Noun and verb processing in aphasia and healthy aging: Online behavioural and ERP investigations

Vanessa Meitanis

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Department of Language & Cognition
Division of Psychology and Language Sciences
University College London

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Declaration

I, Vanessa Meitanis, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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To Mumsili, Pupsi, Nini, Juli, Burçi and Talay

Abstract

Nouns, verbs and function words are reported to be differentially impaired in individuals with aphasia. However, the behavioural evidence of selective word class impairments relies heavily on observations from single word production or offline comprehension studies. This thesis applied online measures to probe noun and verb input processing in individuals with aphasia and in healthy aging. Experiments 1, 2 and 3 employed an online reaction time task (word-monitoring) to investigate differential processing of noun (NP) and verb phrases (VP) in three different conditions, 1) phrase structure violations (*much/*many milk*), 2) premodification (*Tom kicked* vs *Tom* <u>*should have*</u> *kicked*) and 3) phrase frequency (high: *asked for directions*; low: *looked for directions*).

Experiment 1 was conducted with neurotypical younger and older adults to explore age effects in language processing using a word-monitoring task (WMT), and to establish normative performance. The results showed that both groups were equally sensitive to NP and VP manipulations, although older adults were more disrupted by phrase structure violations. Experiment 2 employed the WMT with a group of individuals with aphasia, while Experiment 3 followed up on the group findings by examining single case evidence for NP/VP dissociations in two individuals with severe impairments, two agrammatic and one anomic individual. Together, the findings from the group and individual case analyses indicated that noun/verb dissociations are absent in input processing, while also showing residual sensitivity to function words in the form of verb premodifiers. However, there is some evidence at the individual level, that more severely impaired individuals have greater difficulties processing nouns relative to verbs.

In the final experiment with neurotypical younger and older adults, event-related potentials (ERPs) were recorded in responses to verbs in facilitatory contexts and ungrammatical sentences. The findings revealed no age-related changes in electrophysiological responses to verbs in both contexts.

Impact statement

Aphasia is an acquired language impairment most commonly caused by a stroke and results in difficulties producing or understanding language. Nouns, verbs and function words are the basic building blocks of sentences. They are reported to be selectively damaged in aphasia, whereby some individuals have greater difficulties producing verbs relative to nouns – or vice versa. Similarly, observations of greater difficulties producing function words (e.g. *the*, *up*, *should*), relative to content words (e.g. *animal, playing, fantastic*), have been reported. Previous studies have largely focused on how selective word class impairments affect speech production, focusing on difficulties retrieving single words. In comparison, far fewer studies have examined whether similar patterns are observed in language comprehension. This thesis highlights the importance of addressing and incorporating evidence from comprehension and input studies into our models of the mental lexicon which so far rely heavily on findings from speech production.

To date, little is known about how aphasic listeners process nouns, verbs and function words in real-time. In a series of four experiments, this thesis applied online behavioural methods and recorded brain responses to explore real-time processing of nouns and verbs embedded in different sentence contexts. The current work also developed a novel way of probing function word processing by examining the degree to which premodifiers, consisting largely of function words, facilitate recognition of head nouns and verbs. An advantage of this design over traditional approaches, is that it avoids the problems of comparing content and function words that are not matched in phonological saliency, stress, frequency and imageability, factors that are known to influence processing. Importantly, the designs of the behavioural and electrophysiological tasks developed in this thesis moved away from measuring single word processing, to probing nouns, verbs and function words embedded in sentences. Verbs and function words are rarely encountered as single words. The sentence-level investigations probe processing of words in their "natural environment", reflecting how they are encountered in everyday settings.

The findings in this thesis contribute towards our understanding of noun, verb and function word processing in aphasia. They also have implications for clinical practice. Clinical assessments largely employ offline or single word tasks in order to assess residual language abilities in individuals with aphasia. However, performance in these tasks may not necessarily reflect individuals' language abilities in naturalistic settings and, in particular, real-time language comprehension. The online methods employed in this thesis, are designed to measure implicit and automatic processes. Importantly, they capture real-time processing of spoken language and thus provide further insight into the functional difficulties individuals with aphasia may have during spoken discourse comprehension in everyday situations. These methods, with appropriate adaptation, could be a powerful tool for speech and language therapists who want to assess functional difficulties with input processing in aphasia.

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1. Introduction

Nouns, verbs and function words are the basic building blocks of sentences. They may be selectively damaged in aphasia, impacting an individual's ability to produce and understand language. In this thesis, I explore word-class specific deficits in healthy and aphasic listeners and determine the implications for cognitive models of the organization of the mental lexicon. Traditionally, observations of selective word class impairments are used to distinguish between fluent and non-fluent aphasia subtypes. In particular, agrammatism, linked to inferior frontal gyrus lesions, is claimed to be associated with verb and function word deficits, while anomia, associated with temporo-parietal damage, is linked to noun impairments (Caramazza & Hillis, 1991; Damasio & Tranel, 1993; Miceli et al., 1984). However, more recently, studies have reported greater verb than noun impairments in both fluent and non-fluent aphasia, indicating that aphasia subtype is an inadequate predictor of selective word class impairments (Mätzig et al., 2009).

