprehension. Before each trial a central dot appeared on the screen to check the accuracy of the eye gaze track. In order to direct eye gaze to the left side of the screen, each trial began with a fixation cross, presented on the left side of the screen followed by the sentence. Participants were instructed to press a large button on the gamepad when they had read the sentence. A comprehension question presented visually and via the loudspeakers followed each sentence. The auditory version was implemented to ease comprehension for the individuals with aphasia. Accuracy of the comprehension questions was measured. For answering *yes*, participants had to press the right button, and for answering *no*, they had to press the left button. Participants were asked to minimise head movements. Each list started with five practice sentences to make sure the participants became used to the task. They were given time to ask questions before the experiment started. Participants could have a break whenever they needed one, usually once halfway through the session. The eye tracking procedure took approximately 60 minutes.

7.2.5. Overview of analyses

Conditions

The experiment consisted of four conditions. Fourteen word pairs differing in word frequency were placed into a predictable or unpredictable sentence context. Table 6.1 in the previous chapter is reprinted here as Table 7.6, showing example sentences for the critical words *student* and *florist*.

Table 7.6. Example target word pair in a predictable and unpredictable context

Condition abbreviation	Frequency	Context Predictable/ unpredictable	Example sentence
HF P	high frequency	predictable	Anna was able to get a reduced ticket for the show because she is a *student* working there.
HF U		unpredictable	Claire loves flowers and wants to be a *student* learning how to make nice bouquets.
LF P	low frequency	predictable	Claire loves flowers and wants to be a *florist* learning how to make nice bouquets.
LF U		unpredictable	Anna was able to get a reduced ticket for the show because she is a *florist* working there.

Measurements

In order to investigate whether the PWA differ from the NHI in terms of sentence comprehension, accuracy (number/proportion of questions answered correctly) was used as offline measure. Only half of the comprehension questions target the critical word, hence, accuracy results did not necessarily reflect difficulties regarding the target word comprehension.

For an understanding of how eye tracking may reflect sentence reading behaviour, global measurements were selected that referred to the whole sentence, independent of experimental conditions: number of fixations, number of first pass regressions, average fixation durations, number of blinks and blink ratio, and average sentence reading time.

Eye movement measurements, which have shown effects of word frequency and predictability in previous studies of healthy reading, were chosen (see Figure 7.2). These measurements were analysed for each of the critical regions.

First, **gaze duration** was chosen to capture the initial processing of the text. Gaze duration sums up the duration of all fixations on the target word until a fixation is made to another area, either progressive or regressive to the critical word. Gaze duration is 0 if the first fixations on the target word occur after fixations were made further along in the text.

Second, **total fixation duration** (also referred to as total reading time) was used to capture more global and later processing of the text. This measurement includes all fixations within the critical area, including those from first-pass and those from second-pass or other re-reading stages. A difference between gaze and total fixation durations indicates that the target word was re-read.

Third, the **probability of a first pass regression** was measured. This indicates whether the first fixation following fixation(s) on the target region was regressive relative to the target region or not (provided that the region was not skipped during first-pass reading and provided that the target region had not already been fixated and exited). The probability of first pass regressions was calculated for all words that were fixated. If readers skipped a target word, neither regressions nor other eye movement measures were included in the analysis.

First fixation duration is another measure that captures the earliest moment of processing. It refers to the duration of the first fixation on the critical word until a fixation is made to another area. However, people with aphasia usually make more than one fixation on a word, hence gaze duration was thought to be a more critical measure in this experiment.

Figure 7.2 presents an overview of the measurements on one of the experimental sentences with the target word *geology* in the low frequency and unpredictable condition. It also shows fixations and saccades.

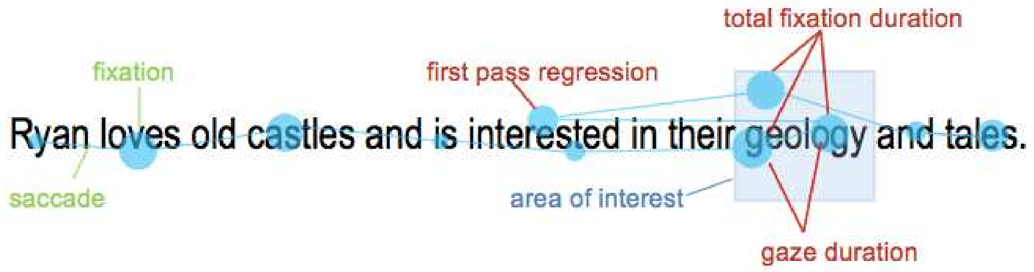

Figure 7.2. Analysed eye movement measures in Experiment 1

Statistical analysis

Statistical analyses were carried out for global eye movement measures that referred to the whole sentence, for accuracy data, and for eye movement data referring to the target words only.

From the global eye movement measurements relating to the whole sentence, average fixation durations were the only measurement that was normally distributed and showed homogeneity of variance. Average fixation durations were compared between the PWA and the NHI using independent t-tests. First pass regressions also revealed a normal distribution, but no homogeneity of variance. The other global eye movement measures were not normally distributed, and showed no homogeneity of variance. Hence, the non-parametric Mann Whitney

U test was used to compare the groups on their number of fixations, number of first pass regressions, and number of blinks as well as blink/fixation ratio. The global dataset was not transformed to improve the distribution, because simple group comparisons were sufficient for this analysis.

The accuracy dataset violated assumptions of both a normal distribution and homogeneity of variance. A visual inspection of histograms and checking skewness showed that some of the conditions were mildly negatively skewed. The Shapiro-Wilk test confirmed a significant non-normal distribution for both groups. Additionally, the Levene's Test revealed that all but the predictable low frequency condition violated the assumption of homogeneity of variance. Data transformations were explored, but none of these approached a normal distribution. As a consequence, mixed model Anovas could not be conducted, and the non-parametric Mann-Whitney U test was used instead of independent tests, and the Friedman's Anova as well as the Wilcoxon signed rank test replaced repeated measure comparisons.

Most of the eye movement data from the target word analysis again violated assumptions for a mixed model Anova. Histograms and skewness showed a normal distribution for some measurements and conditions, but a mild positive skew for others. The Shapiro-Wilk test showed deviations from normality for gaze and total durations in the PWA group in particular, but also in the NHI group. First pass regressions were mildly positively skewed for the NHI in sentences with predictable items. However, regressions were normally distributed for the PWA who regressed more overall. Regarding homogeneity of variance, equal variance across pairs of the within-group conditions was assumed since there were only two levels of each within-group factor. Between groups, the assumption of homogeneity of variance was given for both gaze durations and first pass regressions, but not for total durations.

Eye movement data from the target word analysis were log-transformed. This was necessary in order to perform Anova analyses, which were not needed for the group comparisons of the global eye movement data. The advantage of transformations is that they can correct for both a non-normal distribution and for violence of homogeneity of variance. Further, transformations manipulate the whole data set equally whereas other procedures like trimming manipulate only segments of the data (Field, 2013). For first pass regressions, the number one was added to all data points before the transformations so that they did not lead to infinity. As a result of the log transformations the skew was considerably reduced. All conditions showed a normal distribution for the PWA, however, for the NHI the predictable high frequency condition was still mildly skewed in all measurements ($W(20)$ = 0.88-0.90, p = .02 - .03. However, the largest skew was 1.1 in total durations logs, and this was considered near-normal. The Levene's Test showed homogeneity of variance after the log transformations.

The eye movement data were then analysed with mixed multi-factorial (three-way) Anovas (2x2x2). The independent between-group variable was group (NHI vs. PWA), the within-group independent variables were frequency (high vs. low) and predictability (predictable vs. unpredictable). The dependent continuous variables were the fixation measurements as explained above. Anovas were conducted for participants (F_1) and items (F_2). Running the Anova with both participants as well as items as random factors meant that it could be guaranteed that result were not only driven by participants. Anovas were calculated for each measurement. Results were considered significant if the p-value was ≤ .05, and a trend effect was defined at a *p*-value ≥ .05 and ≤ .08. If interactions were significant at ≤ .05, independent and dependent t-tests were used as post hoc tests. Due to multiple comparisons, the Bonferroni correction was used for Anovas and post hoc tests. Since a different number of multiple comparisons was carried out depending on the analysis, there is no reduced alpha-significance level that is appropriate for all outcomes. Rather, Bonferroni corrections are applied separately for each analysis in the results section.

For comparisons of the size of the word frequency and predictability effect scores, t tests were used, as these scores showed a normal distribution. For the correlation of these effect scores with the results from the background language assessment scores, the Pearson's correlation test (r) were used for correlations with assessment scores showing a normal distribution, and the Spearman's correlation test (r_s) was used for the others. All correlations between the fixation durations and the assessment results were carried out with the Spearman's test. Unless stated otherwise, tests were two-tailed.

Results from the t-tests, the Mann Whitney U tests and Wilcoxon tests are reported with Pearson's r effect sizes. A small effect was interpreted at .10, medium at .30, and .50 as a large effect (Cohen, 1992). For the Anovas, generalised Eta-Squared (η_G^2) are reported (Bakeman, 2005). A small effect was interpreted at .02, medium at .13, and large at .26 (Bakeman, 2005). For all statistical data analysis R was used (R Core Team, 2013). Mixed model Anovas were conducted using the *ez* package (Lawrence, 2011), and both the Wilcoxon signed rank test and the Spearman's test were carried out using the coin package, which implements permutation based tests (Hothorn, Hornik, Wiel, & Zeileis, 2008). Graphs were developed using the ggplot2 package (Wickham, 2009).

Cleaning of the data and dealing with outliers

To reduce error in the data, fixations were drift corrected. Recorded fixation locations were adjusted only vertically (i.e. not horizontally), and only if it was unquestionable that fixations were in the area of interest but showing above or below the text (as recommended by SR research). Within a trial (i.e. a single sentence) either all fixations in the sentence or a group of fixations were drift corrected. Following general practice, eye movement data were filtered with pre-determined cut-offs (Juhasz & Rayner, 2006; Kliegl et al., 2004; Rayner et al., 2006, 2011; Schattka et al., 2010). Fixations that were shorter than 80ms, and which were within one character adjacent to another fixation (equal to a visual angle of 0.3° and equal to the size of one letter on the screen), were combined with that fixation. It is assumed that readers cannot extract information in fixations shorter than 80ms. Fixations shorter than 80ms with no near neighbour as well as fixations longer than 1200ms were excluded (Juhasz et al., 2006). Altogether this eliminated about 5% of the data. A loss of data of up to 5% is common in eye tracking studies within the healthy population (Ashby et al., 2005; Rayner et al., 2011), and a data loss of 7-10% is reported in eye tracking studies including neurologically impaired participants (Ablinger et al., 2013; Schattka et al., 2010).

The dataset was checked for outliers by analysing the global results as well as the eye movement duration measures. A participant's data set was excluded from the analysis if it deviated more or less than two standard deviations from the average of the group within a condition. For the global results the number of fixations, average sentence reading time, and average fixation durations were inspected. For the eye movement results, all three critical regions, conditions and duration measurements were inspected. Further, boxplots were visually checked for outliers.

7.3. Results

The results are described in different sections. First, a summary of the outlier analysis is given (7.3.1). Second, results of the global eye movement characteristics that refer to the whole sentence are outlined (7.3.2). This section focuses on group differences that are independent of the experimental conditions. Also results from the accuracy data (offline measurements) will be presented. Third, the results from the eye movement data (online measurements) will be described (7.3.3). Fourth, an individual analysis of the PWA's dataset is carried out, showing individual differences in word frequency and predictability effects, and correlating the results from the background assessments with effect scores (7.3.4). Finally, the fifth section presents the results from the correlations between the language background tests and the eye movement durations, independent of the experimental manipulations (7.3.5). The last section summarises the findings against the research questions (7.3.6).

7.3.1. Outlier analysis and blink analysis

As already mentioned in the description of the participants, one participant with aphasia presented as an outlier in all measurements. The mean average fixation duration of the aphasia group was 265.11ms, the outlier had a mean of 340.69ms. The mean number of fixations of the group was 52.87, the outlier showed a mean number of 209.36 fixations per sentences. Finally, the mean sentence reading time of the aphasia group was 17605.67ms, and the outlier read sentences in an average time of 79805.80ms. Equally, in the eye movement dataset of the target words, all three measurements were analysed. For total fixation duration the outlier showed durations that exceeded the mean of the aphasia group by more than two standard deviations in all four conditions. Hence, this participant was excluded from the analysis. This means that seventeen participants with aphasia were included in the study.

7.3.2. Global characteristics of the data

Before presenting the results in relation to the two main research questions, this subsection presents the overall reading characteristics, comparing the PWA with the NHI. The first paragraph refers to the global reading characteristics referring to the whole sentence, and the second paragraph presents the accuracy results.

Global reading characteristics of the sentence

All global eye movement measurements for NHI and PWA are presented in Table 7.7. They refer to the whole sentence rather than the target word (e.g. *hospital/campsite*) and are measured in ms for average fixation durations, in number (of fixations, first pass regressions, blinks) or ratio (blink/fixation ratio). Measurements were compared using non-parametric tests for the fixation count, blink count, and for sentence reading times. These measures showed heterogeneity of variance. The average fixation durations were compared using an independent t-test as this measurement showed both a normal distribution and homogeneity of variance.

Comparisons indicated that there was a significant difference in average fixation durations between NHI and PWA, with the PWA showing longer fixation durations that the NHI. Also there was a significant difference in number of fixations with the PWA making more fixations overall than the NHI. The PWA also demonstrated a larger number of first pass regressions, and they showed longer sentence reading times than the NHI. PWA also exhibited more blinks, however, there was no significant difference in the blink/fixation ratio (the number of blinks divided by the number of fixations) between the PWA and the NHI. This suggests that the higher blink number was an artefact of longer reading times in the aphasia group.

An example of the difference in number of fixations is given in Figure 7.3. It presents a sentence with the target word *hospital* in the high frequency predictable condition read by a NHI participant (top picture) and by a PWA participant (bottom picture). The blue dots present fixations with numbers indicating the length of the duration in ms. The dots also vary in size, with larger dots representing longer durations than small dots.

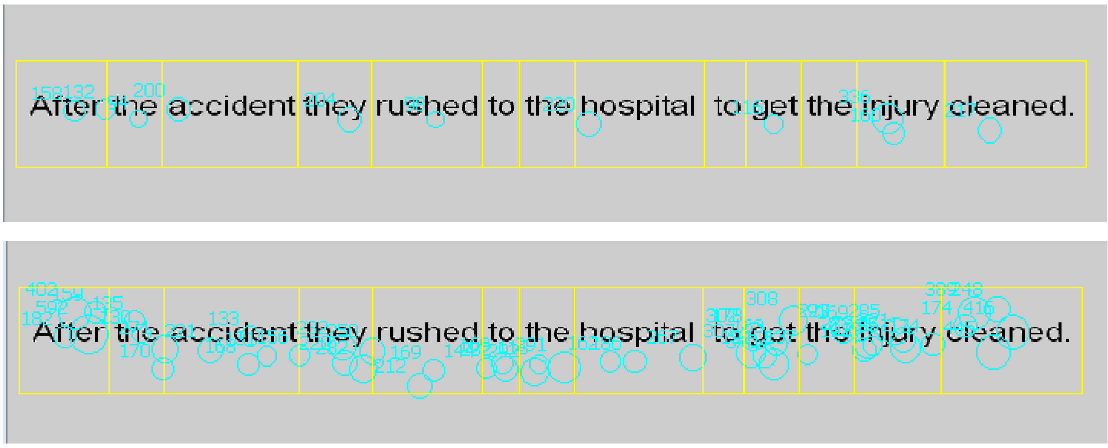

Figure 7.3. Fixations (blue dots) in the reading of NHI (top) and PWA (bottom)

Table 7.7. Global characteristics of reading comparing NHI and PWA

	NHI			**PWA**		**Comparison of groups**				
Measure	**M (SD)**	**Median (IQR)[1]**	**Range**	**M (SD)**	**Median (IQR)[a]**	**Range**	**t[b]**	**z**	**p**	**r**
Average fixation duration (ms)	224.34 (24.12)	n.a.	176.97-269.36	260.67 (26.60)	n.a.	220.76-323.06	-4.32***	n.a.	< .0001	.60
Mean number of fixations	15.13 (3.40)	15.34 (11.97-18.21)	9.93-21.05	43.67 (17.46)	43.71 (31.39-55.86)	13.02-85.73	n.a.	-4.78****	< .0001	.79
Mean number of first pass regressions	3.16 (1.49)	2.82 (2-4.4)	1.07-6.43	10.37 (3.44)	10.43 (8.29-12.66)	3.20-15.39	n.a.	-4.89****	< .0001	.52
Average sentence reading time (ms)	3875.10 (999.47)	3678.05 (2981.94-4872.90)	2543.66-5485.04	13946.84 (7172.55)	13660.95 (9574.875-17812.91)	3958.55-34587.59	n.a.	-4.91****	< .0001	.81
Mean number of blinks	0.89 (1.15)	0.41 (0.21-1.35)	0.02-5.02	3.78 (4.29)	1.93 (1.11-4.91)	0.29-14.13	n.a.	-3.19***	< .001	.52
Blink/fixation ratio	0.07 (0.09)	0.03 (0.01-0.08)	0.009-0.42	0.08 (0.03-0.09)	0.05 (2.53-8.66)	0.14-0.59	n.a.	-1.07	ns	.18

[a] Median and inter-quartile ranges (IQR) are only reported for measures compared with non-parametric tests. [b] t refers to the independent t-test; z refers to the Mann-Whitney U test; r refers to the Pearson's r effect size.

**p<0.01, ***p<0.001, ****p<0.0001; ns=non-significant

Blink analysis

As the previous analysis revealed, the participants from both group showed a high percentage of blinks. There was a concern that the presence of blinks could be a confounding factor in the eye movement analysis. Hence, all trials with a blink on the critical word, the previous word, or the following word of the sentence were removed and saved in a separate file. For the NHI, 12.86% of the trials had a blink on one of the three words, for the PWA 27.73% of the trials included blinks. Subsequently, lengths of gaze durations on those trials that excluded blink trials were compared to the lengths of gaze durations on the blink trials. Since the datasets were not normally distributed, the non-parametric Wilcoxon Signed rank test was used. Results showed that there was no significant difference in gaze durations for NHI, $z = -.45$, $p = .68$, r = .10, nor for PWA, $z = -.12$, $p = .93$, r = .03. Since these comparisons showed that there was no effect of blinks on the gaze durations, blink trials were kept in the dataset for the eye movement analysis.

Accuracy

Non-parametric tests were used to analyse the accuracy dataset as assumptions of parametric tests were violated. It was hypothesised that the NHI would perform at ceiling in all conditions, and that the PWA would be less accurate in answering the comprehension questions than the NHI. Results from the comparison of all conditions and the overall accuracy scores are presented in Table 7.8 and in Figure 7.4. First, accuracy across the groups was compared using the Mann-Whitney U test. The PWA ($M = 85.22\%$; $Mdn = 92.86\%$) were about 10% less accurate in answering the comprehension questions than the NHI ($M = 95.63\%$; $Mdn = 100\%$), $U = 3966$, $z = 5.04$, $p < .0001$, $r = .83$. The PWA ($Mdn = 92.86\%$) were also less accurate than the NHI ($Mdn = 100\%$) in the predictable high frequency condition, $U = 253.5$, $z = 3.00$, $p = .002$, $r = .49$. Further, PWA ($Mdn = 92.86\%$) were less accurate than the NHI ($Mdn = 100\%$) in the predictable low frequency condition, $U = 237$, $z = 2.22$, $p = .03$, $r = .36$. Finally, the PWA ($Mdn = 85.71\%$) were less accurate than the NHI ($Mdn = 100\%$) in the unpredictable low frequency condition, $U = 282$, $z = 3.57$, $p < .001$, $r = .59$. There was no significant group difference in the unpredictable high frequency condition. All significant comparisons except for the predictable low frequency condition remained significant after the Bonferroni correction that reduced the α level to .0125.

Next, the predictable and unpredictable conditions as well as the high and low frequency conditions were compared for each group using the Wilcoxon sign rank test for repeated measures. The hypothesis regarding an effect of frequency and predictability on accuracy was that there would be no influence of the factors on the accuracy in NHI, but that there would be an effect of predictability on accuracy by the PWA. For NHI, there was a significant predictability effect across high and low frequency conditions, $z = -2.95$, $p = .002$, $r = .66$. The same predictability effect showed for PWA, $z = 3.13$, $p < .001$, $r = .70$. Further, there was an effect of frequency on predictable and unpredictable items in the non-expected direction for NHI, $z = -2.14$, $p = .03$, $r = .52$ but not for PWA. The predictability effects were strong and remained significant after the Bonferroni correction (α level at .0125), whereas the frequency effect did not.

Lastly, all conditions were compared with each other, for both groups separately. Results from a Friedman's Anova revealed a significant effect of condition on accuracy for NHI, $X^2(5) = 83.57$, p < .0001, and equally for PWA, $X^2(5) = 63.45$, $p < .0001$. Post hoc tests for NHI revealed a significant effect of predictability on the high frequency conditions with more errors in the unpredictable condition (*Mdn*= 90%) than the predictable condition (*Mdn*= 98.93%), $z = 3.77$, $p < .001$, r= .84. There was no predictability effect on the low frequency items. There was no frequency effect on predictable items, but a frequency effect on the unpredictable items, $z = -3.38$, $p < 0.001$, $r = .76$. NHI were more accurate on sentences with low frequency items (*Mdn*= 96.79%) than high frequency items (*Mdn*= 90%), this was an effect in the non-predicted direction. After applying the Bonferroni correction due to four post hoc analyses (α level at .0125), the effects were still significant.

For the PWA, there was a significant effect of predictability on sentences with high frequency items, $z = 1.96$, $p = .04$, $r = .48$. They were more accurate in sentences with predictable items (*Mdn*= 88.66%) than unpredictable items (*Mdn*= 80.78%). The effect of predictability on low frequency items with better accuracy on predictable (*Mdn* = 92.86%) than unpredictable items (*Mdn*= 85.71%) just missed significance but reached a trend, $z = 1.88$, $p = .06$, $r = .46$. There were fewer errors in sentences with predictable items (*Mdn*= 89.55%) than unpredictable items (*Mdn*= 85.71%). There was no effect of frequency. None of the effects for the aphasia group was significant after the Bonferroni correction (α level at .0125).

In summary, the NHI performed near ceiling in comprehension accuracy, and the PWA showed mild comprehension difficulties in these sentences. Comparisons between predictable and unpredictable conditions revealed significant differences for both group. Both NHI and PWA answered more questions correctly when the sentence contained predictable items than unpredictable items. The NHI also showed a frequency effect in the non-predicted direction in that they were more accurate in questions with low frequency than with high frequency items.

Table 7.8. Accuracy in % as a function of sentence condition and participant group

	Word frequency					
Predictability	**High**		**Low**		**Mean**	
	Median (IQR)[a]	**Range**	**Median (IQR)**	**Range**	**Median (IQR)**	**Range**
NHI						
Predictable	100 (100-100)	92.86-100	100 (92.86-100)	85.71-100	100 (92.86-100)	85.71-100
Unpredictable	89.29 (85.71-92.86)	78.57-100	100 (92.86-100)	85.71-100	92.86 (85.71-100)	87.57-100
Mean	100 (89.29-100)	78.57-100	100 (92.86-100)	85.71-100	100 (92.86-100)	78.57-100
PWA						
Predictable	92.86 (78.57-100)	42.86-100	92.86 (86.67-100)	42.86-100	92.86 (85.71-100)	42.86-100
Unpredictable	85.71 (73.33-92.86)	50-100	85.71 (78.57-92.86)	21.43-100	85.71 (73.33-92.86)	21.43-100
Mean	92.86 (78.57-92.86)	42.86-100	92.86 (78.57-92.86)	21.43-100	92.86 (78.57-92.86)	21.43-100

[a] IQR refers to the inter-quartile range.

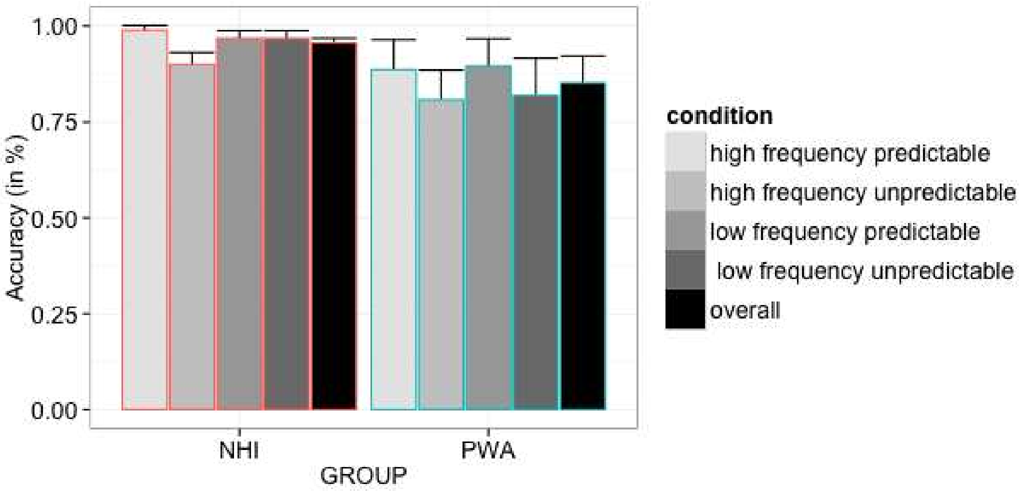

Figure 7.4. Accuracy correct in %, comparison of groups (error bars represent standard deviations.)

7.3.3. Eye movements – Correct and incorrect trials

Prior to the data analysis of eye movements on target words, an Anova was carried out to examine whether eye movements from trials with correctly answered questions differed from those with incorrectly answered questions. Results from an analysis of correct trials and results from an analysis of incorrect trials can have different implications. An analysis of correct trials shows eye movement patterns of successful processing whereas an analysis of incorrect trials may reflect eye movement patterns associated with reading difficulties. However, incorrect answers do not necessarily indicate reading difficulty as incorrect answers to comprehension questions can also be due to inattention in reading, pressing the wrong button, or can show difficulties with comprehension questions. Word frequency, context and accuracy were entered as independent variables in this repeated measures Anova, and total durations were entered as the dependent variable. There was no main effect of accuracy, $F(1, 4) = 0.13$, $p = .73$, $\eta_G^2 = .01$. Further, there were no interactions between accuracy and context or accuracy and word frequency. This was regarded as evidence that eye movements do not differ between trials that were understood correctly and trials that were not understood correctly. Further, since the experimental manipulation involved words only (and not sentence structures), it was unlikely that incorrect trials reflect difficulties with the target words. Hence, the data below is analysed including both correct and incorrect trials.

This section addresses the first research question. This asked whether NHI and PWA show an influence of word frequency and contextual predictability on the recognition of words embedded in a sentence context, and whether influences would be equivalent between the groups. In the following paragraphs, a frequency effect refers to shorter fixation durations for high frequency words compared to low frequency words, and a predictability effect refers to shorter fixation durations for words in highly predictable contexts compared to unpredictable contexts. If effects arise, follow-up questions concern the time course of those effects, and whether factors are independent or interactive.

Assumptions of the mixed model Anova were not met and the present analysis is based on log-transformed data. Mean fixation durations and proportions of first pass regressions for both groups and all conditions are presented in Table 7.9. The table represents the raw, i.e. untransformed data[26]. However, the following graphs present the transformed data so that the graphs match the results from data analysis. Results from the mixed model Anovas are reported for each of the eye movement measurements separately. Results will be first reported for gaze durations, then for total durations, and finally for first pass regressions. First main effects will be reported, followed by interactions and post hoc tests. Table 7.10 presents an overview of statistical results with p- values for all measurements. Non-significant values will not be reported. The Bonferroni correction was applied at 0.05/3 (α level at .017), because three measurements were analysed. Results before and after corrections are described.

Table 7.9. Mean fixation durations (and SD) in ms and first pass regression (in %) for target words

NHI	**HF P**	**HF U**	**LF P**	**LF U**
Gaze duration	214.62 (33.77)	241.99 (41.86)	255.77 (55.99)	285.91 (64.60)
Total duration	312.37 (115.19)	396.55 (96.39)	340.97 (90.67)	460.57 (150.34)
First pass regression	14.18 (13.86)	21.57 (16.00)	14.82 (13.73)	18.83 (12.69)

PWA	**HF P**	**HF U**	**LF P**	**LF U**
Gaze duration	309.32 (99.95)	328.84 (99.55)	345.51 (99.37)	436.47 (178.20)
Total duration	752.18 (277.82)	1027.63 (422.61)	794.79 (308.07)	1331.88 (767.89)
First pass regression	25.85 (15.04)	35.31 (15.02)	33.39 (12.43)	36.89 (17.25)

Note. HF P = high frequency predictable words; HF U = high frequency unpredictable words; LF P = low frequency predictable words; LF U= low frequency unpredictable words.

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[26] Tables with transformed data can be found in Appendix B.5.

Table 7.10. Overview of p-values for main effects and interactions on the target word

	GD		TD		FPR	
	p for F1[a]	**p for F2**	**p for F1**	**p for F2**	**p for F1**	**p for F2**
group	<. 0001	< .0001	< .0001	< .0001	< .0001	< .0001
frequency	<. 0001	< .001	< .0001	ns	ns	ns
predictability	<. 0001	< .0001	< .0001	< .0001	< .0001	= .01
group x frequency	ns	ns	ns	ns	= .03	ns
group x predictability	ns	ns	= .01	= .01	ns	ns
frequency x predictability	= .06	= .05	ns	ns	ns	ns
group x frequency x predictability	= .08	ns	= .05	ns	ns	ns

[a] F1 one refers to the analysis by participants, and F2 refers to the analysis by items.
Note. GD = gaze duration, TD = total duration, FPR = first pass regression

Gaze durations

For gaze durations (log-transformed), all factors revealed main effects with the analysis by participants and by items. There was a main effect of group, with gaze durations significantly longer in the aphasia group (*M* = 355.04ms) than in the neurologically healthy group (*M* = 249.57ms), $F_1(1, 35) = 1.95$, $p < .0001$, $\eta^2_G = .30$; $F_2(1, 26) = 118.05$, $p < .0001$, $\eta^2_G = .49$. There was a main effect of frequency with longer durations on low frequency words (*M* = 326.05ms) than high frequency words (*M* = 270.01ms), $F_1(1, 35) = 6.35$, $p < .0001$, $\eta^2_G = .12$; $F_2(1, 26) = 15.37$, $p < .001$, $\eta^2_G = .24$. Finally, there was a main effect of predictability with longer gaze durations on unpredictable words (*M* = 318.49ms) than predictable words (*M* = 277.57ms), $F_1(1, 35)=3.59$, $p < 0.0001$, $\eta^2_G = .07$; $F_2(1, 26) = 26.86$, $p < 0.0001$, $\eta^2_G = .13$. Two interactions reached a trend effect. First, there was a trend interaction between frequency and predictability, $F_1(1,35) = 3.71$; $p = .06$, $\eta^2_G = .01$; $F_2(1, 26) = 4.15$, $p = .05$, $\eta^2_G = .02$. Second, there was a trend higher order interaction between group, frequency, and predictability, $F_1(1,35) = 3.36$; $p = .08$, $\eta^2_G = .01$. These interactions can be seen in Figure 7.5. An inspection of the graph for NHI in gaze durations suggests that word frequency and predictability are independent of each other. Specifically, the predictability effect was 27.37ms for high frequency words, and 30.14ms for low frequency words. The frequency effect was 41.15ms for predictable words, and 43.92ms for unpredictable words. Hence, there is no evidence that word frequency and context effects operate independently of each other.

For the PWA on the other hand, the graph shows a trend for greater interaction between frequency and predictability effects. The predictability effect was 19.51ms for high frequency words, and 90.96ms for low frequency words. The word frequency effect was 36.19ms for predictable items and 107.63ms for unpredictable items. Hence, for PWA the predictability effect was larger for low than high frequency words, and the frequency effect was larger for unpredictable than predictable items. However, since the higher interaction was only a trend effect, no post hoc tests were carried out, and the results have to be regarded with caution. Since the Anova on the critical word is carried out for three measurements, the Bonferroni corrections (α level = .05/3 = .016) was applied. Only the main effects remained significant after this correction.

Total durations

For total durations, there was again a main effect of all factors, in the same direction as above and as predicted. First, there was a significant group difference with longer total durations by the aphasia group (*M* = 976.62ms) than the neurologically healthy group (*M* = 377.61ms), $F_1(1, 35) = 73.82$, $p < .0001$, $\eta_G^2 = .63$; $F_2(1, 26) = 1389.98$, $p < .0001$, $\eta_G^2 = .79$. Second, there was a main effect of frequency for the analysis by participants only, $F_1(1, 35) = 15.68$, $p < .001$, $\eta_G^2 = .03$. Total durations were longer on low frequency words (*M* = 705.19ms) than on high frequency words (*M* = 600.47ms). Third, there was a main effect of predictability, $F_1(1, 35) = 140.08$, p < .0001, $\eta_G^2 = .19$; $F_2(1, 26) = 70.43$, $p < .0001$, $\eta_G^2 =.33$. Total fixation durations were longer on unpredictable words (*M* = 773.70ms) than on predictable words (*M* = 531.96ms).

Further, there was a significant interaction between group and predictability by participants and by items, $F_1(1, 35) = 6.60$, $p = .01$, $\eta_G^2 = .01$; $F_2(1, 26) = 7.44$, $p = 0.01$, $\eta_G^2 = .02$. Post hoc tests were carried out using dependent and independent t-tests. Tests revealed a significant group difference for predictable items, $t(59.17) = -10.43$, $p < .0001$, $r = .81$, as well as for unpredictable items, $t(52.81) = -10.75$, $p < 0.0001$, $r = .83$. The effect of predictability was significant for the NHI, $t(39) = -8.53$, $p <.0001$, $r = .81$, and equally significant for the PWA, $t(33) = -8.04$, $p < .0001$, $r = .81$. These effects all remained significant after the Bonferroni correction (α level at .0125). The predictability effect was 101.88ms for the NHI, and 406.28ms for the PWA. In order to analyse whether this difference was significant, a difference score was created for the log-transformed total fixation durations. A t-test showed that the predictability difference score was significantly larger for the PWA than the NHI, $t(55.35) = -2.45$, $p = .02$, $r = .31$.

Finally, there was an interaction of group, frequency, and predictability, $F_1(1, 35) = 4.08$, $p = .05$, $\eta^2_G = .001$; this just missed significance by items, $F_2(1, 26) = 3.13$, $p = .09$, $\eta^2_G = .01$. This interaction is depicted in Figure 7.6. The interaction was further analysed with post hoc tests (α level at .0125). For the NHI, there was a predictability effect for high frequency words ($t(19) = -5.78$, $p < .0001$, $r = .80$) as well as for low frequency words ($t(19) = -6.29$, $p < .00001$, $r = .82$). There was no statistical difference in the magnitude of this effect for high compared to low frequency items ($t(19) = 0.30$, $p = .76$, $r = .07$). There was a word frequency effect for predictable words ($t(19) = -2.12$, $p = .05$, $r = .44$) but the word frequency effect for unpredictable words only reached the level of a trend (t(19 = -1.88, $p = 0.08$, $r = .40$). The predictability effects remained significant after correcting for multiple analyses, but the word frequency effects did not.

For the PWA, there was a predictability effect for the high frequency ($t(16) = -4.74$, $p < .001$, $r = .76$) as well as the low frequency words ($t(16) = -710$, $p < .0001$, $r = .87$). The predictability effect was stronger for the low frequency items than the high frequency items ($t(16) = -2.12$, $p = .05$, $r = .47$). Further, there was a word frequency effect for the unpredictable items ($t(16) = -3.08$, $p = .007$, $r = .61$), but there was no word frequency effect for the predictable items ($t(16) = -0.69$, $p = .50$, $r = .17$). The effects were significant (α level at .0125). This is where the groups differ: NHI showed a mild but significant frequency effect for predictable items and a trend frequency effect for unpredictable items. The PWA showed a word frequency effect only for the unpredictable items. The groups also differ with regard to the predictability effect: For the NHI, the predictability effect is independent of word frequency, but for the PWA the predictability effect is larger for the low frequency items than for the high frequency items, hence there is more interaction. The main effects and the interaction group x predictability remained significant after the Bonferroni correction whereas the interaction group x frequency x predictability did not (α level at .017).

First pass regressions

For first pass regressions, analyses of variance showed a main effect of group and predictability. PWA made more regressions (*M* = 32.86%) than NHI (*M* =17.35%), F_1(1, 35) = 1.61, $p < .001$, η^2_G = .23; F_2 (1, 26) = 63.67, $p < .00001$, η^2_G = .30. Also readers made more regressions on unpredictable items (*M* = 27.51%) than on predictable items (*M* = 21.45%), F_1(1, 35) = 1.33, $p < 0.001$, η^2_G = .04; F_2 (1, 26) = 7.06, $p = .01$, η^2_G = .07. There was an interaction between group x frequency by participants, F_1(1, 35) = 5.40, $p = .03$, η^2_G < .01. Post hoc analyses showed that PWA made more regressions than the NHI in both the high frequency (t(71.28) = -3.62, $p < .001$, $r = .39$) as well as the low frequency conditions (t(70.38) = -5.66, $p < .0001$, $r = .56$). The group difference was stronger for the low frequency conditions. Paired t tests showed that the effect of word frequency on regressions was neither significant for the NHI (t(39)= 0.48, $p = 0.64$, r = .08) nor for the PWA (t(33) = -1.69, $p = 0.10$, $r = .28$). Hence the interaction between group and frequency originated from a larger group difference in the number of first pass regressions from low frequency words. Figure 7.7 suggests that the groups showed different patterns of behaviour in that the NHI made more regressions in sentences with high frequency words compared to low frequency words, and the PWA regressed more out of sentences with low frequency compared to high frequency target words. However, as paired t-tests show, this difference was not significant. Results that remained significant after the Bonferroni correction were the main effect of group and predictability, but not the interaction between group and frequency (α level at .017).

Summary

This section analysed whether eye movements by NHI and PWA are influenced by word frequency and contextual predictability in sentence reading. First of all, analyses of variance showed that there are large and significant group differences in all three measurements. PWA show prolonged first and second pass eye movements as compared to the NHI, and regress more frequently out of target words than neurologically healthy participants. Secondly, word frequency had a significant effect on eye movements by both groups for gaze and total durations. Readers fixated longer on low than high frequency items. However, the frequency effect was not significant for the by item analysis for total durations, and also not for the first pass regressions. Predictability was the most robust factor and influenced both groups in all measurements. Both gaze and total durations were longer if the word was unpredictable as compared to when it was predictable. Further, readers made more first pass regressions if the word was unpredictable than when it was predictable. Even though both word frequency and predictability were significant on early and late measures, there were also some differences. First, for gaze durations (early processing stage), the word frequency effect was slightly larger than the predictability effect. The difference in fixation durations between high and low frequency words was 56.04ms, whereas the difference in fixation durations between predictable and unpredictable words was 40.92ms. Second, for total durations (later processing stage), the predictability effect was more pronounced than the word frequency effect. The difference in fixation times between the predictable and the unpredictable words was 241.74ms, and the difference between the high and low frequency words was 107.42ms. This suggests that word frequency facilitates an early stage of processing more than the context, and the context facilitates a later stage of processing more than word frequency.

Next to the strong main effects, some interactions were significant, too. The interaction between group and predictability for total durations was the strongest. This showed that the effect of predictability was larger for the PWA than the NHI. An interaction between group, frequency and predictability for total durations indicated some different group patterns. For the NHI, effects of word frequency and predictability were independent. Control participants showed a word frequency effect independent of predictability, and an effect of predictability that was independent of word frequency. The PWA on the other hand showed a more interactive pattern. They showed a frequency effect for the unpredictable words only, and a predictability effect that was much stronger for the low as compared to the high frequency items. These results have to be considered with caution as the three-way interaction just reached significance, and did not remain significant after the Bonferroni correction.