Selective word class impairments are often investigated through the use of single word production and offline sentence tasks. However, there are several limitations that may contribute to the poorer performance of verbs and function words on such tasks. Verbs and function words are inherently relational and rarely encountered outside of phrases or sentences. By testing them in isolation, they are removed from elements that scaffold their form and function. While offline tasks such as sentence-picture matching probe processing at the sentence-level, they often assess meta-linguistic knowledge by requiring individuals to make explicit and strategic choices about grammatical aspects of linguistic stimuli. Performance may not necessarily reflect individual's language ability in naturalistic settings and, in particular, real time language comprehension.

In this thesis, I employ online methods to re-examine selective word class impairments. Online tasks that use reaction time or electrophysiological measures, are designed to measure implicit cognitive processes. These address automatic and non-reflective processing and capture the temporal aspect inherent in language comprehension (Marinis, 2010; Schmitt & Miller, 2010). Given how language processing is dynamic and unfolds over time, it is advantageous to use methods with high temporal resolution that measure processing in real time. The word-monitoring task (WMT) is an online task that captures sensitivity to linguistic information by measuring differences in reaction times (RTs) to target words embedded in different sentential contexts. Although the WMT paradigm has been used to investigate syntactic and semantic processing in individuals with aphasia (Baum, 1989; Friederici, 1983, 1985; Tyler, 1989; Tyler & Marslen-Wilson, 1977; Tyler & Cobb, 1987; Wayland, Berndt, & Sandson, 1996), it has not been widely adopted in the field and has not been applied to examine noun/verb dissociations and sensitivity to function words. Event-related potentials (ERPs), a further online technique, measures small voltages changes in the brain in response to sensory or cognitive events. It has been extensively used to investigate natural language processing in neurotypical adults and is a promising tool for examining residual receptive language abilities in individuals with aphasia. The high temporal resolution provides key insights into the time course of language processing. For example, detection of syntactic anomalies in sentences (e.g. **The toddler* <u>bounce</u> *on the bed*) is reflected by a P600 response, a positive going wave approximately 600ms post violation. Electrophysiological markers, including the P600, were utilized to investigate age-related changes in verb processing.

Differentiating pathological processing from changes due to neurotypical aging is another important factor in understanding patterns of language processing in aphasia. Healthy aging is associated with changes in sensory-perceptual and cognitive processes that can affect language production or comprehension (Shafto et al., 2012; Wingfield et al., 2003). Although language comprehension is believed to remain largely stable throughout the lifespan, evidence from behavioural and electrophysiological studies is not always consistent and suggests a more complicated picture of preservation and decline (Federmeier & Kutas, 2005; Kemmer et al., 2004; Shafto et al., 2012). Research on language and aging typically distinguishes between semantic and syntactic processing. The research in the current thesis will focus specifically on syntactic processing. Age effects in syntactic processing can at least partly be explained whether interpretative (online) or post-interpretative (offline) processes are probed. Tasks which tap offline comprehension are more likely to report age-related decline than online tasks. Remarkably, electrophysiological methodologies have rarely been applied and could provide new insights into syntactic processing in neurotypical aging.

1.1 Research questions & Structural outline of thesis

The main aim of this thesis is to use online sentence-level tasks to explore differential processing of noun phrase and verb phrases, and sensitivity to function words both in individuals with aphasia and healthy aging. In addition to group level analyses, individual case analyses evaluated the degree to which noun, verb and function word processing is moderated by impairment severity and aphasia subtype.

In a series of three experiments, this thesis aimed to answer the following main research questions:

1) Do aphasic listeners show differential processing of nouns and verbs?
2) Are individuals with aphasia sensitive to function words?
3) Are individuals with aphasia sensitive to phrasal frequency?
4) Does healthy aging affect online syntactic processing?

This thesis is organised into the following chapters:

Chapter 2 provides an overview of the behavioural evidence of noun/verb dissociations and selective function word impairments in aphasia. It outlines the key theoretical accounts that explain reported selective word class deficits in aphasia. It discusses the impact of modality-specific word class impairments on theoretical accounts and addresses methodological concerns of single word and offline tasks. Finally, the chapter introduces principles of usage-based approaches and provides an overview of empirical research that has applied re-examined language processing in aphasia using frequency-based measures.

Chapter 3 evaluates behavioural and electrophysiological investigations into age-related changes in language processing, with an emphasis on syntactic processing as well as frequency-based approaches. Further, it highlights three key theories of cognitive aging that have been applied to language processing; resource deficit, general slowing and working memory.

Chapter 4 reports the design and results of an experiment that investigates the effects of healthy aging on language processing. An online word-monitoring task (WMT) was designed to probe noun phrase (NP) and verb phrase (VP) sensitivity across three different conditions: phrase structure violations; premodification; and phrase frequency. A mixed factorial ANOVA was conducted to analyse reaction time patterns of neurotypical older and younger adults.

Chapter 5 reports an experiment that explored NP and VP sensitivity in individuals with aphasia. Using the same WMT paradigm and conditions as described in Chapter 4, Experiment 2 reports group level analyses of NP/VP patterns of 21 individuals with aphasia and 20 neurotypical age-matched controls. In addition, aphasic performance in the WMT is compared to traditional offline measures of lexical and sentence comprehension and production.