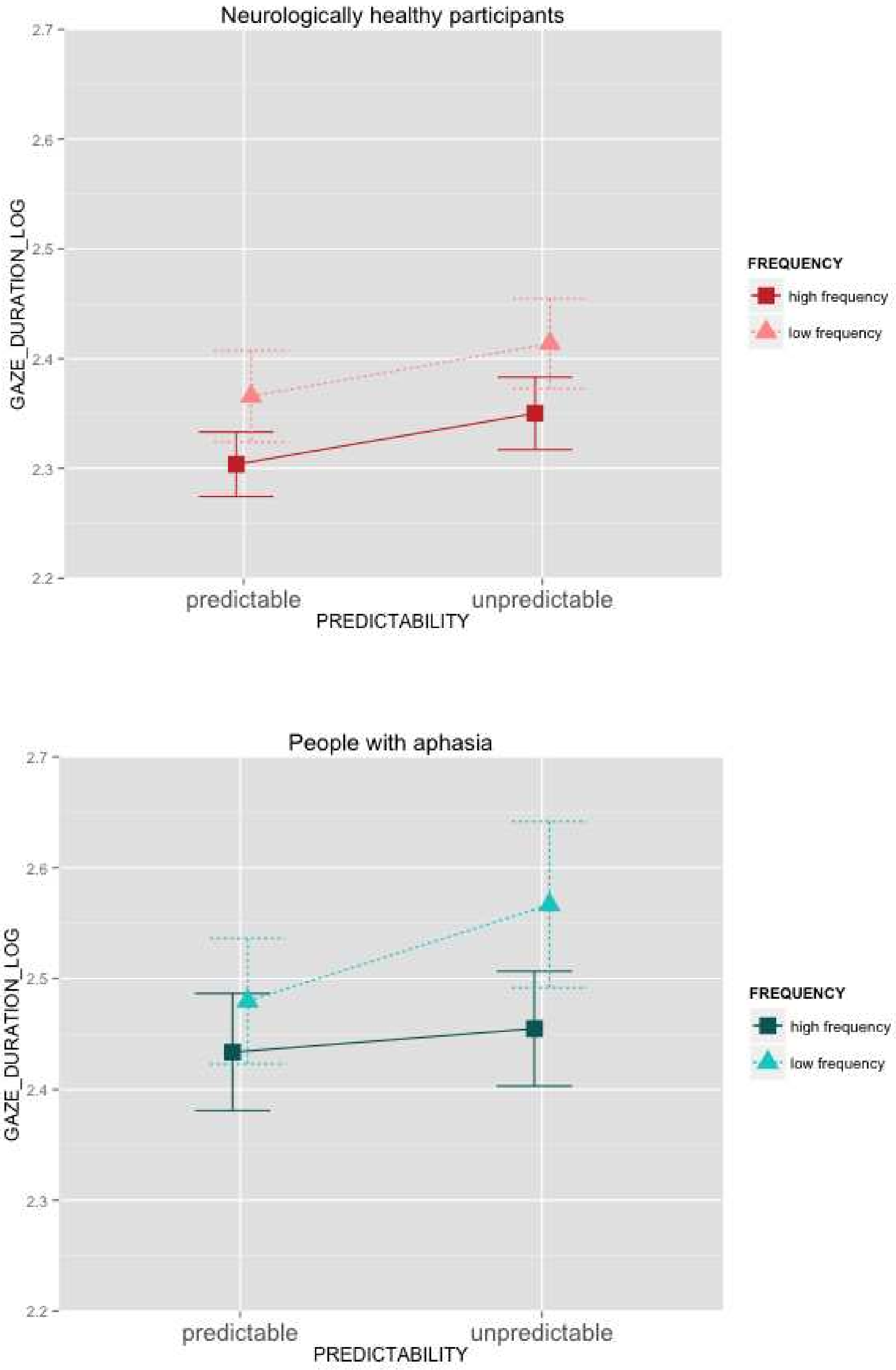

Figure 7.5. Gaze durations as a function of frequency and predictability for NHI and PWA

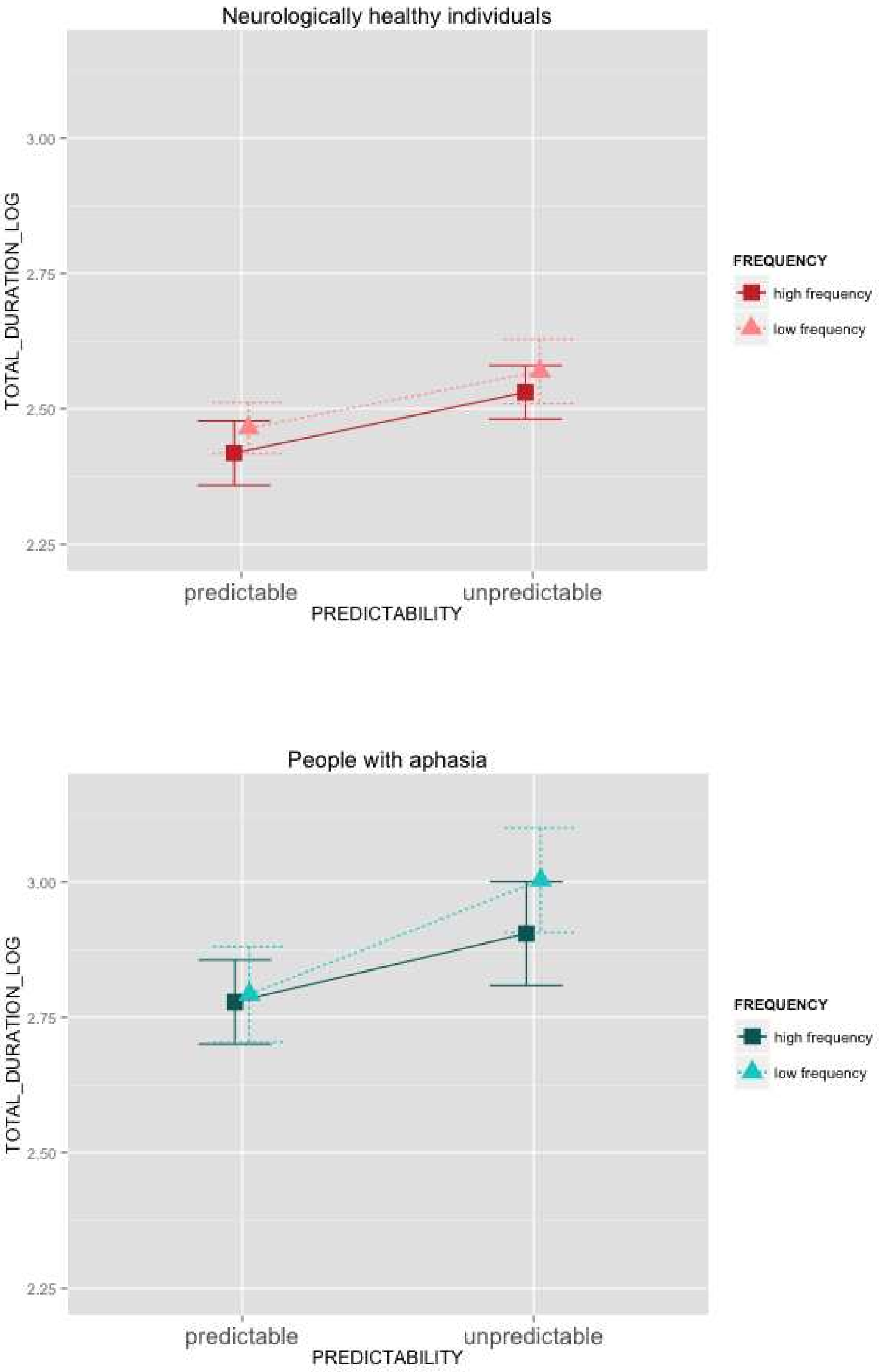

Figure 7.6. Total durations as a function of frequency and predictability for NHI and PWA

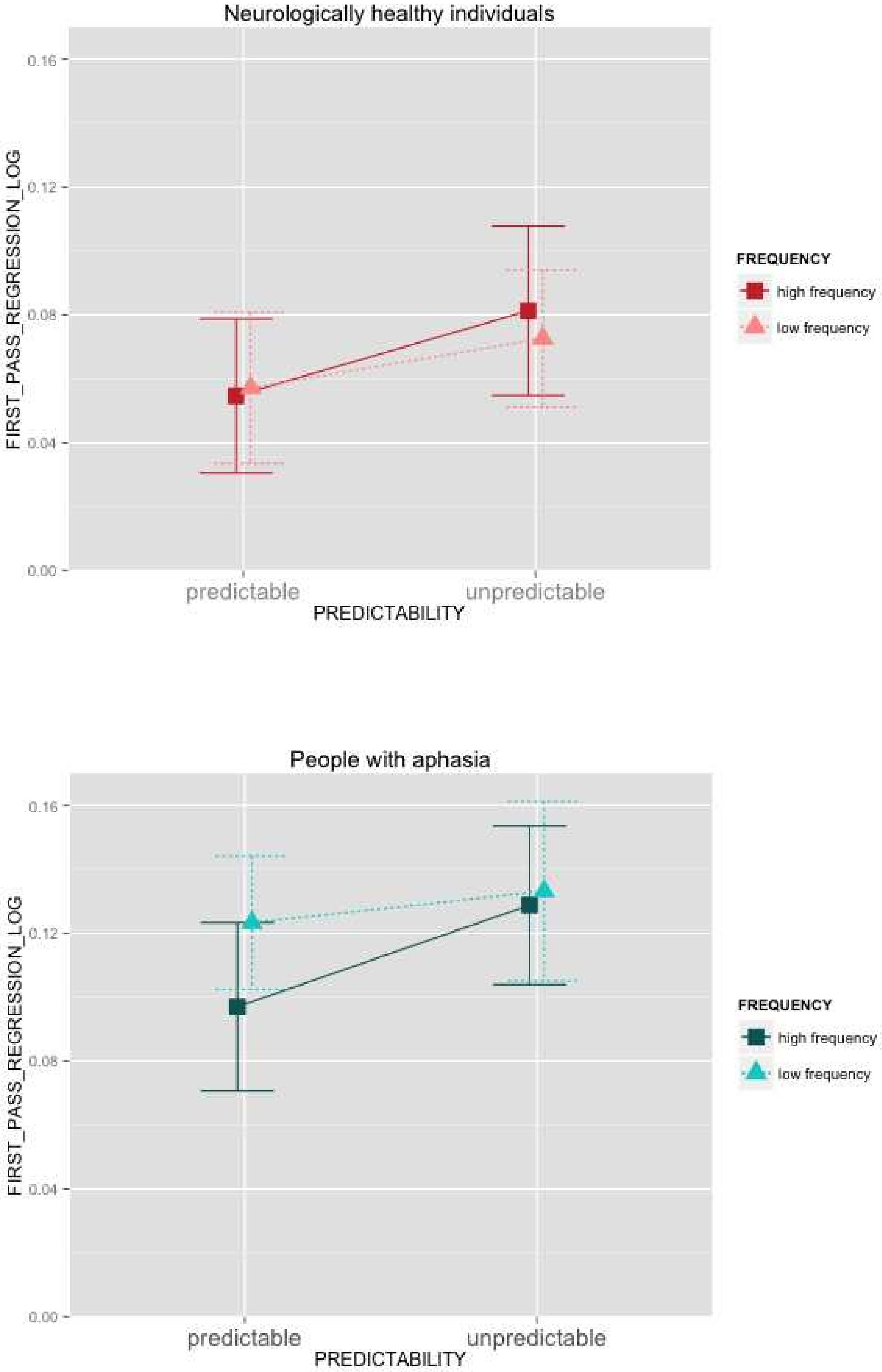

Figure 7.7 First pass regressions as a function of frequency and predictability for NHI and PWA

7.3.4. Individual analysis PWA

In this section, effects of word frequency and predictability are analysed individually for the PWA. This addresses the second research question: whether PWA show any individual differences of word frequency and predictability effects, and if, whether this relates to their underlying language impairment. The first part of this section relates to the first part of the research question. Frequency and predictability effect scores are calculated for gaze and total durations, and scores of individuals with aphasia are compared to the overall effects of the NHI group. In order to limit the analysis to only one first and one second pass measure, the individual effect scores are not calculated for first pass regressions. In the second part, word frequency and predictability effect scores are correlated with the results from the background assessments aiming to find whether underlying lexical/semantic skills are related to the effects of word frequency and predictability.

Individual analysis of the word frequency and predictability effect

In order to be able to compare results between participant groups, and to account for differences in overall fixation durations, frequency and predictability effect scores were recalculated as proportions for each participant in the sample. Simple difference scores (calculated by subtracting fixation durations in the high frequency items from fixation durations in low frequency items) ran the risk of confounding the group differences. For the word frequency effect score, fixation durations in the low frequency conditions were divided by the fixation durations in the high frequency conditions. For the predictability effect score, fixation durations in the unpredictable conditions were divided by the fixation durations in the predictable conditions. From both effect scores 1 was subtracted to gain a proportional effect score, and to show the difference in percentages. As an example, an effect score of 1.5 would mean that fixation durations in one condition are 1.5 times longer than in the other conditions. Having subtracted the 1, 0.5 means that fixation durations are 50% longer in one as compared to the other condition.

The proportional effect scores for word frequency and predictability for both gaze and total durations are shown in Figure 7.8. The ID on the x-axis refers to the seventeen individuals with aphasia. So each bar represents a participant with aphasia. Data is presented in the context of mean NHI and PWA group data. The panels on the left picture the frequency effect, and the panels on the right present the predictability effect. The effects for gaze durations are shown in the upper part, and the effects for total durations are shown in the lower part. Hence, the individual effects are shown for both first and second pass reading. Bars in the positive represent the predicted effects whereas the bars in the negative represent effects in the non-predicted direction.

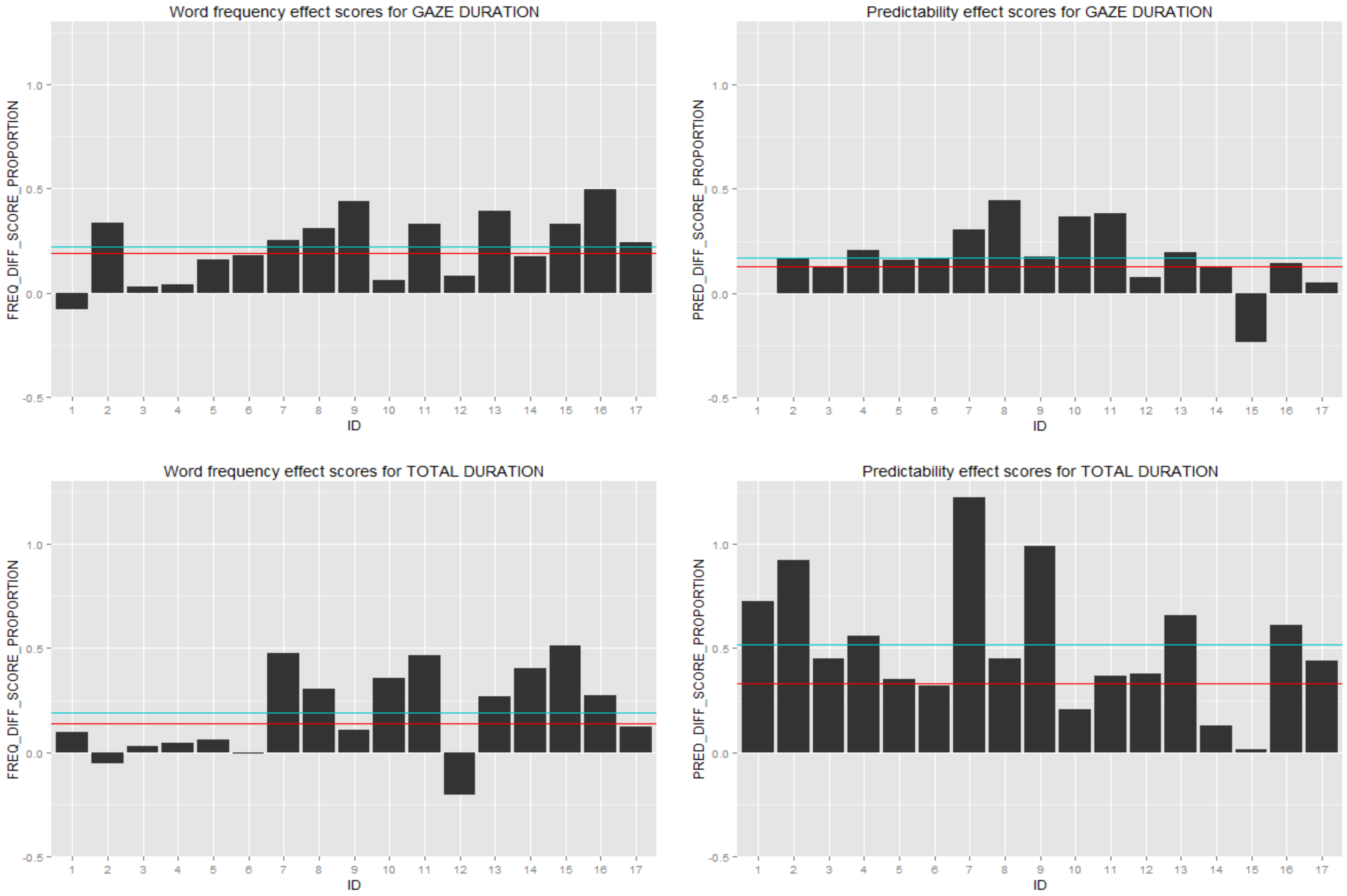

Figure 7.8 Bar graphs showing individual proportional effect scores by the PWA for word frequency and predictability. Note. Lines in turquois represent the average effect score for the PWA; red lines represent the average effect score for the NHI. ID 1 has the predictability effect score 0.0002 for gaze duration, hence the effect is too small to be visualised in the graph.

Word frequency effect

The left graphs in Figure 7.8 show that both gaze and total durations by the majority of the PWA were longer on low frequency as compared to high frequency words. However, there was variation regarding the size of the effects. ID 9 and 16 show gaze durations on low frequency words that are nearly 50% longer than those on the high frequency words. ID 7, 11, and 15 show the same pattern for total durations. Other individuals show smaller word frequency effects. There was one individual (ID 1) who showed a mild word frequency effect for gaze duration that was in the non-expected direction with longer gaze durations on the high than the low frequency words. However, the word frequency effect for ID 1 showed a mild effect in the predicted direction in total durations pictured on the panel in the bottom left. ID 2 who exhibited a large frequency effect in gaze durations, showed a mild frequency effect in the non-expected direction for total durations. Equally, ID 12 had longer total fixation durations for high than low frequency items. Overall, this pattern of individuals with aphasia led to a word frequency effect that was minimally larger than that of the NHI, as represented in Figure 7.8 by the red and turquois lines respectively.

Predictability effect

The panels on the right side in Figure 7.8 show individual variation of proportional effect scores for the predictability effect. Similarly to the word frequency effect, nearly all individuals showed a predictability effect for both gaze and total durations in the predicted direction. The predictability proportional effect scores were however more pronounced for total durations, which include the sum of all fixations on the target word. There was, particularly regarding the total durations, much variability in the effect sizes. Whereas some individuals showed proportional effect scores of about 0.3, other individuals demonstrated proportional effect scores of up to 1.25, hence they fixated unpredictable words more than twice as long as predictable words. There were only two individuals who revealed no predictability effect in gaze durations. ID 1 had an effect score that was close to zero (0.0002), and hence is not represented as a bar in the figure on the top right. Further, ID 15 showed a predictability effect in the non-predicted direction, with longer gaze durations on predictable compared to unpredictable items. For total durations, all individuals showed the predictability effect in the predicted direction, including ID 15. For gaze durations, the red and turquoise lines suggest that the average predictability effect is of a similar size between the

PWA and the NHI. However, for total durations, the average predictability effect was larger for the PWA than for the NHI, consistent with the significant group interaction of group and predictability observed in the Anovas.

The relation between language skills and word frequency and predictability effects

As demonstrated above, there was much variability in the aphasia dataset, both regarding the word frequency and the predictability effect. As the different degrees of sensitivity may be due to differences in language skills, the following analysis examines this relationship further. The word frequency and predictability effect scores for both gaze and total duration were correlated with the background assessment scores. Pearson's correlation r was used for most analyses, but the Spearman correlation r_s was used for those assessment score correlations that were not normally distributed. It was predicted that lexical and/or semantic skills relate to both word frequency and predictability, with lexical skills particularly related to the former, and semantic skills particularly related to the latter. It was expected that the severity of aphasia, sentence comprehension skills as well as working memory capacity might also have an impact on the effects. Hence, the Aphasia Quotient and all lexical/semantic composite scores (semantics overall, lexical-semantics written comprehension, lexical-semantics overall) were correlated with the word frequency and predictability effect scores for both gaze and total duration. The sentence overall score and the WM scores (WM digit forward, WM digit backward, WM sentence span) were similarly correlated with the experimental effects. Table 7.11. reports the results of the correlation analyses with the effect scores of total durations. None of the correlations involving word frequency and predictability effects for gaze durations were significant; thus the results are not reported here.

Table 7.11 The relationship between language/working memory skills (composite scores) and effect scores of word frequency and predictability for total durations

	Word frequency effect score		**Predictability effect score**	
	r	**p**	**r_s**	**p**
WAB AQ (severity)	-.44	.08	ns	ns
Semantics overall	ns	ns	ns	ns
Lexical-semantics written comprehension	ns	ns	ns	ns
Lexical-semantics overall	.54	.03*	ns	ns
Sentence overall	ns	ns	.48	.05*
WM digit score forward	ns	ns	ns	ns
WM digit score backward	ns	ns	ns	ns
WM sentence span	ns	ns	ns	ns

*p≤0.05; r refers to the Pearson's correlation test.

There were two significant relationships between composite scores and the word frequency effect scores for total durations. There was a trend negative correlation between the frequency effect score and the Aphasia Quotient of the WAB. The higher the AQ score (and hence the milder the aphasia), the smaller the word frequency effect. Further, the effect of frequency correlated negatively with the lexical-semantics overall score. This is shown in Figure 7.9. The better participants were in the lexical-semantics tasks, the smaller was their effect of word frequency in the eye tracking experiment.

Correlations between composite scores and the predictability effect scores for total durations revealed that neither the aphasia quotient nor any of the lexical or semantic scores were associated with the predictability effect. There was however a positive relationship between the sentence overall score and the predictability effect score. This correlation is presented in Figure 7.10. Interestingly, the better the readers performed in sentence comprehension tasks, the larger was their context effect in the experiment.

In summary, the correlation analyses suggest some relationships between the individuals' linguistic skills and the effects of word frequency and predictability. The more reduced the lexical skills in the participants, the bigger was the effect of word frequency. The better the sentence comprehension skills, the bigger the effect of predictability. There was no relationship between either semantic skills or working memory capacity and the effect scores, in relation to frequency and predictability respectively.

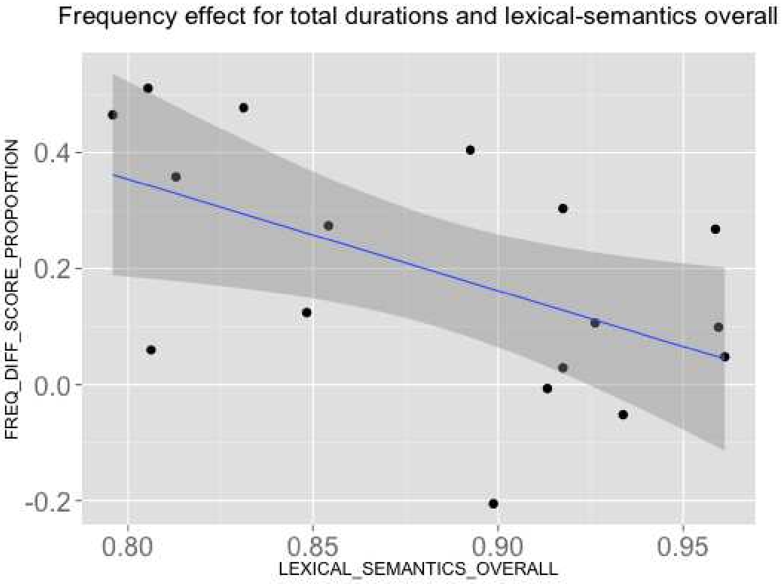

Figure 7.9 Scatterplot showing the correlation between the lexical-semantics overall score and the word frequency effect in total durations.

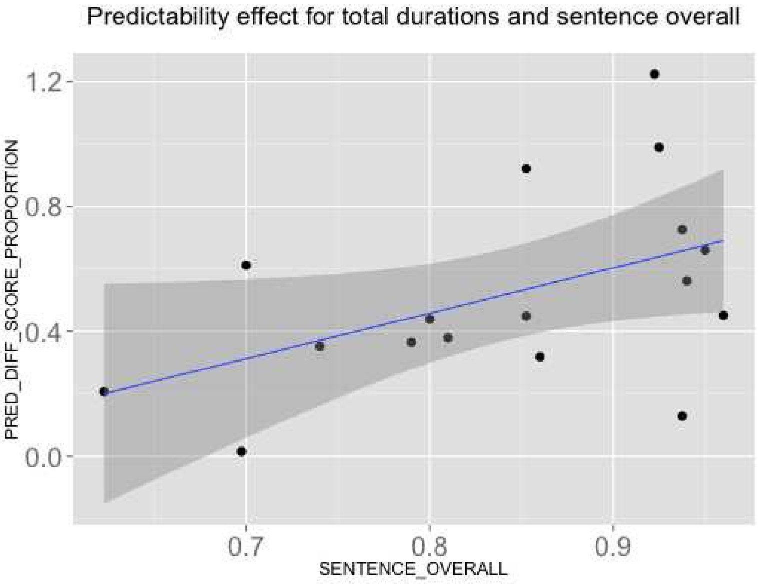

Figure 7.10 Scatterplot showing the correlation between the sentence overall score and the predictability effect in total durations

7.3.5. The relationship between language skills and eye movements

This section aims to answer a follow-up question of the second research question. The question was whether specific underlying language impairments are related to prolonged fixation durations and hence slower reading, as compared to the control group. This question does not refer to the experimental manipulations, but aims to explore a more general association between language skills and eye movements. Expectations were that reduced lexical and/or semantic skills correlate with longer fixation durations, particularly with total fixation durations, which is the global measure. Otherwise the analysis was largely exploratory.

The background assessment scores from the individuals with aphasia were correlated with the mean gaze and total durations, independently of the experimental conditions. All composite scores were entered into the correlation analyses. Since neither gaze nor total fixation duration were normally distributed, the Spearman's correlation test was used for all comparisons. All results are presented in Table 7.12.

Gaze durations were negatively correlated with the aphasia quotient. The more severe the aphasia was, the longer were the first pass fixation durations. Further, for both gaze and total durations, there was a significant negative correlation between the semantics overall score and total fixation durations. Figure 7.11 shows this correlation for total durations. Higher semantic skills were associated with shorter total fixation durations. It is likely that the synonym judgment test drove this correlation, given that the other tests were subject to ceiling effects. Further, the WM digit forward score and the WM digit backward score, as well as reading pleasure after stroke correlated with fixation durations. Better working memory skills as well as more reading enjoyment after stroke were associated with shorter total fixation durations.

Table 7.12. The relationship between language/working memory skills (composite scores) and gaze and total fixation durations

	Total durations		Gaze durations	
	r_s	**p**	**r_s**	**p**
WAB AQ (severity)	ns	ns	– .52	.04*
Semantics overall	-.57	.02*	-.56	.03*
Lexical-semantics written comprehension	ns	ns	ns	ns
Lexical-semantics overall	ns	ns	ns	ns
Sentence overall	ns	ns	ns	ns
WM digit score forward	-.47	0.06	-.56	0.03*
WM digit score backward	-.60	0.02*	-.55	0.03*
WM sentence span	ns	ns	ns	ns
Reading confidence after stroke	ns	ns	ns	ns
Reading pleasure after stroke	-.54	0.03*	-.60	0.02*

*p<0.05; r_s refers to the Spearman's correlation test.

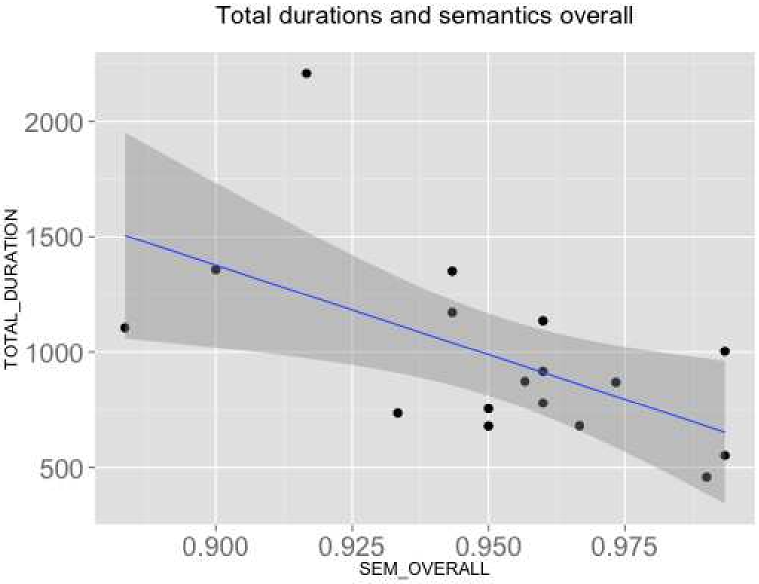

Figure 7.11. Scatterplot showing the correlation between total durations and the overall semantics score.

Additionally, correlation tests were carried out between the comprehension accuracy scores from this experiment and the three eye movement measurements. First, both the PWA as well as the NHI were included in the dataset. This showed a significant relationship between accuracy and gaze durations, $r = -.53$, $p < .001$, as well as between accuracy and total durations, $r = -.63$, $p < .0001$. The correlation between accuracy and total duration is presented in Figure 7.12. Second, a correlational analysis was run for the groups separately. This analysis demonstrated that accuracy scores by PWA and NHI neither correlated with gaze nor with total duration respectively. Finally, accuracy was mildly correlated with first pass regressions. This analysis reached the level of a trend for the PWA, $r = .45$, $p = .074$. Interestingly, this correlation was of a positive nature: higher accuracy meant a higher number of first pass regressions. The NHI showed the opposite but non-significant, $r = -.17$, $p = .48$, pattern: higher accuracy meant a lower number of first pass regressions.

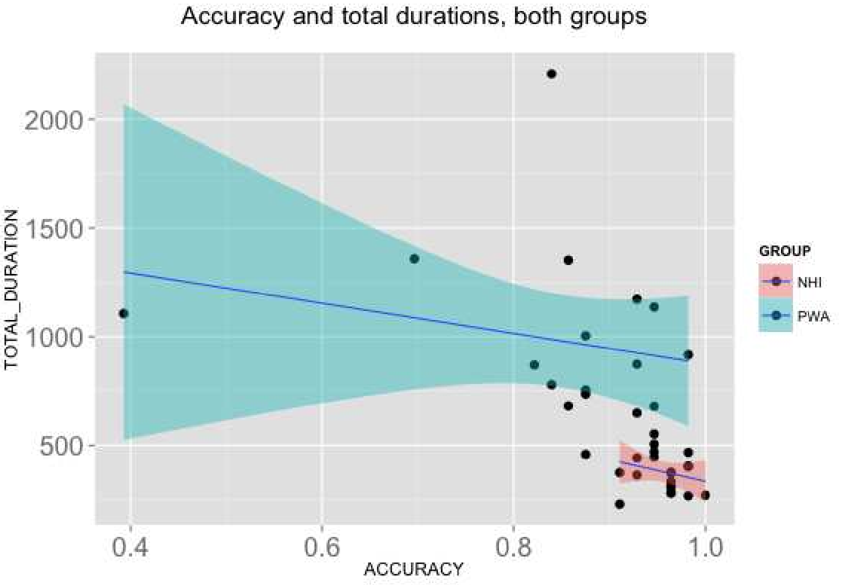

Figure 7.12. Scatterplot showing the correlation between total durations and the overall accuracy score

7.3.6. Summary of the results

This chapter presented a number of different analyses and different datasets. In this section, results are summarised. The first paragraph will summarise the global characteristics of the data. Subsequently, results are compiled by referring to the two main research questions, and the follow up questions.

Global characteristics of the data

For an overview of global reading characteristics of the PWA compared to the NHI, several eye movement measures relating to the whole sentence were compared.

This revealed that the groups differed in all measurements except in the blink/fixation ratio. Average fixation durations by the PWA were longer than those by the NHI. Also, the PWA demonstrated more fixations and more first pass regressions during sentence reading. Finally, PWA showed longer sentence reading times. These results confirm general expectations, and indicate that the presence of mild to moderate aphasia influences the process of visual word recognition and reading. This further suggests that eye tracking is a valid tool to study silent reading by people with aphasia, and that it can reveal reading impairments.

Results from the accuracy analysis are consistent with the sentence-reading-measures. As predicted, the NHI had no difficulties understanding the experimental sentences and scored close to ceiling. The comprehension accuracy score by the PWA was significantly lower, reflecting mild written comprehension difficulties. Also, both groups were influenced by contextual predictability, and showed reduced accuracy in unpredictable items as compared to predictable items. The NHI also revealed a word frequency effect in the non-predicted direction. It is difficult to account for this finding. It may be an artefact of testing, for example, arising more from the questions than the sentences, or a 'rogue' result driven by a few items in the unpredictable high frequency condition. It is striking that the finding is not mirrored in the eye tracking data.

First research question (effects of word frequency and predictability)

The first research question asked whether NHI and PWA show an influence of word frequency and contextual predictability on visual word recognition when they read sentences, and whether these effects would be equivalent between the groups.

Results from mixed model Anovas revealed that word frequency strongly influenced the eye movement behaviour of both groups. Both gaze and total fixation durations were longer on low frequency words compared to high frequency words (although, the word frequency effect was only significant in the analysis by participants for total durations). Further, both individuals with aphasia as well as healthy controls exhibited strong influences of the context on eye movements in all measurements. Both gaze and total durations were longer on unpredictable words compared to predictable words. Readers made more first pass regressions after reading unpredictable words compared to predictable words. Even though both groups showed strong effects of predictability, the effect was even greater in the aphasia group. This group difference indicates that PWA rely more on the sentence context than the NHI.

The finding that the NHI revealed a word frequency effect in the non-predicted direction in offline results but not in the eye movement analysis makes the differences between on-and offline measures evident. The offline measure targeted comprehension accuracy whereas the online measure targeted processing times. Incorrect answers can be due to a number of factors such as poor concentration/attention, difficulty with the comprehension question or pressing the wrong button on the gamepad. Hence, any of these variables may have led to the frequency effect in the accuracy data. Eye tracking measures on the other hand reveal how long participants needed to move through different stages of reading comprehension. The word frequency effect in reading in the predicted direction indicates that low frequency items need more processing resources than high frequency items. Since one would think that higher processing demands would result in more errors than fewer, it may be that a frequency effect in the non-predicted direction is caused by a difficulty answering comprehension questions.

First research question (effects of word frequency and predictability – follow up questions)

If effects arise, follow-up questions concerned when word frequency and predictability exert an influence on reading, and whether factors are independent or interactive.

The question about the time course relates to whether word frequency and context influence lexical access or post-lexical integration, and whether these processes are distinct or allow interaction. As explained in more detail in Chapter 4, gaze durations, which occur in first-pass reading, are sensitive to lexical factors, but can also be related to predictability. Total duration, which also encompass second pass reading, are thought to reflect later processing such as lexical integration. Finding that word frequency affects both gaze and total durations suggests that word frequency has an influence on the lexical access stage as well as on later processing stages. Results indicate that early and late processing is slower for low frequency words than high frequency words. The finding of a predictability effect on all measurements including first pass regressions emphasises the dominant role of the context for different stages of processing. Since context affects first pass reading, it is employed during lexical access, and since predictability also influences total durations, the context is used for the stage of lexical/semantic integration. Further, the effect on first pass regressions suggests that readers notice early if a word does not fit into the context and the generated expectations. However, closer scrutiny of the data revealed some differences between the factors. For gaze durations the word frequency effect was stronger than the predictability effect, and for total durations the predictability effect was stronger than the word frequency effect. Thus bottom-up factors play a role in both stages, but more dominantly in the stage of lexical access. Top-down processing influences lexical as well as post-lexical processing stages, but has a more profound influence on post-lexical processing.

There was no indication that the word frequency or the predictability effect occur in a later stage for the PWA than for the NHI as was expected[27]. However, a general delay in visual word recognition for the PWA as compared to the NHI was evidenced by strong group differences on all measures. The PWA showed longer gaze durations, total durations, and a larger number of regressive fixations. The gaze durations by the PWA were double the length of those by the NHI, and total durations were triple the length. Hence the PWA needed more time for both lexical access and integration but particularly so for the latter. The fact that the PWA had pronounced difficulties during the stage of lexical integration is consistent with the finding that this is where they showed a significantly larger context effect compared to the NHI.

The results summarised lead to the following question of whether factors were showing an independent or interactive pattern. Overall, there were some trend indications of a mild interactive pattern, particularly in the aphasia group. The analysis of gaze durations revealed a trend interaction between frequency and predictability, and a trend interaction between group, frequency and predictability. This suggests that gaze durations in the NHI group show an independent pattern of word frequency and predictability effects. For the PWA on the other hand, the predictability effect was larger for low than high frequency words, and the frequency effect was larger for unpredictable than predictable items. The analysis of total durations showed a significant interaction of group, frequency and predictability. Similarly to the finding for gaze durations, results suggest a group difference regarding the interaction between frequency and predictability. Both effects were of a parallel nature for the NHI; their total fixation durations were affected by word frequency independently of predictability, and they were affected

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[27] It should be noted, however, that a later effect of word frequency could have been shown by a “spillover effect”, that is, a word frequency effect on the word occurring after the target word.

by predictability independently of word frequency. In contrast, the effects were of an interactive nature for the PWA. Their total fixation durations were affected by word frequency if the item was unpredictable, and the effect of predictability was larger on low than on high frequency items. Since this was not significant after the Bonferroni correction, it can only be interpreted as a trend effect. On the whole, these results suggest that there were independent effects of word frequency and context on both lexical access and lexical integration in the NHI group. Both effects also influenced lexical access and lexical integration in the PWA group, but there were mild interactions during the stage of lexical integration.

Second research question (individual effects and correlations)

The second research question asked whether PWA show any individual differences in the effects, and if, whether this relates to their underlying language impairment.

An inspection of individual effect scores in the aphasia group showed that nearly all participants with aphasia demonstrated word frequency and predictability effects, but the PWA demonstrated much variability in the size of these effects. One individual showed a reverse frequency effect for gaze duration, and two for total durations. Regarding the predictability effect, one individual presented a reverse context effect for gaze durations, none for total durations. Correlation analyses between the background assessment scores and the effect scores revealed that the frequency effect was more pronounced if lexical skills were reduced. The predictability effect was larger if sentence comprehension scores were higher. Finally, correlations showed a significant relationship between gaze durations/total durations and accuracy for both groups. The less accurate readers were in answering comprehension questions, the longer were their reading times.

Second research question (individual effects and correlations – follow up questions)

A follow-up question asked whether specific underlying language impairments were related to prolonged fixation durations and hence slower reading, as compared to the control group. In other words, the question was whether certain language impairment predict eye movement behaviour.

Correlation analyses between the background assessment composite scores and gaze and total durations revealed several relationships between the off- and online measurements. First of all, findings suggest that aphasia severity was associated with first pass reading behaviour. Participants with lower aphasia severity scores showed longer first pass fixation durations than those with higher aphasia severity scores. Second, semantic impairments as well as a reduction in working memory were related to prolonged gaze and total durations. Interestingly, there was a relationship between how participants with aphasia rated their reading pleasure and how long it took them to read. Participants who rated their reading pleasure after stroke low on a scale had longer fixation durations that those who rated their reading enjoyment higher.

7.4. Discussion

Experiment 1 investigated sentence reading by PWA compared to NHI. Word frequency and contextual predictability were manipulated to discern whether both groups show equivalent or different effects, and to establish how this relates to bottom-up and top down processing. The results are discussed in this subchapter. The first section (7.4.1) refers to reading differences between the two groups that are independent of the experimental factors. These results will also be compared to findings from other types of populations such as developmental dyslexia for example. The second section (7.4.2) discusses the effects of word frequency and predictability. We compare the findings to previous studies and situate them into theories that might be able to account for the results. The third section of the discussion (7.4.3) addresses the time course of processing. Results will be discussed within the context of models of visual word recognition, and the implications for sentence comprehension in aphasia are discussed. Section 7.4.4 identifies clinical implications of this study, and Section 7.4.5 provides a short summary and a conclusion.

7.4.1. Group differences in reading (independent of factors)

The presence of aphasia affected all measures of eye movements. The PWA exhibited longer average fixation durations, more fixations and more regressions per sentence than the NHI. The eye movement data from the target word analysis supported the quantitative group differences. PWA revealed longer gaze and total durations on the target words as compared to the NHI, and showed more regressions out of the target words. Hence, the eye movements of the groups differed both on the first pass measures, associated with visual word recognition and lexical access, and on second pass measures associated with later processing stages. The results suggest that the PWA needed additional time to recognise the target words as well as to read whole sentences. The increased proportion of regressions which may have contributed to the prolonged total durations may signal difficulties in word recognition that motivated readers to move their eyes back to earlier parts of the sentence to attempt re-reading (Ashby et al., 2005; Boland, 2004; Rayner, 1998). Finding such strong differences between the groups in the eye movement analysis is illuminating, given that most participants only had mild aphasia. Their overall comprehension accuracy of the sentences studied here was only 10% lower than that of the control group. This would suggest that eye movement analysis is a very sensitive method to investigate mild reading difficulties in aphasia.

Results are consistent with studies showing that reading skill can affect the rate and efficiency of visual word recognition (Ashby et al., 2005; Jared, Levy, & Rayner, 1999). Ashby and colleagues compared the silent reading of highly skilled readers with average readers (all college-level). They found quantitative differences in early fixation durations as well as in re-reading durations. However, the differences between skilled and average readers were smaller than observed here. As an example, the skilled readers showed a mean of 280ms (gaze durations) on the high frequency words whereas the average readers had a mean of 286ms on the high frequency words. In this experiment, the average difference was much larger (NHI: 228.31ms; PWA: 319.08ms). This would be expected, as the average readers reported in Ashby and colleagues differed in reading skill, but had no reading impairments.

Further, results from this study are similar to quantitative differences that Rayner and colleagues (2006) revealed by comparing silent reading between young (M = 23.9 years) and old readers (M = 77.5 years). Rayner and colleagues demonstrated that old readers have longer sentence reading times than the young readers; they had longer fixation durations, and they made more regressions per sentence. Kliegl at al (2004) lend further support to these age differences in reading. They observed more regressions in older readers than young readers. However, similar to the study by Ashby and colleagues, the quantitative differences between young and old readers were not as great as between the PWA and NHI in this experiment.

Finally, results from this study can be compared to eye tracking studies that examined reading difficulties in other clinical populations. First, oral word reading in acquired dyslexia is also characterised by more fixations and by overall longer total reading times as compared to healthy reading (Schattka et al., 2010).

The study by Schattka and colleagues also demonstrated that individuals with dyslexia had longer re-reading durations than the control participants, demonstrating reduced lexical processing and consequently higher monitoring demands in reading out loud. Second, the finding of increased fixation durations is compatible with previous findings on developmental dyslexia. De Luca and colleagues, for instance, found longer fixation durations in the dyslexia group compared to age-matched controls during the reading of short passages (De Luca, Di Pace, Judica, Spinell, & Zoccolotti, 1999). Individuals with dyslexia also showed an increase in regressions as compared to the control readers. In an investigation of the reading of words and pseudowords in developmental dyslexia (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002), De Luca and colleagues observed more saccades in the dyslexia group compared to the control group. Further, individuals with dyslexia showed more regressions per words than controls, and there was a trend towards longer fixation durations in the dyslexia group compared to controls. Third and finally, our results are consistent with an eye tracking study of silent reading in aphasia which demonstrated increased gaze durations on target words and sentences as well as an increase in the number of fixations per sentence (Kim & Bolger, 2012). The aphasia participants in the study by Kim and Bolger also made more regressions per target word and per sentence in comparison to the control group.

The results from this study suggest that eye tracking is a beneficial method to investigate the process of reading in aphasia. The analysis of eye movements can identify mild reading difficulties in aphasia, consistent with other studies showing that differences in reading skill are revealed by an increased number of fixations, prolonged fixation durations both in first and second pass measures, and an increased number of regressions. Interestingly, the eye movement pattern from the aphasia group reflects their subjective ratings of reading enjoyment. However, more research on sentence reading in aphasia is needed, and with technologically advanced eye trackers available, this is certainly an achievable goal for future research.

7.4.2. Bottom-up and top-down processing in aphasia

Influences of word frequency and predictability - group similarities

As expected, results from this experiment showed that both groups were influenced by word frequency and predictability during reading. This supports the general claim that both bottom-up as well as top-down processes influence the process of visual word recognition by NHI, and provides new evidence for this claim in PWA. Additionally, the finding suggests that words that are more likely to occur are processed more quickly, and that this predictive manner of reading is a resilient feature of reading. Predictive reading persists even if the reading process is compromised due to language impairment.

The finding of word frequency and predictability effects during reading in the healthy population is in line with a large number of studies showing these influences on eye movements (Altarriba et al., 1996; Ashby et al., 2005; Calvo & Meseguer, 2002; Juhasz & Rayner, 2006; Kliegl et al., 2004; Rayner et al., 2004, 2006).

Results of word frequency and predictability effects in silent reading in aphasia are consistent with findings of these effects in other tasks (Hough et al., 1989; Jescheniak & Levelt, 1994; Kittredge et al., 2008; Nozari, Kittredge, Dell, & Schwartz, 2010; Zingeser & Berndt, 1988). Further, the results extend previous findings from a self-paced reading study that demonstrated that word frequency effects can be found at the sentence level (DeDe, 2012a). Establishing word frequency and predictability effects using eye tracking further emphasises their integral part in language processing as eye movements are known to be strongly related to cognitive processes (Rayner et al., 2012). Further, the eye movement analysis revealed that the effects are shown in largely automatic reading that is free of meta strategies and not influenced by having to focus on an additional task.

Since word frequency is known to be a robust factor in aphasia, it was expected that it would exert a stronger influence on reading than in the control group. Contrary to these expectations, there was no significant difference in the magnitude of the effect between groups. The word frequency effect in the NHI group was 42.53ms and in the PWA group it was 71.41ms. This may indicate that the participants with aphasia had no severe impairment in lexical access (even though it does not say that the time course of lexical access was the same as for the NHI – this will be discussed in the next subsection). This argument would be supported by the relatively good accuracy on lexical measures in the background assessments. A group with more marked lexical impairments may have shown magnified frequency effects, as word frequency effects signal weakened lexical representations (DeDe, 2012a). It would be expected that lexical impairments increase the difference in processing high frequency compared to low frequency items as the latter have higher activation levels. However, another reason for the absence of a group interaction could be a trade off between fixation durations and first pass regressions. Results revealed an interaction between group and word frequency for first pass regressions, showing that the group difference in the number of regressions was larger for low frequency than for high frequency words. The PWA showed an increase in regressions when approaching a low frequency word. It has been argued in psycholinguistics that first pass regressions can occur because of incomplete lexical access (Engbert, Nuthmann, Richter, & Kliegl, 2005). Hence, instead of fixating low frequency words for longer, PWA may have regressed out of the low frequency word to reread the sentence from an earlier point, possibly to gain facilitation in lexical access through the sentence context. A similar explanation has been put forward by Ashby and colleagues for a missing word frequency effect in gaze durations in their average reader group in their second experiment (Ashby et al., 2005). The average readers did not show an increase in gaze durations on low frequency words, but regressed out from low frequency words. They also showed a word frequency effect on the word following the target word (referred to as "spillover effect").

Even though the aphasia group did not show a magnified frequency effect, correlational analyses revealed that a relationship between lexical skills and word frequency did hold. Lower lexical skills were associated with larger word frequency effects. The variability in lexical scores in this aphasia group was however limited with many participants scoring close to ceiling. This may explain why no significant group interactions were found in the mixed model Anovas when the group was analysed as a whole. However, the correlation supports the assumption that mild lexical impairments in some individuals in this group did have a small influence on their eye movement behaviour in that they fixated low frequency words for longer than high frequency words, and the frequency effect was larger than for PWA who had no lexical impairment.

In summary, whilst global eye movement characteristics revealed large differences between the reading behaviour of PWA and NHI, both groups showed similar processing patterns in that both were influenced by the manipulations of word frequency and predictability. However, there were differences between the groups in the magnitude of the context effect as will be discussed in more detail below.

Influences of word frequency and predictability - group differences

Similarly to word frequency, a larger effect of predictability was also predicted for the PWA compared to the NHI. The results confirmed these expectations. A larger effect of contextual predictability for the PWA than for the NHI was revealed for total durations, and hence at a later stage of processing that includes re-reading behaviour. Thus, compared to the NHI, the PWA relied more on the sentence context during reading. This result supports interactive compensatory processing theories (Stanovich, 1986, 1988), which assume that the use of a sentence context to facilitate reading is dependent on reading efficiency. More precisely, according to interactive compensatory theories, the magnitude of a context effect is inversely related to word recognition abilities (Stanovich, 1986). If bottom-up processing is not fully efficient, the system can compensate by posing more demands on other information sources such as the context. Thus readers use top-down processing as compensation for poor bottom-up processing. This relation has previously been shown in developmental dyslexia. Readers with phonological dyslexia in which the sublexical route in word recognition is particularly difficult, rely more on the influence of a context than a reader would normally do (Whitney, 1998). The sentence context is particularly facilitative for the reading of low frequency words. In line with interactive compensatory processing theories, results from this study suggest that mild difficulties in lexical access were facilitated by top-down processing in the aphasia group. PWA showed an influence of context particularly for low frequency words that are more difficult to access than high frequency words. Overall, this is also in line with the failure to find a magnified effect of word frequency in the aphasia group. Some readers who had difficulties with lexical access, may have regressed to earlier parts of the sentence to re-read with support from the sentence context.

Results showing a magnified context effect for the aphasia group are consistent with previous offline studies. Some of these revealed that the context is employed if the support is needed, but not if comprehension is unimpaired or mildly compromised (Pashek & Tompkins, 2002; Pierce & Wagner, 1985). Pierce and Wagner, for example, observed that the effect of a context can be particularly robust for PWA who have profound difficulties in sentence comprehension (Pierce & Wagner, 1985). They found a beneficial effect of a sentence context on the comprehension of reversible passive sentences for those participants with aphasia whose comprehension of that sentence type was poor. They argue that individuals with relatively good comprehension skills are less likely to need the context sentence to facilitate interpretation, but those with poor comprehension skills are more likely to. Consistent with these results, Pashek and Tomkins carried out correlational analyses and found that more severe auditory comprehension was related to greater context effects (Pashek & Tompkins, 2002). Results from this experiment are in line with this argument as the PWA have lower comprehension accuracy than the NHI, and have therefore relied more on the sentence context. However, it is more difficult to account for the finding of a positive correlation between overall sentence comprehension skills and the context effect. One tentative explanation would be that – even though all PWA use the context for compensation – they may be most successful in doing so if their sentence comprehension skills are better overall. Equally it could be that using the sentence context results in better sentence comprehension. More research in this area is needed to understand the association between sentence comprehension skills and the influence of a context better.