Chapter 6 presents the analysis of an individual case series based on three subgroups of individuals; agrammatic, anomic, and severe aphasia. It explores the effects of severity of impairment and aphasia subtype on noun/verb dissociation. To this end, individuals' online language profile (WMT), speech samples, as well as their performance standard language and cognitive measures are examined.

Chapter 7 describes the final experiment that explores age-related changes during online verb processing. An ERP experiment was designed that measured electrophysiological responses to verbs in violated and facilitated (premodified) contexts. Latency and mean amplitude of the P600 response to number verb agreement violations (e.g. *The toddler* <u>*bounce*</u> *on the bed*) was compared across younger and older participant groups. Due to the exploratory nature of the investigation into whether premodifiers facilitate verb processing (e.g. *Rose* <u>*must have*</u> *finally travelled to Scotland to visit her relatives*), it was unclear whether it would be associated with an electrophysiological marker.

Finally, Chapter 8 provides a summary of the main findings across the aphasia and healthy aging experiments, and integrates findings with the existing literature. It will discuss limitations of the current studies and explore future directions.

2. Language processing in aphasia

This chapter examines the behavioural evidence for noun/verb dissociation with an emphasis on studies probing selective word class impairments in perception/recognition and comprehension. It outlines three main theoretical accounts that explain selective word class deficits in aphasia and addresses methodological differences between production and input processing tasks and their implications for capturing noun/verb dissociations. Section 2.2 describes function word impairments and outlines associated theories of content and function word processing. Section 2.3 introduces usage-based principles in investigating language processing in aphasia. Finally, Section 2.4 provides a short chapter summary.

2.1 Noun/verb dissociations

Aphasia is an acquired language impairment usually resulting from left-hemisphere damage in the perisylvian region. Individuals with aphasia have difficulties expressing or understanding language, and impairments range in severity. In its milder forms, individuals may struggle with retrieving proper nouns (e.g. *Jane, London*), and understanding speech in taxing conditions. In its severest form, the person may struggle to understand many written and spoken words and sentences, although understanding of high imageability words (e.g. *dog*) is often retained (Varley & Zimmerer, 2018). Classical clinical classifications of aphasia primarily distinguish aphasia subtypes according to fluent and non-fluent speech output. Fluent aphasia is linked to lesions in posterior regions of the temporal lobe. One subtype of fluent aphasia is Wernicke's aphasia. It is characterized by production of (fluent) islands of speech produced with regular prosody and articulation.

[1] *I saw a niece of one. Comes from London. And she came with her mother first and he said that if I were her, he would go into hospital.*

The sentences in extract 1 contain grammatical morphemes (inflections and function words) that are largely grammatically correct, but also present are errors such as switching between gender specific pronouns. This phenomenon is called paragrammatism. These word choice errors are considered to be a result of difficulties accessing lexical items, rather than a primary grammatical impairment (Varley & Zimmerer, 2018). Individuals with fluent aphasia also experience prominent word-finding difficulties, which can result in incomplete and abandoned sentences. Individuals with Wernicke's aphasia also have marked difficulties understanding spoken language. A milder form of fluent aphasia is anomic aphasia. While speech output is fluent and appears grammatically correct, an anomic patient has difficulties retrieving words, usually nouns, and may substitute them with more general terms such as "thing" (Damasio & Geschwind, 1984).

More anterior lesions in the region of the inferior frontal gyrus (IFG) are traditionally associated with non-fluent speech. Non-fluent speech is characterized by short utterances, slowed speech rate and errors in articulation. A canonical form of non-fluent aphasia is Broca's aphasia. It is characterized by limited connected speech, impaired articulation, and grammatical errors, as in extract 2.

[2] *Ehm, ehm the mother and two children, a boy and a girl. Ehm ehm ehm mother, washing up and ehm sink ehm ehm ehm sink flows down s- ehm ehm cupboard and floor and ehm mother very angry.*

Agrammatism refers to simplified syntax, as well as omission of words with syntactic functions (e.g. *about, with, his*) and inflections (–ed, plural –s) (Goodglass, Kaplan, & Barresi, 2001). Omissions of function words result in utterances that lack markers that signify the relationship between content words (McCarthy & Warrington, 1985). Verbs and their associated arguments are often omitted as well. Individuals with milder forms of agrammatism can be described as having telegraphic speech, where sentences lack function words, but the structure is partly retained. Although measures of fluency are used to distinguish between aphasia subtypes, all patients with aphasia exhibit disfluencies as they experience different degrees of difficulty retrieving words and formulating sentences (Goodglass, Kaplan, & Barresi, 2001).

2.1.1 Behavioural evidence of noun/verb dissociations in aphasia

Nouns and verbs are reported to be differently impaired in aphasia. A substantial body of research has investigated the patterns of noun/verb dissociations in language production. In a seminal study, Miceli et al., (1984) found that in single word elicitation tasks, agrammatic patients produced fewer verbs compared to nouns, while anomic patients displayed the reverse pattern. Numerous subsequent studies reported greater verb than noun impairments in both fluent and non-fluent aphasia in picture naming tasks and other single word tasks (Bastiaanse & Jonkers, 1998; Berndt, Burton, Haendiges, & Mitchum, 2002; Breedin & Martin, 1996; Breedin, Saffran, & Schwartz, 1998; Caramazza & Hillis, 1991; Jonkers & Bastiaanse, 2006; Kim & Thompson, 2000a; Kohn, Lorch, & Pearson, 1989; Luzzatti et al., 2002; Mätzig et al., 2009; Shapiro & Caramazza, 2003b, 2003a; Williams & Canter, 1987). In a meta-analysis, reviewing data of 280 patients from 38 studies, Mätzig et al. (2009) found that verb impairment was prevalent in 75% of cases (209), while 14% (40) did not show relative impairment of one word class over the other, and a further 11% (31) showed a noun retrieval impairment. The prevalence of verb impairments has resulted in a shift from investigating double dissociations of nouns and verbs to focusing on one-way dissociations of greater verb impairments relative to nouns. This led researchers to claim that verbs are more difficult to process as they are more complex. However, greater complexity of verbs fails to explain occurrences of differential noun impairments (Breedin et al., 1994; Zingeser & Berndt, 1988).

In contrast to production, studies probing comprehension have found limited evidence for noun/verb dissociation, and in particular, for greater vulnerability of verbs. In an early study, Miceli et al. (1988) investigated noun/verb dissociations in comprehension in seven individuals with aphasia using a word-picture matching task. The individual case analysis demonstrated that three participants showed noun/verb dissociations in comprehension, with two making more errors matching spoken verbs to pictures compared to nouns, while one participant showed the reverse pattern. However, the number of errors in the comprehension task were generally low (selective verb impairment participants 16%; selective noun impairment 12%). The relatively small difference between word classes raises the question whether they are functionally distinct and theoretically relevant. More recently, Soloukhina & Ivanova (2018) used a computerized auditory single word-picture matching task to compare reaction times to nouns and verbs. Their results showed that participants with aphasia responded more slowly and less accurately to verbs than to nouns. Although neurotypical controls showed no difference in accuracy between word classes, they also responded more slowly to verb trials. The authors suggested that slowed recognition of verbs in neurotypical adults was further evidence that verbs are more complex and require more resources to process.

However, the majority of investigations probing input processing reported intact or nearly intact levels of accuracy in both word categories (Alyahya, Halai, Conroy, & Lambon Ralph, 2018; Bates, Chen, Tzeng, Li, & Opie, 1991; Berndt, Haendiges, & Wozniak, 1997; Cho-Reyes & Thompson, 2012; Crepaldi et al., 2006; Kim & Thompson, 2000b; Marshall, Pring, & Chiat, 1998; Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro & Levine, 1990; Thompson, Lukic, King, Mesulam, & Weintraub, 2012). For example, Alyahya et al. (2018) reported an absence of noun/verb dissociation in a group of 48 individuals with aphasia using a word-picture matching task, in which linguistic stimuli were matched in terms of psycholinguistic variables such as frequency, age of acquisition, and imageability. In a series of studies, Thompson and colleagues (Cho-Reyes & Thompson, 2012; Kim & Thompson, 2000; Thompson et al., 2012) probed noun/verb dissociations in input processing using various single word and offline sentence level tasks. Combining data across several studies, none of their participants (101 agrammatic, 42 anomic), displayed selective word class impairments in input processing or comprehension, showing near-normal processing of both nouns and verbs. To investigate verbs more specifically, they compared processing of simple verbs (one argument structure verbs e.g. *The dog is barking*) to more complex verbs (two or more arguments verbs e.g. *The boy is catching the ball*) in a grammaticality judgment task. The results showed that sentences with more complex verbs did not result in an increase in errors, as would be expected if they were more difficult to process. The data from the participants in Thompson and colleagues' studies suggested residual decoding of both nouns and verbs and, contrary to the pattern observed in production, no greater impairment of verbs. However, the majority of individuals assessed in the studies by Thompson and colleagues presented with only mild comprehension impairments as indexed by the Western Aphasia Battery (WAB – Kertesz, 2007). Given the mild impairments of the participant sample, it is likely that their result may not generalise across the full spectrum of aphasic impairment.

Overall, the behavioural evidence for noun/verb dissociations is conflicting. Observations from production studies consistently report noun/verb dissociations, with verbs more often impaired relative to nouns, whereas evidence from input studies indicates that processing of both verbs and nouns remains intact. The contradictory findings across input processing and production raise two key issues. The first issue concerns the implications of modality-specific noun/verb dissociations for deficit accounts that explain the locus of breakdown, as well as for models of the organization of the mental lexicon. The second issue concerns differences in task demands between input and production experiments and their sensitivity and appropriateness in capturing noun/verb dissociations. Both issues are discussed in subsequent sections.