Interestingly, results are also aligned with a recent study using eye tracking that indicated that a semantic context can be facilitatory in reading for PWA, and additionally, that the effect is magnified for the PWA as compared to NHI (Kim & Bolger, 2012). Similarly to our results, they found a magnified context effect in total fixation durations (they refer to this measure as 'total gaze duration'). PWA also differed from NHI by a larger effect of the context on the number of regressions. Further there is some evidence suggesting that a larger reliance on top-down processes is not an observation inherent to language difficulties in aphasia or developmental dyslexia. Larger context effects have also been found for average readers compared to skilled readers (Ashby et al., 2005). Ashby and colleagues investigated effects of word frequency and predictability on eye movements in reading comparing highly skilled readers with average readers (all college-level readers). The skilled readers showed relatively stable word frequency effects, independent of whether the context was neutrally-constraining, high in predictability or low in predictability. The average readers on the other hand showed predictability effects in the expected direction for high frequency words. For low frequency words, they showed a predictability effect in that low frequency words attracted longer processing times in the neutral non-constraining than in the high predictable condition.

In contrast to these findings, a study examining age effects on silent reading revealed that both young and old readers were similarly affected by both word frequency and context manipulations, with a marginally larger frequency effect for the older readers (Rayner et al., 2006). Rayner et al. observed that older readers undertake a more risky reading strategy than younger readers. They skip more words and rely more on information gained through parafoveal vision (Rayner et al., 2006). A comparison of the study by Rayner and colleagues with the present study as well as previous ones cited above may suggest that the reliance on top-down processing is not directly modulated by age, but depends on reading skill and reading strategy.

Taken together, reading and/or comprehension difficulties may be associated with a larger reliance on the context as this compensates for less efficient bottom-up processing. This online study shows (as many did before) that a sentence context also facilitates healthy reading. Hence, the context influence is part and parcel of the normal reading process, but can be magnified if reading is compromised, consistent with interactive compensatory theories.

7.4.3. The time course of processing

The question about time course of processing refers to several theoretical issues. First, it relates to when and how word frequency and context influence processing, and how this relates to bottom-up or top-down processes. This again has implications for reading models. Second, it relates to the theoretical question of the nature of lexical-semantic processing impairments in aphasia.

Results from this experiment showed that for both groups, word frequency and context influenced gaze durations as well as total durations. Predictability also influenced the proportion of regressions. Hence, both word frequency and predictability exert an influence on both early and late processing stages. The effect of word frequency was slightly stronger for gaze durations, and the effect of predictability was stronger for total durations. As mentioned before, the mapping of gaze durations and total durations onto different processing stages is by all likelihood an oversimplification (Rayner & Liversedge, 2011). However, based on previous findings of eye tracking studies, the results suggest that word frequency exerts a strong influence on initial lexical processing associated with lexical access, even though it still influences later processing stages. Predictability predominantly influences the later stages of processing such as the construction of meaning and the integration of the item into the sentence even though it also plays a role in lexical access. Moreover, the context influenced whether readers make a regression, and then also influenced re-reading. The key implication is that bottom-up factors play a role in both stages, but more dominantly in the stage of lexical access. Top-down processing influences lexical as well as post-lexical processing stages, but has a more profound influence on post-lexical processing. These results support other eye tracking studies in the healthy population showing influences of word frequency and predictability on both early and late processing (Kliegl et al., 2004; Rayner et al., 2004, 2006). Kliegl and colleagues found the same pattern in that both factors affected first and second pass reading, but the predictability effect was more pronounced in second pass reading (Kliegl et al., 2004). Regarding healthy processing, these results further coincide with results from a study investigating word frequency and predictability effects on event-related potentials (ERPs) during a word-by-word reading task (Dambacher et al., 2006). They examined an early time window (P200) and a late time window (P400). The P200 and P400 are waveform components of the ERP. Dambacher and colleagues found a word frequency effect in the early P200 range, which was independent of the context manipulation. The later P400 range was influenced by the context, particularly for low frequency words.

With respect to models of visual word recognition and reading, the results from this experiment are at odds with modular/serial reading models. These models assume that the lexical stage is autonomous and independent of higher-level (top-down) information sources like a sentence context (Carreiras et al., 2014). According to Forster (1981), syntactic or semantic information can only exert an influence on post-lexical processing. Eye movements that would support this view would be those that show context influences on later measures such as total durations only, but not on gaze durations. Rather, the results showing an influence of both word frequency and context on an early stage of processing support models that, in principle, allow an interaction of bottom-up and top-down processes. This is suggested by interactive models (Coltheart et al., 2001; McClelland & Rumelhart, 1981; Plaut, 1999; Seidenberg & McClelland, 1989). However, even though the results support the view that bottom-up and top-down processes play a role in both stages of lexical processing, the results did not demonstrate an interaction between word frequency and predictability for the NHI. Word frequency and predictability effects were independent of each other. This finding is consistent with some previous eye tracking studies in psycholinguistics (Altarriba et al., 1996; Ashby et al., 2005; Rayner et al., 2004). Thus results for the NHI show independent effects of word frequency and predictability on processing even though an interaction should be possible as the factors influence the same stage of processing.

In contrast to the data from the control participants, there were mild indications of interactions in the results from the aphasia group. This could imply that the extent of interaction depends on the efficiency of the processing system.

Interaction may only take place if one of the bottom-up/top-down processes needs support from the other process. For the aphasia group, the word frequency effect was significant for unpredictable words only, and the predictability effect was magnified for low frequency words. A similar pattern of word frequency and predictability effects was previously established for skilled and average readers (Ashby et al., 2005). Their results showed independent effects of word frequency for skilled readers. Their word frequency effects were stable over the predictable and the unpredictable conditions. However, the average readers showed more interaction: their word frequency effects were modulated by predictability. Average readers showed longer processing times on low frequency words compared to high frequency words in a neutral non-constraining condition, but not in a predictable condition. In line with the compensatory model mentioned above, the results from this study as well as those from Ashby and colleagues suggest that interaction may be more likely to take place if processing efficiency is reduced.

Finally, results also have implications regarding the time course of lexical-semantic processing in the PWA. Lexical-semantic impairments in aphasia can have different sources. So far there is still controversy about the exact nature of these. To reiterate, some priming and eye tracking studies showed slowed or reduced lexical activation, particularly in Broca's aphasia (Ferrill et al., 2012; Love et al., 2008; Prather et al., 1997; Utman et al., 2001; Yee et al., 2008). In a study on the auditory comprehension of passive sentences using the visual world paradigm, PWA showed a tendency to look at the correct picture of a picture panel only after hearing the sentence offset (Meyer et al., 2012). The NHI on the other hand were able to fixate on the correct word as soon as the sentence structure could be clearly understood. This was taken as evidence that the PWA needed more time for lexical processes before they could determine sentence structure. Other studies found that people with Broca's aphasia are delayed or have difficulties in the integration of lexical items (Dickey et al., 2007; Grindrod & Baum, 2002; Swaab et al., 1998). In the context of lexical ambiguity, Swaab and colleagues (1998), for example, revealed that PWA activated both meanings of the ambiguous word, but were not able to select the context-appropriate meaning at the same time course as the NHI; they were only able to select the context-appropriate meanings in a slower condition. Based on the previous findings of lexical delay in processing, it was expected that the word frequency effect would occur later for the PWA as compared to the NHI. The analyses in this experiment were restricted to the target word, and it was not investigated whether word frequency effects occurred on a word following the target word. Hence, it could not be investigated whether word frequency effects occur at a later stage in the PWA compared to the NHI. However, the aphasia group revealed slower processing by both longer gaze durations and total durations. This suggests that their demands in the processes of lexical access and later processing stages that may involve lexical integration were higher than for the NHI. Thus, results showed that early and later processing stages were slowed in comparison to the NHI. The largest difference emerged in total durations where the durations by the PWA were triple the length compared to the NHI. This indicates that PWA experienced the severest difficulties in later processing stages that involve cognitive processes after lexical access occurred. This is also the stage in which PWA needed more facilitation from the sentence context. If lexical integration is compromised, the use of top-down processes can lend its support. The context can reduce lexical competition particularly for predictable words, making it easier to integrate them into the sentence. These results are consistent with other eye tracking studies that examined the auditory comprehension of structurally complex sentences in aphasia (Dickey et al., 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009). These studies suggest that eye movements in the initial process of sentence comprehension were similar between PWA and NHI, but differences emerged towards the end of sentences. This is where the PWA showed lexical competition effects. PWA revealed more fixations on a lexical competitor picture as compared to the target picture. The pattern from these sentence comprehension studies suggests that difficulties in processing for the aphasia group occur in later stages of processing, and may point to difficulties in lexical integration. Further, the assumption of integration impairments is consistent with a reading study by Sung and colleagues (2011), in which self-paced reading durations were longer on a noun following two adjectives compared to just one. This suggests that adjective padding increases processing costs, leading to difficulties in lexical integration of written information. Overall, the eye movement pattern observed in this experiment is consistent with both assumptions of delay in lexical access as well as an impairment or a delay of lexical integration, but more predominantly with the latter. It could be that if lexical representations are weakened, this could lead to both a delay in lexical access and integration (DeDe, 2012a). Importantly, whereas previous studies emphasised difficulties in lexical access or integration in only some subtypes of aphasia, this study found difficulties in the dynamics of lexical activation in a group of mixed subtypes, consistent with findings by DeDe (2012a).

7.4.4. Clinical implications

Results from this study also have implications for clinical practice. Some of these refer to the theoretical outcomes of this study, and some relate to the use of eye tracking to investigate silent reading in aphasia.

First of all, it was found that the PWA showed magnified effects of predictability. However, within the aphasia group, the context effect was larger for those PWA with good comprehension skills. This may suggest that the use of a sentence context is a worthwhile reading strategy. It was also observed that all but one participant with aphasia used this strategy to varying extents. Thus it can be expected that a larger reliance on the context is an automatic strategy applied by the processing system. However, for individuals who do not use the sentence context, this could be a beneficial strategy to focus on during reading treatment. Additionally, results from this study revealed that word frequency and predictability can interact in the aphasia group. It was shown that the context particularly facilitates the understanding of low frequency words. This interaction could also be incorporated into treatment of silent reading in aphasia; for example, if low frequency words are to be targeted, they might first be practised in predictable sentence contexts before they are practised in unpredictable contexts.

What is more, correlations between language background tests and gaze and total durations (independently of the experimental manipulations) revealed that both semantic skills and working memory capacity are related to eye movements in reading. Good semantic skills and good working memory capacity were associated with short eye movements, suggesting that these components of cognition impact reading rate and efficiency. Practice of semantics and working memory might therefore be particularly important in reading therapy. Some treatments for acquired reading difficulties include treatment for lexical-semantic working memory. Mayer and Murray for example (Mayer & Murray, 2002) employed a cognitive treatment aiming to improve cognitive processes that are needed for successful reading. In this treatment, two tasks have to be carried out in parallel. A sentence has to be both read and judged for grammaticality, and the semantic category of the last word of the sentence has to be named. The more sentences included in the sets, the more words had to be kept in memory for the naming of the category. Outcome tests revealed improved reading rate, however little or no gain in comprehension.

As mentioned above, this experiment showed that eye tracking can serve as a method to reveal silent reading impairments in aphasia. Results can show difficulties with visual word recognition and lexical access, processes of lexical integration, as well as reading difficulties at the sentence level. It is further interesting to note that the eye movements reflected the PWA's own judgment of reading. Across the group, reading pleasure after stroke was rated as 4.53, placing it in the mid range ("somewhat enjoy reading"); and many individuals gave very low ratings. This judgment is rather at odds with their background assessment scores, which showed only mild difficulties. However, the judgments were perhaps more reflective of the eye movement data, which revealed a striking differences between the PWA and the NHI group. These data show that reading is slow and highly laborious for PWA, in a way that is likely to undermine enjoyment.

7.4.5. Conclusion

This experiment investigated the influence of word frequency and predictability on moment-by-moment processing by PWA and NHI during silent reading. Outcomes contribute to the current stage of reading research in aphasia in several ways.

First, the experiment showed that the analysis of eye movements can identify mild reading difficulties at the sentence level. Longer fixation durations and a larger number of fixations and regressions indicated reading difficulties in the aphasia group. Since reading comprehension was only mildly reduced in the group studied here, findings indicate that eye tracking is a beneficial tool to reveal reductions in reading efficiency.

Second, the study shed more light on the process of visual word recognition and silent reading in aphasia, and has implications for theories and models. Results of this study demonstrated large effects of word frequency and predictability on both first pass and second pass eye movement measures by both groups. This suggests that both the early stages as well as later stages and re-reading are subject to bottom-up as well as top-down processes. These results support views of interactive models of reading (Coltheart et al., 2001; McClelland & Rumelhart, 1981; Plaut, 1999; Seidenberg & McClelland, 1989). The groups differed, however, in the magnitude of the context effect. The larger reliance on the context in the aphasia group was interpreted as compensation for less efficient bottom-up processing, consistent with interactive compensatory processing theories (Stanovich, 1986, 1988). Since there was also more interaction in the aphasia group, results suggest that interactions can result from reduced reading efficiency.

The groups differed further in their time course of processing, as the aphasia group showed slower processing in all measures, with the greatest delay during a later stage of processing that may be associated with lexical integration. This indicates that the processes of lexical access and lexical integration in particular, posed higher demands on cognitive processes for the PWA compared to the NHI. In the later processing stage, the PWA also relied more on top-down processing than the controls, and further showed more interactive patterns than the control group. This pattern is consistent with both hypotheses of reduced/delayed lexical access as well as reduced/delayed integration.

Third, whilst the majority of research studies have examined single word reading, this experiment investigated lexical-semantic influences on silent reading at the sentence level. This line of research begins to fill the gap between word reading and reading comprehension at the text level. Apart from the effects of the experimental manipulations, further analyses also exhibited that both semantic skills and working memory are essential aspects of successful reading. These are important component processes that should be targeted in clinical settings.

Overall, this study strongly suggests that reading in aphasia is – as is the case for controls – influenced by word frequency and predictability. These are factors that are related to language usage. Even if the reading process is slower and less accurate as in aphasia, these factors are still a natural part of reading. The next experiment focuses on more detail on probabilistic influences on reading, and investigates whether these can facilitate the comprehension of mild garden path sentences.

Chapter 8. Experiment 2. Materials and design

This chapter describes the development of the experimental stimuli for Experiment 2. The first subsection introduces the original data that this experiment is based on, and explains how the target and context sentences were developed (8.1). It further describes two norming studies on the sentence stimuli. The second subsection describes the development of filler sentences and comprehension questions (8.2). Moreover, a norming study on comprehension questions is summarised. Subsequently, the design of the experiment is presented (8.3), and the last subsection provides a short summary (8.4).

8.1. Stimulus development - sentences

This experiment is adapted from a study by Hare and colleagues (2003) into sense-contingent argument structure frequencies in the healthy population. This original study involved 20 polysemous verbs that can take both a sentence complement (SC) and a direct object (DO) argument, and have more than one sense listed in WordNet (Miller, Beckwith, R., Fellbaum, Gross, & Miller, 1990). Hare et al. (2003) carried out a corpus analysis using four different corpora, to determine whether form- and sense-based argument structure patterns of these polysemous verbs differ. The corpus analysis showed that the argument structure preferences for the form-based argument structure varied between corpora. The verb *acknowledge*, for example, was DO-biased in the Brown corpus but SC-biased in the Wall Street Journal. In order to analyse sense-based argument structures, Hare and colleagues identified two distinct senses that allow different argument structures for each of the 20 verbs. In most of the cases, the senses involved a concrete sense (e.g. an action) and an abstract sense (e.g. a mental or cognitive sense). The abstract sense was generally a meaning extension of the concrete one. The corpus analysis of these sense-based argument structures revealed that all verbs had a DO-bias for one sense of the verb, and were SC-biased for the other sense of the verb. Hence the analysis revealed a probabilistic relationship between the verb senses and their argument structures (Hare et al., 2003).

This study used 10 verbs, which are a subset of those in the original study by Hare et al. It was necessary to limit this experiment to a smaller number of items as the original dataset is too large for testing people with aphasia who get fatigued easily. In order to investigate whether people with aphasia can access form-sense probabilities in the reading of ambiguous sentences, the experimental design consisted of context sentences followed by target sentences including the polysemous verbs. The context sentences were designed to bias readers for either sense of the verb. The target sentences were either ambiguous between the DO/SC structure or were non-ambiguous. The goal was to examine whether the readers with aphasia are sensitive to the context-biased verb sense and its associated structure. For each of the verbs, two context and two target sentences were either taken from the original study, or were adapted. Where possible, the context biasing sentences were simplified to render them more suitable for a study involving people with aphasia. Keeping them as simple as possible, they were at the same time designed to be meaningful enough to create a sense bias. Following Hare et al., context sentences included no SC-structures to avoid structural priming, and context sentences did not invoke strong expectations for the specific target verbs, but evoked a semantic scenario. Also, the contexts for the verbs never included any target verbs. The target sentences either included the complementiser *that*, which makes the sentence non-ambiguous, or they omitted *that*, which created the ambiguity. For example as in the sentence: *They found (that) the book was written poorly and difficult to understand*, target sentences contain a personal pronoun (*they*), the target verb (*found*), the second (ambiguous) noun phrase (*the book*) and continue with a sentence complement (*was written poorly and difficult to under*). The noun phrase was constructed to be plausible both as a direct object of the target verb and as a subject of the following sentence complement clause. This was so that plausibility was not a confound in this experiment. The two words following the noun phrase were the disambiguating region (*was written*), followed by 2-3 words as the post-disambiguation region (*poorly and*), and an ending (*difficult to understand/regretted searching for it*). The tail of the sentences had to be different in the different context conditions in order to be semantically plausible.

Overall, the material comprised four conditions: 1) SC-biasing context and non-ambiguous target sentence (including *that*); 2) SC-biasing context and ambiguous target sentence (omitting *that*); 3) DO-biasing context and non-ambiguous target sentence (including *that*); and 4) DO-biasing context and ambiguous target sentence (omitting *that*). Since each of the 10 verbs appeared in four different conditions, there were 40 experimental sentences. A set of conditions for the target verb *find* is given in Table 8.1.

Table 8.1. Experimental sentences Experiment 2

Target verb	**Contexts and target sentences**	**Verb sense and conditions**
find	**Context biasing SC**	**discover#4, find#9 (make a discovery)**[28]
	The students hated having to read the textbook on biology.	
	(1) They found that / **the book** / was written / poorly and / difficult to understand.	(1) SC-bias non-ambiguous
	(2) They found / **the book** / was written / poorly and / difficult to understand.	(2) SC-bias ambiguous
	Comprehension question Was the book easy to understand? (no)	
	Context biasing DO	**find#3, regain#2 (come upon after searching; find the location of something that was missed or lost)**
	Susan and her friends had been searching for the book nearly everywhere, but they were successful in the end.	
	(3) They found that / **the book** / was written / poorly and / regretted searching for it.	(3) DO-bias non-ambiguous
	(4) They found / **the book**/ was written / poorly and / regretted searching for it.	(4) DO-bias ambiguous
	Comprehension question Was the book written poorly? (yes)	

Following Hare et al. (2003), norming studies were conducted in order to examine whether the probabilistic relationships between verb sense and structure identified in the corpus analysis were upheld for the experimental stimuli on the basis of the corpus analysis. The first norming study served to establish what sense and structure of the verb was activated, following the given context sentence. The second norming study served to measure how much the (ambiguous) noun phrases influenced the participants' interpretation of the verb sense and hence the

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[28] The numbers next to the verb senses refer to the sense number in the WordNet Search 3.1 (http://wordnet.princeton.edu/)

structure. The following two sections provide an overview of the two norming studies.

8.1.1. Norming study 1 –completions from verbs in contexts

Hare and colleagues (2003) carried out a norming study in which college students were asked to complete a sentence fragment with a subject noun phrase and the target in past tense (e.g. *They found*…). First, they identified answers as corresponding to the DO- or SC-sense of the verb to determine how frequently each sense is used with the verbs. Second, they categorised completions from each sense as DO-, SC- or other structure. This was to determine the sense-based argument structure frequency. The percentage of the sentence completions with a SC-sense/structure and a DO-sense/structure respectively can be seen in the first row of Table 8.2.

The out-of-context norming study established that verb sense is marginally but non-significantly biased towards a DO-interpretation (52% DO-sense vs. 41% SC-sense; the rest was defined as other). When the verb was used in the DO-sense, the majority of completions were in the DO-structure (85% DO-structure vs. 1% SC-structure). The sense-based argument structure frequency of the SC-sense was less strong (54% SC-structure vs. 32% DO-structure). Hence, the verbs in this study have a DO-bias that make the SC-biasing contexts more challenging.

In the first norming study here, participants were provided with the context sentence followed by the subject noun phrase and the target verb. They were then asked to complete the sentence. The data were analysed to determine whether the contexts stimulated the target verb sense and the associated sentence structure. So, for example, a SC-biasing context was anticipated to stimulate the SC-sense and hence a SC-completion. A DO-biasing context was anticipated to stimulate the DO-sense, and hence a DO-completion.

Methods

Participants

Seventy participants without brain damage (different to the participants in the eye tracking experiment) were recruited via personal contacts and social network sites (age *range* = 18-76, *M* = 41.35). Eleven were male, and fifty-nine were female. They were either native speakers of British English or started to speak English as their main language from a young age and used it as their main language. Participants were entered into a raffle to win a £20 shopping voucher in each of the norming studies.

Materials and procedure

For each of the ten verbs, a pair of sentence contexts was constructed, one biasing towards the DO sense, and the other towards the SC sense. Two lists (A and B) were created so that the participants read each verb only once and only in one context (see example below). The sentences and fragments were interspersed with twelve filler items in varying syntactic structures and truncated at different points in the sentence. The filler sentences included different verbs and structures. An example is *Tim and his friends went to the festival for the weekend. After they arrived*...Each subject saw half of the verbs following a DO-biasing context, and half following an SC-biasing context. Thirty-one participants completed list A, and thirty-nine participants completed list B. All sentences were randomised. The online platform *Sosci Survey* was used for the norming study. Participants were presented with the context sentence and the target sentence that was truncated following the verb. They were asked to produce sentence completions. Consider this example for the verb *find*:

List A
SC biasing context (sense: DISCOVER)
The students hated having to read the textbook on biology.
They found ____

List B
DO biasing context (sense: REGAIN)
Susan and her friends had been searching for the book nearly everywhere, but they were successful in the end.
They found____

Results and discussion

The sentence completions were coded for the use of the verb sense and the structural choice. The sense of the verb was judged on the basis of the overall meaning of the sentence completion (the senses corresponded to a DO-sense or an SC-sense as established in WordNet). The percentage of sentence completions that used the target verb sense and the SC- and DO- argument structure was calculated (for an overview of these see the second row in Table 8.2). The results showed that the DO sense was mostly used following a DO-biasing context (92.45%), and the SC sense was used in the majority of cases following a SC-biasing context (95.17%). This showed that the context-biasing sentences performed well in creating a semantic scenario and activating one of the verb senses. Results from this norming study and results from the out-of-context norming study mentioned above differed largely (Hare et al., 2003). The difference can be seen by comparing the data in the first row with the data in the second row in Table 8.2. All norming results for individual verbs are presented in Appendix C.2.

Second, the argument structure uses were classified. For each of the target senses, the structure was classified as DO, SC or other. This analysis showed that the percentage of SC sentence completions was greater than the percentage of DO completions when the verb was used in the SC-sense (SC-structure: 81.77% vs. DO-structure: 14.63%). The percentage of DO sentence completions was greater than the percentage of SC completions when the verb was used in the DO-sense (DO-structure: 99.39% vs. SC-structure: 0.29%). This demonstrates that when verbs are used in the SC-sense, they prefer an SC-structure, and when they are used in the DO-sense, they prefer a DO-structure. However, it also shows that when the verb is used in the SC-sense, a DO-structure is generally possible. This was previously established by the out-of-context norms by Hare and colleagues who found that even when the verb is used in the SC-sense, the DO-structure was used in about a third of occasions. This may reflect the overall tendency for verb + DO in the English language.

8.1.2. Norming study 2 – completions from the NP in context

The second norming study was also a completion study. It contained the same context sentences as the first one, but the sentence fragment included the post-verbal noun phrase. The aim was to establish whether the noun phrase influenced the sense of the verb and the argument structure frequencies that were established in the first norming study. Ideally, the sentence fragments including the noun phrase should not lead to different sentence completions than the first norming study, because the noun phrases were developed to be plausible for either sense or structure of the verb.

Methods

Participants

As in norming study 1, healthy participants who did not take part in the eye tracking experiment completed the norming study online (*N* = 57). The age range of the participants was 22-70 (*M* = 40.62). Forty-four were female and twelve were male, one did not to say. Two out of these were not native speakers of English, but spoke English from an early age, and used English as their main language.

Materials and procedure

The sentences were the same as in the first experiment, but included the post-verbal NP. For example, participants saw sentences such as:

> *List A*
> *SC biasing context (sense: DISCOVER)*
> The students hated having to read the textbook on biology.
> They found the book ____
>
> *List B*
> *DO biasing context (sense: REGAIN)*
> Susan and her friends had been searching for the book nearly everywhere, but they were successful in the end.
> They found the book ____

The lists and filler items were the same as in the first norming study. Also the procedure was identical to the first norming study. Thirty-two participants completed list A, and twenty-five completed list B.

Results and discussion

The results of this norming study can be seen in the third row of Table 8.2, showing the use of the SC/DO-sense and structures per verb (+NP) in percentage. The data in Table 8.2 demonstrate that adding a noun phrase has not significantly reduced the biasing effects of the context. The verb senses are still, overwhelmingly, consistent with the context, as are the structures chosen to complete the sentences. None of the numerical changes between the verb alone and the verb + NP conditions are significant. Results from these two norming studies revealed very similar results to those from Hare and colleagues. As already shown by a corpus analysis and a series of norming studies in this original work (in American English), there are reliable associations between verb sense and argument structure frequencies in the verbs studied here. Even though most of the sentences here were altered to make them more accessible for people with aphasia, the context sentences can bias a particular verb sense and its associated argument structure.

Table 8.2. Use of DO- and SC-sense and structure of verbs in sentence completions (comparing results from the verb without a context, context with verb, and context with verb and NP)

Norming experiment verb without context (from Hare et al., 2003)						
	% Use of SC sense	% SC structure	% DO structure	% Use of DO sense	% SC structure	% DO structure
Verb, no context	41.00	54.00	32.00	52.00	100	85.00
Norming experiments verb with context						
	SC-biased context			**DO-biased context**		
	% Use of SC sense	% SC structure	% DO structure	% Use of DO sense	% SC structure	% DO structure
Context + verb	95.17	81.77	14.63	92.45	0.29	99.39
Context + verb + NP	84.79	87.80	2.94	96.67	4.79	95.19

8.2. Stimulus development – filler sentences and comprehension questions

Filler sentences

Thirty filler sentences were employed to make sure that participants did not guess the nature of the task and form predictions or expectations about the sentences. Another reason for the filler sentences was to achieve a mixture of sentence structures. Since all target sentences are in a SC-structure, participants could learn to expect these structures. Hence, the filler sentences were of different syntactic structures. Fillers were designed to be similar to the 20 experimental sentences. They also included verbs that could occur in both DO- and SC-sentence frame, but in contrast to the experimental sentences, they occurred in a DO-structure. Hence there was the same number of SC and DO sentences within the sets of stimuli, ensuring that readers did not develop anticipations for either structure apart from those generated from the context biases. Out of these 20 filler sentences (and their context biases), some verbs were DO-biased, some SC-biased, and some had equal or no bias. Ten further sentences employed completely different structures; these were taken from the original experiment by Hare and colleagues. The contexts for the filler verb sentences never included any test verbs. There were six practice trials, which included neither a target verb nor a SC structure.

Comprehension questions

Yes/no-comprehension questions were developed to guarantee that participants were reading the experimental sentences for comprehension, and to analyse comprehension accuracy. The questions were designed to be simple and to avoid ambiguity. The questions for the ambiguous and non-ambiguous sentences were the same as these sentences only differed with respect to the presence or absence of the complementiser. The questions differed for both contexts since the participants would otherwise read the same question four times. However, the questions were designed to be as similar as possible. For each verb, one context condition was paired with a *yes*-question, and the other context condition with a *no*-question. This was alternated over the verbs so that the DO- and SC-context conditions had the same number of *yes*-, and *no*-questions. Examples are presented in Table 8.1 above. The comprehension questions were read by a female native speaker of British English. All sentences were read with a natural intonation, and the speaker was blind to the answers of the questions. The comprehension questions were recorded in a soundproof room using a standard voice recorder.

8.2.1. Norming study – comprehension questions

In the third norming study, the comprehension questions were normed to guarantee that the level of difficulty is even across all four conditions. Participants were given *yes/no*-comprehension questions for the target sentences, and were further asked to rate the difficulty of each question on a scale from one to seven.

Methods

Participants

As in the other norming studies, healthy participants who did not take part in the eye tracking experiment completed this norming study online (*N* = 28). The age range was 25-64 (*M* = 34.5). Twenty-one were male and seven were female. There was only one participant who was not a native speaker of British English but started to speak English as their main language from a young age.

Materials and procedure

This norming study employed both the context and the target sentences. Again two lists were created. Each list contained the ambiguous and the non-ambiguous target sentence in a different context. Hence, each context condition was only read once, and the target verb was read twice, once in the ambiguous and once in the non-ambiguous condition. The comprehension questions for the context conditions were different, but alternated across the verbs so that there was the same number of *yes*- and *no*-questions for each context condition. Fifteen respondents completed list A, and 13 completed list B. The sentences were randomised. As in the other norming studies, the online platform *Sosci Survey* was used. The norming participants were given the sentence and were asked to read it, and subsequently, answer a *yes/no*-question. After this, they were asked to rate (scale 1-7) the difficulty of the question. One meant that the question was very easy and seven meant that it was very difficult. Consider this example for the verb *find*:

List A

SC biasing context (sense: DISCOVER)

The students hated having to read the textbook on biology because it was boring.

They found that the book was written poorly and difficult to understand.

Was the book easy to understand? (no)

DO biasing context (sense: REGAIN)

Susan and her friends had been searching for the book nearly everywhere, but they were successful in the end.

They found the book was written poorly and regretted searching for it.

Was the book written poorly? (yes)

List B

SC biasing context (sense: DISCOVER)

The students hated having to read the textbook on biology because it was boring.

They found the book was written poorly and difficult to understand.

Was the book easy to understand? (no)

DO biasing context (sense: REGAIN)

Susan and her friends had been searching for the book everywhere, but they were successful in the end.

They found that the book was written poorly and regretted searching for it.

Was the book written poorly? (yes)

Results and discussion

The criteria for a successful comprehension question were a maximum number of errors of 2, and an average mean rating level of 2. Hence, if a question attracted more than two incorrect answers, or a mean difficulty above, 2, the comprehension question was altered for simplification. Overall, there were two verbs for which comprehension questions led to three errors, and three different verbs for which the mean rating was 3. These questions were adapted to make them easier/less ambiguous. Table 8.3 shows the mean difficulty ratings for the different conditions. There were no significant differences between the difficulty ratings of these conditions.

Table 8.3 Mean difficulty ratings of the four conditions

Condition	**Mean difficulty rating**
SC-bias non-ambiguous	2.08
SC-bias ambiguous	2.31
DO-bias non-ambiguous	2.44
DO-bias ambiguous	2.23

Note. The scale was 1-7, with 1=easy; 7=difficult

8.3. Design of Experiment 2

The experiment consisted of 10 verbs in four conditions, and thus 40 experimental sentences of which 20 were ambiguous and 20 were non-ambiguous. Prior to the target sentences there were 20 context sentences, which occurred twice. Overall there were 40 trials that consisted of one context and one target sentence. The context and target sentences were rotated across two lists. For each verb, one list contained the non-ambiguous SC-biasing context as well as the ambiguous DO-biasing context, and the other list contained the ambiguous SC-biasing context and the non-ambiguous DO-biasing context. The conditions were counterbalanced across the lists, and tested in two separate sessions. This design guaranteed that each participant read only one context-bias per list. However, this also meant that each target verb was read twice per list. This choice was made to limit the eye tracking procedures to two sessions. It would have been difficult for many participants to travel to the university for four separate eye-tracking sessions. The 20 experimental trials per session were mixed with 30 filler sentences per session. Further, there were six practice trials, which included neither a target verb nor a SC-structure. Each trial was followed by a question aiming a *yes/no*-response in order to test comprehension of the sentences and to gain off-line measurements of accuracy.

8.4. Summary

This chapter described how the experimental material was designed for Experiment 2. The experimental design is adapted from a study in the healthy population (Hare et al., 2003). A subset of ten verbs was taken from the original work. Context biasing sentences and target sentences were adapted for the purpose of this study. Subsequently, a series of norming studies was carried out to test whether the assumed associations between verb sense and argument structure frequencies can be found in the developed material. Norming studies confirmed that the context biases influenced the interpretations of the verb sense, resulting in sense-contingent argument structure frequencies. The post-verbal noun phrases were shown to not alter these associations greatly and are hence not a confound in this study. Finally, a norming study tested the difficulty of the developed comprehension questions. This revealed that a small number of questions were more difficult than others, and these were consequently simplified. Subsequently, there were no differences regarding the difficulty of comprehension questions amongst the four conditions. Overall, this chapter demonstrates that the material for Experiment 2 was developed and tested thoroughly to render it suitable for people with aphasia, and to guarantee that the experimental manipulation was successful. Chapter 9 will present the methods and results of Experiment 2.

Chapter 9. Experiment 2. The influence of context-cued argument structure frequencies on ambiguity resolution in aphasia

9.1. Introduction

The first experiment of this thesis explored whether the frequency and the predictability of a word in a sentence context influence eye movements during the reading of syntactically simple sentences. Both individuals with aphasia and neurologically healthy individuals showed shorter fixation durations on frequent and predictable words than on infrequent and unpredictable words. However, the people with aphasia relied more on the sentence context than the control group. On the basis of the interactive compensatory processing theory (Stanovich, 1986) this reliance on top-down processing was interpreted as a compensation for poor bottom-up skills. Further, results revealed that word frequency and context effects were independent for the neurologically healthy individuals whereas they were more interactive for the individuals with aphasia. This further supports theories of interactive compensatory processing suggesting that there is more interaction between different stages of processing in the aphasia group, and that bottom-up factors can also facilitate top-down processes. However, since the observations were not significant after correcting for multiple analyses and the participant groups were small, more research in this area is needed before it is possible to make conclusive statements.

In summary, the first experiment established that eye tracking is a beneficial tool to assess silent reading by people with aphasia, and can reveal mild to moderate reading impairments. It demonstrated that probabilistic factors of a noun (the frequency of a noun as well as the context it can be used in) can facilitate the comprehension of that noun in a sentence. The second experiment advances from this, and investigates whether probabilistic factors of verbs can facilitate the reading of structurally ambiguous sentences. This will demonstrate whether the facilitation observed in Experiment 1 is purely limited to lexical access and integration, or whether facilitation from frequency and context factors go beyond this, influencing reading at a structural/syntactic level.

The remainder of this introduction will summarise the research on context-cued argument structure frequency (9.1.1), and will focus on a more detailed description of the aims and research question of this experiment (9.1.2). The methods section (9.2) introduces the aphasia group and the group of neurologically healthy individuals who participated in this experiment. The procedures will be explained, and an overview of the statistical analyses will be given. The results section (9.3) divides the results into global characteristics of the data, accuracy results, and finally, the results from the eye movement analysis. It also provides an analysis of individual data. The discussion (9.4) will relate the findings from this experiment to previous research, and refer to theoretical accounts that were introduced in Chapter 3.

9.1.1. Summary of previous research

The research aim of this experiment originates from observations that healthy readers are sensitive to sense-based argument structures when they read temporarily ambiguous sentences (Hare et al. 2003). As found during a self-paced reading study, healthy readers can use a sentence context to prime a particular sense of the verb and hence develop expectations about argument structure. So, for example, context might prime the abstract meaning of the verb *find* (to realise something mentally) and hence the SC argument structure. This shows that readers are sensitive to sense-based structures and hence strong associations between form and meaning. So far it has not been studied whether individuals with aphasia may also be sensitive to such form and meaning associations. It is also not known whether a context sentence can create a cue towards a verb sense in the aphasia group.

Research on sentence comprehension in aphasia suggests that individuals with aphasia can be sensitive to probabilistic factors such as argument structure frequency. This is in line with research showing an influence of argument structure frequencies on sentence processing in the healthy population. As mentioned before, one study has shown that people with aphasia can employ argument structure frequencies during the processing of sentences in the DO/SC ambiguity (DeDe, 2013a). However, PWA relied more on the probabilistic factor than on the presence of the complementiser – even though this is the more reliable cue in these sentences and this is the cue that the control group relied on. Hence this study suggested that individuals with aphasia differ from the control group in the use of cues or constraints when they resolve temporarily ambiguous sentences. Based on this research it may be expected that people with aphasia and neurologically healthy individuals differ in their sensitivity to some cues in the processing of ambiguous sentences. In order to shed more light on this issue, this experiment uses eye tracking to investigate the DO/SC ambiguity.

9.1.2. Aims of the experiment

This experiment examines whether readers with aphasia use the knowledge of a verb's sense-based argument structure frequency to resolve structural ambiguities online. Replicating the study design of the experiment described by Hare and colleagues (2003), sentences are presented following a context that biases either a direct object (DO-bias) or sentence complement (SC-bias) reading of the verb. Hence sense-based argument structure frequencies of the verb are cued by a context sentence. All target sentences contain a sentence complement structure (e.g. *The woman* ***saw*** *(that)* <u>*the traffic lights*</u> *were red*). Half of the stimuli sentences do not contain *that* and are structurally ambiguous. The target sentences contain half of the verbs used in the study by Hare and colleagues, and the sentences are either newly constructed or simplifications of the original study (see Chapter 8 on the development of the materials and the underlying norming studies). In summary, two cues are manipulated in this experiment: context and ambiguity.

If this experiment shows results of a verb's sense congruent argument structure frequency on sentence comprehension in aphasia (context effect), it will show that people with aphasia remain sensitive to statistical properties in their language, and that they can access associations between meaning and structure. Such a finding will not only support theories claiming that processing can be mediated lexically (MacDonald et al., 1994), but also suggest that the language system encodes strong links between the meanings of verbs and their syntactic structures (Seidenberg & MacDonald, 1999). If we find an effect of sense contingent argument structure frequency on sentence comprehension in aphasia, it will support the argument that syntactic processing is linked to lexical-semantic factors. In general, this result will add to the relevance of researching usage-based factors in sentence comprehension in aphasia. On a more general level, the experiment can also show whether PWA can be cued for understanding abstract verb meanings. The experimental sentences all contain sentence complement structures using an abstract sense of the target words.

If the experiment shows an ambiguity effect, it will present when readers find sentences without the presence of the complementiser *that* more difficult to read than sentences with the presence of *that*. If we find such an effect, it will indicate that individuals with aphasia can (i) access the word, and (ii) it will show that including *that* facilitates reading. If an ambiguity effect reveals in an early eye movement measure, it will indicate that people with aphasia are sensitive to the syntactic marker *that* during the early stage of sentence processing. If an ambiguity effect is on the other hand shown in a late eye movement measure, it will indicate that people with aphasia may have difficulties in using *that* as a cue in the early analysis stage.

Turning to context, if we find an early effect of the context manipulation it will suggest that people with aphasia use the context to form expectations regarding the upcoming sentence structure. A late effect will indicate that the readers are drawing on the context during the re-reading stage. This may point to slowed processing.

An interaction of the context cue and ambiguity will indicate that individuals with aphasia can exploit both cues, and can integrate them during the same stage of processing. If the factors are not interactive, the cues cannot be integrated successfully.

If there are differences in the effects between the PWA and the NHI, investigating individual patterns regarding the sentence manipulations is essential. It might show whether certain underlying language impairment are responsible for the effects or lack of effects respectively.

As mentioned previously, there is also reason to believe that individuals with aphasia are not sensitive to these probabilistic features of verb representations. The sentence structures tested in this experiment are more complex than the ones used in Experiment 1. If the people with aphasia have lexical-semantic impairment, this may lead to facilitation in using frequent form-meaning associations, but if the impairment is too severe, then it may be impossible for individuals to access the frequent associations stored within lexical representations.

Research Questions

The first research question is whether NHI and PWA show an influence of a verb's sense-based argument structure frequency (measured as context effect) and the influence of the presence or absence of the complementiser *that* (measured as ambiguity effect) on the reading of structural ambiguities. If effects arise, follow-up questions concern the time course of those effects, and whether factors are independent or interactive.

In line with previous research it is anticipated that the NHI are sensitive towards the sense-based verb bias (Hare et al., 2003) as well as towards the complementiser *that* (Garnsey et al., 1997; Hare et al., 2003; Trueswell et al., 1993). More specifically, it is expected that they would show most sensitivity to the sense-based verb bias if the sentences are ambiguous (Hare et al., 2003). This would mean that they do not exploit the sense-based argument structure frequency if the sentence is non-ambiguous, but that they do in the case of ambiguity, hence showing interaction between the two factors. This would mean that they can combine and integrate both cues. Such a result would be shown by extended fixation durations in the DO-bias ambiguous condition compared to shorter and relatively similar fixation durations in the DO-bias non-ambiguous and the SC-bias conditions. In the DO-bias ambiguous condition, the context bias leads to the expectation of a DO-structure, and there is no *that* to counter this expectation. As a result, expectations are at odds with the target sentence. Regarding the time course, predictions are that the NHI reveal an influence of the experimental sentences at an early stage of processing as suggested by constraint-based theories. This would show by effects on first pass reading measures.

Predictions for the aphasia group are as follows. A general sense-independent verb bias effect has been demonstrated before in aphasia and in the reading of temporarily ambiguous sentences (DeDe, 2013a). Further, the first experiment of this thesis showed a strong influence of context on eye movements by people with aphasia. Hence it is expected that PWA are – equally to NHI - sensitive to the sense-based verb bias. Since most participants with aphasia in this experiment have a mild type of aphasia, it is also expected that they show at least some sensitivity to the presence or absence of the complementiser *that* and hence the ambiguity manipulation. These predictions would be reflected by longer fixation durations in the DO-bias than in the SC-bias condition, and longer fixation durations in the ambiguous compared to the non-ambiguous condition. However, since a recent study on ambiguity resolution in reading by people with aphasia found that verb bias is a stronger cue for PWA than the complementiser (DeDe, 2013a), it is expected that PWA are less sensitive to *that* in comparison to the context-bias. This would be shown by a larger context effect size compared to the ambiguity effect size. This would suggest that PWA and NHI show differences in terms of how the factors can be accessed during sentence comprehension. Another expected difference between the groups relates to the question whether effects may show an independent or interactive pattern. Whereas an interaction between the context and the ambiguity effect is expected for the control group, no such interaction is expected for the participants with aphasia. This is because an interaction presupposes parallel processing of both factors, leading to higher processing demands. Further an interaction would imply that both factors are integrated successfully. Given the research on processing limitations in aphasia, it can be expected that this would lead to difficulties.

Finally, since it may take the PWA more effort and more time to read and understand the sentences, it is predicted that effects from the context and the ambiguity manipulation would be shown later than in the NHI group. Hence, later eye movement measures like total fixation durations may reveal the effects from the aphasia group whilst both early and late measurements show effects for the NHI. This assumption is also consistent with many eye tracking studies carried out in listening paradigms. These indicate that lexical processing is slowed in aphasia, reflected in a delay of eye movements compared to control participants (Hanne et al., 2011; Meyer et al., 2012).

The second research question is whether the PWA show any individual differences in terms of ambiguity and context effects, and if yes, whether these can be related to their underlying language profile. In order to answer this research question, individual effects are correlated with the PWA's results from the language background assessments.

First, it may be expected that the extent of disruption in the ambiguous sentences and in the DO-bias sentences is dependent on the individual's lexical or semantic processing impairment. This assumption is consistent with research in psycholinguistics which revealed that readers with better vocabulary knowledge were less disrupted when the verb bias in the sentence was inconsistent with the target sentence structure in the DO/SC ambiguity (Traxler 2007). Traxler argued that better lexical knowledge could imply that lexical representations have stronger connections between entries of verbs and their less frequent argument structures. Since this experiment focuses on sense-based verb bias, it can be expected that both lexical and semantic knowledge are needed to access the cues. Predictions were that better lexical-semantic processing is associated with smaller context effects.

With respect of the ambiguity bias it is predicted that PWA who have no impairments at the lexical level should show the same ambiguity bias as the NHI. However, if they have lexical impairments they may not show an effect of ambiguity as they may have difficulties accessing the complementiser, particularly as it is a closed class word (DeDe, 2013a). This would be consistent with the finding of a reduced effect of ambiguity for readers with aphasia (DeDe, 2013a).

Further, predictions are that the susceptibility to context-cued argument structure frequencies is dependent on working memory skills. This is again based on research in the healthy population showing that readers with a large reading span are better in accessing probabilistic cues than readers with low reading spans (MacDonald et al., 1994). Particularly the presence of the context bias may induce working memory skills in the second experiment. Hence we predicted that there will be a positive correlation between working memory abilities and the effect of the context bias.

9.2. Methods

This study obtained ethical approval from the School of Community and Health Sciences Research Ethics Committee, City University London. All participants gave informed consent before being any of the study procedures commenced. This experiment used a reading whilst eye tracking paradigm to investigate the influence of context-cued subcategorisation probabilities on ambiguity resolution in NHI and PWA. The stimuli sentences were developed through a range of norming studies. As these were described in detail in Chapter 8, they will not be repeated here.