2.1.2 Noun/Verb Deficit accounts

Observations of selective noun/verb impairments, in particular in production, have led researchers to propose several accounts as to the functional differences between word classes (Caramazza & Hillis, 1991; Damasio & Tranel, 1993; Luzzatti, Aggujaro, & Crepaldi, 2006; Tyler, Randall, & Stamatakis, 2008; Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). A commonality across theories is their reliance on evidence from studies using single word production tasks in order to infer how nouns and verbs are accessed, processed and stored. Evidence from comprehension studies is under-represented. The patterns of findings across production and comprehension studies suggest that selective word class impairments are modality specific (Berndt, Mitchum, Haendiges, & Jennifer, 1997; Kim & Thompson, 2000; Marshall et al., 1998; Miceli, Silveri, Nocentini, & Caramazza, 1988; Shapiro, Shelton, & Caramazza, 2000; Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro & Levine, 1990). The dissociation between modalities raises important questions about the organization of the mental lexicon and the locus of breakdown. However, while noun/verb dissociations in production are used to make inferences about the mental lexicon, few accounts directly address the differential findings across modalities. Most accounts are agnostic about whether production and comprehension share processes and how the absence of noun/verb dissociations in comprehension constrains their models of the mental lexicon.

Lexical based accounts claim that the mental lexicon is organized according to grammatical classes, where nouns and verbs are stored separately. Components of Levelt's (1989; Levelt, Roelofs, & Meyer,

1999) two stage-model of sentence production have been widely applied to describe selective word class impairments in production, as well as observations of modality-specific impairments. In the first stage of production, a lemma is activated, which includes the conceptual and grammatical information of the word. For example, the lemma for the verb "*put*" specifies that it is a di-transitive verb that takes three arguments, a subject as well as direct and indirect objects. In the second stage, the lexeme, which comprises the word's phonological, orthographic and morphological properties, are retrieved. Within lexical accounts, researchers point to different processing stages as the locus of breakdown. Caramazza and colleagues (Caramazza & Hillis, 1991; Hillis & Caramazza, 1995; Miceli et al., 1988; Rapp & Caramazza, 2002) proposed that noun/verb dissociation occurs at a late stage in processing and places the locus of damage at the lexeme level in Levelt's model. The hypothesis is motivated by observations of individuals who were selectively impaired in producing verbs but had intact comprehension. The researchers concluded that residual comprehension indicated an intact lemma, but damage to its phonological form (lexeme) which is necessary for production. However, other researchers have suggested that selective word class impairments occur earlier in the Levelt's two stage model, at the lemma level. Berndt and colleagues (Berndt, Haendiges, et al., 1997; Berndt, Mitchum, et al., 1997) claim that disruptions at the lemma level may impact production and comprehension differently. They hypothesize that damage to the lemma level may still allow sufficient semantic activation for residual comprehension, however, partial activation may not be sufficient for production. This hypothesis rests on evidence that individuals made mostly semantic errors (e.g. *shoe* instead of *boot*) in production, which points to difficulties at the conceptual level (represented in the lemma).

One point of controversy is whether the reported noun/verb dissociations reflect a true word class deficit. Vigliocco et al. (2011) claim that the majority of findings of noun/verb dissociations should not be taken as evidence for a true deficit of a grammatical class, as experiments confound word class and semantic factors. Typically studies probe verbs which refer to actions, and nouns which refer to objects (Bird et al., 2001, 2002; Bird, Howard, et al., 2000; Bird, Lambon Ralph, et al., 2000; Vigliocco et al., 2011). Verb impairments arise as a result of greater semantic complexity relative to nouns. Verbs may differ to nouns in terms of their imageability - the capacity of a word to evoke mental imagery of the word (Paivio et al., 1968)(Paivio et al., 1968)(Paivio et al., 1968)(Paivio et al., 1968)(Paivio et al., 1968). With regard to grammatical class, verbs usually are regarded as less imageable than nouns (Bird et al., 2001; Bird, Lambon Ralph, et al., 2000). For example, the verb *keep* is rated as lower in imageability (286) than the noun *place* (*406*), on a rating scale of 100 to 700, despite being similarly frequent (2.81 and 2.8 log frequency respectively) (Bird et al., 2001). Words with higher imageability are understood and named quicker in picture naming tasks in neurotypical participants (Walker & Hulme, 1999) and in individuals with aphasia (Allport & Funnell, 1981; Bastiaanse et al., 2016; Franklin et al., 1994; Nickels & Howard, 1995) suggesting that the richer perceptual saliency of high imageability words facilitates their processing. Evidence in support of this account comes from the disappearance of word class effects in both production and comprehension when items are matched in imageability (Aggujaro, Crepaldi, Pistarini, Taricco, & Luzzatti, 2006; Alyahya et al., 2018; Bird, Howard, & Franklin, 2003; Crepaldi et al., 2006; Luzzatti et al., 2002). Further evidence in favour of the semantic account would come from noun/verb comparisons that untangle semantics and grammatical class by including action-type nouns (e.g. *arrival*) and non-action verbs (e.g. *thinking*). Superiority of nouns, regardless of action or object type, would challenge the semantic account.

However, the semantic account cannot provide an explanation for all noun/verb dissociations. For example, reports of individuals who show superior verb and impaired noun retrieval are not easily explained, since verbs are expected to be more impaired due to their lower imageability (Berndt, Mitchum, et al., 1997; Luzzatti et al., 2002; Miceli et al., 1984; Zingeser & Berndt, 1990). A greater challenge to the semantic account comes from observations of modality-specific impairment, where individuals show selective impairment of a word class in production but not comprehension. Marshall (2003) suggests that comprehension may be intact because it places less demand on semantic processes compared to verb production. Thus, partial or degraded activation of semantic information may be sufficient for residual comprehension but not for production. Few proponents of the semantic account have addressed this issue, and it remains largely unexplained how semantic factors of verbs, such as low imageability, lead to difficulties in retrieval but not in comprehension.