9.2.1. Participants

Eleven people with aphasia (8 women, 3 men, *mean* age = 55.55 (SD= 8.95), *range* = 41-71) and eleven neurologically healthy participants (5 women, 6 men, *mean* age = 51.82 (*SD* = 12.06), *range* = 36-71) completed this experiment. Ten of the eleven PWA, and five of eleven out of the NHI had also taken part in the first experiment. For both groups, the recruitment, the inclusion criteria and the administered screening assessments were the same as described in Chapter 7.2.2.

All people with aphasia were native speakers of English, had a single left hemisphere stroke, were at least 6 months post-stroke, and presented without evidence of visual (-spatial) impairment (e.g. glaucoma, visual field impairment, or visual neglect). Their aphasia was mild or moderate; they did not have any other neurological impairment, no history of developmental dyslexia, and no cognitive impairment such as dementia. All were right-handed. The participants were given an information sheet that explained the details of the experiment in an accessible manner. Consent was elicited when the participants had no further questions and volunteered to take part. All background language assessments were carried out at the participant's home or at City University London. The demographic information is shown in Table 9.1.

The neurologically healthy participants were all native speakers of English, had no history of neurological impairment, no history of speech/language impairment or reading difficulties such as developmental dyslexia. Further, they had age-appropriate cognitive functioning as assessed by the Mini-Mental State Examination (MMSE-2) (Folstein et al., 2010). They had no visual (-spatial) impairments. All participants were right-handed. The control group was given an information sheet explaining the experiment, and participants had time to ask questions. After the information process, consent was elicited. Table 9.1 presents an overview of the demographic information. The NHI did not differ from the PWA in terms of age (U = 49.00, z = - 0.76, p = .45, r = .16) or level of education (U = 44.00, z = -1.11, p = .27, r = .02).

9.2.2. Background assessments PWA

Participants completed a range of background language assessments. This was to understand the language profile of the individual participants, and to investigate whether certain underlying language impairments are associated with an influence of the context-cued argument structure frequencies or an influence of the structural ambiguity. This will be explained in the individual analysis (see section 9.3.4). For a detailed description of all assessments see Chapter 7. The results from the background language assessments are presented in Table 9.2-9.5. In order to achieve a summary on different aspects of language, composite scores were calculated by taking the straight average of scores from the subtests. All composite scores are shaded in grey.

Individual and mean scores on the Western Aphasia Battery - Revised (Kertesz, 2007) are shown in Table 9.2. The **Aphasia Quotient** shows that nine of the eleven participants had a mild type of aphasia, and two moderate. The most widely represented syndrome was Anomic aphasia, two had Conduction aphasia, and one participant Broca's aphasia.

Table 9.3. summarises the participants' lexical-semantic scores. The **semantics overall** score comprises the mean result of the non-verbal semantic test from the Comprehensive Aphasia Test (Swinburn et al., 2004), the written synonyms score, and the written word to picture matching score, the latter taken

from the Psycholinguistic Assessments of Language Processing in Aphasia (Kay et al., 1997). Overall, the participants scored close to ceiling in semantic tasks, with a range of 93%-99%. Scores from the more challenging synonym test show that some individuals had slightly more difficulties than others, with a range between 78% and 98%. A **lexical-semantics written comprehension** score was calculated to gain a composite score that only includes written tests. It presents the mean of the visual lexical decision and the written word to picture matching test. Again, this shows a close to ceiling performance of 95% overall, with the lowest score being 84% and the highest 100%. The **lexical-semantics overall** score represents the average of the lexical-semantics written comprehension score and the noun and verb naming scores taken from the PALPA, and had a mean of 90%.

Table 9.4. presents the participants' scores of written sentence comprehension as well as working memory. The **sentence overall** score is the average of the sentence to picture matching test (PALPA, Kay, Lesser, & Coltheart, 1997) and the canonical and non-canonical sentence comprehension score from the Verb and Sentence Test (VAST, Bastiaanse, Edwards, & Rispens, 2002). The mean is 85% with a range of 70-96%. There was a difference in performance between the comprehension of canonical (M =95%) and non-canonical (M = 71%) sentences (z = -2.94, p = .003). Some of the participants had severe difficulties understanding the non-canonical structures, with a range of 35-90%. This suggests that even though many participants in this study were classified as having Anomic aphasia, many (particularly ID 1, 3, 4, 7, 9, 11) show typical symptoms of agrammatism, i.e. difficulties with the comprehension of sentences involving structural movement.

The working memory (WM) score from the Wechsler Memory Scale (Wechsler, 1997) in Table 9.4 represent the average of the **WM digit forward** and **WM digit backward** span as well as the **WM sentence span** task. The people with aphasia had a mean score of 5 for the forward span, 3.55 for the backward span (forward norm[29]: M = 5.98, SD = 1.12; backward: M = 4.30, SD = 1.11), and 4.36 for the sentence span.

Finally, Table 9.5. summarises the scores on each individual's rating of reading confidence and emotions towards reading before and after stroke, using the Reading Confidence and Emotions Questionnaire (RCEQ) (Cocks et al., 2013).

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[29] Norms are from the manual of the Wechsler Memory Scale (Wechsler, 1997) and are based on a group of healthy participants (N = 46) within the age group of 40–49.

Reading pleasure before stroke had a mean score of 94%, and **Reading pleasure after stroke** 45%.

Overall, the background assessments show that the people with aphasia were mildly affected by their aphasia. On average the group shows good lexical semantic skills but somewhat more pronounced impairments in written comprehension at the sentence level, particularly with respect to non-canonical sentence types. These mild impairments seem to have a profound impact on reading pleasure and confidence, as shown in the RCEQ. Further, the group has mildly compromised working memory skills.

As outlined in Chapter 7, all participants with aphasia were tested for the presence and type of acquired dyslexia. This was to gain more background information about the type of reading difficulties in the group of participants. The overview of the acquired dyslexia profile is located in the Appendix C.1.

9.2.3. Background assessments NHI

As in the first experiment, the participants from the NHI group completed a questionnaire on their personal details, and their medical history. This was to ensure that they fulfilled the in-/ exclusion criteria (e.g. no history of developmental dyslexia, no neurological impairment, no speech or language impairments, no visual difficulties).

Further, the control participants were screened with the Mini-Mental State Examination, 2nd Edition Standard Version (MMSE-2: SV, Folstein, Folstein, White, & Messer, 2010) to obtain an overall summary of their cognitive ability. The scores of the MMSE are presented in Table 9.1. Participants had to score within one standard deviation from the mean score of their age group and education level from the MMSE-2 data. The control participants experienced no difficulties in the test (*M* = 29.73, *SD* = 0.65, *range*: 28-30/30).

Table 9.1. Demographic information for participants

Group	**ID overall**	**ID (group)**	**Gender m/f**	**Age**	**Handedness left/right**	**Years.Months post Onset**	**Aetiology (all left hemisphere)**	**MMSE**[a]	**Education (Group)**[b]
NHI	1	1	m	51	right	n.a.	n.a.	29	A levels/Project Management Qualifications (3)
NHI	2	2	f	54	right	n.a.	n.a.	30	Master's (6)
NHI	3	3	m	41	right	n.a.	n.a.	30	Bachelor's (5)
NHI	4	4	m	39	right	n.a.	n.a.	30	Master's (6)
NHI	16	5	m	36	right	n.a.	n.a.	30	Master's (6)
NHI	5	6	f	55	right	n.a.	n.a.	28	A levels (3)
NHI	6	7	f	65	right	n.a.	n.a.	30	Bachelor's (5)
NHI	7	8	m	53	right	n.a.	n.a.	30	Bachelor's (5)
NHI	8	9	f	71	right	n.a.	n.a.	30	Master's (6)
NHI	9	10	f	66	right	n.a.	n.a.	30	Diploma (4)
NHI	10	11	m	39	right	n.a.	n.a.	30	Master's (6)
Mean				51.82				29.73	5.0
PWA	11	1	f	62	right	14.6	CVA, ischemic	n.a.	Master's (6)
PWA	12	2	f	50	right	16	CVA, left MCA infarct	n.a.	No formal (1)
PWA	13	3	f	52	right	2.6	CVA, parietal infarct	n.a.	Apprenticeship (NVQ as carer) (3)

PWA	14	4	f	65	right	1.11	CVA, MCA infarct	n.a.	GCSE (2)
PWA	15	5	m	47	right	9	CVA, secondary haemorrhage, left frontal parietal craniotomy performed	n.a.	Diploma in shipping (4)
PWA	16	6	f	41	right	5.1	CVA, post central left parietal lobe	n.a.	Apprenticeship (City & Guilds in Mechanic) (3)
PWA	17	7	f	55	right	16.5	CVA, MCA infarct, left carotid dissection leading to stroke	n.a.	Bachelor's (5)
PWA	18	8	f	47	right	2.5	CVA, MCA infarct	n.a.	PhD (7)
PWA	19	9	m	71	right	8.3	CVA	n.a.	Diploma (4)
PWA	20	10	m	66	right	3.8	CVA	n.a.	Bachelor's (5)
PWA	21	11	f	55	right	5.4	CVA, large insular infarct with small area of haemorrhagic transformation	n.a.	Master's (6)
Mean	n.a.	n.a.	n.a.	55.55	n.a.	7.72	n.a.		4.18

[a]MMSE=Mini-Mental-State Examination [b]Education groups: (1) no formal, (2) GCSE, (3) A levels/Apprenticeship, (4) Diploma/College Degree, (5) Bachelor's Degree, (6) Master's Degree, (7) Doctoral Degree

Table 9.2. Individual (and mean) scores on the Western Aphasia Battery-Revised

PWA ID	**Spontaneous Speech (max=20)**	**Auditory Comprehen-sion (max=10)**	**Repetition (max=10)**	**Naming (max= 10)**	**Aphasia Quotient (max= 100)**	**WAB Subtype (Clinical Picture)**	**Aphasia Severity**
1	17	10	8.2	9.5	89.4	Anomic	mild
2	12	5.95	6	8.9	65.7	Broca	moderate
3	15	7.95	4.8	7	69.5	Conduction	moderate
4	18	9.15	7.2	7.1	82.9	Anomic	mild
5	17	9.9	9	9.1	90	Anomic	mild
6	17	10	9.3	9.5	91.6	Anomic	mild
7	14	8.7	6.4	9.2	76.6	Conduction (Broca)[a]	mild
8	17	10	9.6	8.7	90.6	Anomic	mild
9	19	9.95	9.1	8.9	93.9	Anomic	mild
10	14	9.8	8.6	9	82.8	Anomic	mild
11	15	9.4	9.2	8.5	84.2	Anomic (Broca)[b]	mild
Mean	15.91	9.16	7.95	8.67	83.38	na	na

[a/b] ID 7 and ID 11 were classified as Conduction/Anomic, but presented the clinical picture of Broca's aphasia. This was supported by their comprehension advantage of canonical over non-canonical sentences as shown in Table 9.4.

Table 9.3. Individual (and mean) scores on semantic and lexical processing (all in %)

PWA ID	Nonverbal semantics (CAT)	Synonyms (PALPA)	Word - picture matching (PALPA)	Semantics overall	Visual lexical decision (PALPA)	Lexical-semantics written comprehension	Naming nouns (VAST)	Naming verbs (VAST)	Lexical Production (VAST)	Lexical-semantics overall
1	1.00	0.98	1.00	0.99	1.00	1.00	0.95	0.79	0.87	0.93
2	1.00	0.78	0.93	0.90	0.91	0.92	0.87	0.68	0.77	0.85
3	1.00	0.97	0.95	0.97	0.93	0.94	0.83	0.68	0.76	0.85
4	1.00	0.85	0.98	0.94	0.87	0.93	0.92	0.65	0.78	0.85
5	1.00	0.88	1.00	0.96	0.93	0.97	1.00	0.91	0.95	0.96
6	1.00	0.90	0.98	0.96	0.89	0.94	1.00	0.98	0.99	0.96
7	1.00	0.83	1.00	0.94	1.00	1.00	0.95	0.65	0.80	0.90
8	1.00	0.92	0.98	0.97	0.94	0.96	0.95	0.80	0.88	0.92
9	1.00	0.92	0.93	0.95	0.99	0.96	0.93	0.80	0.87	0.91
10	1.00	0.98	1.00	0.99	1.00	1.00	0.98	0.95	0.97	0.98
11	1.00	0.87	0.93	0.93	0.74	0.84	0.85	0.71	0.78	0.81
Mean	1.00	0.90	0.97	0.96	0.93	0.95	0.93	0.78	0.85	0.90

Table 9.4. Individual scores on sentence comprehension (in %) and working memory (digit score)

PWA ID	**Sentence-picture matching (PALPA)**	**Total canonical (VAST)**	**Total non-canonical (VAST)**	**Sentence overall**	**WM digit forward (Wechsler)**	**WM digit backward (Wechsler)**	**WM sentence span (based on Caspari et al., 1998)**
1	0.88	1.00	0.65	0.85	5	5	4.0
2	0.73	0.85	0.80	0.78	4	4	3.5
3	0.85	0.85	0.65	0.80	2	3	5.5
4	0.75	0.90	0.40	0.70	4	3	2.5
5	0.95	1.00	0.90	0.95	4	3	4.5
6	0.98	0.95	0.85	0.94	5	3	6.0
7	0.77	0.95	0.75	0.81	4	3	4.0
8	0.97	1.00	0.90	0.96	7	4	4.5
9	0.87	1.00	0.70	0.86	7	5	5.0
10	0.90	0.95	0.90	0.91	5	3	6.0
11	0.83	0.95	0.35	0.74	8	3	2.5
Mean	0.86	0.95	0.71	0.85	5	3.55	4.36

Table 9.5. Reading Confidence and Emotions Questionnaire

PWA ID	Reading confidence before stroke	Reading confidence after stroke	Reading pleasure before stroke	Reading pleasure after stroke	Reading negative emotions after stroke
1	1.00	0.33	1.00	0.40	0.92
2	1.00	0.23	1.00	0.50	0.25
3	0.80	0.28	0.80	0.40	0.40
4	0.65	0.47	0.60	0.20	0.80
5	0.90	0.78	0.90	0.70	0.38
6	0.65	0.33	1.00	0.40	0.55
7	1.00	0.33	1.00	0.20	0.68
8	1.00	0.32	1.00	0.30	0.57
9	1.00	0.80	1.00	1.00	0.17
10	1.00	0.40	1.00	0.40	0.60
11	1.00	0.49	1.00	0.50	0.82
Mean	0.91	0.43	0.94	0.45	0.56

Note. The scores relate to the proportion of scores on a scale between 1 (“not confident at all”) – 10 (“completely confident”) out of the maximum score

9.2.4. Procedures

Apparatus and Set-up

An EyeLink 1000 video-based eye tracker (SR-Research) was used. The set-up was the same as in the first experiment (see Chapter 7). Eye tracking was binocular at a sampling rate of 500 hz, which means that the position of the eye was measured 500 times per second. If participants experienced problems with one eye, tracking was done with the better eye. The viewing distance was 89cm. The sentences were presented in black Arial 14 point font. The visual angle of a letter was 0.3°.

Procedure

The stimuli sentences were tested in two different lists and thus in two sessions with a minimum of seven days between testing of the first and the second list. Participants read each context condition only once per list and session. The presentation of the lists was counterbalanced across the participants and the order of sentences was pseudo-randomised. Experimental sentences were interspersed with filler sentences and a maximum of two experimental sentences were adjacent to each other. All eye tracking sessions took place at City University London. The participants were told that the experiment is about reading comprehension, comparing unimpaired reading to reading with aphasia after stroke. When participants sat down in front of the eye tracker, they were told that each trial consisted of three different sets. The first would show a sentence (biasing context sentence), the second one another, related, sentence (target sentence), and the third screen shows a question referring to what they just read. Participants were told to read the sentences silently for comprehension at their own speed. They were instructed to use the gamepad to indicate that they finished reading a sentence, and to record their answer to the comprehension question. The experiment started with a 9-point grid calibration procedure. Participants placed their chin on the chinrest to minimise head movements. The calibration was successful if there was an average error of less than 0.5° and a maximum error of less than 1°. These degrees of visual angle refer to the accuracy, indicating the correspondence between the calculated fixation location and the actual fixation location (Raney et al., 2014). Since the visual angle of a letter was 0.3° it meant that an error of 1° would show the fixations about 3 letters away from its actual place. If this level of tracking accuracy was not achieved, the set up was changed to improve calibration. It was re-calibrated during the experiment when necessary, this was at least once during the experiment. Five practice trials were presented before the experimental trials so that participants could get used to the task. Before each trial, participants had to fixate a central dot on the screen to check the accuracy of the eye gaze track. Each trial started by showing a cross on the left side of the screen in order to direct eye gaze to the place where the sentence started. After reading the first sentence, participants pressed a button on the gamepad and the screen displayed the second sentence. After reading this sentence they pressed the button again to display the comprehension question. The question was presented both visually and via the loudspeakers. The participants had to press the right button on the gamepad to answer “yes”, and the left button to answer “no”. As in the first experiment, buttons that were not used in the experiment were covered so that the gamepad was easier to handle. Also, the gamepad was turned upside down for individuals with a right hemiparesis, this made it easier to use the gamepad with one hand. Participants were given breaks during the eye tracking experiments. The eye tracking session lasted between 30-60min.

9.2.5. Overview of analyses

Conditions

Reading is analysed comparing four conditions. As shown in Table 9.6, there are two different context manipulations (DO-bias and SC-bias), and two conditions in which sentences either include the complementiser *that* (non-ambiguous), or omit the complementiser (ambiguous).

Table 9.6. Example sentence for Experiment 2 in four conditions

Context	Ambiguity	Example
DO-bias		When Billy went to the party he did not know any familiar faces.
	ambiguous	(1) After a while he **recognised** <u>his old friend</u> had adopted a different look and appeared completely different.
	non-ambiguous	(2) After a while he **recognised** that <u>his old friend</u> had adopted a different look and appeared completely different.
SC-bias		Gordon had moved in with his old friend, but they argued a lot.
	ambiguous	(3) After a while he **recognised** <u>his old friend</u> had adopted a different lifestyle and living together would not work out.
	non-ambiguous	(4) After a while he **recognised** that <u>his old friend</u> had adopted a different lifestyle and living together would not work out.

Regions of Interest (areas of interest)

Whereas in Experiment 1 the analysis was carried out for one critical word, in this experiment each sentence was divided into five regions of which three were analysed. Table 9.7 shows an example for the verb *recognise*. Region one, two and three were analysed statistically. The main region of interest is region 2, which is the disambiguating region (*had adopted*). This is the region in which the structure unfolds. Region 1 is the (ambiguous) noun phrase (*his old friend*). This was analysed to investigate whether any early effects occur or whether participants show re-reading patterns in this region. The final region that was analysed is region 3, which is the post-disambiguating area (*a different*). This region may show a delay of the effects, or may equally show a recovery of the garden path effect.

Table 9.7. Example of an experimental sentence with three regions of interest

Region	**1**	**2**	**3**
Sentence	…he *recognised* (that) * his old friend * had adopted * a different * look…		

Note. The asterisks indicate the region breaks and did not appear in the experiment.

Measurements

The offline measurement was accuracy, i.e. number/proportion of questions answered correctly. The questions were designed to make sure that participants were reading all sentences for comprehension, and to obtain a basic measure of the participants' comprehension skills. Another reason was to compare accuracy in both groups. However, the questions were not intended to check parsing abilities.

Global eye movement measurements across all stimuli and analysed for the whole sentence were: number of fixations, average fixation durations, number of blinks as well as blink ratio, and average sentence reading time. These measures were analysed in order to gain an indication of overall sentence reading difficulty.

Eye movement measures for the critical regions were analysed to capture online processing regarding the experimental manipulations, and to investigate the time course of processing. **First fixation duration** (measured in ms) was used to assess the earliest phase of lexical processing. First fixation duration refers to the mean duration of the first fixation on a target region, given that it occurs before any fixations land on words further along in the text. First fixation duration is associated with lexical activation (Rayner, 1998; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006), and is sensitive to word frequency effects (Pickering et al., 2004; Rayner et al., 2004).

Gaze durations were used as another measure of first-pass reading. Whereas first fixation duration refers to the first fixation only, gaze duration refers to the sum of all fixations in first-pass reading within a critical region until a fixation is made to another area, either progressive or regressive to the critical region. Similarly to first fixation durations, gaze durations capture lexical access and show effects of word frequency (Rayner et al., 2004, 2006), but can also reveal processes of lexical integration as measured by predictability effects (Inhoff, 1984). Even though first fixation durations and gaze durations tend to be very similar in their outcome (Rayner, 1998), first fixation durations were additionally included because one of the aims of the experiment was to analyse the time course of processing.

Another measure used was the **probability of a first pass regression** which indicates whether the first fixation following fixation(s) on the target region was regressive relative to the target region or not (provided that the region was not skipped during first-pass reading and provided that the target region had not already been fixated and exited). First pass regressions are associated with early processing as the reader moves the eyes back to an earlier stage in the sentence after the first fixation. First pass regressions have been shown to be sensitive to temporal ambiguities (Traxler & Tooley, 2007).

Finally, **total fixation duration** (or total duration) served as a measure of later cognitive processing. It measures the duration of all fixations within the critical region, both from first-pass and those from re-reading stages, and including regressions to the target region. When total reading time differs from gaze duration, this indicates that the region was reread. Hence, total fixation durations can capture later processing and have been observed to indicate reanalysis or integration processes, such as predictability effects (Kliegl et al., 2004; Rayner et al., 2004, 2011).

When a region of interest was not fixated, i.e. skipped, first fixation duration, gaze duration and total duration are zero and are not included in the analysis and not included in the reported means. If a word was skipped, it is not included into the analysis of regressions either. Hence, the proportion of first pass regressions is calculated from all trials that included first pass fixations.

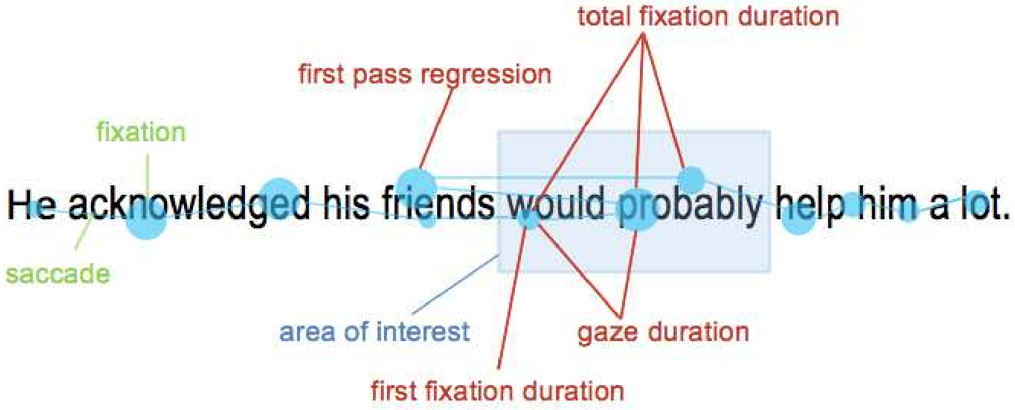

Figure 9.1. Analysed eye movement measurements in Experiment 2

Statistical analysis

Global results across all stimuli were analysed by comparing the groups for the number of fixations, the average fixation durations, the blink ratio, and the average sentence reading time. The only measure that showed a normal distribution was average fixation durations. These were compared between the groups using an independent t-test. Since the other data were not normally distributed (Shapiro-Wilk, all $p < .05$), NHI and PWA were compared using non-parametric Mann-Whitney U tests. The data were not transformed to approach a normal distribution, because simple group comparisons were sufficient for this dataset and this could be realised with non-parametric tests.

Similarly to the global results, the accuracy data violated assumptions of parametric tests. A visual inspection of histograms showed that some conditions did not approach a normal distribution, and this was confirmed by the Shapiro-Wilk test. The accuracy scores were normally distributed for the PWA in the DO-bias conditions but not in the SC-bias conditions. The scores were never normally distributed in the NHI group. The Levene's test showed that also the assumption of homogeneity of variance was violated for all conditions. Planned mixed model Anova tests could not be conducted since neither a log, a square root nor an inverse transformation of the data lead to a normal distribution and to homogeneity of variance. Since assumptions of analysis of variance were not met, the non-parametric tests Mann-Whitney U, Wilcoxon sign rank test and Friedman's Anova were used instead.

For the eye movement dataset, total fixation durations were normally distributed in all three analysed regions (all $p \geq .17$), but the other measures showed a normal distribution in some but not all of the conditions. Further, homogeneity of variance was violated, as there was much variability in the PWA dataset. It was suspected that two marginal outliers were the reason for the heterogeneity of the variance. In order to control for a non-normal distribution and for the heterogeneity of variance, different transformations were performed. Log and square root transformation were not successful, but reciprocal transformations (inverse transformations), which can correct for positive skew as well as unequal variances (Field, 2013), resulted in a near normal distribution and in homogeneity of variance. However, since inverse transformations of first pass regressions (in proportion) led to infinity for the lowest proportions, this dataset was not transformed, and analysed with non-parametric tests. The inversely transformed eye movement data were analysed in 2 (group: NHI vs. PWA) x 2 (context: DO vs. SC) x 2 (ambiguity: ambiguous vs. non-ambiguous) Anovas. The independent between-group variable was group, the within-group independent variables were context and ambiguity, and the dependent continuous variables were the fixation measurements as explained above (first fixation duration, gaze duration, total reading time, and proportion of first pass regression). Variance was computed over participants (F_1) and items (F_2). The Anovas were calculated for each of the three critical regions, and for each eye movement measurement. Results were considered significant if the p-value was $\leq .05$, a trend effect was defined at a p-value $\geq .05$ and $\leq .08$. Post hoc tests (independent and dependent t-tests) were used to analyse the nature of significant interactions if they were significant at ≤ .05. For correlational analysis, Pearson's and Spearman tests were used depending on distribution.

Unless stated otherwise, statistical tests were two-tailed, and all Bonferroni corrections are mentioned in the results section. Pearson's *r* effect sizes are reported for Mann-Whitney U, Wilcoxon signed rank tests and dependent t-tests (post hoc tests). Correlation coefficients of .10 were interpreted as small effect, .30 as medium, and .50 as large effect (Cohen, 1992). For effect sizes of the mixed model Anovas, generalised Eta-Squared (η_G^2) are reported (Bakeman, 2005). A small effect was interpreted at .02, medium at .13, and large at .26 (Bakeman, 2005). Accuracy data were analysed in SPSS, all other data were analysed in R (R Core Team, 2013). The *ez* package for R was used to run mixed model Anovas (Lawrence, 2011), and the Wilcoxon signed rank test as well as the Spearman test were carried out using the coin package which implements permutation based tests (Hothorn et al., 2008). Graphs were developed using the ggplot2 package (Wickham, 2009).

Cleaning of the data and dealing with outliers

First, fixations were drift corrected in order to reduce error in the dataset. Fixation locations recorded by the eye tracker were adjusted vertically (as recommended by SR research). Single fixations were never drift corrected. Either all fixations in a single sentence or a group of fixations were drift corrected. Second, data were filtered according to predetermined cut-offs and as conventional in eye tracking research (Juhasz & Rayner, 2006; Kliegl et al., 2004; Rayner et al., 2006, 2011; Schattka et al., 2010). Fixations smaller than 80ms and adjacent to a larger neighbouring fixation (within 0.3° of a visual angle) were merged. Fixations shorter than 80ms that were not adjacent to a larger neighbouring fixation and fixations longer than 1200ms were excluded (Juhasz et al., 2006). All trials with track loss were also excluded (3 for NHI, and 4 for PWA). A track loss occurred for example because of a lack of attention or because the participant looked in a different direction so that eye movements could not be recorded. Cleaning with cut-offs and track loss lead to a loss of 4.47% of the data (number of fixations before cleaning: 22037; number of fixations after cleaning: 21051=95.53%). A loss of data of up to 5% is common in eye tracking studies within the healthy population (Ashby et al., 2005; Rayner et al., 2011), and a data loss of between 7-10% is reported in eye tracking studies including neurologically impaired participants (Ablinger, Huber, Schattka, & Radach, 2013; Schattka, Radach, & Huber, 2010).

For the outlier analysis, both the global results as well as the eye movement duration measures were examined. If a participant's dataset deviated more or less than two standard deviations from the average of the group within a condition it was excluded.

9.3. Results

The results chapter starts with a description of the outlier analysis (9.3.1). The second results section provides a short overview of the global eye movement characteristics of the two groups (9.3.2). This presents global reading characteristics as well as accuracy results. In Section 9.3.3, an Anova analysis compares whether eye movements differ in correct and incorrect trials and provides an eye movement analysis of the disambiguation region with both correct and incorrect trials (9.3.3). The results from the eye movement analyses including correct trials are presented in Section 9.3.4. Results in these sections are presented against each research question or group of research questions. Subsequently, individual variation in the results in the aphasia group is examined, and correlational analyses between results from the language background tests and the effects from the experiment carried out (9.3.5). The results chapter ends with a summary of all findings (9.3.6).

9.3.1. Outlier analysis

The global dataset as well as the eye movement dataset were analysed for outliers. An outlier was defined as an individual data mean which exceeded the group mean by two standard deviations. For the global dataset, average fixation durations, the number of fixations and sentence reading times were analysed, and no outlier was detected. For the analysis of outliers in the eye movement dataset, first fixation duration, gaze duration and total duration were analysed. None of the participants had means that exceeded the group mean by more than two standard deviations. As this was the exclusion criterion, none of the participants was excluded. It should be noted, however, that there was much variability in the dataset which has consequences for the statistical analyses, as will be described in the next two subchapters.

9.3.2. Global characteristics of the data

Before reporting on the analyses to answer the research questions, this paragraph presents an overview of the overall reading patterns of the two groups (see Table 9.8), and of accuracy (see Table 9.9). As in Experiment 1, the global reading characteristics refer to an analysis of the whole sentences whereas the eye movement dataset described in Section 9.3.3 onwards refers to the analysis of critical sentence regions.

Global reading characteristics of the sentence

The global patterns of eye movements are shown by the average fixation durations (measured in ms), the number of fixations and the sentence reading times (measured in ms); all measurements refer to the whole sentence rather than a critical region. Apart from the average fixation durations none of the datasets were normally distributed. Hence average fixation durations were compared using the independent t-test, and all other measurements were compared with the non-parametric Mann-Whitney U test. As mentioned above, data were not transformed because simple group comparisons were envisaged, and non-parametric tests are sufficient for these. Results show that the groups did not differ in average fixation durations, but they differed in all other measures. The people with aphasia made significantly more fixations per sentence than the neurologically healthy individuals. Further, people with aphasia showed longer sentence reading times per sentences than the control participants, and they made more blinks. The difference was also significant for the blink/fixation ratio. This means that the larger number of blinks by the people with aphasia cannot be explained by longer reading times and hence an increased number of fixations overall. All significant results remained significant after the Bonferroni correction (α level = .05/5 = .01).

Table 9.8. Global characteristics of reading (NHI and PWA)

	NHI			**PWA**			**Comparison of groups**			
Measure	**Mean (SD)**	**Median (IQR)**[a]	**Range**	**Mean (SD)**	**Median (IQR)**[a]	**Range**	**t**[b]	**z**	**p**	**r**
Average fixation duration (ms)	271.43 (45.65)	n.a.	170.20-481.14	269.83 (33.20)	n.a.	187.58-377.75	0.53	n.a.	ns.	.04
Mean number of fixations	14.14 (4.30)	13 (11-16)	7-34	34.11 (16.78)	30 (22-43)	10-114	n.a.	-22.19***	< .001	-.73
Average sentence reading time (ms)	3828.98 (1174.59)	3704.00 (3044.50-4526.50)	1308.00-8872.00	10462.69 (5756.47)	9122.50 (6466.75-13537.25)	2528-43187	n.a.	-22.52***	< .001	-.79
Mean number of blinks	0.55 (0.84)	0 (0-1)	0-6	2.04 (2.31)	1 (1-3)	0-15	n.a.	-13.52***	< .001	-.88
Blink/fixation ratio	0.04 (0.05)	0 (0-0.08)	0.00-0.29	0.06 (0.05)	0 (0-0.08)	0-0.29	n.a.	-7.16***	< .001	-.53

[a] Median and inter-quartile ranges (IQR) are only reported for measures compared with non-parametric tests. [b] t refers to the independent t-test; z refers to the Mann-Whitney U test; r refers to the Pearson's r effect size

**p < .01, ***p < .001, ns = non-significant

Accuracy

Before performing statistical analysis on the accuracy data, results were checked for normal distribution and homogeneity of variance. Since assumptions of the analysis of variance were not met, the non-parametric tests Mann-Whitney U, Wilcoxon signed rank test and Friedman's Anova were used. The accuracy scores (Median, Interquartile range (IQR) and Range) for both groups are presented in Table 9.9.

People with aphasia were less accurate (*Mdn* = 87.50%) than the control group overall (*Mdn* = 100%). A Mann-Whitney U test indicated that this difference was significant, $U = 24.00$, $z = -2.49$, $p = .013$, $r = .53$. People with aphasia made more errors than controls in the ambiguous DO-bias condition, $U = 19.5$, z = -3.03, $p = .002$, $r = -.65$, as well as in the non-ambiguous DO-bias condition, $U = 29.00$, z =-2.34, $p = .019$, $r = .50$. The groups also showed a significant difference in the ambiguous SC-bias condition, $U = 34.50$, $z = -1.99$, p = .047, $r = .42$, and in the non-ambiguous SC-bias condition, $U = 34.00$, $z = -2.11$, $p = .035$, $r = -.45$. Only the significant differences overall and in the DO-bias conditions remained significant after correction for multiple analyses (α level = .05/4 = .013).

Next, the DO-bias and SC-bias conditions as well as the ambiguous and non-ambiguous conditions were compared for each group using the Wilcoxon sign rank test for repeated measures. There was no context effect and no ambiguity effect for the neurologically healthy participants. However, there was an effect of ambiguity on accuracy in the aphasia group, $z = -2.12$, $p = .03$, $r = .45$. PWA answered more questions correctly if the complementiser was included. This effect was not significant after the Bonferroni correction (α level = .05/2 = .25).

In order to investigate whether there was a significant effect of sentence type on the controls or the PWA's performance, Friedman's Anova was conducted. This showed that there is no significant difference in accuracy across the conditions, neither for the controls, $X^2(3) = 0.46$, $p = .93$, nor the people with aphasia, $X^2(3) = 6.13$, $p = .11$.

In summary, both NHI and PWA were able to resolve sentences with a temporal ambiguity, there was no chance performance. The control participants performed near ceiling in all conditions whereas the people with aphasia performed less accurately (see Figure 9.2). Even though not significant, the PWA were the least accurate in the ambiguous DO-bias condition.

Table 9.9. Accuracy correct in % as a function of sentence condition and participant group

	Ambiguity					
Context	**ambiguous**		**non-ambiguous**		**mean**	
	Median (IQR) [a]	**Range**	**Median (IQR)**	**Range**	**Median (IQR)**	**Range**
NHI						
DO-bias	100 (100-100)	90-100	100 (100-100)	90-100	100 (95-100)	95-100
SC-bias	100 (100-100)	90-100	100 (100-100)	89-100	100 (100-100)	89-100
Mean	100 (95.50-100)	95-100	100 (95.50-100)	94-100	100 (97.50-100)	95-100
PWA						
DO-bias	90 (70-100)	50-100	90.00 (80-100)	67-100	90 (75-100)	58-100
SC-bias	90 (80-100)	30-70	90.00 (90-100)	78-100	95 (80-100)	74-100
Mean	85 (80-100)	60-100	90 (83.89-100)	75-100	87.50 (82.05-100)	69-100

[a] IQR refers to the inter-quartile range.

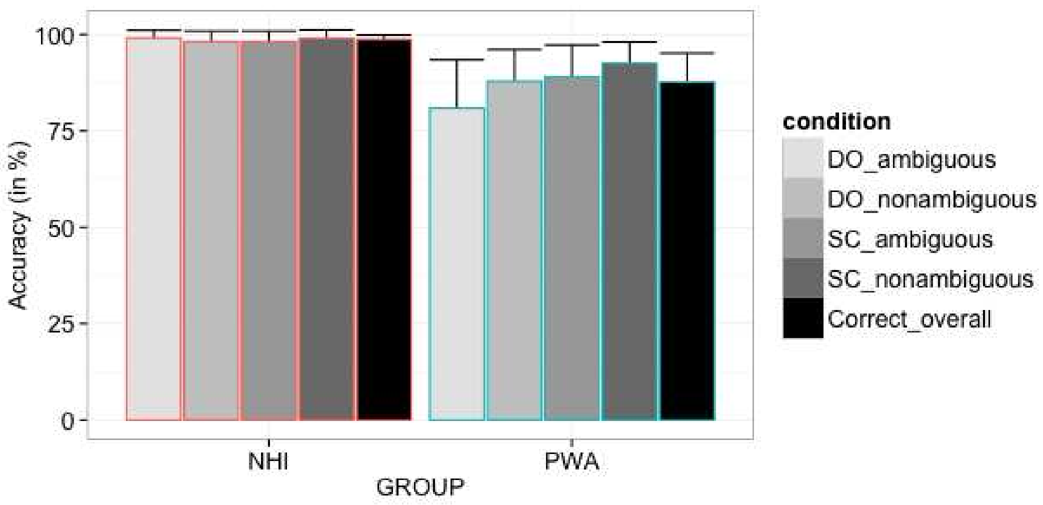

Figure 9.2. Accuracy in %, comparison of groups (error bars represent standard deviations)

9.3.3. Eye movements

For the eye movement data, assumptions of the mixed model Anova were again violated, and inverse transformations were employed, except for the first pass regressions. These were analysed using non-parametric tests. The analyses in this and the following subsection served to answer the first research question, which asked whether NHI and PWA show an influence of a verb's sense based argument structure frequency (measured as context effect) and an influence of the presence or absence of the complementiser *that* (measured as ambiguity effect) on the reading of structural ambiguities. If effects arise, follow-up questions were at what time course they do, and whether factors are independent or interactive. In the following subsections, a context effect refers to shorter fixation durations on trials with SC-bias contexts compared to trials with DO-bias contexts, and an ambiguity effect refers to shorter fixation durations on trials including the complementiser compared to trials omitting the complementiser.

For each of the following sections, results are structured by describing results from the different eye movement measures separately, starting with the earliest eye movement measurements (first fixation durations), continuing with gaze durations, total durations, and ending with first-pass regressions. Main effects are reported first, followed by interactions and post hoc tests.

9.3.3.1 Correct and incorrect trials

It has been suggested that PWA may show a different pattern of results when they answer trials incorrectly as compared to correctly (Dickey et al., 2007; Hanne et al., 2011). Hence, an analysis of incorrect trials may indicate eye movements associated with reading and sentence comprehension difficulties. A four-way Anova including accuracy (correct vs. incorrect) x region (1 vs. 2 vs. 3) x context (DO vs. SC) x ambiguity (ambiguous vs. non-ambiguous) was carried out for the aphasia group to explore whether total durations differ in the three regions of interest, dependent on whether the trials were understood correctly or incorrectly. Since total durations are a global measure, they were used as the dependent variable. The dataset with incorrect trials was very small; only five PWA had incorrect trials in all of the four conditions. These five participants were included in the Anova. Results showed that there was a trend main effect of accuracy on the total durations, $F_1(1,4) = 6.21$, $p = .07$, $\eta_G^2 = .02$. Total durations were shorter for the correct trials (M = 1196.83ms) than for the incorrect trials (M = 1406.27ms), presented in Figure 9.3. The Anova result suggests that there was at least some reason to assume that accuracy affected eye movements of correct and incorrect trials differently. Since the experimental manipulation involved sentence structures (and not words as in Experiment 1), it was possible that incorrect answers to the comprehension questions reflected difficulties with target structures, even though it could not be guaranteed that some incorrect trials were due to inattention or pressing the wrong button. In order to explore further whether sentence comprehension difficulties were related to influences of context and ambiguity, this subsection presents an analysis of the disambiguation region (the main region of interest) involving both correct and incorrect responses. An analysis of the incorrect trials was not meaningful due to the small sample size and hence a lack of power. Consequently, the analyses of all sentence regions are carried out on correct trials only (Section 9.3.3.2).

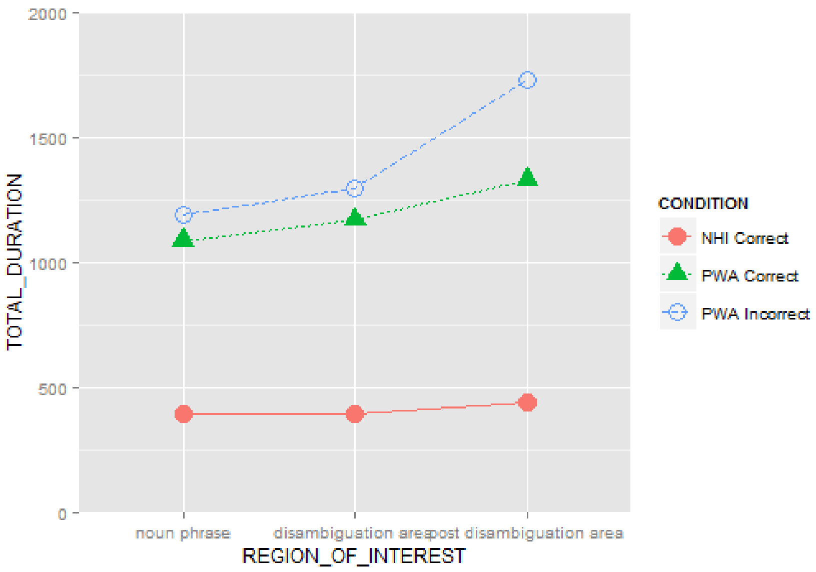

Figure 9.3. Total durations for correct and incorrect trials by PWA, and correct trials by NHI

Disambiguation region – primary analysis

(He acknowledged (that) * his friends * **would probably** * help him * a lot.)

First fixation durations

For first fixation durations, results from an Anova with correct and incorrect trials showed a main effect of group and context. First fixation durations were longer in the aphasia group (*M* = 264.86ms) compared to the control group (*M* = 207.56ms), $F_1(1,20) = 19.58$, $p < .001$, $\eta^2_G = .39$; $F_2\ (1,9) = 41.21$, $p < .001$, $\eta^2_G = .55$. First fixation durations were also longer in the DO-bias context (*M* = 251.95ms) as compared to the SC-bias context (*M* = 229.87ms), $F_1(1,20) = 13.67$, $p = .001$, $\eta^2_G = .06$; $F_2\ (1,9) = 6.83$, $p = .03$, $\eta^2_G = .05$. Both main effects remained significant after the Bonferroni correction. There were no other effects, all *Fs* ≤ 7.

Gaze durations

The analysis of gaze durations revealed an influence of group in that durations were longer in the aphasia group (654.49ms) than in the control group (293.64ms), $F_1(1,20) = 14.40$, $p = .001$, $\eta^2_G = .37$; $F_2\ (1,9) = 72.73$, $p < .0001$, $\eta^2_G = .55$. Further there was an effect of ambiguity with longer gaze durations in ambiguous trials (558.57ms) compared to gaze durations in non-ambiguous conditions (451.30ms), $F_1(1,20) =$

19.59, $p < .001$, $\eta_G^2 = .39$; F_2 (1,9) = 21.24, $p = .001$, $\eta_G^2 = .09$. Both of these effects were significant after the Bonferroni correction. All other *Fs* ≤ 3.

Total durations

Total durations were influenced by the participant group, context and ambiguity. First, total durations were longer in the aphasia group (1354.89ms) than in the control group (402.50ms), F_1(1,20) = 68.94, $p < .00001$, $\eta_G^2 = .71$; F_2(1,9) = 311.39, $p < .00001$, $\eta_G^2 = .77$. Second, total durations were longer in the DO-bias condition (1113.64ms) compared to the SC-bias condition (801.29ms), F_1(1,20) = 21.62, $p < .001$, $\eta_G^2 = .08$; F_2(1,9) = 11.87, $p < .01$, $\eta_G^2 = .11$. Third, total durations were longer in ambiguous trials (1074.85ms) as compared to non-ambiguous trials (845.94ms), F_1(1,20) = 8.51, $p = .008$, $\eta_G^2 = .05$; F_2 (1,9) = 35.57, $p < .001$, $\eta_G^2 = .07$. All three effects remained significant after the Bonferroni correction. There were no other effects, all other *Fs* ≤ 2. Table 9.10 presents the means and standard deviations for all eye movement measures as a function of condition, for the disambiguation region.

Table 9.10. Mean fixation durations and SD for the disambiguation region (correct and incorrect trials)

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	215.14	219.84	194.03	201.34
SD	36.46	59.71	29.79	21.98
Gaze duration	328.89	288.99	276.20	282.35
SD	95.75	76.92	75.58	62.30
Total duration	456.36	392.39	410.92	350.46
SD	100.57	97.60	157.90	68.16
First pass regression in %	9.35%	12.80%	11.05%	1.97%
SD	10.20%	27.49%	27.22%	4.60%

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	288.05	261.58	261.17	246.11
SD	90.76	49.75	57.59	71.11
Gaze duration	750.68	534.81	721.93	606.26
SD	493.30	295.08	490.04	392.08
Total duration	1789.38	1359.47	1220.54	998.78
SD	1277.51	636.34	593.15	403.77
First pass regression in %	13.87%	24.15%	12.92%	9.07%
SD	19.36%	27.61%	18.18%	2.15%

First pass regressions (not transformed)

The two groups differed significantly in the number of first pass regressions. The aphasia group made more regressions out of the disambiguation region (M = 15%, Mdn = 0%) than the control group (M = 9%, Mdn = 0%), U = 1443.5, Z = -1.93, p = .05, r = .41. A Friedman's Anova for the NHI revealed a significant effect of condition type on the number of regressions, $X^2(6) = 59.30$, $p < .00001$. Multiple post hoc tests showed a significant difference between the DO-bias ambiguous condition and the SC-bias non-ambiguous condition, z = 2.11, p = .03, r = .64. The control group made more regressions in sentences in the DO-bias ambiguous condition (9.35%) compared the SC-bias non-ambiguous condition (1.97%) condition. For the aphasia group, there was also a significant effect on first pass regressions, $X^2(6) = 54.49$, $p < .00001$. Multiple post hoc tests revealed that the people with aphasia made more first pass regressions in the non-ambiguous trials if the trials were in the DO-bias condition (24.15%) than if they were in the SC-bias condition (9.07%), z = 2.82, $p < .004$, r = .60.

The group effect as well as the context effect on non-ambiguous trials in the aphasia group remained significant after the Bonferroni correction.

Summary disambiguation region

The analysis of the disambiguation region with correct and incorrect trials showed significant differences between the two participant groups. The aphasia group had longer fixation durations in all measurements, and also showed more first pass regressions compared to the control group. The experimental manipulations of ambiguity and context also influenced the reading durations in the predicted direction. The context effect was significant for first fixation durations and total durations. The ambiguity effect was significant for gaze and total durations. These results suggest that readers from both groups were able to use the cue of the complementiser *that*, which facilitated reading in the non-ambiguous conditions. Further, readers from both groups were sensitive to the context-biases, and their reading was less disrupted if the context sentence was SC-biasing, and hence consistent with the target sentence structure. Both groups showed longer fixation durations if the context sentence was biasing them towards the DO-sense and structure of the verb, which did not match the sense and structure of the target sentence. NHI also made more first pass regressions in the ambiguous DO-bias condition as compared to the non-ambiguous SC-bias condition. The aphasia group also revealed more first pass regressions in the non-ambiguous DO-biasing condition compared to the non-ambiguous SC-biasing condition. This shows that the aphasia group was not able to integrate the context and the ambiguity cue. If they did the context effect would have been expected to occur for the ambiguous trials only. In summary, the effects of ambiguity and context were both observed in early as well as in late eye movement measurements. There were no interactions between them, indicating that the effects were independent of each other. Further, there were no differences between the groups regarding the influences of the experimental manipulations, except small differences in first pass regressions. This shows that the groups were largely behaving similarly with respect to the context bias and the structural cue. The following subsection presents the analysis of correct trials.

9.3.3.2 Correct trials

The correct and incorrect trials were separated, and the following analyses are based on the correct trials. Since the answer to the first research question depends on the analysis of the disambiguation region, this analysis will be presented first as the primary analysis. Subsequently, the analysis of the (ambiguous) noun phrase and the post-disambiguation region will be presented[30]. These secondary analyses will answer the follow-up questions regarding the time course.

For each region, a table presents the mean and standard deviations of all measurements for both groups, referring to the raw data. All figures presenting the results will also refer to raw data as inversely transferred data are difficult to view visually (Figure 9.4-9.7). Further, Table 9.11 summarises the p-values for all effects and interactions in all regions. These results refer to the analyses that were carried out for transformed scores. For purposes of clarity, non-significant results will not be mentioned, even though trend effects will be reported. Since four eye movement measurements were analysed per region, the Bonferroni correction was applied at α level = (.05/4) = .0125. Results before and after corrections are reported.

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[30] Additionally, an Anova was conduced across all regions with including region as a factor. Results were similar to those from separate analyses.

Table 9.11. Overview of p-values for main effects and interactions.

Region		**FFD**[a]		**GD**		**TD**	
		p for F1	p for F2	p for F1	p for F2	p for F1	p for F2
Noun phrase	group	= .02	< .001	= .02	< .0001	< .0001	<.0001
	ambiguity	ns	ns	= .07	ns	= .02	ns
	context	= .07	ns	ns	ns	ns	= .04
	group x ambiguity	ns	ns	ns	ns	ns	ns
	group x context	ns	ns	ns	ns	ns	ns
	ambiguity x context	ns	ns	ns	ns	=0.05	= .01
	group x ambiguity x context	ns	ns	ns	ns	ns	ns
Disambiguation region	group	< .0001	< .0001	< .001	< .0001	< .0001	< .0001
	ambiguity	ns	= .05	= .002	= .002	= .02	< .001
	context	ns	ns	= .06	= .04	< .0001	= .01
	group x ambiguity	ns	ns	ns	ns	ns	= .08
	group x context	ns	ns	ns	ns	= .07	ns
	ambiguity x context	ns	ns	= .07	ns	ns	ns
	group x ambiguity x context	ns	ns	ns	ns	ns	ns
Post disambiguation region	group	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001
	ambiguity	ns	ns	ns	ns	ns	ns
	context	ns	ns	ns	ns	= .04	ns
	group x ambiguity	ns	ns	ns	ns	ns	ns
	group x context	ns	ns	ns	ns	ns	ns
	ambiguity x context	ns	ns	ns	ns	ns	ns
	group x ambiguity x context	ns	ns	ns	ns	ns	ns

Note: results from first pass regressions are not included, as they were not analysed using Anova. [a] FFD = first fixation duration, GD = gaze duration, TD = total duration

Disambiguation region – primary analysis

(He acknowledged (that) * his friends * **would probably** * help him * a lot.)

For the disambiguation region, Table 9.12 presents the means and standard deviations for all eye movement measures as a function of condition, for the disambiguation region[31].

First fixation durations

For first fixation durations, there was a main effect of group in that first fixation durations were significantly longer in the aphasia group (M = 263.49ms) than in the neurologically healthy group (M = 202.73ms). This was significant by participants as well as by items, $F_1(1, 20) = 24.09$, $p < .0001$, $\eta^2_G = .44$; $F_2(1,9) = 72.63$, $p < .0001$, $\eta^2_G = .67$. The group effect is strong and remains significant after the Bonferroni correction (α level = .0125). There were no other effects, all $Fs \leq 2.3$.

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[31] For an overview of the same measurements with transformed data, see Appendix C.6.

Table 9.12. Mean fixation durations (in ms) and first pass regressions (in %) and standard deviations for all eye movement measures as a function of condition, for the disambiguation region

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	206.87	199.99	199.49	204.56
SD	23.70	16.61	29.06	19.87
gaze duration	330.97	281.71	273.14	278.01
SD	100.14	74.40	56.06	63.41
Total duration	470.03	403.91	367.82	352.32
SD	93.06	96.41	83.60	71.17
First pass regression in %	10%	6%	4%	2%
SD	10%	9%	6%	5%

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	273.98	250.67	272.09	257.26
SD	62.59	48.84	57.35	50.86
Gaze duration	789.73	595.42	643.20	604.68
SD	481.31	344.74	415.45	441.98
Total duration	1451.03	1368.49	1172.32	1066.48
SD	513.81	565.37	442.80	436.16
First pass regression in %	14%	23%	15%	14%
SD	15%	20%	17%	16%

Gaze durations

The analysis of gaze durations showed a main effect of group and ambiguity. Gaze durations of the aphasia group (M = 658.26ms) were 367.3ms longer than gaze durations of the control group (M = 290.96ms), $F_1(1,20) = 15.01$, $p < .001$, $\eta^2_G = .37$; $F_2 = 112.87$, $p < .0001$, $\eta^2_G = .60$. Across DO-and SC-biasing contexts, gaze durations were significantly longer if the trials were ambiguous (M = 509.26ms) as compared to non-ambiguous (M = 439.95ms), i.e. including *that*, $F_1(1,20) = 11.99$, $p = .002$, $\eta^2_G = .04$; $F_2 = 18.57$, $p = .002$, $\eta^2_G = .10$. Further, there was a trend effect of context, $F_1(1,20) = 3.95$, $p = .06$, $\eta^2_G = .01$; $F_2 = 5.91$, $p = .04$, $\eta^2_G = .02$. Gaze durations in the disambiguation region were 49.7ms shorter if the target sentence followed SC-biasing contexts (M = 449.76ms) than when the target sentence followed DO-biasing contexts (M = 499.46ms). There was also a trend interaction between context and ambiguity, $F_1(1,20) = 3.68$, $p = .07$, $\eta^2_G = .01$. As can be seen in Figure 9.5, gaze durations were longer in the ambiguous (*M* = 560.35ms) than in the non-ambiguous condition (*M* = 438.56ms) when the context was DO-biasing, but the difference between ambiguous and non-ambiguous sentences was small if the context sentence was SC-biasing. Here, gaze durations for the SC-bias condition were only marginally longer in the ambiguous condition (*M* = 458.17) than in the non-ambiguous condition (*M* = 441.34). However, these comparisons were not followed up with post hoc tests as the interaction was only a trend. Both the group and the ambiguity effect were strong effects and were significant after the Bonferroni correction (α level = .0125).

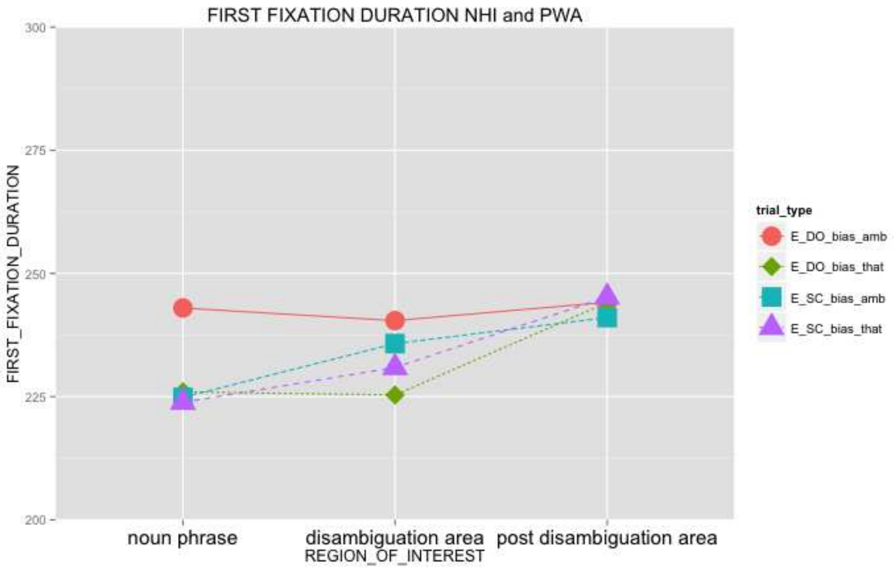


Figure 9.4. Mean first fixation duration for all conditions compared.

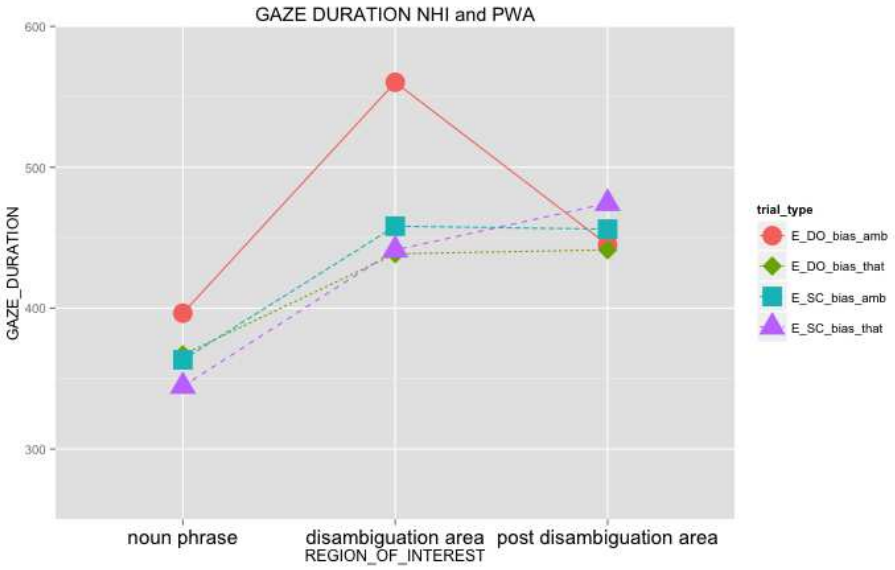


Figure 9.5. Mean gaze duration for all conditions compared.

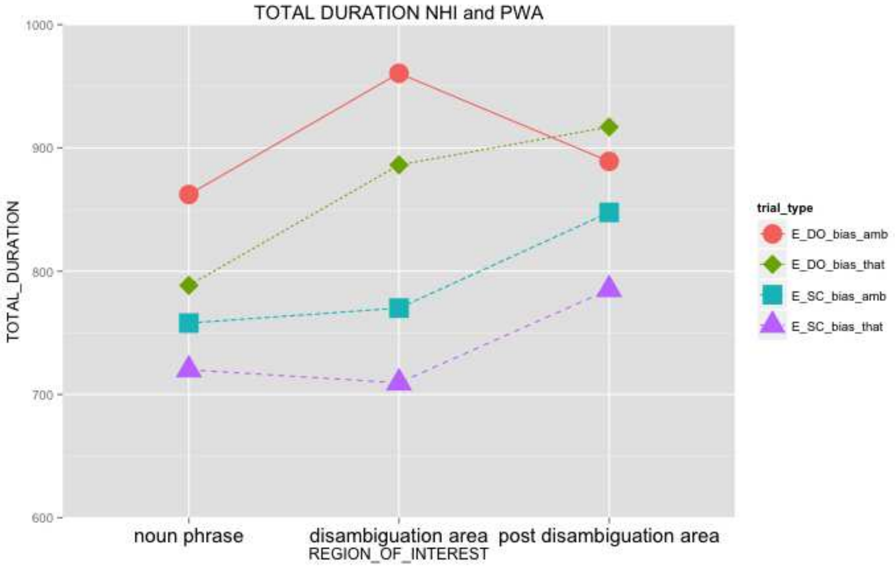


Figure 9.6. Mean total duration for all conditions compared.

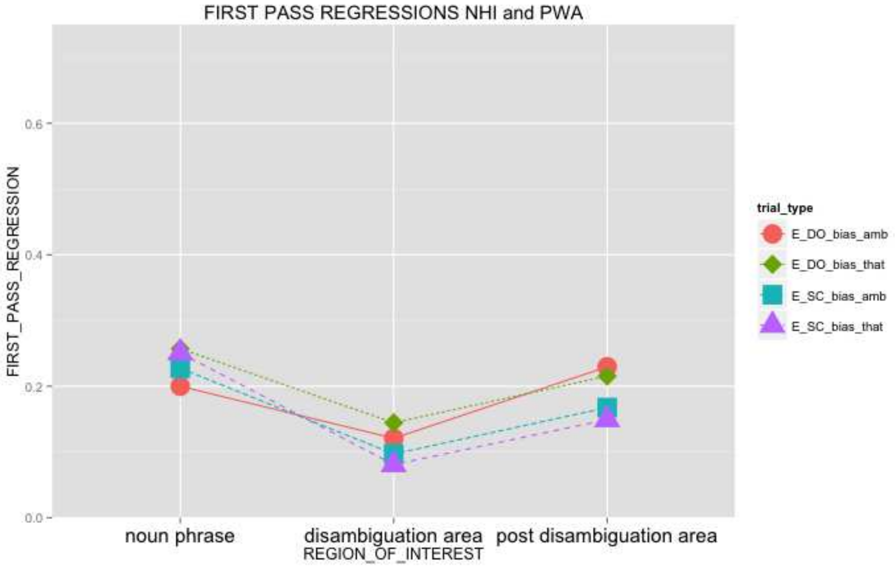
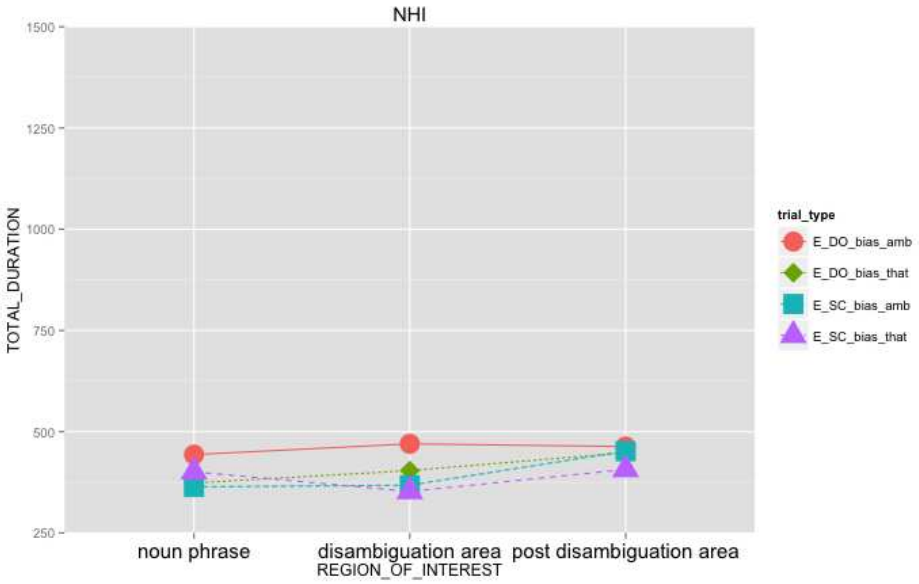


Figure 9.7. Mean proportion of regressions for all conditions compared

Total durations

For total durations, there was again a main effect of group, $F_1(1,20) = 69.98$, $p < .0001$, $\eta^2_G = .72$, in that total durations were longer in the aphasia group ($M = 1264.58$ms) than in the control group ($M = 398.52$ms); $F_2(1,9)= 358.09$, $p < .0001$, $\eta^2_G = .77$. There was a main effect of context, $F_1(1, 20) = 38.12$, $p < .0001$, $\eta^2_G = .10$; $F_2(1,9) = 10.25$, $p =$

.01, η_G^2 = .12. Across both ambiguous and non-ambiguous trials, fixations were longer in the DO-bias conditions (*M* = 923.37ms) than in the SC-bias conditions (*M* = 739.73ms). There was further a main effect of ambiguity, F_1(1, 20) = 6.70, *p* = .02, η_G^2 = .03; F_2 (1,9) = 28.72, *p* = .001, η_G^2 = .04. Total fixations were longer in the ambiguous (*M* =865.30) than in the non-ambiguous trials (*M* = 797.80ms). Finally, there was a trend interaction between group and context for the analysis carried out by participants, F_1(1, 20) = 3.69, *p* = .07, η_G^2 = .01. For the PWA, the average difference between total durations on sentences following a DO-bias and sentences following a SC-bias was 290.36ms. For the NHI, the average difference between total durations on sentences following a DO-bias and sentences following a SC-bias was 76.90ms. Since the interaction between group and context was the only one involving a between and within group variable, Figure 9.9 presents total durations for both groups separately. A visual inspection of the graph shows that the trend interaction is due to the PWA showing a context effect for both ambiguous and non-ambiguous trials whereas the context effect is restricted to the ambiguous trials in the NHI group. However, this was not significant. Applying the significance level of p = .0125 means that the group and the context effect remain significant, but the ambiguity effect (*p* = .017) lost its significance.



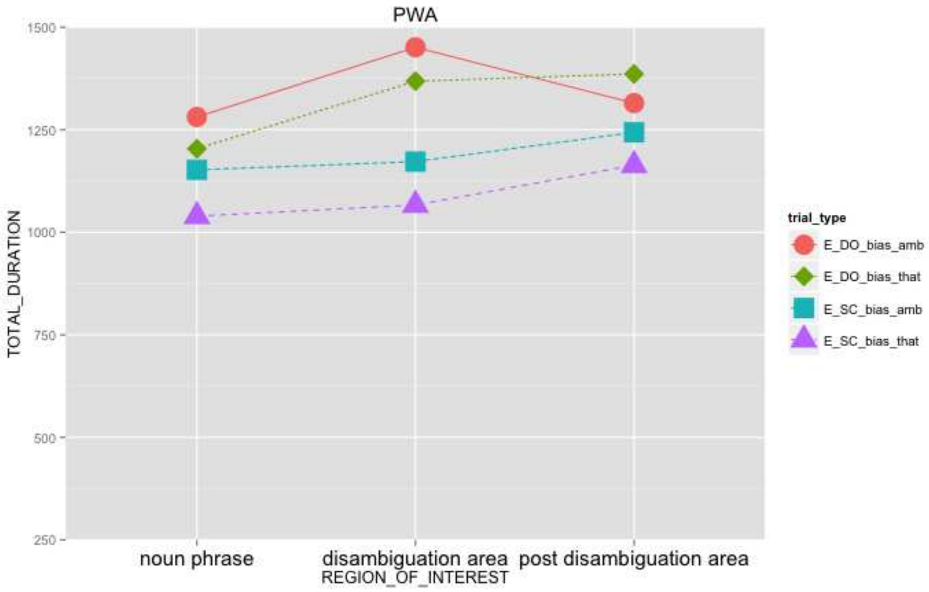


Figure 9.8. Mean total duration as a means of condition for NHI (top picture) and PWA (bottom picture)

First pass regressions (not transformed)

The groups differed significantly in their proportion of first pass regressions, *U*= 598.5, *Z* = -3.30, *p* < .001, *r* = .70. The PWA (*M* = 16.56%, *Mdn* = 11.11%) made more regressions out of the disambiguation region than the NHI (*M* = 5.59%, *Mdn* = 0.00%). This group effect was again significant after the Bonferroni correction. A Friedman's Anova for the NHI showed a significant effect of condition type on the proportion of regressions, $X^2(6) = 59.30$, $p < .0001$. Running multiple comparisons with Bonferroni adjustments revealed no significant effects between any of the conditions. Equally for the PWA there was an effect of condition on regressions, $X^2(6)= 56.69$, $p < .0001$, but no significant differences after multiple comparisons.

Summary disambiguation region

In summary, all eye movement measures show highly significant differences between the groups in that the PWA show longer fixation durations and more first-pass regressions than the NHI. This would be expected as the aphasia group presents with mild impairments in written comprehension at the sentence level. More interestingly, eye movements by both the NHI and the PWA in the disambiguation region were influenced by the biasing contexts as well as by the ambiguity manipulation. The ambiguity effect was strongest for gaze durations, and less pronounced for the total durations. The context effect was strong for total durations, and appeared as a trend effect in gaze durations for the analysis by participants, and as a significant effect for the analysis by items. These results indicate that readers from both groups were sensitive to the syntactic marker *that*, and readers from both groups had prolonged fixation durations on target sentences that followed context sentences cueing them for the DO-sense of the verb which did not match the target sentence structure (SC). As can be seen in Figure 9.4. – 9.7., the longest first fixation, gaze and total durations in the disambiguation region occurred in the ambiguous condition following a DO-bias context. However, the interaction between context and ambiguity only showed as a trend effect for gaze durations, hence, the influences of syntactic ambiguity and context were only mildly interactive. Overall, both groups experienced a garden path effect and reanalysed the disambiguation area in the ambiguous and DO-bias context conditions.

The results were similar to the results from the analysis that included both correct and incorrect trials. However, in the analysis with correct trials only, the context effect was shown as a trend in gaze durations whilst it was shown as significant effect on first fixation durations in the analysis including both correct and incorrect trials. Further, the analysis with correct trials showed two trend interactions that were not revealed in the analysis of all trials. This may suggest that difficulties in comprehending the target sentences were associated with a difficulty integrating both the context cue and the complementiser.

(Ambiguous) noun phrase region – secondary analysis

(He acknowledged (that) * **his friends** * would probably * help him * a lot.

The previous section presented the results for the disambiguation region. In this section, results from an eye movement analysis of the noun phrase region (which is ambiguous if *that* is omitted) will be presented. This is the secondary analysis as results may provide additional details in terms of the time course at which ambiguity and context effects show, and when the sentence is re-analysed. Together with the next section focussing on the post disambiguation region, this section addresses follow up questions from the first research question. All mean fixation durations for the noun phrase region are presented in Table 9.13.

Table 9.13. Mean fixation durations and SD for the noun phrase region (correct trials).

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	208.13	206.59	199.14	212.44
SD	24.22	42.62	33.53	48.65
Gaze duration	267.18	271.52	260.27	283.06
SD	50.74	65.42	60.34	95.58
Total duration	443.38	373.25	363.71	400.92
SD	121.87	113.86	111.87	152.27
First pass regression in %	13%	14%	8%	11%
SD	16%	19%	11%	13%

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	277.84	245.36	250.57	235.25
SD	66.11	42.23	68.58	30.25
Gaze duration	525.73	462.44	466.39	406.06
SD	190.74	196.88	214.97	154.16
Total duration	1281.11	1203.67	1152.14	1039.11
SD	468.21	591.33	475.36	429.50
First pass regression in %	27%	38%	38%	30%
SD	18%	26%	19%	28%

First fixation durations

The analysis of first fixation durations during the noun phrase region showed an effect of group, $F_1(1,20) = 6.63, p = .02, \eta_G^2 = .017$; $F_2(1,9) = 38.35, p < .001, \eta_G^2 = .28$.

Durations were longer for the PWA (*M* = 252.25ms) than for the controls (*M* = 206.58ms). After the Bonferroni correction this difference was not significant for the analysis by participants. There was a trend effect of context, $F_1(1,20) = 3.77$, $p = .07$, $\eta^2_G = .01$. First fixation durations were longer on sentences following a DO-bias context (*M* = 234.48ms) than first fixation durations that followed a SC-bias context (*M* = 224.35ms). All other *Fs* ≤ 1.10.

Gaze durations

For gaze durations the mixed model Anova showed a main effect of group, $F_1(1,20) = 7.04$, $p = .02$, $\eta^2_G =. 20$; $F_2(1,9) = 44.98$, $p < .0001$, $\eta^2_G = .30$. Durations were longer for the PWA (*M* = 465.15ms) than for the controls (*M* = 270.51ms). As for the first fixation durations, this difference was not significant for the analysis by participants after the Bonferroni correction. There was also a trend effect of ambiguity, $F_1(1,20) = 3.73$, $p = .07$, $\eta^2_G = .02$. Gaze durations were longer in ambiguous trials (*M* = 379.89ms) than in non-ambiguous trials (*M* = 355.77ms). There were no other effects, all *Fs* ≤ 2.42.

Total durations

Compared to the early eye movement measurements, the analysis of total durations showed a larger group effect, $F_1(1, 20)= 30.87$, $p < .0001$, $\eta^2_G = .55$; $F_2(1,9) = 541.14$, $p = .0001$, $\eta^2_G = .79$. The total fixation durations by the PWA (*M* =1169.01ms) were nearly three times longer than the total fixation durations by the NHI (*M* = 395.31ms). The group effect remained significant after applying the Bonferroni correction. There was also an effect of ambiguity, $F_1(1,20) = 6.95$, $p = .02$, $\eta^2_G = .01$. As predicted, total durations were longer in the ambiguous trials (*M* = 810.08ms) as compared to the non-ambiguous trials (*M* = 754.24ms). This effect was surmounted by a significant interaction between ambiguity and context which was significant for the analysis by participants as well as the analysis by items, $F_1(1,20) = 4.47$, $p = .05$, $\eta^2_G = .02$; $F_2(1,9) = 9.40$, $p = .01$, $\eta^2_G = .04$. Post hoc tests revealed that there was an ambiguity effect for the DO-bias context, $t(21) = -3.39$, $p <.003$, r = .60, in that total durations were longer in the ambiguous trials (*M* = 862.24ms) than in the non-ambiguous trials (*M* = 788.46ms). There was no ambiguity effect for the SC context. Further, there was a context effect for ambiguous trials, $t(21) = -3.82$, $p = .001$, r=.64. Total durations were longer in the DO-bias condition (*M* = 862.24ms) as compared to the SC-bias condition (*M* = 757.92ms). There was no context effect for non-ambiguous trials. The results of the post hoc tests are conforming to the predictions that the ambiguous DO-bias condition leads to the greatest processing disruptions. However, the interaction was not significant after the Bonferroni correction.

First pass regressions

For first pass regressions, there was also a significant group difference, $U = 356.5$, $z = -5.26$, $p < .0001$, $r = -1.10$. The NHI made fewer regressions out of the target region ($M = 11.68\%$, $Mdn = 10.00\%$) than the PWA ($M = 35.09\%$, $Mdn = 31.67\%$). A Friedman's Anova showed that for NHI there was an effect of the trial type on the proportion of regressions, $X^2(6) = 56.59$, $p < .0001$. However, paired comparisons with the Bonferroni correction applied showed no significant effects between conditions. For PWA, there was again an effect of condition on the proportion of regressions, $X^2(6) = 54.38$, $p < .001$. Pairwise comparisons showed no further significant group differences.

Summary noun phrase region

Similarly to the disambiguation region, the analysis of the noun phrase region showed significant group differences for all eye movement measurements, with the group effect being biggest for total durations where the effect remained significant after the Bonferroni correction. In terms of the sense-cued argument structure frequencies, there was an early trend context effect in the noun phrase region for first fixation durations, and an early trend ambiguity effect for gaze durations. This indicates that the readers show early sensitivity to ambiguity and context. For total durations the ambiguity effect was significant. Ambiguity and context also interacted for total durations in that ambiguity influenced the sentences in the DO-biasing context, and context influenced the sentences that were ambiguous. Hence, total durations were longest for the ambiguous DO-bias condition, in which both ambiguity and context bias towards the wrong DO frame. The fact that the interaction was significant in a measurement that includes second-pass reading as well as first-pass reading indicates that the cues may have been integrated during the stage of re-reading.

Post disambiguation region – third analysis
(He acknowledged (that) * his friends * would probably * **help him** * a lot.)

First fixation durations

The analysis of first fixation duration showed a main effect of group in that first fixation durations were longer in the aphasia group (*M* = 274.74ms) than in the control group (*M* = 212.51ms), $F_1(1, 20) = 28.18$, $p < .0001$, $\eta^2_G = .41$; $F_2(1,9) = 81.43$, $p < .0001$, $\eta^2_G = .47$. This strong effect remained significant after the Bonferroni correction. There were no other effects, all *Fs* ≤ .08. Table 9.14 presents an overview of fixation durations in the post-disambiguation region.

Table 9.14. Mean fixation durations and SD for the post-disambiguation region (correct trials).

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	210.81	215.07	211.78	212.37
SD	29.48	32.74	40.64	25.34
Gaze duration	286.19	327.40	318.44	313.85
SD	52.96	88.84	95.61	70.15
Total duration	463.33	447.93	451.71	406.74
SD	94.87	82.92	98.24	103.94
First pass regression in %	21%	0.09%	0.17%	0.11%
SD	12%	11%	12%	12%

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	277.50	273.11	270.31	278.03
SD	51.13	47.74	44.75	54.48
Gaze duration	603.81	555.37	593.78	634.96
SD	333.80	316.79	338.56	352.57
total duration	1314.88	1386.05	1243.70	1163.48
SD	344.23	468.92	400.34	364.23
First pass regression in %	25%	34%	16%	19%
SD	13%	23%	10%	13%

Gaze durations

Gaze durations also showed a main effect of group, $F_1(1, 20) = 18.99$, $p < .001$, $\eta^2_G = .38$; $F_2(1,9) = 59.60$, $p < .0001$, $\eta^2_G = .49$. The aphasia group had longer durations (*M* =

596.97ms) than the control group (M = 311.47ms). This was again significant after the Bonferroni correction. There were no other effects, all $Fs \leq 2.54$.

Total durations

Total durations yielded main effects of group, $F_1(1, 20) = 88.76$, $p < .0001$, $\eta^2_G = .76$; $F_2(1,9) = 66.18$, $p < .0001$, $\eta^2_G = .66$ and of context, $F_1(1,20) = 4.94$, $p = .04$, $\eta^2_G = .01$. The PWA had total durations (M = 1277.03ms) that were almost three times longer than those by the NHI (M = 442.43ms). Across ambiguous and non-ambiguous sentences, total durations in the DO-biasing context were longer (M = 903.05ms) than in the SC-biasing context (M = 816.41ms). The effect of group was strong and remained significant after the Bonferroni correction. The context effect did not remain significant after this correction.

First pass regressions

As mentioned in sections above, first pass regressions were analysed with non-parametric tests since the transformation was not successful for all regions. The Mann Whitney U test showed that there was a significant group effect showing more first pass regressions out of the target region for the PWA (M = 23.50%; *Mdn*= 22.22%) than the NHI (M = 14.60%; *Mdn* = 11.11%), $U = 642$, $z = -2.74$, $p = .006$, r= .58. For the NHI, the Friedman's Anova revealed that there was an effect of condition type on the data, $X^2(6) = 57.814$, $p < .0001$. Paired comparisons with the Wilcoxon test using the Bonferroni correction showed that there was a significant ambiguity effect for the DO-bias context ($p = .04$) but not for the other comparisons. The NHI made more regressions in the ambiguous condition (M = 21.41%) than the non-ambiguous condition (M = 9.40%). For the PWA, the outcome of the Friedman test was again highly significant, $X^2(6) = 54.84$, $p < .0001$. However, non-parametric paired comparisons with the Bonferroni correction applied showed that that there were no significant differences.

Summary post disambiguation region

Again all measures in the post disambiguation region showed highly significant group differences in that PWA showed longer fixation durations than the NHI, and made more regressions. There was no indication of an effect of the manipulated factors in the post disambiguation region for early duration measurements, i.e. first fixation duration and gaze duration. However, the NHI regressed more out of ambiguous sentences than non-ambiguous sentences, an eye movement behaviour that was not revealed for the PWA. Total durations showed a lasting effect of context of 86.64ms in the expected direction.

9.3.4. Individual analysis PWA

One difficulty with group analyses is that group results can conceal individual variation in the data. In order to account for this, this subchapter analyses individual data of the PWA with the aim of addressing the second research question. This asked whether the PWA show any individual differences in terms of ambiguity and context effects, and if yes, whether these can be related to their underlying language profile. In order to answer this research question, individual effects are correlated with the PWA's results from the language background assessments.

The analysis is based on eye movement data from the disambiguation region as this is the main region of interest (DeDe, 2013a). First, individual effects of both ambiguity and context of the PWA will be presented. These will be calculated for gaze and total durations to have one measure for first pass reading and one that includes second part reading subjectively. Subsequently, the effect scores will be compared to the individual's underlying language profile.

Individual analysis of the ambiguity and context effect

In order to relate the individual effects of the PWA to the NHI group, ambiguity and context effects were calculated in proportions. For the proportional ambiguity effect score, fixation durations in the ambiguous conditions were divided by the fixation durations in the non-ambiguous conditions. For the proportional context effect score, fixation durations in the DO-bias context were divided by those in the SC-bias context. From both scores, 1 was subtracted so that the resulting number shows the difference between the conditions in percentage. Hence, a score of 0.2 means that the fixation durations in one condition are 20% longer than in the other condition. Simple difference scores (e.g. fixation duration in ambiguous condition minus fixation duration in non-ambiguous condition) could not have accounted for the total durations that were longer overall for the PWA as compared to the NHI. This difference in durations is shown in the boxplot in Figure 9.8.

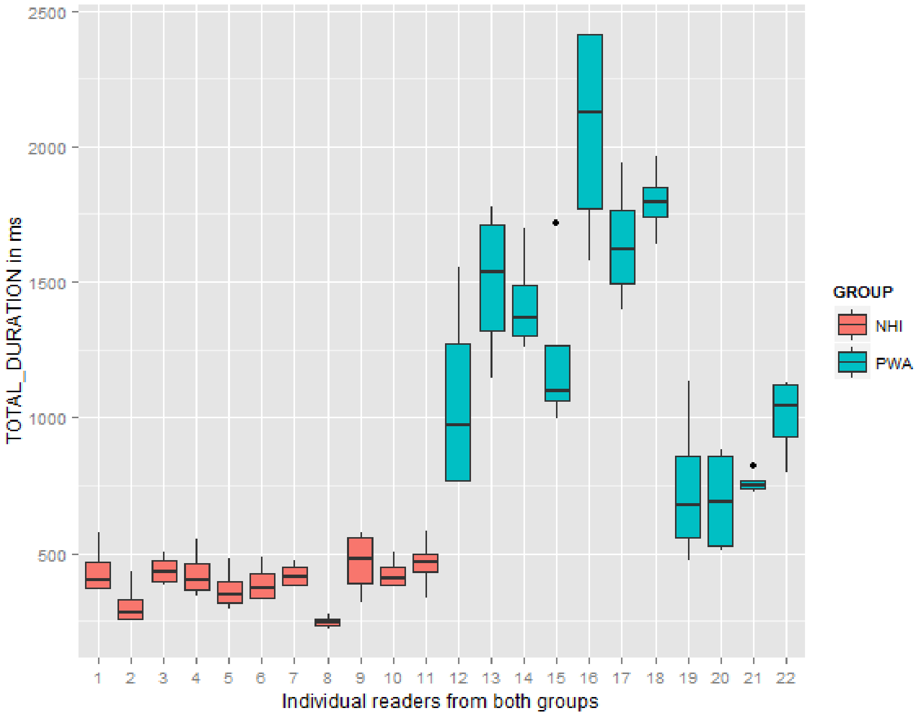


Figure 9.9. Individual variation for both groups

As can be seen in the boxplots (and consistent with the group effects reported in the last subsection) the PWA show much longer total fixation durations than the NHI. If an individual ambiguity/context effect from a participant with aphasia is 80ms, this cannot be compared to an effect of 80ms in the healthy group. Figure 9.10 presents the proportional effect scores for the syntactic ambiguity and the context bias for all individuals with aphasia, compared to the overall effect scores of the NHI group. The proportional ambiguity effect scores are shown in the left column and the proportional context effect scores in the right column. The upper pictures represent the effects for gaze duration, and the lower pictures represent the effects for total duration. The bars in the positive show the predicted effects whereas the bars in the negative represent reverse effects, e.g. longer fixation durations in the non-ambiguous trials than in the ambiguous trials.

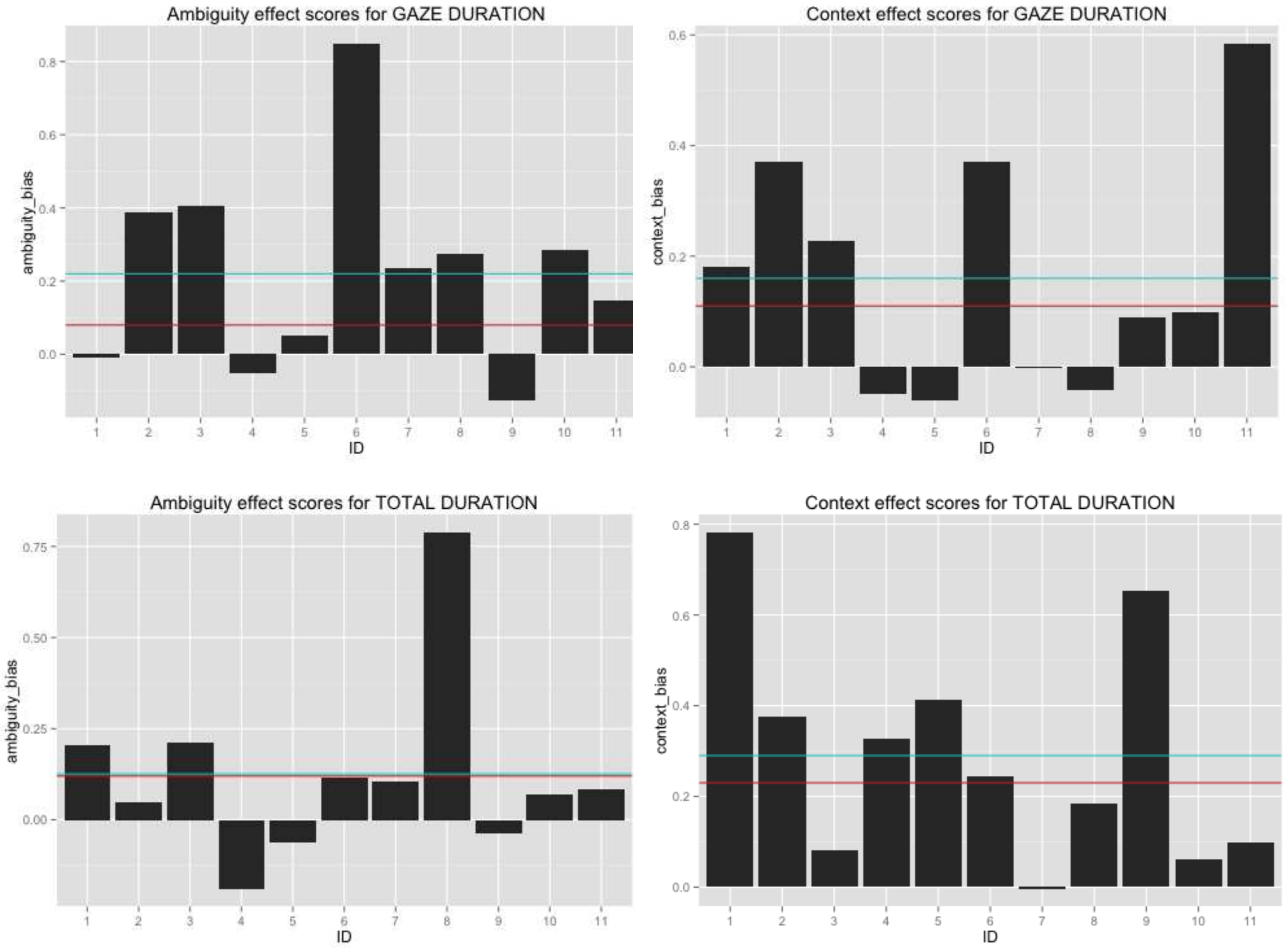


Figure 9.10. Bar graphs showing individual proportional effect scores by the PWA for ambiguity and context.

Note. Lines in turquoise represent the average effect score for the PWA; red lines represent the average effect score for the NHI.

Ambiguity effect

Seven out of eleven PWA showed an ambiguity effect in the predicted direction for gaze durations whereas three individuals showed a small reverse ambiguity effect, and one showed a minimal reverse effect. For total durations, eight out of eleven PWA revealed an ambiguity effect in the predicted direction, and three revealed a small reverse effect. Two out of three with mild reverse ambiguity effects in gaze durations also showed longer durations in the non-ambiguous compared to the ambiguous trials in total durations. Out of those individuals showing an ambiguity effect, there was variation in terms of the size of that effect. In gaze durations, ID 2, 3 and 6 showed an effect of ambiguity with durations at least 30% longer in the ambiguous compared to the non-ambiguous trials. ID 6 showed a very strong effect of ambiguity in gaze durations, with gaze durations being more than 80% longer in the ambiguous as compared to the non-ambiguous trials. ID 8 shows a very large ambiguity effect in total durations (over 0.75). As can be seen by the red (NHI) and the turquoise lines (PWA), the PWA were more sensitive to the ambiguity effect in gaze durations than the NHI, but there was no difference in the effect sizes for total durations.

Context effect

Similarly to the ambiguity effect, there was also much variation amongst individuals with aphasia regarding the context effect. Seven out of eleven PWA showed a context effect in the predicted direction in gaze durations, and nine in total durations. For gaze durations, the largest effects were shown by ID 2, 6 and 11 who demonstrated an effect of context with fixation durations at least 30% longer in the DO- compared to the SC-biasing sentences. ID 4, 5, 7 and 8 showed small context effects in the non-expected direction. For total durations, ID 1 and 9 showed the largest context effects, with fixations at least 60% longer in the DO-bias compared to the SC-biased conditions. Other individuals how varying but moderate context effects. In fact, only one individual (ID 7) showed no context effect. Overall, the context effect scores for gaze duration and total duration in the aphasia group were larger than for the control group. This is consistent with the trend interaction between group and context found in the Anova analysis.

Summary

The individual analyses of both the ambiguity and context effects revealed the heterogeneity of the aphasia group. Even though the majority of individuals were sensitive to the experimental manipulations, the proportional effect sizes varied. A small number of individual participants revealed reverse effects, although none of these effects was large. The following analysis aims to find reasons for the heterogeneity by correlating results from the background language assessments with the proportional effect sizes.

Correlation of bias effects with background assessments

In order to find out whether the ambiguity and context effects are related to the PWA's language skills, correlation analyses were run between the proportional effect scores for gaze and total durations and the results from the background assessment. Depending on the distribution either Pearson's or Spearman test were used.

Results from the correlations show two significant relationships between language/cognition skills and the context effects, but no significant relationships between language/cognition skills and the ambiguity effects. First, there was an association between the lexical written scores from the background assessments and the context effect in gaze duration, *r* = .70, *p* = .02. Readers with good lexical skills (95-100%) showed a smaller context effect than those with more impaired lexical skills (80-95%). Further, a significant negative relationship was found between the working memory digits backward test and the context bias for total duration, *r* = .67, *p* = .04. The more difficulties participants had in the digit backward task (e.g. with a score of 3) the smaller was the context effect.

9.3.5. Summary of the results

In this section, a summary of the results is given and an interpretation provided. In order to have a reference, an example experimental sentence is re-printed here, with both context bias conditions:

Table 9.15. Example of an experimental sentence with three regions of interests.

Context bias	**DO**	When Billy went to the party he did not know any familiar faces.		
	SC	Gordon had moved in with his old friend, but they argued a lot.		
Region		noun phrase (1)	disambiguation region (2)	post disambiguation region (3)
Sentence	…he *recognised* (that) *	his old friend *	had adopted *	a different * …

Global characteristics of the data

First of all, several eye movement measures relating to the whole sentence were analysed to compare global reading patterns between the people with aphasia and the neurologically healthy individuals. This revealed that the groups did not differ in average fixation durations, but differed in all other measures. The PWA showed more than the double number of fixations per sentences compared to the control group. They also had longer sentence reading times than the control group. As generally expected, accuracy analyses demonstrated that the NHI scored near ceiling whereas the PWA showed lower accuracy overall. Even though this difference in accuracy between the groups was significant, it shows only mild reading impairments by the PWA. The accuracy scores of the neurologically healthy individuals showed no sensitivity to the experimental manipulations. The aphasia group made most errors in the ambiguous DO-bias condition but this was not significant compared to the other conditions. Overall, there was an influence of ambiguity in that the PWA made more errors in ambiguous trials than in non-ambiguous trials, but this did not remain significant after the Bonferroni correction.