A third account localizes the breakdown to a difference in syntactic complexity (Badecker & Caramazza, 1991; Shapiro et al., 2000; Thompson, 2003). Verbs are syntactically more complex as they determine how other words and phrases relate to each other. An early interpretation of the syntactic account suggested that verb (and function word) deficits were due to a general impairment of syntactic processing (Saffran et al., 1980). This view was challenged by observations that verb retrieval difficulties were not always accompanied by syntactically impoverished speech (Randrup Jensen, 2000) or impaired verb comprehension (Miceli et al., 1988). A subsequent reiteration focused on the syntactic complexity of verbs as expressed by their argument structure. It has been shown that verbs with more complex argument structures (e.g. *lend*) are more difficult to produce than verbs requiring only one argument (e.g. *look*) (Collina, Marangolo, & Tabossi, 2001; Kim & Thompson, 2000; Thompson, Lange, Schneider, & Shapiro, 1997). The exact locus of breakdown is less defined and it is unclear as to what mechanisms result in greater impairments of verbs that require more arguments. In what seems a tentative explanation, Thompson and colleagues suggest that disruption of verb processing occurs at a post-lemma level in order to accommodate findings of intact comprehension. Greater impairment of verbs with more complex relative to simple argument structures may be explained by increased processing load of verbs with multiple arguments.

2.1.3 Methodological considerations

Modality-specific noun/verb dissociations have raised important questions regarding the locus of breakdown and the organizational principles of the mental lexicon. The deficit accounts described above have rarely incorporated findings from input processing studies into their models, which as a result, limits their explanatory power to production only. Another key issue that is seldom discussed is differences in the methodologies used to assess selective word class impairments. As mentioned earlier, evidence for noun/verb dissociations relies heavily on studies which have used single word naming tasks, such as action and object naming (e.g. Arévalo et al., 2007; Bastiaanse et al., 2016; Benetello et al., 2016; Mätzig et al., 2009). There are several factors that suggest that probing nouns and verbs in isolation may contribute to the differences observed. First, verbs are relational and usually require a subject (and direct object) and are therefore more often encountered within a phrasal or sentential context (e.g. *Mary sewed cushions for her niece*). By testing verbs in isolation, elements which scaffold their form and function are removed. Findings from studies with neurotypical individuals show that verbs are named less accurately and more slowly than nouns when probed in isolation, suggesting that greater verb difficulty is not specific to aphasic individuals (Bogka et al., 2003; Szekely et al., 2005 but also see, Mackay et al., 2002). On the one hand, this could indicate that verbs are inherently more difficult to process; on the other hand, it could suggest that single word tasks inherently disadvantage verb processing, a disadvantage that is accentuated in brain-damaged individuals.

Second, single word naming tasks overwhelmingly employ static pictures to elicit nouns or verbs. While this might be appropriate for object naming, verbs usually refer to actions (e.g., *chasing*) or mental states (e.g., *knowing*). Mental state verbs are difficult to depict in pictures, which biases verb evaluation to action verbs. Action verbs are, by essence, dynamic and, in order to unambiguously depict them in a static format, pictures require additional symbols or figures, to convey action. The person is required to make inferences about the intended target. For example, in Figure 1 participants need to inhibit the more nameable element of the image (*ship*) and infer the action in order to identify the correct verb (*sailing*).

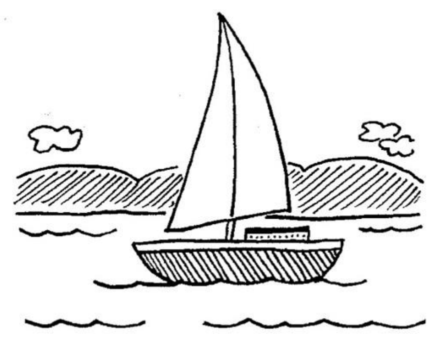


Figure 1 Object and action naming battery (Druks & Masterson, 2000) Item 67 probing the verb "sailing"

In contrast to production studies, observations of noun/verb dissociations have generally been absent in studies probing input processing. The absence of noun/verb dissociations findings are largely based on single word or offline sentence tasks (e.g. Cho-Reyes & Thompson, 2012). One commonly used offline sentence task is the picture-sentence matching task, in which a participant hears a sentence and selects a picture that best matches the target sentence. While they are easy to administer, they have several limitations that may render them insensitive to noun/verb dissociations. One limitation of the task is that it measures processing of a sentence *after* a listener has heard the complete sentence. This requires listeners to process the auditory sentence while visually scanning all four scenes and inhibiting closely associated items before choosing the best matching one. A further limitation concerns the type of knowledge that is being assessed. The procedure of the task allows individuals to reflect on the sentence and utilize their meta-linguistic knowledge to make strategic choices. For example, a listener may decode the thematic roles of the sentence based on their explicit knowledge of word order, by inferring that the first noun is the agent. Thus, these types of tasks may over- or underestimate individuals' language abilities.