In summary, these findings suggest that the aphasia group had more difficulties reading ambiguous and non-ambiguous sentences than the control group. The PWA's offline comprehension was also mildly influenced by the presence of ambiguity. The fact that the groups did not differ in average fixation durations suggests that reading difficulty in this group was not driven by longer durations of each fixation, but by a larger number of fixations and re-reading patterns. This may imply that average fixation durations are largely automatic whereas the number of fixations are more sensitive to sentence difficulty and cognitive influences.

First research question (effects of context and ambiguity)

The first research question was whether eye movements show an influence of a verb's sense-based argument structure frequency (measured as context effect) and/or an influence of the presence or absence of the complementiser *that* (measured as ambiguity effect). Results are summarised for the disambiguation region (*had adopted*).

Both neurologically healthy and participants with aphasia showed longer fixation durations when the context sentence was DO-biasing (e.g. *When Billy went to the party he did not know any familiar faces. After a while he recognised (that) his old friend* <u>*had adopted*</u> *a different look and appeared completely different.*) than when it was SC-biasing (*Gordon had moved in with his old friend, but they argued a lot. After a while he recognised (that) his old friend* <u>*had adopted*</u> *a different lifestyle and living together would not work out.*). In the DO-biasing condition, readers were primed for the concrete meaning of *recognise.* They hence expected a DO-structure in the target sentence, as this is the most frequent structure to occur with the concrete meaning of *recognise*. Since the target sentence was a SC-structure, misanalysis occurred as shown by longer fixation durations in the region *had adopted*. In the SC-biasing condition, readers were biased towards the abstract meaning of *recognise*, i.e. 'realise'. This primed the readers for the SC-structure as this is the structure that most frequently aligns with the abstract meaning. As this was consistent with the target argument structure, no misanalysis occurred and fixation durations were not prolonged. Regarding the analysis of correct trials in the disambiguation region, the context effect was a trend effect for gaze durations and a significant effect for total durations, which remained significant after the Bonferroni correction. In the analysis of both correct and incorrect trials, context significantly influenced first fixation and total fixation durations (both significant after the Bonferroni correction). Context also influenced first pass regressions in that the NHI made more regressions out of the disambiguation region if the context was DO-biased than when it was SC-biased. The people with aphasia also made more first pass regressions if the trials were DO-biased compared to SC-biased, but only for the non-ambiguous trials. Again these effects were significant after correcting for multiple analyses.

Further, readers from both groups revealed longer fixation durations on the disambiguation region (*had adopted*) when the trial was ambiguous (*After a while he recognised his old friend had adopted a different look and appeared completely different.*) than when it was non-ambiguous (*After a while he recognised that his old friend had adopted a different look and appeared completely different.*). The ambiguity effect suggests that when readers accessed the complementiser *that*, this signalled a complement structure, which was indeed the target structure. When *that* was omitted, they expected the noun phrase to be the direct object, but this was revealed not to be the case when the disambiguation region was encountered. The analysis of the correct trials in the disambiguation region showed that the effect of ambiguity was significant after the Bonferroni correction for gaze durations, and less pronounced and not significant after the Bonferroni correction, for total durations. Regarding the analysis of both correct and incorrect trials, the ambiguity effect was significant for both gaze and total durations.

The results from the analysis of correct trials further showed a trend group interaction in total durations revealing that the PWA showed a stronger effect of context than the NHI. Even though this was not significant, results suggest that the aphasia group was sensitive to the context manipulation in both ambiguous and non-ambiguous trials whereas the control group was mainly influenced by the context in ambiguous trials. This may point to a difficulty in integrating both cues. There were no other group differences.

In summary, the analysis of the disambiguation region of the correct trials as well as of the correct and incorrect trials showed an influence of both context and ambiguity on the eye movements by the NHI and the PWA respectively.

First research question (effects of context and ambiguity – follow up questions)

If effects of context and ambiguity arise, additional questions were at what time course effects are shown, and whether factors are independent or interactive.

There are two sources of evidence that address the time course of processing. First, results can be compared regarding early vs. late eye movement measures. First fixation, gaze duration and first pass regressions are a measure of first pass reading. Total durations are a measure of first and second pass reading; hence a difference between gaze and total durations can be interpreted as being caused by second pass reading behaviour. Second, results can be compared regarding early vs. later regions of the sentence. In the following, result from the first pass measures of reading will be discussed, moving through the three regions of interest. Afterwards, results from the second pass measures will be discussed, again, reflecting all regions in turn.

For first pass measures, context was a trend effect on first fixation durations in the noun phrase region (*his old friend*) for the analysis by participants. Ambiguity also showed a trend effect in the noun phrase region for the analysis by participants, namely on gaze durations. Reading was less disrupted when *that* was present, and when the context biased for the SC interpretation. This suggests that when the NHI and PWA read the noun phrase, they were mildly aware of the biases – before they fixated on the disambiguation region. It is difficult to account for this finding of a processing advantage of the non-ambiguous trials and those in the SC-bias condition before the target structure unfolds. One reason might be that the readers benefited from parafoveal vision, and were thus already aware of the following structure. However, the extent that information from parafoveal vision, particularly lexical information, can affect the fixated region is controversial (White, 2008). When the readers approached the disambiguation region (*had adopted*), ambiguity was a significant effect on both first fixation durations and gaze durations for both the analysis by participants and by items, and context was a trend effect for gaze durations (a trend effect by participants and a significant effect by items). The ambiguity effect was robust and remained significant after the Bonferroni correction. This indicates that both NHI and PWA experienced a garden path. Further, there was a trend interaction between ambiguity and context on gaze durations, for the analysis by participants. This may suggest that the readers tried to integrate both cues at this early stage, i.e. in their first pass reading. When they read on to the post disambiguation region (*a different*), no effects were shown for duration measurements, but the NHI showed an influence of ambiguity on first pass regressions. The NHI made more regressions out of the region when the sentence was ambiguous.

For second pass measures (total durations), the ambiguity effect was significant in the noun phrase region (*his old friend*) for the analysis by participants, suggesting that the structural cue had an influence on re-reading behaviour. Context had an influence on total durations only in the analysis by items. Total durations further showed an interaction between ambiguity and context, indicating that readers from both groups re-read the noun phrase area to process and integrate both cues. In the disambiguation region (*had adopted*), total durations were affected by both ambiguity and context (for both analyses), but the latter effect was more robust than the former, and remained significant after the Bonferroni correction. This suggests that the later sentence processing stage was more affected by the context manipulation than by ambiguity. Participants were using the context cue to make sense of the sentence structure. Finally, in the post disambiguation region, the context effect still persisted in the analysis by participants, whereas ambiguity did not.

The analysis of both correct and incorrect trials for the disambiguation region revealed an early context effect on first fixation durations, and an early ambiguity effect for gaze durations. The later stage was equally affected by both ambiguity and context. All of these effects were significant for the analysis by participants and by items, and remained significant after the Bonferroni correction.

In summary, the analysis of the time course revealed both early and late effects of context and ambiguity on the eye movements by the NHI and PWA. However, in the analysis of the correct trials, the ambiguity effect was stronger in the early stage than in the late stage of reading, and the context effect exerted a stronger influence during the re-reading stage than during first pass reading.

The second follow up question was whether factors were independent or interactive. For the analysis of correct trials, there was a trend interaction between context and ambiguity for both groups in the disambiguation region for gaze durations, and a significant interaction between context and ambiguity in the noun phrase region for total durations. Durations were longest for ambiguous sentences following a DO-biasing context (*When Billy went to the party he did not know any familiar faces. After a* *while he recognised his old friend had adopted a different look and appeared completely different.*). This means that eye movements were mostly prolonged when both factors supported a DO-reading of the sentence, and when the effect of one factor was dependent on the effect of the other factor. The interaction between context and ambiguity was not found for total durations in the disambiguation region, but it was found for the noun phrase region. This indicates that the readers were successful in integrating both factors when they were re-reading the ambiguous noun phrase. However, the analysis of both correct and incorrect trials did not show any interactions. Results suggest that the manipulations in this experiment were only mildly interactive, and only if the sentences were understood correctly. This might indicate that comprehension difficulties of the sentences were related to an inability in integrating the cues successfully.

Second research question (individual effects and correlations)

The second research question was whether the PWA showed any individual differences in terms of ambiguity and context effects. Further questions were whether these can be related to their underlying language profile.

The PWA varied extensively with respect to their sensitivity to the context and ambiguity manipulations. The majority of participants showed effects in the expected directions, but some showed effects in the non-expected direction. Further, the participants varied in the size of the effects. Correlational analyses were carried out to find whether there was a relationship between language skills or working memory and the sensitivity to the studies factors. Consistent with the predictions, this showed that individual variations in written lexical skills were related to the context effects in first pass reading. The context effect was reduced when readers had very good lexical skills, that is, similar to the control group. Hence more lexical impairment leads to a greater reliance on the context sentence, but only for first pass reading. This could indicate that the biasing context sentence facilitated lexical access for those participants with reduced written lexical skills. However, there was no relation between lexical skills and the context effect for total durations which may suggest that mildly reduced lexical skills are more related to the speed of lexical activation than to lexical or semantic integration. In contrast to our predictions, no such relation was found for the ambiguity effect. This may suggest that all participants in this study had lexical skills that were sufficient enough to read and understand the complementiser *that*.

Another significant negative relationship proved to hold between working memory skills and the context bias for total durations. The magnitude of the context effect was larger if people scored higher and hence better in the working memory digit backward task. This suggests that working memory capacity is needed to use the meaning of the context sentence to reanalyse or reread the sentence. No other correlations between the background assessment results and the ambiguity and context effect were significant.

9.4. Discussion

This experiment examined whether sense-contingent argument structure frequency can affect the reading of structurally ambiguous sentences by people with aphasia compared to neurologically healthy individuals. Two factors were manipulated: context and ambiguity. The context biased the reader towards either the DO- or SC-sense of the verb and therefore hypothetically, its associated argument structure frequency. The ambiguity factor was the presence or absence of the complementiser *that*. The main aim was to establish whether these cues influence reading by people with aphasia and neurologically healthy individuals equally, or whether they differ, either in their sensitivity to them, or in their time course of processing.

In the following subsections, results are discussed and compared to previous research on probabilistic influences in sentence comprehension. The discussion is based on the results from the analysis of trials answered correctly, and some comparisons are made with the results from the analyses of both correct and incorrect trials. The first section starts with a discussion of the influences of context and ambiguity (9.4.1). The second section (9.4.2) addresses how the factors of context and ambiguity relate to each other, and whether they were integrated successfully during the process of sentence comprehension. The third section (9.4.3) will consider the time course of the effects, and will discuss implications for theories of sentence processing in the healthy population as well as in aphasia. Section 9.4.4 addresses individual differences in lexical knowledge and working memory skills, and how these relate to the results from the eye movement analysis. Section 9.4.5 considers the role of a general transitivity (DO-) bias in the English language. Finally, the last section (9.4.6) provides a conclusion.

9.4.1. Meaning-structure correlations in the reading by the PWA compared to the NHI

As predicted on the basis of constraint-based theories and on findings from previous studies, both the NHI and the PWA showed an influence of both context and ambiguity. Results from the eye movement analysis revealed that both groups had shorter fixation durations on trials in the disambiguation region if the context sentence primed for the correct SC-sense and structure, and when the sentence contained the complementiser *that*, which equally cued the SC-structure. These results were revealed by the analysis of the correct trials, and also by the analysis of the dataset including both correct and incorrect trials. Thus, findings from this experiment suggest that participants from both groups used the context cue that supported the target structure. Even though the sentence complement argument structure is the more complex sentence type, the difficulty of reading and understanding a sentence complement structure was mitigated by the presence of a context. This emphasises that non-syntactic factors can have a strong influence on reading and sentence comprehension. The context effect implies that readers could access correlations between meaning and structure since it cued a particular verb sense and its associated argument structure frequency. Some views of language acquisition argue that syntax and semantics are tightly linked, and that children learn such associations early (Gleitman, 1990; Pinker, 1984). Verbs that entail different meanings occur with different types of sentence structures, and these occurrences have different frequencies. Results from this study indicate that readers, both NHI and PWA, are sensitive to such frequencies during the process of sentence comprehension, and are more likely to expect the structures that frequently co-occur with certain verb meanings. The resilience of these form-meaning pairings to disruptions through language impairment may suggest that they are tightly encoded within the lexical representation of a verb and are a core aspect of language. If structure was constructed during sentence processing by referring to syntactic representations (i.e. tree structures), an early effect of the context bias would have not been expected. Instead, only ambiguity (the structural cue) should have an impact on parsing decisions.

For unimpaired processing, these results support findings from Hare and colleagues (2003) who originally used this design during self-paced reading. The study by Hare et al. equally showed an influence of both context and ambiguity on the reading durations of the segments corresponding to the disambiguation region. The results from the current study were largely consistent with the predictions set up by Hare et al., but were less straightforward. Results from the original study showed not only main effects of the context prime as well as ambiguity, but further, neurologically healthy individuals were influenced by syntactic ambiguity for those sentences that followed a misleading prime, pointing to an interaction between the variables. In the present study, the interaction between ambiguity and context was significant for the noun phrase region and was only a trend effect during the disambiguation region. This could indicate that both factors were strong and competing with each other in the disambiguation region. Hence, the context bias did not completely override the cue from *that*, and *that* did not completely override the context cue. The integration of the factors was successful when the noun phase was re-read in second pass reading. Overall, the findings suggest that associations between verb sense and structure influence the way healthy readers interpret garden path sentences (Hare et al., 2003). As argued my Hare and colleagues, this association is one of a variety of constraints that is accessed to determine the syntactic structure of the sentence.

Findings from Experiment 2 are also consistent with research on general argument structure frequencies that influence the comprehension of sentences with a temporal ambiguity (Garnsey et al., 1997; Spivey-Knowlton & Sedivy, 1995; Traxler & Tooley, 2007; Trueswell et al., 1993). According to these studies, frequency information can be encoded at a lexical level (MacDonald et al., 1994), and readers can use this information for structural decoding. This contrasts with other studies that emphasise the dominant role of structural rules in sentence processing (Calvo & Meseguer, 2002; Ferreira & Henderson, 1990; Kennison, 2001). The implications of findings with respect to theories of sentence processing will be discussed in more detail in Section 9.4.3.

Regarding the aphasia group, finding an influence of meaning-structure correlations supports previous research showing that PWA retain knowledge of statistical regularities within a language, and that these can facilitate sentence comprehension (DeDe, 2008, 2012b, 2013a, 2013c; Gahl, 2000, 2002; Gahl et al., 2003). The influence of probabilistic factors on the sentence comprehension of structurally simple sentences in aphasia has previously been shown in auditory comprehension (Gahl, 2000, 2002; Gahl et al., 2003), as well as in reading (DeDe, 2013c). If the experimental sentences were consistent with the verb's argument structure frequency, the people with aphasia made fewer errors, or showed faster reading times than for sentences that occurred in a different structure. Results from the current study further confirm that different subtypes of aphasia can be sensitive to probabilistic influences. This is consistent with a study by Gahl (2002) who has shown an influence of verb bias for people with Anomic aphasia. Intriguingly, results from the current study also add to the evidence that probabilistic relationships between lexical-semantic factors and structure facilitate the interpretation of sentences with a temporal ambiguity (DeDe, 2012b, 2013a). Therefore, probabilistic factors cannot only facilitate sentence comprehension and the rate of comprehension, but they also influence syntactic decoding. This extends claims of the lexical bias hypothesis (Gahl, 2002). According to this hypothesis, people with aphasia have fewer difficulties comprehending sentences that are consistent with verb bias than those that are inconsistent.

Importantly, results from this eye tracking study also expand the previous findings by showing that statistical regularities can be linked to subtleties of verb meaning. The results from the present study indicate that probabilistic cues are not only activated via specific lexical items. Readers with aphasia can also access probabilistic relationships between specific meanings of verbs and their associated argument structure frequencies. Showing that PWA can employ this information indicates that encoded meaning-structure relations are very entrenched in memory. This is consistent with exemplar-based models that assume that information needed for sentence processing is not accessed via rules but is accessed as a representation in memory (Bod, 2006). The assumption is that speakers store specific examples of linguistic experiences. During the process of sentence comprehension, we draw on such exemplars from memory (Bod, 2006). The influence of meaning-structure probabilities on sentence comprehension further underscores the fact that the syntactic composition of a sentence is influenced by an interplay of semantic, lexical and syntactic factors in combination with factors such as statistical regularities.

However, not all results conformed to our predictions. Like the NHI, PWA were sensitive to the presence or absence of the complementiser during the disambiguation region. The ambiguity effect was a robust finding for gaze durations. An effect of ambiguity was also shown on offline comprehension. PWA made more errors in ambiguous sentences than non-ambiguous sentences. Hence, the ambiguity effect was not reduced in comparison to the context effect as predicted. This is at odds with a previous study investigating verb bias and structural ambiguity effects in aphasia using self-paced reading (DeDe, 2013a). In the self-paced reading study, the PWA showed an influence of verb bias, but not ambiguity in the disambiguation region. For seven out of the nine participants with aphasia the verb bias was larger than the ambiguity effect. In this respect, they differed from the NHI who were sensitive to the presence or absence of *that*. The only region where PWA were sensitive to the complementiser was in the ambiguous noun phrase, as shown by an interaction between ambiguity and verb bias in the predicted direction. However, even though PWA in the study by DeDe (2013a) did not show sensitivity to the ambiguity in reading durations within the disambiguation region, they showed a greater number of comprehension errors in the ambiguous trials. DeDe (2013a) accounted for the difference between the groups by suggesting that the PWA relied more on the less reliable cue (verb bias), perhaps due to delayed processing of closed-class words. This interpretation cannot be supported by results from the current study, as the effect of ambiguity was significant for gaze durations, which are associated with the processing stage of lexical access. This suggests that the access of *that* was indeed successful. One reason for the discrepancy between the study by DeDe and the current study could be the magnitude of lexical impairment in the aphasia group. Whereas many PWA in this study performed near ceiling in lexical written comprehension tasks at the word level (e.g. 97% in the PALPA written word to picture matching subtest, (Kertesz, 1996), the group in DeDe's study presented with more pronounced difficulties as shown by a mean score of 75% on a written word to picture matching task from the Boston diagnostic aphasia exam (Goodglass, Kaplan, & Barresi, 2000). Hence it is plausible that PWA in this experiment had sufficient lexical skills to access the complementiser, and hence relied less on the context cue compared to the PWA in the previous reading study. This is consistent with other research finding that PWA can process the complementiser *that,* as shown in a grammaticality-judgment experiment (Dickey, Milman, & Thompson, 2008), and as revealed in a production task (Llinàs-Grau & Martínez-Ferreiro, 2014).

Results from the present study further demonstrated that the aphasia group diverged from the control group quantitatively but not qualitatively. The PWA showed (1) poorer accuracy in the comprehension questions, (2) differences in most of the global eye movement measures referring to the whole sentence, and (3) longer fixation durations and more regressions in all critical regions. However, even though the groups differed quantitatively in nearly all measurements, meaning-structure correlations had the same effects on both groups. Admittedly, the lack of a group difference in the experimental effects could be due to a lack of statistical power. The statistical analysis was based on eleven NHI and eleven PWA - undoubtedly a small group size. Another reason could be the severity of aphasia. The aphasia group in this current experiment had overall mild aphasia with an average AQ of 83.38. Nevertheless, the finding that probabilistic factors influence sentence comprehension in aphasia as well as in the healthy population confirms previous studies (DeDe, 2012b, 2013a, 2013c; Gahl, 2000; Gahl et al., 2003). The observation of similar effects of context and ambiguity in both groups could also suggest that the investigated meaning-structure correlations are very resistant to language impairment. This may also support the hypothesis that meaning-structure correlations are encoded within lexical representations. If the access of this information is intact, it may influence the resolution of structural ambiguity. Therefore, sentences that employ the probabilistically preferred structure for the verb sense are read faster than those that occur with a less frequent structure.

Interestingly, the influence of the context bias was not revealed in the offline measurements in this study, i.e. there was no significant difference in the comprehension scores between target sentences following a DO-bias and those following a SC-bias context. However, a context effect was shown by the analysis of eye movements. This may be due to the fact that the questions did not necessarily probe aspects of meaning that were commanded by the verb, i.e. they were not closely tied to the experimental manipulation. The discrepancy between off- and online measurements may also indicate that eye tracking is a very sensitive method that can reveal subtle differences in processing speed. It also underscores the fact that eye movements reveal automatic processing behaviour by the PWA, which is similar to normal processing. This is consistent with previous eye tracking studies that demonstrated that PWA and NHI show similar processing behaviour during the interpretation of structurally complex sentences even if offline comprehension is impaired (Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009).

9.4.2. Cue integration (independent or interactive patterns)

Another question of this study was how the factors of context and ambiguity relate to each other. One advantage of studying multiple influences on sentences with a temporary ambiguity is that results can show which factors or cues were employed, and whether some were weighted higher than others. If readers are sensitive to both cues and integrate them successfully, they should show an interaction between ambiguity and context as demonstrated in studies in the healthy population (Garnsey et al., 1997; Hare et al., 2003; Trueswell et al., 1993). This would be indicated by prolonged fixation durations in the disambiguation region in the ambiguous DO-bias condition, in which both the context and the ambiguity suggest the ultimately incorrect sentence structure.

The present study showed that the interaction between context and ambiguity was significant in the noun phrase region for total durations, and a trend effect for gaze durations in the disambiguation region. This may indicate that NHI and PWA showed an influence of both cues as soon as they read the disambiguation region, and regressed back to the noun phrase region in order to re-read. At this point, they were integrating the cues successfully. Interestingly, DeDe (2013a) found an interaction between verb bias and ambiguity during the noun phrase for self-paced reading for the PWA, suggesting that the integration process occurred before reading on to the next part of the sentence, which indicated the target structure. In our experiment on the other hand, the interaction was revealed in a measure that involves both first pass and second pass reading, and presumably after the target structure had been fixated. It is suspected that this difference is due to the nature of the different tasks. In self-paced reading participants can only see the next part of the sentence once they have pressed a button. They are thus more likely to complete processing before reading on. It could be that readers were processing both cues before they pressed the button to see the next reading segment. According to DeDe (2013a), this showed sensitivity to the verb bias and the complementiser before the disambiguation region. During eye tracking on the other hand, the reader can read through the whole sentence before re-visiting regions for interpretation or monitoring purposes. This can imply that reading difficulty due to a garden path effect motivated the readers to re-visit earlier parts of the text where the integration of the cues occurred successfully.

Based on the finding of an interaction in the study by Hare et al, an interaction was expected for Experiment 2 for the NHI group. For the PWA, no interaction between context and ambiguity was predicted, as they may have more difficulties integrating the cues. In contrast to our predictions, such group differences were not observed. Rather, both groups showed an interaction between context and ambiguity that was significant in the noun phrase region for total durations, and a trend effect for gaze durations in the disambiguation region. However, there was a trend interaction between group and context for total durations, suggesting that there were mild group differences. This showed that for the PWA, the effect of the context-cued subcategorisation probabilities occurred for both ambiguous and non-ambiguous trials, as found by DeDe (2013a). This was different to the NHI who showed the context effect predominantly for the ambiguous conditions. The pattern may indicate that the PWA did experience at least some difficulty in the integration of cues, and may have driven the missing interaction between context and ambiguity for total durations. Interestingly, this mild group difference was only observed in total durations, i.e. in the measure including first and second pass reading. In gaze durations, which showed a trend interaction between context and ambiguity for both groups, the PWA showed less indication of difficulty integrating the context cue (mean difference between fixations in DO- and SC-bias conditions for ambiguous trials: 146.53ms; context effect for non-ambiguous trials: 9.26ms) and the ambiguity cue (mean difference between fixations in ambiguous and non-ambiguous trials for DO-bias trials: 194.43ms; ambiguity effect for the SC-bias trials: 38.52ms). Hence, in gaze duration, the PWA behaved similarly to the NHI (context effect for ambiguous trials: 57.83ms; context effect for non-ambiguous trials: 3.7ms; ambiguity effect for DO-bias trials: 49.2ms; ambiguity effect for SC-biased trials:

4.87ms). This indicates that mild group differences with regard to the experimental manipulations occurred during the later stages of processing, when the PWA tried to re-read the disambiguation region, suggesting that they had difficulties overcoming the structural ambiguity.

It should be noted that no interactions or trend interactions between context and ambiguity were found for the groups in the analysis containing both correct and incorrect trials. This could indicate that there was more interaction in the correct trials than in the incorrect trials, implying that the sentences were less likely to be understood correctly if the factors were not integrated successfully. However, this tentative assumption cannot be confirmed by the results from the analysis of the incorrect trials as the number of aphasia participants with incorrect trials in all four conditions was too low to be meaningful. In summary, the data of both NHI and PWA show mild interactions between the context bias and the structural cue, the interaction was significant for total durations in the noun phrase region and a trend effect for gaze durations in the disambiguation region.

9.4.3. The time course of processing, and implications for theories of sentence comprehension

It was predicted that the groups would differ with respect to the time course of processing. This section first refers to the differences in processing speed between the groups, independent of the experimental manipulations. Subsequently, the time course of processing the influence of context and ambiguity are discussed.

First of all, the groups showed significant quantitative differences in nearly all measurements. People with aphasia showed more fixations, more regressions, and longer sentence reading times per sentence, and longer first fixation durations, gaze durations, and total durations in all analysed regions. The only difference to the result from the first experiment was that the global results showed no significant difference in average fixation durations between the two groups even though they did in the first experiment. Whereas the average fixation durations by the PWA were similar between the experiments, the average fixation durations from the NHI were much longer in the second experiment compared to the first one (M = 224 ms in Experiment 1 vs. 271ms in Experiment 2). This increase in durations may be caused by the more complex and longer sentences in the second experiment. It is known that typographical variables including line length influence eye movements (Rayner, 1998).

As in Experiment 1, the quantitative group difference was most pronounced in total fixation durations, suggesting that the aphasia group needed more time to re-read the sentence and to integrate lexical items into the sentence structure. Similarly, Knilans and Dede (2015) found that PWA differed from controls in that their first pass reading was relatively fast but their subsequent passes were much longer and involved re-reading, particularly the last word. The authors suggest that this behaviour may reveal that PWA spent more time in clausal wrap-up processes, or may reflect difficulties in syntactic parsing. The quantitative group differences had already been shown in the first experiment, and were discussed in Chapter 7. Finding similar differences in eye movements between the groups in Experiment 2, which involved more complex stimuli, underscores the assumption that eye tracking is a method that can reveal both difficulties in visual word recognition as well as sentence processing. As discussed in Chapter 7, the differences in eye movements between the PWA and the NHI are consistent with a number of previous eye tracking studies that showed that sentence processing by PWA is associated with either delays in lexical processing, lexical integration difficulties, or both (Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Meyer et al., 2012; Thompson & Choy, 2009).

Expectations regarding the time course of processing the influence of context and ambiguity were that the PWA would show effects at a later time point than the NHI. The time course of processing these effects can be explored in two ways. One relates to the region of the sentence (early vs. late regions), and the other relates to the nature of the measures with some recording first pass reading (such as first fixation duration, gaze duration, first pass regression) and the other recording second pass reading (such as total durations). The first sources of evidence found no difference between PWA and NHI. Context and ambiguity influenced first and second pass measures in both groups. There was a trend interaction between group and context for total durations. As discussed in the section above, the nature of this interaction was a non-significant context effect for the PWA for both ambiguous and non-ambiguous trials. This suggests that the PWA may have had difficulties integrating the context and the structural cue when they were re-reading the disambiguation region. An earlier measure (gaze duration) did not show any indication that the groups behaved differently. This could mean that the PWA started the reading process similarly to the NHI, but when they experienced the garden path, it was more challenging for them to integrate the cues in order to interpret the correct sentence structure. Hence, neither context nor ambiguity influenced reading by the PWA in a later region compared to the NHI. The influence of context did not, for instance, show in the disambiguation region for the NHI but in the post-disambiguation region for the PWA. This finding is inconsistent with previous studies. DeDe (2012b), for example, found that both NHI and PWA were sensitive to lexical and prosodic cues in the auditory comprehension of early closure ambiguities, but the PWA showed the effect of the cues one region later than the NHI. According to DeDe, the slowed integration of cues into the sentence context supports the argument that aberrant lexical integration influences syntactic parsing, consistent with results by Thompson and Choy (2009) and Meyer and colleagues (2012). Other studies using eye tracking whilst listening observed effects for the aphasia group after sentence offset whereas the neurologically healthy controls showed the same effect in an earlier sentence region (Meyer et al., 2012).

In contrast to the evidence relating to the regions, the second source of evidence regarding the time course did show differences in the time course of processing the sentence cues. Group differences in this study were pronounced in total durations, which include re-reading and regressions. Hence, prolonged total durations indicate longer processing time, and is evidence for delayed processing of the ambiguous and the non-ambiguous sentences. One reason why group differences did not show by the analysis of regions, but did by the analysis of eye movement measures might be the modality of the experiment. Previous studies that found experimental effects at a later time region for PWA compared to NHI investigated auditory, rather than written processing (DeDe, 2012b; Thompson & Choy, 2009; Meyer et al., 2012; Mack et al., 2013). Participants listened to the sentences that were divided into regions. It was not possible to move back to an earlier region in the sentence and listen to it again. Hence, listeners could not control the rate of the input (DeDe, 2013a). In contrast, during written sentence comprehension, the reader has more control and can move the eyes back and forth in the text. Another study on verb bias on reading in aphasia showed effects in the same region as neurologically healthy individuals (2013a), and in line with findings from the current study. This strongly indicates that differences between previous results and findings from the current study are due to the modality studied (DeDe, 2013a). It is assumed that in reading, delayed processing shows through a prolonged late measure, but in a region that creates the difficulty, or that is essential to interpret the sentence.

A delay in the integration of lexical context information has also been found in a priming study on the processing of lexical ambiguity (Swaab et al., 1998). Participants listened to sentences including a lexically ambiguous word. The ambiguous word appeared in a concordant, a discordant and unrelated context. Results suggested that the people with Broca's aphasia activated both meanings of the lexically ambiguous word, and had difficulties integrating the meaning that was appropriate in the concordant context. The control participants on the other hand were able to suppress the contextually inappropriate meaning. When participants listened to the same sentences but at slower pace, the people with aphasia and the control participants showed the same patterns. This points to a delay in the integration of lexical information.

Interestingly, a previous study has also shown that PWA are delayed in their use of a verb meaning cue (Mack et al., 2013). Mack and colleagues carried out two visual-world paradigm studies to investigate whether PWA can use cues from verb meaning to predict and facilitate the integration of noun phrases arguments. In their second experiment, the NHI and PWA listened to incomplete sentences, which entailed either a restrictive verb (e.g. *Tomorrow Susan will open the…* – compatible with one picture) or an unrestrictive verb (e.g. *Tomorrow Susan will break the…*– compatible with all four pictures) and looked at an array of four pictures whilst their eye gaze was recorded. Result showed that the control participants were able to use the verb meaning (restrictive vs. unrestrictive) in a predictive manner; they showed an effect of verb meaning on the eye movements 500ms after verb onset. This is an effect of prediction as the noun phrase was omitted in the second experiment. The PWA did not show the effect of verb meaning as immediately, but they showed the same effect as the control participant's 1000-1500ms after the verb offset, hence very delayed. Mack et al. argue that the PWA can access the verb meaning but cannot make timely predictions about the upcoming arguments. The observed difference in the time course of processing cues from verb meaning/context may be comparable to the results from the current research, as the PWA showed such prolonged fixation durations compared to the NHI.

Our results are most similar to a recent eye tracking study on the processing of lexical ambiguity in a sentence context in Russian (Laurinavichyute et al., 2014). Their visual world paradigm study examined the process of lexical access, lexical selection and integration, comparing people with non-fluent and with fluent aphasia to a control group. They found that all participants showed an influence of a context bias under a slowed speech rate: when the context biased the target meaning of the ambiguous words, participants fixated the target picture more than the competitor picture. As argued by Laurinavichyute and colleagues, this suggests that the PWA could perform lexical access and integration. However, the people with non-fluent aphasia showed slower activation of the meanings of the ambiguous words. They showed lower target advantage scores in the disambiguation region. This was interpreted as an impairment in activating multiple interpretations in a later stage. These results are consistent with the finding from the current reading study that early measurements showed difficulties in integrating the context bias with the presence and absence of *that*. However, integration was successful in later processing stages. In conclusion, the current experiment points to slowed lexical access, and a delay when available information has to be integrated in order to successfully disambiguate structure.

The influence of context and ambiguity on the time course of processing has implications for theories of sentence processing. These theories give rise to different predictions. To reiterate, the garden path model predicts that probabilistic influences such as the context bias cannot influence syntactic parsing, but can be accessed to re-analyse a misinterpreted structure. The results from this experiment are not consistent with this approach as there was an early trend effect of the context bias. Further, in the analysis of the disambiguation region with correct and incorrect trials, context had a strong effect on first fixation durations. These findings demonstrate that readers were sensitive to the context manipulation at the moment that their first fixation landed on the disambiguating sentence region. This may suggest that this region was not in line with their expectations based on the context. According to constraint-based theories, any sources of information including probabilistic influences such as the context bias can influence the initial stage of processing. The results from this study mostly support this theory. While the context effect was the strongest for later measurements it was nevertheless present in the early ones, as trend effect for gaze duration in the correct trials, and as significant effect on first fixation durations in the dataset including incorrect trials. Since the garden path theory does not allow any early influence from a sentence context, the data are most compatible with constraint-based theories.

9.4.4. Individual differences

The second aim of this study was to examine whether the PWA show any individual differences in terms of ambiguity and context effects, and if yes, whether these can be related to their underlying language profile or to differences in working memory. It was expected that better lexical-semantic skills would be associated with smaller context effects. Regarding working memory capacity, it was predicted that greater capacity is associated with larger context effects.

Correlational analyses confirmed these predictions, showing that better lexical written scores from the background assessments were correlated negatively with the context effect for gaze durations. This suggests that while all readers use the context cue, those with reduced lexical written skills rely on the context cue more than those with good lexical skills. This result may seem surprising as it implies that the people with reduced lexical written skills are able to access information about associations between form and meaning that are assumed to be entailed within lexical representations of the verb. However, the more frequent an association between meaning and form is, the easier it might be to access that information. Hence, people with mild to moderate lexical impairments are able to access lexical information, particularly the high frequency information. In this experiment, all stimuli employed highly frequent form-meaning correspondences, and this would explain why people with lexical skills were able to access them. Finding an enlarged effect of context may be similar to finding a magnified word frequency effect in people with aphasia who have lexical impairments (Experiment 1). If it is more difficult to access lexical information, the frequent meaning-structure correlation may be easier to access than the less frequent association. Further, the processing system of readers with reduced lexical skills may have learnt to rely more on the influence of a context in order to compensate for less efficient bottom-up processing, as established by Experiment 1. A dependence of processing on lexical knowledge has previously been found in the healthy population (Traxler & Tooley, 2007). Traxler and Tooley found a correlation between lexical knowledge and the magnitude of ambiguity effects in ambiguous sentence complement sentences with DO-biased verbs. The authors argue that the finding of individual variation based on lexical knowledge conforms with lexically mediated parsing accounts such as constraint-based theories (MacDonald et al., 1994). If processing was contingent on syntactic knowledge per se, lexical knowledge should not have an effect on early parsing. These theories are particularly supported by findings from this study as lexical skills modulated the context effect in gaze durations, and hence the early processing stage.

However, results from this experiment did not reveal a link between lexical impairment and the ambiguity effect. This would suggest that the PWA in this study had sufficient lexical skills to access and process the complementiser. The context cue is more sensitive to lexical skills than the structural cue, and differences in its use can be due to gradual differences in lexical knowledge. Hence lexical skills by the participants from this study modulated the context use, but not the use of *that*. Further research is needed in this area to investigate whether probabilistic factors generally play a larger role in aphasia as compared to the healthy population and whether this relates to patterns of lexical impairments. It would also be informative to study additional ambiguities, which may induce stronger garden paths than the DO/SC ambiguity studied here. A more complex type of ambiguity is, for instance, the temporarily ambiguous reduced relative clause (e.g. *The actress selected by the director believed that*…), where *selected* is the point of ambiguity as it could be the main verb or could indicate a reduced relative clause (Spivey & Tanenhaus, 1998).

As expected, correlations in this study also revealed a significant negative relationship between the working memory digit backwards test and the context bias. This correlation was in a different direction than the one involving written lexical skills. The context bias effect was larger when the participants scored higher in the digit task than when they scored lower. The correlation suggests that the context cue can only be accessed if working memory capacity allows this. Holding information from the context sentence in memory until decoding the sentence structure may pose high demands on working memory. This finding supports the argument by MacDonald and colleagues (1994) that good working memory capacity is associated with a successful access of probabilistic cues in sentence processing. More generally, finding a relationship between language processing and working memory skills is consistent with other research in aphasia (Caplan & Waters, 1999; Caspari et al., 1998; Christensen & Wright, 2010; Friedmann & Gvion, 2003; Haarmann et al., 1997; N. Martin & Reilly, 2012; Miyake et al., 1994; Sung et al., 2009; Wright et al., 2007; Wright & Shisler, 2005). It is interesting though that the relation was found between working memory and context effects, and not between working memory and the ambiguity effect. This may indicate that working memory is more directly linked to a readers' expectation of statistical patterns of language – as learnt through language exposure (MacDonald et al., 1994). If the context cue cannot be accessed due to working memory constraints it, the statistical association to the structure of the verb sense cannot be accessed either. Nevertheless, the reader is sensitive to the structure cue, which can be exploited as long as the complementiser can be accessed in the lexicon, and as soon as it is encountered.

The relation between working memory and use of the context cue fits nicely into the theory by Miyake and colleagues (1994). The sentences used in this experimental paradigm were structurally complex and long, and hence resource-demanding. According to Miyake and colleagues (1994), high resource demands can lead to competition between storage and computation, and this can result in failure of one or parts of the system. Since the correlation was significant for the digit backward test, which involves a manipulation of the digits, it suggests that the computation function was limited during the processing of the ambiguous sentences. The context sentence can then not be used to parse the sentence structure. As mentioned above, the link between lexical skills and the ambiguity effect in the DO/SC ambiguity had also been revealed for the healthy population. However, the study by Traxler and Tooley (2007) did not find such relation between working memory capacity and the ambiguity effect. They assume that this may be due to the rather mild disruption of processing that is caused by the DO/SC ambiguity. It might be that these sentences are not resource-demanding enough to find a significant impact of working memory skills. The finding that there is a relationship between working memory and the use of the context cue in sentence processing in aphasia indicates that first, sentences with a DO/SC ambiguity may be more demanding for people with reduced language skills, and secondly working memory capacities can modulate the use of cues to overcome the experienced disruption of the ambiguity. Finally, it should be kept in mind that variability in working memory capacity after a stroke is likely to be higher than variability in working memory in the healthy population. Most of the participants with aphasia that completed Experiment 2 had mild reductions in working memory.

In summary, this section established that the context effect is modulated by both lexical knowledge as well as cognitive processes such as working memory. This finding indicates that sentence processing depends on non-syntactic influences, and supports constraint-based theories (MacDonald et al., 1994; MacWhinney & Bates, 1989; McRae et al., 1998; Seidenberg & MacDonald, 1999; Spivey-Knowlton & Sedivy, 1995; Trueswell et al., 1993; Trueswell, 1996). Whereas an early influence of lexical skills on the context effect was found, correlational analyses revealed no association between sentence comprehension skills and the influence of *that*. This does not align with the garden path theory, which predicts autonomous syntactic processing in the first stage of analysis. The PWA from Experiment 2 showed significant differences in the comprehension of canonical vs. non-canonical sentences indicating symptoms of agrammatism. Yet, this impairment in sentence comprehension was not found to be related to their ability in using the structural cue.

9.4.5. The role of the SVO preference

As described in the study by Hare and colleagues (2003), the study design used here permitted the analysis of sense-dependent structural tendencies and the influence of temporary ambiguity on sentence reading. However, there are other probabilistic constraints beyond those that have been manipulated, and these might also affect eye movement behaviour. This section discusses the influence of a global transitivity bias in the English language. This bias refers to a general preference for a verb to occur with a direct object (Bever, 1970). The assumption of the global transitivity bias is also accounted for in the maxim of minimal attachment in the garden path theory (Frazier, 1987b). According to minimal attachment the parser adopts the simplest structure for initial analysis, the simplest structure being the one with the fewest syntactic nodes, and hence the transitive structure. A global transitivity bias was previously reflected in two studies involving the resolution of sentences with a temporal ambiguity in aphasia (DeDe, 2012b, 2013a). The study on the comprehension of ambiguous early closure sentences (DeDe, 2012b) showed that the NHI had the shortest listening durations in the ambiguous noun phrase condition that included both a verb bias and a prosody cue, supporting the S, V, O structure – but only at the ambiguous noun phrase *the child* (*While the parents* ***watched*** <u>*the child*</u> *sang a song with her grandmother*, with *watch* being a verb with a transitive bias), i.e. before the misanalysis became apparent. In contrast, the PWA showed long listening times in the ambiguous noun phrase region when the cues biased against the preferred S, V, O structure (*While the parents* ***danced*** <u>*the child*</u> *sang a song with her grandmother*). The S, V, O preference was not observed for the control group. The global bias is also reflected by the verbs employed in Experiment 2: if sense-based argument structure preferences are ignored, then all ten verbs have an overall verb bias towards a DO (form-based argument structure preferences). Hence, in this experiment, the global transitivity bias cannot be distinguished from the form-based argument structure preferences.

If NHI and PWA were sensitive to the global transitivity bias in this experiment (or form-based argument structure preferences/structural simplicity), regardless of the context bias, they should have shown the shortest fixation durations in the noun phrase region for the DO-bias ambiguous condition. In this condition, both the context and the omission of that favoured a DO-structure. However, there was no indication that readers found the noun phrase region for the DO-bias ambiguous condition the easiest to process. Rather, the ambiguous DO-bias condition stimulated the longest first fixation and gaze durations in the noun phrase region. Prolonged fixation durations in the disambiguation region cannot differentiate between predictions of constraint-based theories and the global transitivity bias as prolonged fixations would be predicted by both theories. Overall, findings provide evidence that the transitivity bias/principle of structural simplicity did not play a bigger role than the context bias. If the principles of structural simplicity and the transitivity bias were stronger than the context cue but not stronger than the ambiguity cue, readers should have shown equally extended fixation durations in the disambiguation region for the ambiguous DO-bias as well as the ambiguous SC-bias condition as compared to the non-ambiguous trials. This would mean that there would have been no effect of context, but an effect of ambiguity only. Again, this pattern did not occur. Thus, an overall transitivity bias may have played a role in this study, but results suggest that it was only a partial effect.

9.4.6. Conclusion

This eye tracking experiment showed that both PWA and NHI were sensitive to manipulations from ambiguity and sense-contingent argument structure frequencies when they read sentences including the DO/SC ambiguity. Results showed qualitative similarities between the groups. Both experienced facilitation from the structural marker *that* as well as the context sentence. This suggests that online reading of structurally complex sentences by both groups is influenced by meaning-structure probabilities, and indicates the entrenched nature of these probabilities in the language system.

Investigating the relationship between the ambiguity and the context cue as well as the time course of processing also revealed some differences between the people with aphasia and the neurologically healthy individuals. Findings showed a mild interaction between the variables in the noun phrase region in that the context effect was strongest for the ambiguous trials, as expected. Results also indicated that the PWA may have had difficulties integrating the cues during the later stages of processing, when they re-read the disambiguation region. However, this interpretation rests on a trend effect only, and further research is needed to understand the integration of cues better in aphasia. The later processing stage is where the biggest quantitative differences occurred between the groups, with the PWA showing much longer total durations than the NHI. This finding is consistent with other studies on lexical contributions to sentence comprehension impairments in aphasia that suggest a lexical impairment particularly in later stages in which PWA re-process and attempt to integrate information from the different sources available. However, the PWA also showed longer durations in the first pass fixation measures suggesting that lexical access was slowed as well.

Overall, results are consistent with constraint-based approaches that emphasise the role of probabilistic relationships between lexically encoded meanings and sentence structure (Hare et al., 2003; MacDonald et al., 1994; Seidenberg & MacDonald, 1999; Trueswell et al., 1994, 1993; Trueswell, 1996). Word-level information contributes to reading and interpreting structurally complex sentences. Further support for this was the evidence that the context effect in an early stage of processing was dependent on written lexical skills. A lexical influence on early sentence processing would not be predicted in the garden path model that gives priority to syntactic influences on sentence decoding.

The results are further consistent with processing accounts, which assert that sentence comprehension impairments can be due to impairments in lexical processing (Choy, 2011; Love et al., 2008; Meyer et al., 2012; Thompson & Choy, 2009).

Chapter 10. General discussion

In the introduction to this thesis it was stated that reading is incremental in that multiple information sources are integrated rapidly at each moment in time. The focus of this thesis was on information sources that relate to our experience of language, specifically frequency and context. This chapter begins with a brief summary of the goals and the results of the two experiments (10.1). The second subsection addresses the reading and eye movement characteristics of the individuals with aphasia that were observed in both experiments (10.2). The third subsection considers the influences of frequency and context and relates the experimental findings from both experiments to implications for theories of sentence comprehension (10.3). The fourth subsection describes some implications for clinical practice (10.4). Lastly, some limitations will be addressed (10.5.) before some directions for future studies are proposed (10.6).

10.1. Goals of the experiments and summary of the results

Research has demonstrated that silent healthy reading is influenced by factors of language usage. Employing knowledge of statistical patterns of language may lead to predictions and expectations in reading that can contribute to fast and efficient processing. The frequency of a word as well as the context in which a word appears, are two probabilistic factors that influence eye movement behaviour and reading (Calvo & Meseguer, 2002; Kennedy et al., 2013; Kliegl et al., 2004; Rayner et al., 2004, 2001, 2011). Additionally, frequency and context can also play a role in sentence comprehension. It was shown in healthy reading that the sense-contingent frequency of an argument structure influences the reading of sentences containing a structural ambiguity (Hare et al., 2003). A sentence context that cues readers more towards one verb sense than the other one leads to structural expectations based on the argument structure frequency of the activated verb meaning. Thus, meaning-structure correlations influence structural decoding in ambiguous sentences.

Several studies carried out in aphasia research suggest that people with aphasia may also be sensitive to such probabilistic factors in silent sentence reading. The literature reports influences of word frequency and context in different areas of language such as naming, repetition, reading and sentence comprehension (Bose et al., 2007; Bub et al., 1985; DeDe, 2012a; Kim & Bolger, 2012; Kittredge et al., 2008; Nozari & Dell, 2009; Pashek & Tompkins, 2002; Pierce & Wagner, 1985; Zingeser & Berndt, 1988). Importantly, there is also evidence of argument structure frequency influences on sentence comprehension in aphasia (DeDe, 2013a, 2013c; Gahl, 2000, 2002; Gahl et al., 2003). However, these influences have not always been shown for all types of aphasia and it has not been established whether the factor of argument structure frequency is linked to meaning, as shown for healthy reading. Further, there is much evidence that people with aphasia have lexical and/or semantic impairments (Ferrill et al., 2012; Grindrod & Baum, 2003; Laurinavichyute et al., 2014; Love et al., 2008; Mack et al., 2013; Myers & Blumstein, 2005; Prather et al., 1997; Thompson & Choy, 2009; Utman et al., 2001; Yee et al., 2008). This may suggest that influences of frequency and context, which are interwoven with lexical-semantic factors of language, differ from controls, either in their pattern, or time course of processing.

The goal of this thesis was to establish whether factors of language exposure influence reading of people with aphasia in parallel to that of neurologically healthy individuals. Even though it was expected that the groups would differ in both comprehension accuracy and reading pace, it was assumed that frequency and context might still contribute to reading, even if showing a different pattern and/or time course. The first experiment examined the influence of word frequency and contextual predictability of word recognition at the sentence level. The second experiment examined the influence of sense-contingent verb argument structure frequency on the reading of sentences that are temporarily ambiguous.

The main results demonstrate that the people with aphasia as well as the neurologically healthy controls are sensitive to factors of frequency and context; both in the process of visual word recognition, and in the reading of structurally ambiguous sentences. The first experiment revealed strong effects of word frequency on fixation durations. The context also strongly influenced fixation durations as well as first pass regressions, but the context effect was larger in the aphasia group compared to the control group. The second experiment demonstrated effects of sense-contingent argument structure frequency for both groups. The results from both groups showed a mildly interactive pattern between the influence of the context bias and the presence or absence of the complementiser *that*, suggesting that the readers were able to integrate these cues.

10.2. Eye movement characteristics of mild reading difficulties in aphasia

Whereas reading research in psycholinguistics has hugely benefited from using eye tracking to study the process of reading, this online method has been used much less in aphasia research. The study of sentence-level reading has not gained much attention in aphasia research, which is dominated by examinations of listening ability. Investigating reading at the sentence level in aphasia therefore constitutes a paradigm shift from a focus on auditory sentence comprehension to written sentence comprehension. The recent advances in eye tracking technology made the eye tracking reading paradigm much more applicable for studying reading involving people with aphasia. Thus the current thesis drew on methods from psycholinguistic research to examine eye movement characteristics of people with aphasia who have mild difficulties in reading. These newer methods can provide empirical evidence for observations that were previously limited to measures that revealed the end result of processing (such as accuracy), or implemented measurements that create non-natural reading situations (such as self-paced reading).

A systematic search of the research literature showed that the current thesis adds to very recent and so far limited research on silent reading in aphasia using eye tracking. Findings from the current experiments provide empirical evidence for the observation that silent reading is often slowed and more effortful in a group of participants with mild aphasia of mixed subtypes, which has up to now been an under-researched population. Effortful reading was evidenced by longer sentence reading times, more fixations, and more regressions in the analyses of sentence level reading in both experiments. The analyses of the critical regions confirmed these differences by revealing longer first fixation durations, gaze durations and total durations and more first pass regressions for the aphasia group compared to the neurologically healthy individuals per critical region.

The pattern of eye movement differences between the participants with aphasia and the neurologically healthy individuals (independent of experimental manipulations) is mainly one of degree rather than of type or quality[32]. Similar differences, yet of smaller degree, have been found in psycholinguistic studies that compared young with old readers, and skilled with average readers (Ashby et al., 2005; Kliegl et al., 2004; Rayner et al., 2006). Reading studies using eye movement generally show that the rate and efficiency of visual word recognition is dependent on reading skill (Ashby et al., 2005; Jared et al., 1999). However, group differences from the current study are much more pronounced than those observed in healthy reading. The difference in mean gaze durations of young and old readers was 44ms in the study by Rayner and colleagues (2006) whereas the difference between readers with and

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[32] Finding an increased number of regressions in the aphasia group compared to the control group could also be seen as a qualitative difference to healthy reading as it implies that readers with aphasia moved their eyes back to earlier points in the sentence more often than healthy readers. This could be seen as a different reading behaviour.

without aphasia in this study was 105.49ms. Group differences that manifested in eye movement differences have also been observed in acquired and developmental dyslexia (De Luca et al., 2002, 1999; Schattka et al., 2010). As found in the current study, readers with acquired dyslexia in the study by Schattka et al. differed from healthy readers by having an increased number of fixations and increased total fixation durations when they read word lists out loud (Schattka et al., 2010). The group difference in total fixation durations was larger than in the present study, showing a difference of 1270ms compared to a difference of 599ms in this study. The finding that the people with aphasia from the group in this thesis did not show a group difference of the same size as in the study by Schattka et al. could be due to the fact that they had relatively preserved word reading skills whereas the participants in the study by Schattka and colleagues had reading difficulties at the word level. Further, Schattka et al. investigated oral reading, which leads to longer fixation durations generally, and can be challenging for people with aphasia due to an additional processing level requirement of phonological encoding. It is surprising however that word level difficulties associated with acquired dyslexia were not reflected in gaze durations but they were in the current investigation. The authors note that this could indicate the readers with aphasia left the word before word recognition was completed successfully, and hence extra processing was required in later passes (Schattka et al., 2010). Overall, findings from this research indicate that there are processing similarities between individuals with mild aphasia and healthy readers, and that differences are largely of a quantitative nature.

The data above provide evidence on the time course of processing in aphasia. Prolonged gaze and total durations suggest that reading difficulties arise from delayed processing in both the initial stage of lexical processing as well as later stages of reading. Even though there is no direct correspondence between temporal eye movement measures and specific stages of processing (Rayner & Liversedge, 2011), the eye movement behaviour indicates that readers with aphasia require more time for lexical access, for meaning access, and for the integration of items into a sentence context. This interpretation is further supported by the observation that the people with aphasia in these experiments showed an increased number of regressions. In the first experiment, controls made an average of 3.16 first pass regressions per sentence, and people with aphasia regressed with a mean of 10.43 per sentence. This signifies that the people with aphasia were much more likely to move the eyes back to an earlier region in the sentence in order to re-read, and this must have contributed to the prolonged total fixation durations. An increased number of regressions has also been reported in a recent study on eye movements in reading in aphasia (Kim & Bolger, 2012), and has previously been shown in older readers (Kliegl et al., 2004; Rayner et al., 2006) as well as in developmental dyslexia (De Luca et al., 2002, 1999). Like gaze durations, regressions can indicate difficulties in lexical access (Ashby et al., 2005), or can reflect general comprehension difficulties (Rayner, 1998). Whenever a reader encounters a word that is difficult to access or integrate into the context, he/she leaves the word to re-read from an earlier point in the sentence.

As discussed in Chapter 7, the most pronounced group difference appeared in total fixation durations. This finding is consistent with the hypothesis that people with aphasia have difficulties in the process of lexical integration (Dickey & Thompson, 2009; Thompson & Choy, 2009), which is generally shown in later processing stages as it necessarily occurs after lexical access. However, the group difference in total duration can also reflect poorer linguistic processing in general (Schattka et al., 2010). As noted by Schattka and colleagues, prolonged re-reading durations may also signal increased monitoring demands in reading. These are likely to increase at a later stage of processing, as this is when more resources are needed for the meaning construction of a sentence. The implications of results for theories of sentence comprehension will be discussed in the next subsection.

Finally, further analyses revealed some of the origins of reading difficulties. Intact semantic skills and working memory capacity are associated with efficient reading that bears more similarity to reading in the healthy population. Better semantic skills are related to shorter gaze and total durations. Similarly, better working memory as tested in a digit span task are also related to shorter first and second pass eye reading measurements.

In summary, results from these experiments indicate that eye movements are sensitive to mild reading impairments in aphasia. Having established these findings using eye tracking strongly suggests that the summarised aspects are part of natural reading, and have psychological validity, as eye movements are closely related to cognitive processing. Revealing characteristics of mild reading impairment is highly relevant as traditional reading tests are often not sensitive to reductions in reading speed and efficiency. If comprehension questions are answered correctly, individuals often achieve high scores in such tests. However, the results from the eye tracking experiments demonstrate that even people with mild comprehension impairments show vastly different online reading behaviour compared to neurologically healthy individuals. Revealing these quantitative reading differences is essential as they reflect the individuals' subjective judgments on reading enjoyment, as evidenced by questionnaires on reading confidence and emotions. The difficulties considerably decrease reading enjoyment and have therefore a negative impact on quality of life.

10.3. Effects of frequency and context and implications for theories of sentence processing

Two eye tracking experiments carried out in the present thesis show that frequency and context are factors that strongly influence both visual word recognition as well as structural decoding during the reading of sentences with a temporary ambiguity. Finding a word frequency effect in sentence level reading supports findings from a recent study that revealed a word frequency trend effect at the sentence level using self-paced reading measures (DeDe, 2012a). Results from this eye tracking study extend the previous results by showing a strong word frequency effect in a measure where stimuli reading is naturally controlled by the reader and not limited to segment by segment reading. Word frequency effects have interested researchers for a long time, and have previously been shown in other, mainly offline, tasks (Jescheniak & Levelt, 1994; Kittredge et al., 2008; Nozari et al., 2010; Zingeser & Berndt, 1988).

Next to the word frequency effect, the first experiment revealed that a sentence context influences the process of visual word recognition in both the PWA and the NHI. However, the PWA relied more on the context, which was interpreted as a compensation mechanism: when bottom-up processes and hence lexical access is impaired or delayed, the processing system compensates by relying more on top-down influences such as the context to facilitate visual word recognition and the integration of the word into the sentence. Finding that reading in aphasia is associated with top-down processing support is consistent with a previous eye tracking study in aphasia (Kim & Bolger, 2012) as well as with results from offline tasks (Germani & Pierce, 1992; Hough et al., 1989; Mitchum et al., 2005).

Additionally, the findings from the current experiment extend previous studies that explored the influence of probabilistic factors on sentence comprehension in aphasia. This study is the first to investigate the DO/SC ambiguity in reading in aphasia using eye tracking, and provides the first evidence showing that people with aphasia are sensitive to meaning-structure correlations. The second experiment showed that structural frequency associated with verb sense influences the interpretation of sentences with a temporary ambiguity. A context sentence biased the readers' interpretation of the ambiguous sentence by creating a semantic scenario, which activated the associated verb sense.

Findings from the second experiment in particular have several implications for theories of sentence processing. As illustrated in the literature background of this thesis, two major theories have been suggested to analyse sentences with a temporal ambiguity and sentence comprehension in general. These are the garden path model (Frazier & Rayner, 1982; Frazier, 1987a) and constraint-based theories (MacDonald et al., 1994; McRae et al., 1998; Seidenberg & MacDonald, 1999; Spivey-Knowlton & Sedivy, 1995; Trueswell et al., 1993; Trueswell, 1996). In the following two subsections, these theories will be discussed in turn, relating predictions of the theories to the outcome of this study.

10.3.1. General theories of sentence processing

The garden path model is a two-stage theory of sentence processing. The emphasis is on syntactic knowledge, which is accessed to pursue one single structure in the initial parsing process. Only if the first analysis turns out to be incorrect, re-analysis is employed, and for this process, non-syntactic factors such as probabilistic influences may be used. For the interpretation of the DO/SC ambiguity, the garden path model would predict that readers have no difficulties with non-ambiguous sentences, but that in order to interpret the ambiguous sentences, readers would follow the parsing strategy of minimal attachment. This means that participants initially interpret the ambiguous sentence as DO-structure, as this is the one that has the fewest number of nodes in a syntactic tree structure. This would imply that readers experience no reading difficulty in the ambiguous sentences until they encounter the disambiguation region. This is where they would experience a garden path effect, and this should be shown by prolonged fixation durations or by an increase in regressions. However, since the initial processing stage is argued to be free of probabilistic influences, no effect of context should be apparent in first pass reading measures.

Some results from this experiment are consistent with the predictions made by the garden path model but many others are not. First of all, there was an ambiguity effect on first pass as well as second pass measures in the disambiguation region, showing a garden path effect. The garden path effect was revealed in the analysis of the correct trials and also in the analysis of both correct and incorrect trials. The PWA and the NHI showed longer fixation durations on ambiguous trials than on non-ambiguous trials. This outcome would be predicted by the garden path model, as it suggests that readers attached the ambiguous noun phrase to the verb which turned out to be a misanalysis. However, first pass eye movement measures were not only influenced by the presence or absence of *that*, but also by the context bias. In the analysis of the correct trials, the context bias showed as a trend effect for the analysis by participants and was significant for the analysis by items in the disambiguation region. In the analysis of both correct and incorrect trials, the context effect was significant on first pass measures, again, for both groups. Further, both NHI (for both ambiguous and non-ambiguous trials) and PWA (for non-ambiguous trials) made more first-pass regressions from the disambiguation region if the context-bias was misleading. These early effects and trend effects of the context influence are not consistent with the predictions from the garden path model. What is more, results indicated some interactions between context and ambiguity. This is inconsistent with assumptions made by the garden path model. The model assumes that syntactic rules are autonomously applied in first pass reading, and other factors can only influence the re-analysis stage. Another result that may have been expected on the basis of the garden path model is that sentence comprehension difficulties in the aphasia group are related to the effects of experimental manipulations. If initial syntactic parsing is entirely dependent on syntax, then people with symptoms of agrammatism should show differences in first pass processing as compared to the NHI. However, no such correlation between sentence comprehension skills and the ambiguity effect was found for the PWA, even though many participants had symptoms of agrammatism. Further, there were no significant differences between the groups in first pass eye movement measurements, not even trend effects.

Constraint-based theories differ from the garden path model in that they assume that multiple sources of information can influence the initial phase of sentence processing. These information sources can be lexical, semantic, pragmatic etc., and a particular emphasis is put on probabilistic factors such as argument structure frequency. According to constraint-based theories, predictions for the outcome of the second experiment would be as follows. First, an influence of the presence or absence of *that* would equally be expected. However, the ambiguity effect should be dependent on the context bias. The ambiguity effect should mainly occur in sentences that follow a DO-context bias. The interpretation of the DO/SC-ambiguity would be influenced by the context biasing sentences, as these activate the sense-contingent argument structure of the verb. This should lead the reader to access links between the verb sense and structure which should guide initial syntactic interpretation. Hence, eye movements should be prolonged in the disambiguation region if the context bias misprimes the reader towards the ultimately incorrect DO-sense and -structure. Further, constraint-based theories would be supported by findings that show that the extent of disruption in the ambiguous sentences is dependent on individual lexical knowledge, because it is assumed that argument structure frequency is encoded in lexical representations (Traxler & Tooley, 2007).

The findings from the second experiment are largely consistent with the predictions from constraint-based theories. The participants from both groups showed an influence of both structural ambiguity and context in both first and second pass measures. Additionally, the analysis of correct and incorrect trials revealed an increase in first pass regressions if the context bias cued towards the DO-sense and structure. For the NHI, the ambiguity effect was larger for trials that followed a DO-bias than trials that followed a SC-bias. For the PWA, the context effect was significant for non-ambiguous trials. However, whereas the interaction between context and ambiguity was significant in a later processing stage, it was only a trend effect in first pass measures, and the main effect of context was also stronger in later measures than in early measures. The context bias did not completely override the cue from *that*, and *that* did not completely override the context effect. As argued by Federmeier (2007), early context effects imply that information sources can be used in a predictive and anticipatory manner. Whereas the context bias was more pronounced in a later measure than in earlier measures in Experiment 2, the first experiment showed a strong context effect also on early processing stages. One reason for the different results on the time course between Experiment 1 and 2 could be that the experimental sentences differed in complexity. That is, if more resources are needed to interpret a sentence, the processing system may slow down. Hence, the context may have influenced expectations in reading, but participants particularly relied on the context source in order to re-read the disambiguation region and to interpret the ambiguity. A possibility for the difference between results from the current study and the results from Hare et al. is also that the aphasia group, who experienced some difficulties in the integration of the cues, drove parallel effects in the early measurements in this experiment. The PWA showed a small but non-significant effect of ambiguity on trials in the SC-bias. Another reason could be a lack of statistical power due to the small sample size.

Some other findings more strongly support predictions from constraint-based theories. First of all, the context effect for the PWA on gaze durations, and hence in the initial stage of processing, was shown to correlate with written lexical skills as assessed in language background assessments. The better the lexical skills, the smaller the effect of the context bias. This finding suggests that the context effect was modulated by lexical skills. This result can only be explained by sentence processing theories that assume that syntactic decoding can be mediated lexically as modelled in constraint-based theories (MacDonald et al., 1994; MacDonald & Seidenberg, 2006; Seidenberg & MacDonald, 1999). Second, there was a correlation between working memory capacity and the use of the context cue in second pass measures. The better the working memory capacity, the more pronounced the context effect during the later stage of processing. These findings are consistent with constraint-based theories, as these argue that non-syntactic factors can have an influence on the resolution of structural ambiguities.

Overall, results from the second experiment emphasise the importance of considering multiple factors in theories of sentence processing. This is consistent with findings from psycholinguistic studies with healthy readers showing that they are sensitive to subtle lexical, semantic and pragmatic information during sentence processing (Garnsey et al., 1997; Hare et al., 2009, 2003; McRae et al., 2005; Traxler & Tooley, 2007; Trueswell et al., 1994). The studies by Garnsey et al., Trueswell et al. and Hare et al. have shown that probabilistic factors such as argument structure frequency can influence the interpretation of syntactic ambiguities. However, there are many more sentence constraints beyond verbs that can also be used to create predictions and expectations in language understanding. McRae et al. (2005), for instance, investigated the role of using event-based knowledge. They showed that reading nouns that depict typical thematic roles of certain verbs (e.g. *nun* for *praying*) activate the related verb more quickly than nouns that depict unrelated thematic roles (e.g. *sniper* for *praying*). These studies suggest that information encoded in both verbs and nouns can generate expectations in reading and sentence comprehension.

Further, in this study, the PWA used the same cues as the NHI. The main difference observed was that they showed longer fixation durations and more regressions. This indicates that processing by the PWA is generally slowed, and that they may have used the cues somewhat less effectively than the NHI. This aligns with a previous observation in a study by DeDe on early closure ambiguities (DeDe, 2012b). The PWA from that study were sensitive to both lexical and prosodic cues, but showed effects later than the NHI.

Results from the current research fit into the line of research that does not limit the investigation of sentence comprehension in aphasia to studies on agrammatism. Some previous studies revealed that structural frequencies inherent in lexical representation can influence the comprehension of participants with different types of aphasia (DeDe, 2013a, 2013c; Gahl, 2002). However, it is not fully understood what the differences are between individuals with agrammatism, and those with other types of aphasia. Nearly all participants of both experiments in this research showed better comprehension of canonical over non-canonical sentences, but only a small number was diagnosed with Broca's aphasia. Findings from this study suggest that a mixed group of participants with aphasia can be sensitive to lexical-semantic influences on sentence comprehension. More research is needed to establish how types of lexical, semantic or pragmatic knowledge relate to the comprehension of canonical and non-canonical sentence structures.

Lastly, constraint-based theories are also supported from the results of the first experiment. Those results are not linked to structural decoding, but they have implications for word recognition at the sentence level. Both word frequency and context are probabilistic influences that determine how likely a word is to occur in a sentence. Whereas the word frequency effect relates to general occurrences in language, a predictive sentence context facilitates word recognition since people are exposed to words in context. We hardly ever hear or read words in isolation, but store them with links to their usage. The more often words occur together with related words, the tighter the links between such words in a lexical network. As a result, if words occur with related words within a sentence context, they are activated faster than words that occur with unrelated words in and unpredictable context.

In summary, the results from this thesis are more consistent with constraint-based approaches to sentence comprehension than with the garden path model. However, some results that would be predicted by constraint-based theories were not as strong as expected. For instance, even though the context bias influenced the initial stage of processing, its effect was more pronounced in later measures of sentence processing. Hence, these experiments alone cannot completely settle on these accounts.

10.3.2. Theories of sentence comprehension in aphasia

In this subsection, the theories of sentence comprehension that were outlined in Chapter 3 are briefly discussed. First, structural accounts such as the trace deletion hypothesis make no predictions regarding the processing of structural ambiguities. Further, the theory would not make any predictions regarding non-Broca types of aphasia. However, if syntax plays the most important role as generally assumed in structural accounts, then eye movements by the aphasia group should have been sensitive to the influence of the structural cue *that*, but no effects of context should have occurred. This was not supported by the experimental results.

Rather, the results from both experiments suggest that structural interpretations are not only dependent on syntactic structure, but also on lexical-semantic aspects. This is consistent with slowed processing accounts of sentence comprehension impairments in aphasia. To reiterate, processing accounts assume that syntactic processing is not necessarily impaired, but is dependent on other processing capacities that can be impaired due to aphasia. This can be due to a delay in processing information (Haarmann et al., 1997; Haarmann & Kolk, 1991, 1994), or it can be caused by a reduced capacity in working memory (Caplan & Waters, 1999; Caspari et al., 1998; Friedmann & Gvion, 2003; Haarmann et al., 1997; Miyake et al., 1994; Sung et al., 2009; Wright et al., 2007; Wright & Shisler, 2005).

There are several ways in which results from this study are consistent with slowed processing accounts. First, in both experiments, PWA showed large reductions in processing speed in all measurements. This could be due to resource limitations that affect all aspects of processing in reading. Second, both studies observed an influence of working memory capacity on the fixation durations, and on the use of the biasing context. The slower the digit span in the working memory tasks, the longer were the fixation durations. Those with poorer working memory also made less use of context in the second experiment. This suggests that some cues in sentence processing are dependent on other non-language processes. The third reason is that both groups showed many similarities in processing. Such similarities would not be expected if language impairment is caused by the loss of specific rules. Finally, several studies on sentence comprehension in aphasia that are consistent with slowed processing accounts have suggested that lexical processing plays a larger role in sentence comprehension than previously thought. Studies using eye tracking in auditory processing have demonstrated that sentence processing by PWA is associated with delays in lexical processing, lexical integration difficulties, or both (Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Meyer et al., 2012; Thompson & Choy, 2009). Results from both experiments in this research support results from these studies. Both eye tracking studies revealed that PWA have longer gaze and total fixation durations, suggesting a delayed process of lexical access, and difficulties in lexical integration. The process of lexical integration and re-reading is particularly disrupted in the PWA from this study. This was evident as PWA differed from NHI most dominantly in the later measure.

10.4. Implications for clinical practice

The findings from these two experiments also have a number of implications for clinical practice. As mentioned in Chapter 7, the first experiment established that using top-down support from a sentence context could be a useful strategy for accessing low frequency, or potentially, other difficult words. This points to potential uses of context in rehabilitation. For example, comprehension of low frequency words might be practiced first with contextual support, and then with that context removed. A facilitative context might similarly scaffold production. It should be noted that using a sentence context to facilitate lexical access is far from a new idea, and is often used in speech and language therapy settings. This study contributes to this general insight by providing evidence for a contextual benefit in a near natural reading task using online measures. The finding that context assists reading is also consistent with the outcome of a qualitative study that analysed reading strategies employed by people with aphasia (Lynch et al., 2013). Lynch and colleagues found that all three participants in their case series study used world knowledge to make sense of a text. As one of the participants puts it: "When I come to a word I don't know, I just ask myself what it means in the context of the sentence." (Lynch et al., 2013, p.732).

Results from the second experiment further underscore the relevance of a sentence context, as here it was shown that a sentence context does not only influence word recognition, but also facilitates making structural decisions, and overcoming a mild garden path sentence. The finding that a context bias can activate the argument structure frequency of a verb sense – which then influences the interpretation of an ambiguity – suggests that form-meaning pairings may be robust entities in language. This has several implications for speech and language therapy settings. First, if structures that match these correspondences are easier to process for people with aphasia, then this could be exploited in therapy. Frequent form-meaning pairings could be implemented into different treatment tasks, and potentially, using different modalities. As an example following from this study, concrete verb senses that frequently occur with direct objects should be practiced in exactly these structures, and abstract verb senses that occur with sentential clauses should be trained in those frames.

Additionally, the influence of sense-contingent argument structure frequency suggests that specifications about frequently used sentence frames are stored at word-level. This emphasises the importance of lexical-semantic skills for sentence comprehension; strengthening these should lead to better accuracy in sentence comprehension tasks. At a more general level, applying constraint-based theories in a clinical setting would imply a shift from teaching (syntactic) rules of language to an emphasis on language usage. As an example, instead of emphasizing moved structures in passive constructions, the therapist could use passive constructions with verbs that are used very frequently in the passive. Verbs that are less prototypical in passives could be additionally targeted at a more advanced level. A frequent and repeated training of important target structures may also strengthen connections in the network and make them easier to process.

The use of eye tracking investigations during client assessment is currently very challenging. Clinicians do not have access to the equipment and methods are time consuming, particularly with respect to the analysis. However, if testing and data analysis became more automated, use in practice may become feasible and eye tracking data could usefully augment the knowledge gained from offline testing. This is discussed further in Section 10.6.

10.5. Limitations

This study also has limitations. First of all, most of the participants selected for the experiments had a mild type of aphasia. The decision to focus on individuals with mild reading difficulties was made to ensure that participants were able to read sentences at the sentence level. Further, individuals with mild aphasia and co-occurring mild difficulties in silent reading represent a population that is often under-represented in research. Many studies on reading in aphasia investigate the process of single word reading associated with more moderate or severe aphasia, and a majority of studies on sentence comprehension difficulties focuses on moderate to severe agrammatism. Thus one goal of this study was to examine whether individuals with mild aphasia differ from neurologically healthy individuals if silent reading is analysed using eye tracking. The disadvantage of having a group with mild aphasia was that it is not known whether results would hold in a group with more moderate aphasia. Not having a larger range of severity also limited the correlation analyses that were run to investigate whether specific aspects of language are associated with the effects or eye movements in general.

Secondly, the sample size of the participants in these experiments was small. Seventeen participants with aphasia were involved in the first experiment, and eleven participants with aphasia in the second. Consequently, statistical power was particularly low in the second eye tracking study. This may be another reason why only few group differences were observed with regard to the experimental manipulations particularly in Experiment 2, and may account for the weak interaction effects compared to the strong main effects.

There were some further limitations regarding the analyses in this study. The eye movement analysis was constrained by using a limited set of measures. In order to find out more details about the reading behaviour of people with mild and moderate aphasia compared to neurologically healthy controls, it would be interesting to additionally investigate the skipping behaviour of the readers.

Lastly, the analyses of effects were constrained to specific regions of interest. In the first experiment, a follow up study could examine whether any spillover effects occurred, by analysing word frequency and context effects on the word following the target word. In the second experiment, three regions were analysed that were expected to show effects of the manipulations. However, eye movements on earlier regions were not analysed, for example, fixations on the verb or on the complementiser.

10.6. Future studies

Future studies on silent reading in aphasia may wish to include a larger number of participants as well as individuals with more pronounced reading difficulties. This would lead to more statistical power and could potentially reveal more associations between the underlying language profile and the experimental effects.

This study indicates that using the paradigm of structural ambiguities in aphasia can provide information on how sentence processing unfolds. However, the DO/SC ambiguity studied here is a mild type of garden path. Additional findings may be gained by using slightly more complex ambiguities, which result in a larger number of incorrect answers. An example of a more complex structural ambiguity is the temporarily ambiguous reduced relative clause (e.g. *The actress selected by the director believed that*…). Here, *selected* is the point of ambiguity as it could be the main verb or could indicate a reduced relative clause (Spivey & Tanenhaus, 1998). Analysing eye movements on incorrect trials may provide us with more knowledge of why comprehension difficulties occur.

It would further be of interest to investigate additional aspects of frequency effects in aphasia. In this thesis, only lexical frequency and argument structure frequency were investigated. Another type of frequency that can influence sentence comprehension is *construction frequency* that relates to how frequently a syntactic structure occurs. Corpus studies have shown that active sentence structures are more frequent than passive sentences, and that subject cleft sentences occur more frequently than object cleft sentences (Roland et al., 2007). Effects of such construction frequencies have recently been revealed in both auditory and written comprehension in aphasia using self-paced reading and listening measures (DeDe, 2013b) as well as in a study using eye tracking whilst reading (Knilans & DeDe, 2015). These differences in frequency may also account for the observation that PWA in this study show better accuracy in canonical vs. non-canonical sentences, even though most participants were not diagnosed with Broca's aphasia. The structures tested in this thesis were in fact active and subject cleft sentences and passives and object cleft sentences. Further studies on other sentence structures are needed to determine whether construction frequency does influence sentence comprehension, and how this relates to effects of argument structure frequency. In many cases, both aspects of argument structure frequency and construction frequency are likely to be intertwined. Another area of research using this approach has started to investigate structural frequencies in relation to language production in the healthy population (Tily et al., 2009). Tily and colleagues argue that language production is influenced by probabilistic tendencies for syntactic, semantic and contextual properties of a sentence. They show that producing probable constructions is associated with fluent speech and rapidly produced words whereas the production of less probable constructions can lead to more disfluent speech and fluent words that are spoken less rapidly. Showing such a probabilistic influence on speech in aphasia would have some important clinical applications as it would provide guidance on useful therapy material. Hence, investigating probabilistic factors of language production in aphasia would be an important area for future research.

Another field that is worth investigating is the relation between silent reading and reading aloud. So far research has focussed on either, but research examining how these processes relate to each other is lacking. With respect to models of visual word recognition, there is not much knowledge relating to whether readers adopt the same reading pathway when they read silently or read aloud. For example, if readers adopt the grapheme to phoneme conversion route in reading aloud, they may use a different route for silent reading. Advanced knowledge of similarities and differences in silent reading and reading aloud may lead to different strategies in clinical settings.

There are several recent studies from one research team committed to developing eye tracking as a tool for the diagnosis and therapy for acquired dyslexia (Ablinger, Huber, et al., 2014; Ablinger et al., 2013; Ablinger, von Heyden, et al., 2014; Schattka et al., 2010). Working on methods to improve the remediation of silent reading in aphasia might also be a worthwhile approach. For diagnostics purposes, eye movement measurements (e.g. number of fixations and total durations) could be used as a pre- and post- therapy test tool. It would help to determine whether therapy has changed reading accuracy and strategies (progress only on offline measures) or changed automatic reading processes (progress only on online measures). Additional reading comprehension tests could monitor whether a change in eye movement behaviour accompanies improved comprehension skills. For therapy purposes, a starting point may be to use eye movement analysis on an individual basis. This is because the eye movement pattern may change depending on the language profile. An example would be to begin with an analysis of regressions to examine whether these are successful. This could be analysed by comparing the pattern of regression data in a sample of correctly understood sentences to a sample of incorrectly understood sentences. Results from this study revealed that more first pass regressions by the PWA were associated with higher accuracy. The NHI on the other hand showed a non-significant relationship between first pass regressions and accuracy in the opposite direction; the fewer the regressions, the higher the accuracy. This would suggest that if comprehension is good, regressions are not needed, but if comprehension is compromised, using regressions to re-read and monitor the comprehension process can lead to increased accuracy. If regressions are not successful for an individual with aphasia, a strategy could be to work on how regressions could improve comprehension. The reading strategy can also be shown to the client (via a play back eye movement video of a read sentence), which may improve the understanding of the task. However, it has to be admitted that these suggestions may not be suitable for the clinical context as clinicians may not have the time or equipment for such detailed reading diagnostics. Running a reading study and analysing the data is time consuming, particularly if carried out on a case-by-case basis. However, if the procedures are developed in the future so that eye trackers are easy to use and the output generated automatically there may be some gain in applying eye tracking in practice. This technology could also be used in clinics that specialise in eye tracking for reading impairments, and where clients could be referred to from other institutions. Currently, applying eye tracking in reading could be a fruitful approach for combining reading research with therapy.

10.7. Conclusion

Results from this thesis show that silent reading in aphasia is less efficient than silent reading in the healthy population. The rate of visual word recognition is reduced, but the processing system aims to be as efficient as possible by compensating for less skilled aspects. Hence, readers with reduced bottom-up processing achieve top-down support. Further, this study reveals that similar to healthy readers, people with aphasia draw on meaning structure correlations, which are inherent in verb representations and which can facilitate the reading of mild garden path sentences. This suggests that probabilistic aspects of language are entrenched in our language system, and remain accessible even in the presence of mild aphasia. Further research is needed to determine whether the findings of this study hold if investigated with a larger group of participants and with more varied severity.

Appendix A. Systematic literature search for eye tracking studies in aphasia

A.1 Systematic literature search for eye tracking studies in reading and sentence comprehension in aphasia

The narrative review of eye movement studies in aphasia described in Section 4.2 of this thesis is based on a systematic literature search, which is summarised here. The objective of this search was to provide an overview of research on reading and auditory/written sentence comprehension studies in aphasia employing eye tracking.

Methods

Inclusion and exclusion criteria
Studies were included in the literature review if 1) they used eye tracking methodology to describe reading in aphasia at the word or sentence level; or if 2) they used eye tracking methodology to investigate either auditory or written sentence comprehension in aphasia. Additionally, the studies had to target an adult population, had to be published in English, German or Dutch, and had to include quantitative data.

Search strategy
The EBSCOhost online reference system was used to search for literature. Databases included via this system were: Academic Search Complete, CINAHL Plus with Full Text, Communication Source, eBook Collection, E-journals, MEDLINE Complete, PsychARTICLES, PsychINFO, and SocINDEX with Full Text. The following two search terms were used:

1) (aphas* OR dyspahs*) AND (reading OR listening) AND (eye tracking OR eye movements)
2) (aphas* OR dysphas*) AND (sentence comprehension OR sentence processing) AND (eye tracking OR eye movements).

Data collection and categorisation
All collected titles and abstracts were screened to determine whether articles are relevant given the objective of this literature search, and to check the data collection against inclusion criteria. Articles were assigned to two categories: listening and reading studies.

Results

The defined search strategy resulted in a list of 79 references. Twenty-seven duplicates and 32 references were excluded. Thirteen references did not target reading or listening, three were not quantitative studies, 13 did not target aphasia, and two were published in a different language, other than English, German or Dutch. Additionally, one publication identified through a hand-search (Huber, Lüer and Lass, 1983) was added so that the final collection comprised 21 references. Of these remaining articles, full texts were accessed. All relevant articles were collected and entered into Table A.1.1 (listening) and Table A.1.2 (reading).

Of the 21 publications, 90.48% were peer-reviewed publications (*N* = 19), 4.76 % were abstracts from conference proceedings (*N* = 1). Lastly, 4.76% was a PhD thesis (*N* = 1). Out of the 21 articles, 61.90% targeted listening comprehension (*N* = 13), and 38.10 % examined reading (*N* = 8). The majority of publications was recent, i.e. 42.86% (*N* = 9) was published since 2014, 47.62 % of the articles were published between 2007 and 2015 (*N* = 10), and 9.52% of the data originated from 1983 and 1984 respectively (*N* = 2). The older two studies used either a video camera or electrooculography, a method to record eye movements during fixation.

Eye movement studies on listening sentence comprehension in aphasia - identified through a systematic search of the literature.

Authors	**Publication year**	**PWA (N)**	**NHI (N)**	**Word/ sentence/ discourse level**	**Type of study/materials**	**Eye tracking task/ analysis /procedure**	**Results**
Dickey, Choy, Thompson	2007	12	8	Sentence level	Investigation of sentences involving movement (wh-questions)	Eye tracking while listening	For correct trials, both groups fixated the picture that represented the moved element in the sentence (referring to the answer of "who") which was evidence for successful processing of wh-questions. In incorrect trials, PWA showed a preference to look at the competitor picture.
Dickey, Thompson	2009	8	14	Sentence level	Investigation of wh-movement structures (object relatives) and sentences with NP-movement (passives)	Eye tracking while listening	Both groups revealed similar eye movement patterns during the processing of both sentence structures, but the PWA were more sensitive to interference from incorrect alternative interpretations.
Thompson, Choy	2009	8 (exp. 1); 12 (exp. 2); 8 (exp.	8 (exp. 1); 8 (exp. 2); 14 (exp. 3)	Sentence level	Investigation of pronominal structures and wh-movement, using eye tracking	Eye tracking while listening	Eye movements by PWA evidenced successful gap filling during the processing of the wh-movement structures; eye movements showed no delay in processing, but lexical competition effects in the end of sentences in incorrect trials suggested

		3)					deficits in lexical integration
Choy & Thompson	2010	8	8	Discourse level	Investigation of reflexive and pronoun constructions	Eye tracking while listening	Eye movements showed that PWA were successful in processing the antecedents in both structures, in the absence of any processing delay. However, an increased proportion of fixations on a competitor towards sentence offset suggested an impairment in lexical integration.
Choy	2011	10	10	Sentence level	Investigation of lexical processing deficits	Eye tracking while listening	The analysis of eye movements indicated that both lexical and lexical integration is impaired in Broca's aphasia, but the later affects sentence comprehension.
Hanne, Sekerina, Vasishth, Burchert, De Bleser	2011	7	8	Sentence level	Combination of a sentence-picture matching tasks with analysis of eye movement (comparing canonical and non-canonical sentences)	Eye tracking while listening	For canonical sentences, both groups showed similar eye movement patterns albeit those by the PWA were delayed; for non-canonical sentences, PWA' eye movements diverged from the pattern of the controls.
Meyer, Mack, Thompson	2012	10	10	Sentence level	Comprehension of active and passive sentences	Eye tracking while listening	Comprehension of passive sentences was impaired for the PWA; eye movements showed a delay in processing sentences and differed

							depending on whether the sentence was understood correctly or incorrectly.
Mack, Ji, Thompson	2013	9	10	Sentence level	Investigation of whether participants with agrammatism have access to verb meaning to predict and facilitate lexical integration	Eye tracking while listening	PWA showed an increased number of fixations on the target picture and in the condition reflecting access to verb meaning, but the effect was delayed in comparison to NHI, suggesting difficulties in prediction.
Bos, Hanne, Wartenburger, Bastiaanse	2014	6	12	Sentence level	Comparison of processing future (will + V) and past time reference inflection (has + V-d) between PWA and NHI	Eye tracking while listening	Differences in processing time reference was reflected by eye movement behaviour, and PWA showed delayed processing of past time inflection in comparison to the NHI.
Laurinavichyute, Ulicheva, Ivanova, Kuptsova, Dragoy	2014	23	36	Discourse level	Investigation of temporarily ambiguous words with a context cue.	Eye tracking while listening	The context bias influenced lexical access in both groups (NHI as well as fluent and non-fluent aphasia), but participants with non-fluent aphasia had an impairment in reanalysis shown by fewer fixations on the target picture during the reanalysis region.

Hanne, Burchert, De Bleser, Vasishth	2015	8	20	Sentence level	Combination of a sentence-picture matching tasks with an analysis of eye movements to investigate the use of morphological cues.	Eye tracking while listening	Eye movements showed that PWA were able to use morphological cues, but in comparison to NHI the integration of cues was delayed.
Schumacher, Cazzoli, Eggenberger, Preisig, Nef, Nyffeler, Gutbrod, Annoni, Müri	2015	12	50	Sentence level	Sentence-picture matching task with canonical and non-canonical sentences.	Eye tracking while listening	For non-canonical sentences (O V S), PWA showed delayed fixations on target pictures. Fixation patterns further indicated that PWA had difficulties in the recognition and integration of morphosyntactic cues.
Sheppard, Walenski, Love, Shapiro	2015	8	32	Sentence level	Comprehension of wh-questions	Eye tracking while listening	PWA showed better accuracy for who-questions than wh-questions, this was supported by eye gaze data.

Eye movement studies on reading and written sentence comprehension in aphasia - identified through a systematic search of the literature.

Authors	**Publication year**	**PWA (N)**	**NHI (N)**	**Word or sentence level**	**Type of study/materials**	**Eye tracking task/ analysis/ procedure**	**Results regarding eye movements**
Huber, Lüer, Lass	1983	9	17	Sentence level	Participants were shown an unordered array of sentence constituents on the screen, and had to construct a sentence using some of these constituents.	Eye tracking during the identification of written constituents to construct a sentence (with a video camera)	The NHI showed a correlation between their fixation pattern and their linguistic answer. The PWA did now show such association and their eye movements reflected a semantically based search of the correct constituents.
Klingelhöfer & Conrad	1984	21	40	Sentence level	Investigation of saccadic pattern associated with reading by people with different subtypes of aphasia	Eye tracking during reading (electrooculography)	Saccade behaviour mirrored the speech difficulties associated with aphasia subtypes, for example, participants with Broca's aphasia showed longer reading durations and reading was hesitant.

Schattka, Radach, Huber	2010	6	11	Word level (reading aloud)	Investigation of eye movements during impaired oral word reading (acquired dyslexia)	Eye tracking during reading. Analysis of saccades and temporal eye movement measures	The spatial eye movement measures differentiated hypothesised reading strategies/routes (lexical vs. segmental). Re-reading was prolonged in all participants.
Kim & Bolger	2012 (conference abstract)	10	8	Sentence level (silent reading)	Target nouns were placed into predictable/unpredictable sentence contexts	Eye tracking during reading	PWA showed longer fixation durations and more regressions on unpredictable targets than predictable targets.
Ablinger, von Heyden, Vorstius, Halm, Huber, Radach	2014	8	0	Word level (reading aloud)	Eye movement based reading intervention (acquired dyslexia)	Use of stepwise letter de-masking to motivate sequential reading, and fixation-dependent initial masking of letters in the beginning	Reading improvements were shown by decreased total reading time and reduced number of fixations.

						and end of words were used to support lexical reading.	
Ablinger, Huber, Walter, Radach	2014	5	0	Word level (reading aloud)	Eye movement supported reading intervention (acquired dyslexia)	Analysis of fixation positions during the oral reading of words	Eye movement positions on words reflected the underlying reading strategy/route
Knilans & DeDe	2015	9	8	Sentence level (silent reading)	Comprehension of object and subject cleft sentences	Eye tracking during reading	As NHI, PWA showed longer reading times for object cleft than subject cleft sentences. Second pass eye movements reflected effects of structural complexity for the PWA.
Kim & Lemke	2016	1	0	Sentence level (silent reading)	Reading intervention (acquired dyslexia)	Eye movement assessment of silent reading before and after treatment	Total fixation durations, number of fixations and regressions increased after treatment. Position of first fixation shifted towards the optimal viewing position.