Similarly, the tasks used to probe single word comprehension mostly tap into meta-linguistic knowledge. For example, Kim & Thompson (2000) constructed a categorization task to probe knowledge about verb argument structures. In this task, individuals were required to match written verbs to icon cards that contained symbols that indicated obligatory argument structures. As seen in Figure 2, the icon card depicting one-argument verbs contains an agent and an arrow denoting the verb. The card for two argument verbs additionally contains a rectangle after the arrow denoting the obligatory direct object (the theme). The task is production-like in that it is necessary for individuals to formulate sentences, either aloud or internally, to place verbs in contexts to gauge whether it requires arguments. Thus, rather than measuring processing of auditory or written input, this task requires individuals to generate their own stimuli. This production-like aspect is symptomatic of many single word categorization and judgments tasks that are designed to probe comprehension, raising the question of the suitability of these tasks in measuring processing of language input.

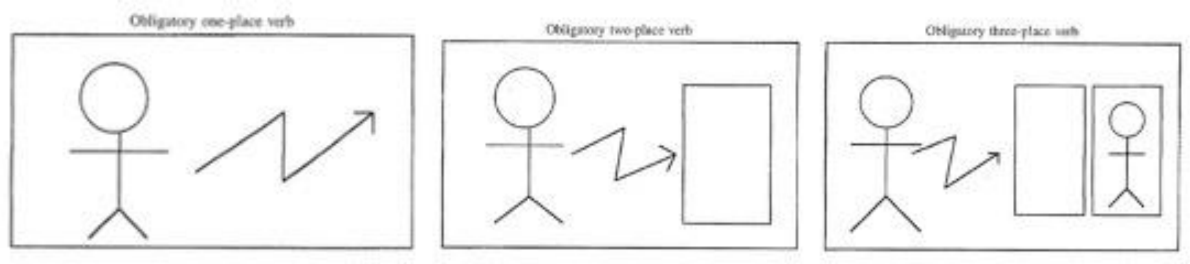


Figure 2 Example of Kim & Thompson (2000) verb categorization task

Both sentence level and single word comprehension tasks appear to measure a combination of different types of processes and knowledge involved in both comprehension and production. The involvement of these processes may mask, selective word class impairments, as the tasks may lack the sensitivity to isolate and capture processes specific to comprehension. Conversely, single word naming tasks are likely to magnify selective word class impairments, particularly in the case of verb retrieval.

An alternative to offline, explicit tasks, is use of online paradigms. The latter are designed to measure implicit and automatic processes involved in natural language processing. Importantly, they measure language processing as it unfolds over time (Marinis, 2010; Schmitt & Miller, 2010). One example of an online task is the word-monitoring task (WMT). In this task, participants listen to a sentence and press a button as quickly as possible when they hear a pre-specified target word (Tyler, 1985). The reaction time (RT) to the same target word in different contexts is a measure of the sensitivity to the linguistic information preceding the target word. For example, RT to the target word "*films*" can be compared across contexts that are neutral [3], ungrammatical [4], or facilitatory [5].

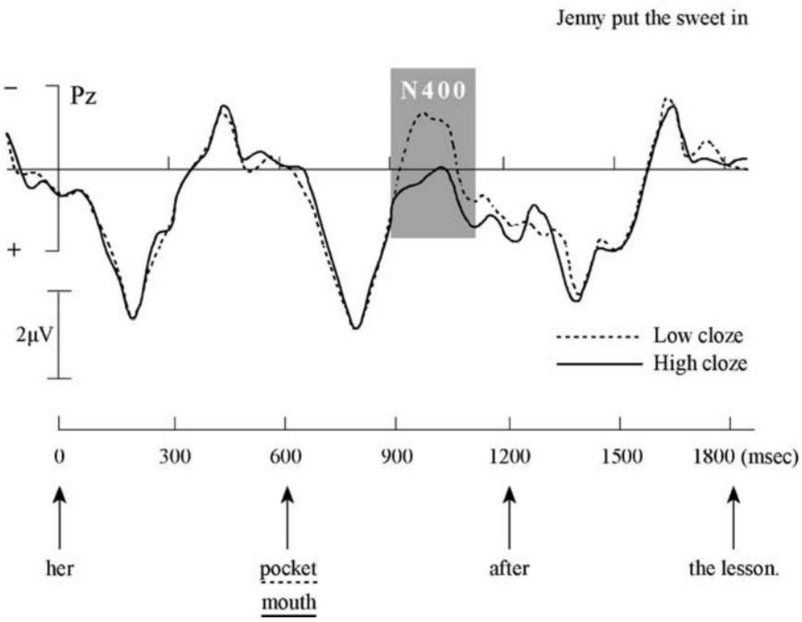
[3] *John is watching films with his friends*