Appendix B. Experimental stimuli and statistical results

Experiment 1

B.1 Acquired dyslexia profile of PWA with results from PALPA reading subtests

PWA ID	High frequen words (PALP 31)	Low frequency words (PALPA 31)	Words mean (PALPA 31)	Nouns (PALPA 32)	Adjectives (PALPA 32)	Verbs (PALPA 32)	Function words (PALPA 32)	Word classes mean (PALPA 32)
1	1.00	0.95	0.98	1.00	1.00	1.00	1.00	1.00
2	1.00	0.98	0.99	1.00	1.00	1.00	0.95	0.99
3	1.00	1.00	1.00	1.00	1.00	0.90	1.00	0.98
4	1.00	0.98	0.99	1.00	1.00	1.00	1.00	1.00
5	1.00	0.93	0.97	1.00	1.00	0.95	1.00	0.99
6	0.98	1.00	0.99	1.00	1.00	1.00	1.00	1.00
7	0.83	0.65	0.74	0.75	0.65	0.55	0.60	0.64
8	0.98	0.95	0.97	0.95	1.00	1.00	0.95	0.98
9	1.00	1.00	1.00	1.00	1.00	0.95	1.00	0.99
10	0.75	0.83	0.79	0.65	0.60	0.70	0.60	0.64
11	0.65	0.65	0.65	0.45	0.60	0.45	0.20	0.43
12	1.00	0.95	0.98	0.90	0.85	0.85	0.85	0.86
13	0.98	1.00	0.99	0.95	1.00	1.00	0.85	0.95
14	0.98	0.95	0.97	1.00	1.00	1.00	1.00	1.00
15	0.85	0.90	0.88	1.00	0.80	0.70	0.50	0.75
16	0.98	0.70	0.84	0.85	0.90	0.90	0.85	0.88
17	0.48	0.43	0.46	0.40	0.55	0.80	0.75	0.63

PWA ID	Morphology regular (PALPA 34)	Morphology derived (PALPA 34)	Morphology irregular (PALPA 34)	Unaffixed phonological control for regular words (PALPA 34)	Unaffixed phonological control for derived words (PALPA 34)	Unaffixed phonological control for irregular words (PALPA 34)	Morphology mean (PALPA 34)
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00	0.93	0.93	0.98
3	1.00	0.87	1.00	0.87	1.00	1.00	0.96
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.27	0.87	0.67	0.87	0.93	0.87	0.75
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	0.20	0.20	0.27	0.40	0.40	0.60	0.35
8	0.93	1.00	0.93	0.93	1.00	1.00	0.97
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.53	0.47	0.53	0.60	0.67	0.73	0.59
11	0.33	0.47	0.20	0.47	0.53	0.73	0.46
12	0.67	0.87	0.87	1.00	1.00	0.93	0.89
13	1.00	0.93	0.73	0.93	0.93	1.00	0.92
14	0.93	0.93	1.00	0.80	0.87	1.00	0.92
15	0.87	1.00	0.67	0.67	0.87	0.87	0.83
16	0.87	0.93	0.80	0.67	1.00	1.00	0.88
17	0.67	0.67	0.53	0.47	0.53	0.67	0.59

PWA ID	Regular spelling sound (PALPA 35)	Exception spelling sound (PALPA 35)	Spelling sound mean (PALPA 35)	Nonwords (PALPA 36)	Oral reading overall mean
1	1.00	1.00	1.00	1.00	1.00
2	0.97	1.00	0.99	0.50	0.89
3	0.90	1.00	0.95	0.58	0.89
4	0.90	1.00	0.95	0.71	0.93
5	0.93	0.87	0.90	0.13	0.75
6	1.00	1.00	1.00	0.96	0.99
7	0.50	0.73	0.62	0.00	0.47
8	1.00	0.90	0.95	0.83	0.94
9	1.00	0.93	0.97	0.96	0.98
10	0.73	0.67	0.70	0.00	0.54
11	0.60	0.60	0.60	0.00	0.43
12	1.00	1.00	1.00	0.33	0.81
13	0.97	0.90	0.94	0.50	0.86
14	0.87	0.97	0.92	0.46	0.85
15	0.73	0.80	0.77	0.25	0.69
16	n.a.	n.a.	n.a.	0.13	0.68
17	0.37	0.60	0.49	0.13	0.46

B.2 Adaption of the reading span test by Caspari et al. (1998) for this study

This section describes the reading span test that was used in this thesis (Experiment 1 and 2). The reading span test was designed for individuals with mild aphasia, and was developed by Caspari and colleagues (Caspari et al., 1998). They altered Daneman and Carpenter's (1980) reading span task to make it feasible for individuals with aphasia with the goal of creating a functional measurement of working memory capacity in aphasia. Daneman and Carpenter's reading span task was designed to include storage as well as processing, and was shown to predict reading performance – an association not shown between a simple span task and reading comprehension (cf. Caspari et al., 1998). In this test, participants read unconnected sentences aloud and remember the last word of each sentence of a series (different numbers of sentences). This test can be problematic for individuals with aphasia who have difficulties in reading. Hence, Caspari and colleagues made the following changes: (1) separating the word to be recalled from the sentence, (2) reducing the sentence length to decrease complexity, and (3) changing the recall task to a recognition task. The task is to read sentences and retain the terminal word(s) that followed each sentence for later recognition. In the first level, there is one sentence and one target word to retain; in the second level there are two sentences and two target words to retain, and this continues until the sixth level. At the end of completing each level, the participant is asked two comprehension questions. This is to guarantee that individuals do not focus on the target words ignoring the processing of the sentences (cf. Caspari et al., 1998). The target words are monosyllabic, high in frequency (18-2110 per million in Francis & Kucera, 1982) and high in imageability. For the recognition task, pictures of the target words are presented together with other pictures unrelated to the target words and unrelated to each other. The first level included two distractor pictures, the third level three and so on until level six that included seven distractors. All are of the same frequency and picturability range. The number of words retrieved corresponds to the index of working memory capacity. The working memory assessment by Caspari et al. is only a functional tool for individuals with mild reading difficulties; it however requires similar demands to the tasks used in the reading eye tracking study. Thus, it was decided to adapt it for the purpose of this study.

Sentences were provided by I. Caspari. Since pictures could not be provided, images were extracted from the IPNP database (Szekely et al., 2004). Words have a log frequency from CELEX (Baayen et al., 1995) of 2-9.889. They are 1-2 syllables long, have a name agreement of 0.70-1, age of acquisition of 0-3, and visual complexity of 3730-62243. Since there were not enough pictures fulfilling these criteria, the final eight words had a log frequency of 0.000-1.000, and these were used as practice stimuli. All words were randomised, and placed into different levels and trials. It was taken care that the words occurring together in a level have different onsets. The scoring procedure is the same as in the test by Caspari et al. (1998). The reading sentence span score is the number of levels that the participant is able to complete. In order to complete a level, the target words have to be recognised correctly on either two or three of the three trials at a level. Thus, if someone completes the third level, the reading span is 3.0. Overall there are 6 trials. If at one level only one trial is completed, partial credit is given. For example, completion of level two and completion of the first trial of level three corresponds to a reading span of 2.5. The number of target words that were selected correctly as well as the number of questions answered correctly are also counted. The latter score is a percentage score relating to the number of questions that were asked.

B.3 Experimental stimuli with word frequency and predictability information

	Experimental sentence	**Con-dition**	**Pre-dic-tabiliy rating**	**Occurrence per million (WebCelex)**	**Occur-rence per million (Subtlex)**
1	The book describes a strong tie between the parent and the *child* living in the country.	HF P	6.80	654.00	157.65
1	Scooby-Doo is a great Dane but Lassie is a *child* who has performed in many movies.	HF U	1.47	654.00	157.65
1	Scooby-Doo is a great Dane, but Lassie is a *collie* who has performed in many movies.	LF P	6.55	0.00	1.04
1	The book describes a strong tie between the parent and the *collie* living in the country.	LF U	2.90	0.00	1.04
2	After a long day the children were hungry for *dinner,* which is healthy.	HF P	6.70	95.00	202.67
2	Popeye is strong because he likes to eat *dinner* in the evening.	HF U	2.90	95.00	202.67
2	Popeye is strong because he likes to eat *spinach i*n the evening.	LF P	6.53	4.00	2.00
2	After a long day the children were hungry for *spinach,* which was their favourite.	LF U	3.90	4.00	2.00
3	Anna was able to get a reduced ticket for the show because she	HF P	7.00	95.00	43.04

	is a *student* working there.				
3	Claire loves flowers and wants to be a *student* learning how to make nice bouquets.	HF U	3.07	95.00	43.04
3	Claire loves flowers and wants to be a *florist* learning how to make nice bouquets.	LF P	6.95	1.00	2.41
3	Anna was able to get a reduced ticket for the show because she is a *florist* working there.	LF U	3.40	1.00	2.41
4	The young couple are saving to buy a *house* to refurbish.	HF P	6.77	490.00	514.00
4	The poor backpackers are staying in a *house* in New York.	HF U	2.90	490.00	514.00
4	The poor backpackers are staying in a *hostel* in New York.	LF P	6.67	3.00	0.57
4	The young couple are saving to buy a *hostel* to refurbish.	LF U	2.30	3.00	0.57
5	To find out about vaccinations they sought the advice of an experienced *doctor* before the trip.	HF P	6.80	136.00	263.94
5	Captain Scott was an Antarctic *doctor* who was not afraid of challenges.	HF U	2.40	136.00	263.94
5	Captain Scott was an Antarctic *explorer* who was not afraid of challenges.	LF P	6.75	2.00	1.90
5	To find out about vaccinations they sought the advice of an experienced *explorer* before the trip.	LF U	3.80	2.00	1.90
6	John withdraws money from the *bank* to go shopping.	HF P	6.70	135.00	84.98
6	Carla keeps her jewellery in a *bank* when she goes on holidays.	HF U	3.75	135.00	84.98
6	Carla keeps her jewellery in a *safe* when she goes on holidays.	LF P	6.33	7.00	143.00
6	John withdraws money from the *safe* to go shopping.	LF U	4.50	7.00	143.00
7	Although she is tired she reads another *chapter* before going to sleep.	HF P	6.75	120.00	11.84
7	Hannah has difficulties with the new computer and consults the *chapter* to find a solution.	HF U	2.67	120.00	11.84
7	Hannah has difficulties with the new computer and consults the *manual* to find a solution.	LF P	6.55	7.00	11.84
7	Although she is tired she reads another *manual* before going to sleep.	LF U	4.33	7.00	11.84
8	Thomas holds shares in a large	HF P	6.73	183.00	147.00

	company but wants to sell them.				
8	Tim was interested in beer making and visited a *company* who explained all about it.	HF U	4.00	183.00	147.00
8	Tim was interested in beer making and visited a *brewery* who explained all about it.	LF P	6.70	2.00	1.80
8	Thomas holds shares in a large *brewery* but wants to sell them.	LF U	4.45	2.00	1.80
9	Before she goes to bed her mum reads her a short *story* written by her father.	HF P	6.90	166.00	220.78
9	Lisa does not like letters, but prefers to write a quick *story* to tell others about her news.	HF U	3.33	166.00	220.78
9	Lisa does not like letters, but prefers to write a quick *email* to tell others about her news.	LF P	6.95	-	2.08
9	Before she goes to bed her mum reads her a short *email* written by her father.	LF U	3.03	-	2.08
10	After a long day at work she forgot her keys and had to go back to the *office* to get them.	HF P	6.57	255.00	203.90
10	After a long day the gambler went to play in the *office* near his home.	HF U	1.85	255.00	203.90
10	After a long day the gambler went to play in the *casino* near his home.	LF P	6.63	4.00	20.37
10	After a long day at work she forgot her keys and had to go back to the *casino* to get them.	LF U	2.70	4.00	20.37
11	Ryan loves old castles and is interested in their *history* and tales.	HF P	6.80	186.00	83.92
11	James wanted to know how rocks were formed so read a book about *history* on Sunday.	HF U	2.47	186.00	83.92
11	James wanted to know how rocks were formed so read a book about *geology* on Sunday.	LF P	6.90	2.00	0.92
11	Ryan loves old castles and is interested in their *geology* and tales.	LF U	2.53	2.00	0.92
12	Every day Liz picks up her 12 year-old from the *school* and goes home.	HF P	6.40	368.00	333.12
12	William needs a new custom made suit and goes to the *school* to get one.	HF U	1.45	368.00	333.12
12	William needs a new custom made suit and goes to the *tailor* to get one.	LF P	6.73	3.00	4.18

12	Every day Liz picks up her 12 year old from the *tailor* and goes home.	LF U	1.65	3.00	4.18
13	The athlete drinks lots of *water* at the weekend.	HF P	6.73	452.00	225.06
13	At the distillery in Scotland the man bought a bottle of *water* to take home.	HF U	3.45	452.00	225.06
13	At the distillery in Scotland the man bought a bottle of *whisky* to take home.	LF P	6.67	35.00	4.00
13	The athlete drinks lots of *whisky* at the weekend.	LF U	2.15	35.00	4.00
14	After the accident they rushed to the *hospital* to get the injury cleaned.	HF P	6.70	108.00	124.20
14	The friends carry their tents to the *hospital* where they want to sleep.	HF U	1.75	108.00	124.20
14	The friends carry their tents to the *campsite* where they want to sleep.	LF P	6.73	1.00	0.59
14	After the accident they rushed to the *campsite* to get the injury cleaned.	LF U	2.30	1.00	0.59

B.4 Filler sentences

practice items (both lists)
She asked her older sister to finally tell her the secret.
Peter is an artist with a particular interest in portrait photography.
The tagine is a dish that is usually served with rice.
The school that Robert visits is one of the best ones in the country.
Helen hoped that the weather would get better over the weekend.
filler items list A
The student typed her essay to achieve better marks.
The woman adjusted her seatbelt to be more comfortable in her seat.
The boy carved a symbol in the bark of the tree.
The shop owner shut the door during the winter season.
The athlete impressed the fans with a world record.
The scout located where they had to go to before dark.
The doctor helped before the condition became worse.
The bank hired to take care of upcoming problems.
The father called via the internet to express his birthday wishes.
The parent visited after moving abroad to ask about childcare.
The man floated the boat in the pond.
The mother hurried her children out of the door.
The man fought his friend in a boxing match.
The couple danced the tango every weekend since the lessons started.

The pilot flew the airplane over the ocean.
The girl grew in the spring.
The woman leaned against the wall.
The car driver raced to the stop sign.
The ambulance rushed to the hospital.
The pensioner sailed on the lake.
The cat was chased by the girl.
The fly was eaten by the frog.
Maria was thinking about moving to South America next year.
Jo is taller than both her older sister and mother.
The farmer has fewer cows than he used to.
The baby was washed by the mother.
The exam was so difficult that the students were complaining about it.
While the parents visited the museum, their daughters went shopping.
When she is grown up, Emma wants to become a doctor.
The painter did not want to sell his work.
The mother did not let her children go on the trip without an adult.
filler items (list B)
The student typed to achieve better marks.
The woman adjusted to be more comfortable in her seat.
The boy carved in the bark of the tree.
The shop owner shut during the winter season.
The athlete impressed with a world record.
The scout located the cottage where they had to go to before dark.
The doctor helped the patient before the condition became worse.
The bank hired an expert to take care of upcoming technical problems.
The father called his son via the internet to express his birthday wishes.
The parent visited a nursery after moving abroad to ask about care.
The man floated in the pond.
The mother hurried out of the door.
The man fought in a boxing match.
The couple danced every weekend since the lessons started.
The pilot flew over the ocean.
The girl grew vegetables in the spring.
The woman leaned the ironing board against the wall.
The car driver raced the motorbike to the stop sign.
The ambulance rushed the injured man to the hospital.
The pensioner sailed a boat on the lake.
The cat was chased by the girl.
The fly was eaten by the frog.
Maria was thinking about moving to South America next year.
Jo is taller than both her older sister and mother.
The farmer has fewer cows than he used to.
The baby was washed by the mother.
The newspaper columnist writes his stories weekly.
The mother did not let her children go on the trip without an adult.

Peter was asked whether he would sell his car.
The child was kicked by the horse.

B.5 Fixation durations for log-transformed data

Log-transformed mean fixation durations (and SD) (in ms) and first pass regression (in %) for critical words (correct and incorrect trials)

NHI	**HF P**	**HF U**	**LF P**	**LF U**
Gaze duration	2.30 (0.06)	2.35 (0.07)	2.37 (0.09)	2.41 (0.09)
Total duration	2.42 (0.13)	2.53 (0.11)	2.46 (0.10)	2.57 (0.13)
First pass regression	0.05 (0.05)	0.08 (0.06)	0.06 (0.05)	0.07 (0.05)

PWA	**HF P**	**HF U**	**LF P**	**LF U**
Gaze duration	2.43 (0.10)	2.45 (0.10)	2.48 (0.11)	2.57 (0.15)
Total duration	2.78 (0.15)	2.90 (0.19)	2.79 (0.17)	3.00 (0.19)
First pass regression	0.10 (0.05)	0.13 (0.05)	0.12 (0.04)	0.13 (0.05)

Note. HF P = high frequency predictable words; HF U = high frequency unpredictable words; LF P = low frequency predictable words; LF U= low frequency unpredictable words.

B.6 Anova results for eye movements on the target word

Overview of Anova results for gaze durations (log)

Effect	**Analysis by participants**			**Analysis by items**		
	df	**F1**	**p**	**df**	**F2**	**p**
group	(1,35)	19.45	< .0001	(1,26)	118.05	< .0001
frequency	(1,35)	63.54	< .0001	(1,26)	15.37	< .0001
predictability	(1,35)	35.93	< .0001	(1,26)	26.86	< .0001
group x frequency	(1,35)	0.83	ns	(1,26)	0.58	ns
group x predictability	(1,35)	0.16	ns	(1,26)	0.84	ns
frequency x predictability	(1,35)	3.71	= .06	(1,26)	4.15	= .05
group x frequency x predictability	(1,35)	3.36	= .08	(1,26)	1.91	ns

Overview of Anova results for total durations (log)

Effect	**Analysis by participants**			**Analysis by items**		
	df	**F1**	**p for F1**	**df**	**F2**	**p for F2**
group	(1,35)	73.82	< .0001	(1,26)	1389.98	< .0001
frequency	(1,35)	15.68	< .0001	(1,26)	2.75	ns
predictability	(1,35)	140.08	< .0001	(1,26)	70.40	< .0001
group x frequency	(1,35)	0.32	ns	(1,26)	0.34	ns
group x predictability	(1,35)	6.60	= .01	(1,26)	7.44	= .01
frequency x predictability	(1,35)	2.87	ns	(1,26)	1.66	ns
group x frequency x predictability	(1,35)	4.08	= .05	(1,26)	3.13	ns

Overview of Anova results for first pass regressions (log)

Effect	**Analysis by participants**			**Analysis by items**		
	df	**F1**	**p for F1**	**df**	**F2**	**p for F2**
group	(1,35)	16.11	< .0001	(1,26)	63.67	< .0001
frequency	(1,35)	2.39	ns	(1,26)	0.28	ns
predictability	(1,35)	13.30	< .0001	(1,26)	7.06	= .01
group x frequency	(1,35)	5.40	= .03	(1,26)	2.09	ns
group x predictability	(1,35)	0.0004	ns	(1,26)	3.83	ns
frequency x predictability	(1,35)	1.57	ns	(1,26)	6.53	ns
group x frequency x predictability	(1,35)	0.17	ns	(1,26)	0.02	ns

Appendix C. Experimental stimuli and statistical results

Experiment 2.

C.1 Acquired dyslexia profile of PWA with results from PALPA reading subtests

PWA ID	High frequency words (PALPA 31)	Low frequency words (PALPA 31)	Words mean (PALPA 31)	Nouns (PALPA 32)	Adjec-tives (PALPA 32)	Verbs (PALPA 32)	Function words (PALPA 32)	Word classes mean (PALPA 32)
1	1.00	0.98	0.99	1.00	1.00	1.00	0.95	0.99
2	1.00	0.95	0.98	1.00	1.00	1.00	1.00	1.00
3	0.48	0.43	0.46	0.40	0.55	0.80	0.75	0.63
4	0.98	0.70	0.84	0.85	0.90	0.90	0.85	0.88
5	0.98	1.00	0.99	0.95	1.00	1.00	0.85	0.95
6	1.00	0.98	0.99	1.00	1.00	1.00	1.00	1.00
7	1.00	0.95	0.98	0.90	0.85	0.85	0.85	0.86
8	1.00	1.00	1.00	1.00	1.00	0.90	1.00	0.98
9	0.98	1.00	0.99	1.00	1.00	1.00	1.00	1.00
10	0.95	0.98	0.97	1.00	1.00	1.00	1.00	1.00
11	1.00	0.93	0.97	1.00	1.00	0.95	1.00	0.99

PWA ID	Morphology regular (PALPA 34)	Morphology derived (PALPA 34)	Morphology irregular (PALPA 34)	Unaffixed phonological control for regular words (PALPA 34)	Unaffixed phonological control for derived words (PALPA 34)	Unaffixed phonological control for irregular words (PALPA 34)	Morphology mean (PALPA 34)
1	1.00	1.00	1.00	1.00	0.93	0.93	0.98
2	1.00	1.00	1.00	0.93	1.00	1.00	0.99
3	0.67	0.67	0.53	0.47	0.53	0.67	0.59
4	0.87	0.93	0.80	0.67	1.00	1.00	0.88
5	1.00	0.93	0.73	0.93	0.93	1.00	0.92
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	0.67	0.87	0.87	1.00	1.00	0.93	0.89
8	1.00	0.87	1.00	0.87	1.00	1.00	0.96
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.80	1.00	1.00	0.93	1.00	1.00	0.96
11	0.27	0.87	0.67	0.87	0.93	0.87	0.75

PWA ID	Regular spelling sound (PALPA 35)	Exception spelling sound (PALPA 35)	Spelling sound mean (PALPA 35)	Nonwords (PALPA 36)	Oral reading overall mean
1	0.97	1.00	0.99	0.50	0.89
2	1.00	0.97	0.99	1.00	0.99
3	0.37	0.60	0.49	0.13	0.46
4	n.a.	n.a.	n.a.	0.13	0.68
5	0.97	0.90	0.94	0.50	0.86
6	0.90	1.00	0.95	0.71	0.93
7	1.00	1.00	1.00	0.33	0.81
8	0.90	1.00	0.95	0.58	0.89
9	1.00	1.00	1.00	0.96	0.99
10	0.97	1.00	0.99	0.63	0.91
11	0.93	0.87	0.90	0.13	0.75

C.2 Norming study results for individual verbs

Results for individual verbs Norming study 1 – completions from verbs in context

	SC-biased context			**DO-biased context**		
verb	**% Use of SC sense**	**% SC structure**	**% DO structure**	**% Use of DO sense**	**% SC structure**	**% DO structure**
acknowledge	100.00%	95.83%	0.00%	94.44%	2.94%	97.06%
add	91.67%	96.97%	3.03%	90.91%	0.00%	100.00%
bet	84.21%	100.00%	0.00%	94.12%	0.00%	96.88%
claim	97.06%	96.97%	0.00%	94.74%	0.00%	100.00%
find	87.88%	34.48%	51.72%	91.67%	0.00%	100.00%
observe	100.00%	100.00%	0.00%	95.45%	0.00%	100.00%
project	90.91%	60.00%	35.00%	88.89%	0.00%	100.00%
recognise	100.00%	100.00%	0.00%	94.29%	0.00%	100.00%
report	100.00%	39.13%	56.52%	100.00%	0.00%	100.00%
reveal	100.00%	94.29%	0.00%	80.00%	0.00%	100.00%
mean	95.17%	81.77%	14.63%	92.45%	0.29%	99.39%

Results for individual verbs Norming study 2 – completions from the verb + NP in context

	SC-biased context			**DO-biased context**		
verb	**% Use of SC sense**	**% SC structure**	**% DO structure**	**% Use of DO sense**	**% SC structure**	**% DO structure**
acknowledge	73.08%	100.00%	0.00%	100.00%	33.13%	66.67%
add	84.21%	100.00%	0.00%	83.87%	0.00%	100.00%
bet	96.55%	100.00%	0.00%	100.00%	0.00%	100.00%
claim	90.48%	100.00%	0.00%	90.00%	14.81%	85.19%
find	95.83%	17.39%	4.35%	100.00%	0.00%	100.00%
observe	65.22%	100.00%	0.00%	100.00%	0.00%	100.00%
project	70.00%	85.71%	0.00%	100.00%	0.00%	100.00%
recognise	92.86%	92.31%	7.69%	100.00%	0.00%	100.00%
report	85.19%	82.61%	17.39%	100.00%	0.00%	100.00%
reveal	94.44%	100.00%	0.00%	92.86%	0.00%	100.00%
mean	84.79%	87.80%	2.94%	96.67%	4.79%	95.19%

C.3 Experimental stimuli with context sentences and sense keys from WordNet

Target verb	SC clause	Condition and target sense of the verb according to WordNet
acknow-ledge	Context biasing towards SC	**acknowledge#1** (declare to be true or admit the existence or reality or truth of)
	For an hour John was bragging that he could move house on his own even though that was silly. (1) Finally though, he acknowledged that **his friends would probably help him** a lot. (2) Finally though, he acknowledged **his friends would probably help him** a lot.	(1) SC bias non-ambiguous (2) SC bias ambiguous In the end, did John think his friends would help? (yes)
	Context biasing towards DO	**acknowledge#4**, recognise#7, recognise#5 (express obligation, thanks, or gratitude for)
	Alex saw his friends sitting down in the first row to watch him in the competitive race. (3) Finally, he acknowledged that **his friends would probably help him** a lot. (4) He acknowledged **his friends would probably help him** a lot.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did Alex think his friends would make it worse? (no)
add	Context biasing SC	**add#2**, append#3, supply#4 (state or say further)
	George suggested reasons for the children's poor grades at school recently. (1) He added that **the children were probably better off** doing fewer after-school activities. (2) He added **the children were probably better off** doing fewer after-school activities.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did George say the children should do fewer activities after school? (yes)
	Context biasing DO	**add#1** (make an addition (to); join or combine or unite with others; increase the quality, quantity, size or scope of)
	James showed his wife the list of children going on the school basketball trip and asked her for a pen. (3) He added that **the children were probably better off** joining the trip than spending	(3) DO bias non-ambiguous (4) DO bias ambiguous Did James think the children should spend the holidays at home? (no)

	the holidays at home. (4) He added **the children were probably better off** joining the trip than spending the holidays at home.	
bet	Context biasing SC	**bet#1**, wager#2 (maintain with or as if with a bet
	Tim was deeply depressed about the damage to his brand new Rolls Royce. (1) He bet that **his car was going to be worth** much less than it used to be. (2) He bet **his car was going to be worth** much less than it used to be.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did Tim think his car had kept its value? (no)
	Context biasing DO	**bet#2**, wager#1, play#30 (stake on the outcome of an issue)
	Jeff likes gambling and this time he took a big risk when playing poker. (3) He bet that **his car was going to be worth** enough to let him stay in the game and win back his money. (4) He bet **his car was going to be worth** enough to let him stay in the game and win back his money.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did Jeff think his car was worth enough to stay in the game? (yes)
claim	Context biasing SC	**claim#1** (assert or affirm strongly; state to be true or existing)
	Phil wrote a letter to thank people for being awarded the peace medal. (1) He claimed that **the honour made him very happy** and was the best thing that ever happened to him. (2) He claimed **the honour made him very happy** and was the best thing that ever happened to him.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did Phil say the honor made him very happy? (yes)
	Context biasing DO	**claim#2**, lay claim#1, arrogate#1 (demand as being one's due or property; assert one's right or title to)
	After he won the competition John went down to the awards centre. (3) He claimed that **the honour made him very happy** and was the best thing that ever happened to him.	(3) DO bias non-ambiguous (4) DO bias ambiguous Was the honour the worst thing that ever happened to John? (no)

	(4) He claimed **the honour made him very happy** and was the best thing that ever happened to him.	
find	Context biasing SC	discover#4, **find#9** (make a discovery), examples: *"She found that he had lied to her"; "The story is false, so far as I can discover"*
	The students hated having to read the textbook on biology because it was boring. (1) They found that **the book was written poorly and** difficult to understand. (2) They found **the book was written poorly and** difficult to understand.	(1) SC bias non-ambiguous (2) SC bias ambiguous Was the book easy to understand? (no)
	Context biasing DO	**find#3**, regain#2 (come upon after searching; find the location of something that was missed or lost)
	Susan and her friends had been searching for the book everywhere, but were successful in the end. (3) They found that **the book was written poorly and** regretted searching for it. (4) They found **the book was written poorly and** regretted searching for it.	(3) DO bias non-ambiguous (4) DO bias ambiguous Was the book written poorly? (yes)
observe	Context biasing SC	**observe#2**, mention#2, remark#1 (make mention of)
	Matt wondered why the government continued to win the elections. (1) He observed that **the people were not aware of any** of the corruption. (2) He observed **the people were not aware of any** of the corruption.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did Matt say the people knew about the corruption? (no)
	Context biasing DO	**observe#3** (observe with care or pay close attention to), **observe#4** (watch attentively)
	In his security job, Joe had to keep an eye on everything. (3) He observed that **the people were not aware of any** dangers around them. (4) He observed **the people were not aware of any** danger around them.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did Joe say the people were not aware of the danger? (yes)
project	Context biasing SC	**project#9**, fancy#1, see#4, figure#3,picture#1, image#2 (imagine; conceive

		of; see in one's mind), examples: *"I can't see him on horseback!"; "I can see what will happen"; "I can see a risk in this strategy"*
	The journalist asked the filmmaker whether he expected the production would be a success. (1) He projected that **the film would be very popular with** teenagers. (2) He projected **the film would be very popular** with teenagers.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did the journalist think the film might be popular? (yes)
	Context biasing DO	**project#4** (project on a screen)
	At the meeting William wanted to show the video he made recently. (3) He projected that **the film would be very popular with** nature lovers. (4) He projected **the film would be very popular with** nature lovers.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did William think nature lovers would dislike the film (no)
recog-nise	Context biasing SC	**recognise#2**, recognise#6, realise#1, realise#5, agnize#1, agnise#1 (be fully aware or cognizant of)
	Gordon had moved in with his old friend, but they argued a lot. (1) After a while he recognised that **his old friend had adopted a different** lifestyle and he should move. (2) After a while he recognised **his old friend had adopted a different** lifestyle and he should move.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did Gordon think living with his friend was working well? (no)
	Context biasing DO	**recognise#3**, recognise#3, distinguish#2, discern#1, pick out#2, make out#1, tell apart#1 (detect with the senses) **recognise#4**, recognise#7 (perceive to be the same)
	When Billy went to the party he did not know any familiar faces. (3) After a while he recognised that **his old friend had adopted a different** look and appeared different. (4) After a while he recognised **his old friend had adopted a different** look and appeared different.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did Billy think his friend looked different now? (yes)
report	Context biasing SC	**report#2** (announce as the result of an investigation or experience or

		finding), examples: "Dozens of incidents of wife beatings are reported daily in this city"; "The team reported significant advances in their research"
	The news presenter had to take a deep breath before he gave details of the deaths at the school. (1) He reported that **the students were caught by surprise when** the fire started. (2) He reported **the students were caught by surprise when** the fire started.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did the news presenter say the students were surprised by the fire? (yes)
	Context biasing DO	**report#6** (complain about; make a charge against, examples: "I reported her to the supervisor")
	The teacher saw two of the high school students smoking. (3) He reported that **the students were caught by surprise when** he saw them smoking. (4) He reported **the students were caught by surprise when** he saw them smoking.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did the teacher say the students expected to be caught? (no)
reveal	Context biasing SC	**reveal#2**, discover#6, expose#2,divulge#1, break#15, give away#2, let out#2, uncover#3 (make known to the public information that was previously known only to a few people or that was meant to be kept a secret)
	Samuel asked Jessica why she allowed the children to play with his expensive camera. (1) She revealed that **the camera had actually been broken** for a long time. (2) She revealed **the camera had actually been broken** for a long time.	(1) SC bias non-ambiguous (2) SC bias ambiguous Did Jessica say the camera worked fine? (no)
	Context biasing DO	**reveal#1** (make visible)
	Steve finally agreed to show Sam the package he had hidden under the bed. (3) He revealed that **the camera had actually been broken** when he got it. (4) He revealed **the camera had actually been broken** when he got it.	(3) DO bias non-ambiguous (4) DO bias ambiguous Did Steve say the camera was already broken? (yes)

C.4 Filler sentences for list A and B

Practice items
prove
Mary took a big step in her career as a mathematician.
She proved a new theory after a year of hard work.
recall
Two students had requested the overdue book so the librarian agreed to get it straight away.
She recalled the novel using the library's computer system.
grasp
Lucy and her friend were walking by the river when Tom suddenly slipped.
She grasped her friend to prevent him from falling into the water.
use
The bananas were too ripe to eat, as Lynne found out when she peeled one.
Therefore, she used them for making muffins instead.
decide
Fiona and her friend were planning to go to a concert, but it got cancelled.
They decided to go to a nice restaurant instead.
20 filler sentences in a DO-structure
(1) Verbs that are DO-biased:
confirm
It was hard to believe the rumours about the politician’s affair.
However, the politician confirmed the story, and apologized.
hear
Jessica enjoyed listening to her favourite song at the music festival.
The following day, she heard the melody over and over in her head.
write
Because the students did so poorly in the exam, the teacher asked them to do some extra work.
The students wrote an essay to achieve higher marks.
warn
The conference had many talks about an early warning system for earthquakes.
The system is designed to warn people when there is still time to flee.
understand
A group of tourists was parking their car, when they were suddenly shouted at by the police.
The tourists did not hear all the words, but they understood the message.
accept
After Rosy missed the last bus home, a friend offered to drive her.
She accepted the lift and was glad to get home safely.
discover
The science team worked in Borneo studying its wildlife.
Within the first year they discovered two thousand new species.
print
The teachers spent a lot of money on booking the tickets for the field trip.
They printed the receipts to claim back the expenses later on.

(2) verbs that are SC-biased:

admit

The students on the waiting list refused to leave the professor’s office until he let them into his class.

Finally he admitted the students to the course.

prove

Mary took a big step in her career as a mathematician.

She proved a new theory after a year of hard work.

suggest

Tim and Lucy were discussing where to go on holidays next.

Lucy suggested the Bahamas even though that was out of the price range.

indicate

The nanny asked the boy to show her which toy he wanted.

He indicated the car because that was his favourite.

believe

Sean’s father became very angry about his son’s excuses for missing school.

He did not believe his stories and thought that they were made up.

(3) Verbs with equal bias or that are not listed in the verb bias norms by Garnsey et al., 1997:

declare

The government was looking for a way to honour the murdered civil rights leader.

They declared a holiday on the day of his murder.

feel

Rick was beginning to get a little cold as he climbed the icy mountain.

He felt the frost numbing his feet.

recall

Two students had requested the overdue book so the librarian agreed to get it straight away.

She recalled the novel using the library's computer system.

know

Sarah and Fiona lost their walking map on the trip through the National Park.

Fortunately, Fiona knew the area well so they found their way back.

sense

Marian saw two people in the street harassing a young woman.

She sensed the need to offer help immediately.

regret

Amber went to watch the marathon but left her umbrella at home.

She regretted her decision when it started to rain.

grasp

Lucy and her friend were walking by the river when Tom suddenly slipped.

She grasped her friend to prevent him from falling into the water.

Different structures (taken from Hare et al., 2003)

An old lady and her grandson went to the circus when it came to town.

One of the clowns gave her a flower and gave her grandson a balloon.

Sheryl works until ten o'clock every night.

Her dream is to get out of sales and become an artist.

The clock outside the old town hall stopped working on Christmas day.

It took a year to repair.
Not all Physics textbooks are equal in terms of readability.
In fact, some of them are nearly impossible to understand.
A girl was walking through the park when she noticed an old man sleeping on a bench.
She asked him if he needed any help.
The key to Virginia's front door got bent in the lock yesterday.
She had to break in through the bathroom window.
Getting a good summer job is tough for most high school students.
Most good jobs are given to permanent employees and their children.
The bananas were too ripe to eat, as Lynne found out when she peeled one.
Therefore, she used them for making muffins instead.
Melanie is pregnant with her second child.
She is having a lot of trouble with nausea and back pain.
Fiona and her friend were planning to go to a concert, but it got cancelled.
They decided to go to a nice restaurant instead.

C.5 Fixation durations for inversely-transformed data, correct and incorrect trials

Mean inverse fixation durations (and SD) (in ms) for the disambiguation region (correct and incorrect trials)

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	0.005	0.005	0.006	0.005
SD	0.0008	0.001	0.0007	0.0005
Gaze duration	0.004	0.004	0.004	0.0004
SD	0.0009	0.001	0.001	0.0009
Total duration	0.003	0.003	0.003	0.003
SD	0.0006	0.0008	0.0009	0.0007

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	0.003	0.004	0.004	0.005
SD	0.0008	0.0009	0.001	0.001
gaze duration	0.002	0.003	0.002	0.003
SD	0.001	0.002	0.001	0.002
Total duration	0.003	0.003	0.003	0.004
SD	0.0006	0.0008	0.0008	0.0007

C.6 Fixation durations for inversely-transformed data, correct trials

Mean inverse fixation durations (and SD) (in ms) for the noun phrase region (correct trials)

NHI	DO amb	DO non-amb	SC amb	SC non-amb
First fixation duration	0.005	0.005	0.005	0.005
SD	0.0007	0.0008	0.0009	0.001
Gaze duration	0.004	0.005	0.004	0.004
SD	0.0008	0.0009	0.001	0.001
Total duration	0.003	0.004	0.004	0.004
SD	0.001	0.0009	0.001	0.001

PWA	DO amb	DO non-amb	SC amb	SC non-amb
First fixation duration	0.004	0.005	0.005	0.005
SD	0.001	0.0007	0.0008	0.0007
Gaze duration	0.003	0.004	0.003	0.004
SD	0.001	0.001	0.001	0.0007
Total duration	0.001	0.002	0.002	0.002
SD	0.0005	0.0001	0.0008	0.0008

Mean inverse fixation durations (and SD) (in ms) for the disambiguation region (correct trials)

NHI	DO amb	DO non-amb	SC amb	SC non-amb
First fixation duration	0.005	0.005	0.005	0.005
SD	0.0006	0.0004	0.0007	0.0004
Gaze duration	0.004	0.004	0.004	0.004
SD	0.0009	0.001	0.0009	0.0009
Total duration	0.003	0.003	0.003	0.004
SD	0.0006	0.0008	0.0007	0.0007

PWA	DO amb	DO non-amb	SC amb	SC non-amb
First fixation duration	0.004	0.004	0.004	0.004
SD	0.0007	0.0008	0.0006	0.0007
Gaze duration	0.002	0.003	0.003	0.003
SD	0.001	0.001	0.001	0.001
Total duration	0.001	0.001	0.001	0.001
SD	0.0005	0.0006	0.0007	0.0006

Mean inverse fixation durations (and SD) (in ms) for the post-disambiguation region (correct trials)

NHI	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	0.005	0.005	0.005	0.005
SD	0.0006	0.0007	0.0009	0.0005
Gaze duration	0.004	0.004	0.004	0.004
SD	0.0008	0.0009	0.001	0.0006
Total duration	0.003	0.003	0.003	0.003
SD	0.0006	0.0007	0.0006	0.0006

PWA	**DO amb**	**DO non-amb**	**SC amb**	**SC non-amb**
First fixation duration	0.004	0.004	0.004	0.004
SD	0.0007	0.0005	0.0008	0.0005
Gaze duration	0.003	0.003	0.003	0.003
SD	0.0007	0.0009	0.001	0.001
Total duration	0.001	0.001	0.001	0.001
SD	0.0004	0.0005	0.0005	0.0004

C.7 Anova results for correct and incorrect trials for the disambiguation region

Overview of Anova results for first fixation durations (inverse transformation)

Effect	***Analysis by participants***			***Analysis by items***		
	df	**F1**	**p**	**df**	**F2**	**p**
group	(1,20)	19.58	< .001	(1,9)	41.21	< .001
ambiguity	(1,20)	1.31	ns	(1,9)	3.82	ns
context	(1,20)	13.67	= .001	(1,9)	6.83	= 0.03
group x ambiguity	(1,20)	1.70	ns	(1,9)	4.32	ns
group x context	(1,20)	0.70	ns	(1,9)	0.14	ns
ambiguity x context	(1,20)	0.009	ns	(1,9)	0.00003	ns
group x ambiguity x context	(1,20)	0.05	ns	(1,9)	0.4	ns

Overview of Anova results for gaze durations (inverse transformation)

Effect	***Analysis by participants***			***Analysis by items***		
	df	**F1**	**p**	**df**	**F2**	**p**
group	(1,20)	14.40	= .001	(1,9)	72.73	< .0001
ambiguity	(1,20)	19.59	< .001	(1,9)	21.24	= 0.001
context	(1,20)	2.88	ns	(1,9)	1.88	ns
group x ambiguity	(1,20)	1.31	ns	(1,9)	1.06	ns
group x context	(1,20)	2.74	ns	(1,9)	5.07	= .05
ambiguity x context	(1,20)	0.50	ns	(1,9)	0.82	ns
group x ambiguity x context	(1,20)	0.57	ns	(1,9)	2.02	ns

Overview of Anova results for total durations (inverse transformation)

Effect	***Analysis by participants***			***Analysis by items***		
	df	**F1**	**p**	**df**	**F2**	**p**
group	(1, 20)	68.94	< .00001	(1,9)	311.39	< .00001
ambiguity	(1, 20)	8.51	= .009	(1,9)	35.57	< .001
context	(1, 20)	21.62	< .001	(1,9)	11.87	= .007
group x ambiguity	(1, 20)	1.76	ns	(1,9)	2.89	ns
group x context	(1, 20)	0.83	ns	(1,9)	0.34	ns
ambiguity x context	(1, 20)	1.01	ns	(1,9)	1.12	ns
group x ambiguity x context	(1, 20)	0.10	ns	(1,9)	0.17	ns

C.8 Anova results for correct trials

Overview of Anova results for first fixation durations (inverse transformation)

Effect	**Analysis by participants**			**Analysis by items**		
	df	**F1**	**p**	**df**	**F2**	**p**
Noun phrase region						
group	(1,20)	6.63	= .02	(1,9)	38.35	< .001
ambiguity	(1,20)	0.51	ns	(1,9)	0.06	ns
context	(1,20)	3.77	= .07	(1,9)	2.38	ns
group x ambiguity	(1,20)	0.006	ns	(1,9)	0.19	ns
group x context	(1,20)	1.10	ns	(1,9)	0.51	ns
ambiguity x context	(1,20)	1.00	ns	(1,9)	0.67	ns
group x ambiguity x context	(1,20)	0.02	ns	(1,9)	0.09	ns
Disambiguation region						
group	(1,20)	24.09	< .0001	(1,9)	72.63	< .0001
ambiguity	(1,20)	2.31	ns	(1,9)	5.25	= .05
context	(1,20)	0.08	ns	(1,9)	3.97	ns
group x ambiguity	(1,20)	0.92	ns	(1,9)	2.70	ns
group x context	(1,20)	0.56	ns	(1,9)	0.38	ns
ambiguity x context	(1,20)	1.68	ns	(1,9)	1.15	ns
group x ambiguity x context	(1,20)	0.01	ns	(1,9)	1.12	ns
Post disambiguation region						
group	(1,20)	28.18	< .0001	(1,9)	81.43	< .0001
ambiguity	(1,20)	0.0001	ns	(1,9)	0.0002	ns
context	(1,20)	0.08	ns	(1,9)	0.31	ns
group x ambiguity	(1,20)	0.02	ns	(1,9)	0.06	ns
group x context	(1,20)	0.02	ns	(1,9)	0.03	ns
ambiguity x context	(1,20)	0.03	ns	(1,9)	0.36	ns
group x ambiguity x context	(1, 20)	0.47	ns	(1,9)	ns	ns

Note: results from first pass regressions are not included, as they were not analysed using Anova.

Overview of Anova results for gaze durations (inverse transformation)

Effect	Analysis by participants			Analysis by items		
	df	**F1**	**p**	**df**	**F2**	**p**
Noun phrase region						
group	(1,20)	7.04	= .02	(1,9)	44.98	< .0001
ambiguity	(1,20)	3.73	= .07	(1,9)	0.77	ns
context	(1,20)	0.73	ns	(1,9)	0.50	ns
group x ambiguity	(1,20)	2.42	ns	(1,9)	0.96	ns
group x context	(1,20)	0.88	ns	(1,9)	0.16	ns
ambiguity x context	(1,20)	0.89	ns	(1,9)	0.27	ns
group x ambiguity x context	(1,20)	0.12	ns	(1,9)	0.08	ns
Disambiguation region						
group	(1,20)	15.01	< .001	(1,9)	112.87	< .0001
ambiguity	(1,20)	11.99	= .002	(1,9)	18.57	= .002
context	(1,20)	3.95	= .06	(1,9)	5.91	= .04
group x ambiguity	(1,20)	0.04	ns	(1,9)	0.11	ns
group x context	(1,20)	0.23	ns	(1,9)	1.01	ns
ambiguity x context	(1,20)	3.68	= .07	(1,9)	1.49	ns
group x ambiguity x context	(1,20)	0.01	ns	(1,9)	2.40	ns
Post disambiguation region						
group	(1,20)	18.99	< .001	(1,9)	59.60	< .0001
ambiguity	(1,20)	0.04	ns	(1,9)	0.32	ns
context	(1,20)	0.49	ns	(1,9)	0.25	ns
group x ambiguity	(1,20)	2.54	ns	(1,9)	1.77	ns
group x context	(1,20)	0.0008	ns	(1,9)	0.05	ns
Ambiguity x context	(1,20)	1.79	ns	(1,9)	0.52	ns
group x ambiguity x context	(1,20)	2.25	ns	(1,9)	2.68	ns

Note: results from first pass regressions are not included, as they were not analysed using Anova.

Overview of Anova results for total durations (inverse transformation)

Noun phrase region						
Effect	**Analysis by participants**			**Analysis by items**		
	df	**F1**	**p**	**df**	**F2**	**p**
group	(1,20)	30.87	<0.0001	(1,9)	541.14	< .0001
ambiguity	(1,20)	6.95	= 0.02	(1,9)	1.83	ns
context	(1,20)	3.18	ns	(1,9)	5.88	= .04
group x ambiguity	(1,20)	0.41	ns	(1,9)	0.28	ns
group x context	(1,20)	0.58	ns	(1,9)	0.85	ns
ambiguity x context	(1,20)	4.47	= .05	(1,9)	9.40	= .01
group x ambiguity x context	(1,20)	0.65	ns	(1,9)	1.19	ns
Disambiguation region						
group	(1,20)	69.98	< .0001	(1,9)	358.09	< .0001
ambiguity	(1,20)	6.70	= .02	(1,9)	28.72	< .001
context	(1,20)	38.12	< .0001	(1,9)	10.25	= .01
group x ambiguity	(1,20)	2.97	ns	(1,9)	4.02	= .08
group x context	(1,20)	3.69	= .07	(1,9)	1.42	ns
ambiguity x context	(1,20)	1.53	ns	(1,9)	1.84	ns
group x ambiguity x context	(1,20)	0.58	ns	(1,9)	0.57	ns
Post disambiguation region						
group	(1,20)	88.76	< .0001	(1,9)	66.18	< .0001
ambiguity	(1,20)	1.47	ns	(1,9)	2.32	ns
context	(1,20)	4.94	= .04	(1,9)	2.38	ns
group x ambiguity	(1,20)	0.11	ns	(1,9)	0.20	ns
group x context	(1,20)	0.38	ns	(1,9)	0.14	ns
ambiguity x context	(1,20)	1.22	ns	(1,9)	1.87	ns
group x ambiguity x context	(1,20)	0.36	ns	(1,9)	0.15	ns

Note: results from first pass regressions are not included, as they were not analysed using Anova.

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