[4] *John is looking films with his friends*

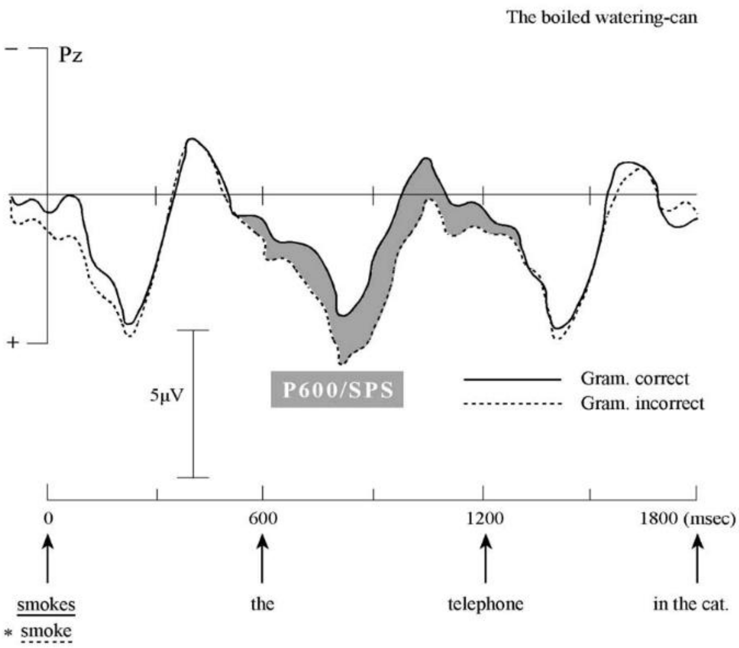
[5] *John will be watching classic black and white films with his friends*

In a WMT, if the listener can process the linguistic context prior to the target word, RT will be modulated by that information. For example, if a listener is sensitive to the intransitive verb-argument structure of "*look*", recognition of the target word "*films"* will be slowed if it is placed in a direct object slot immediately following the verb [4]. By contrast, RT will be faster in a neutral condition [3], and strongly facilitated if the listener is able to process the premodification with the noun phrase (NP) as in [5]. Furthermore, sensitivity to linguistic context is measured as sentential information is processed and integrated over time. Importantly, listeners are not asked to make a judgment about the grammaticality or plausibility of a sentence after hearing it, therefore, RTs are expected to reflect implicit grammatical processing rather than explicit processes.

Electrophysiological measures, such as electroencephalogram (EEG) and event-related potentials (ERPs), are further techniques that record online language processing. The high temporal resolution in electrophysiological recordings provides information about the time course of processes involved in language processing. Both EEG and ERP have been used extensively to investigate natural language processing in neurotypical adults. There are a number of components, such as the N400 and the P600, that are electrophysiological responses with a specific time course and polarity, and are associated with language processing (see Figure 3).



a)



b)

Figure 3 Visualization of the modulation of the N400 amplitude (a) in response to the semantic expectancy of a word give a specific sentential context. Depiction of the P600 (b) in response to grammatical violation. Examples from Hagoort (2003). Negative voltage plotted up.

For example, the N400 is a negative component that is typically largest over centro-parietal electrodes sites and peaks around 400ms after stimulus onset. The N400 is elicited in response to meaningful stimuli, including auditory and written words. The amplitude of the component is modulated by the predictability of a word within a context, with more predictable words (e.g. *mouth*) eliciting a less negative (smaller amplitude) N400 compared to less predictable words (e.g. *pocket* after *Jenny put the sweet in her …*). The P600, a positive-going component most prominent over centro-parietal scalp sites, is recorded in response to sentences which require reanalysis or reparsing as a result of syntactic errors (e.g. **He play*) or ambiguities (e.g. *The broker persuaded to sell the stock was tall*) (Hagoort, 2003; Osterhout & Holcomb, 1992). Differences in the timing and amplitude of a component across different populations are used to make inferences about changes in language comprehension processes. An advantage of this method is that no additional behavioural responses are required beyond listening or reading, reducing task-induced confounds.

To date, only few studies have utilized online measures to probe occurrences of noun/verb dissociations or selective impairments of verbs (Hagoort et al., 2003b; Shapiro et al., 1993; Shapiro & Levine, 1990; Wayland et al., 1996). Using a WMT, Wayland, Berndt, & Sandson (1996) probed recognition of nouns and verbs in syntactically and semantically congruous and incongruous contexts (see excerpts 6 – 9 below).

[6] Noun semantic incongruence: *The woman warned herself not to fall asleep while bathing. She was relaxing in the <u>meal</u> and was afraid she might doze off.*

[7] Noun syntactic incongruence: *The woman warned herself not to fall asleep while bathing. She did not want to <u>meal</u> in the bathroom.*

[8] Verb semantic incongruence: *The woman warned herself not to fall asleep while bathing. She did not want to <u>starve</u> in the bathroom.*

[9] Verb syntactic incongruence: *The woman warned herself not to fall asleep while bathing. She was relaxing in the <u>starve</u> and was afraid she might doze off.*

The results showed that individuals with aphasia were most delayed by syntactic violations where verbs were placed in noun slots [9] and to a lesser degree by nouns in verb slots [7]. This pattern was also observed in neurotypical adults and suggests that both groups were able to form online syntactic representations of sentences. Wayland and colleagues suggest that the greater delay in recognizing verbs in syntactically incongruous contexts relative to nouns, points to the centrality of verbs in determining the syntactic structure of a sentence. Further evidence for intact verb argument knowledge comes from a series of experiments by Shapiro and colleagues (Shapiro et al., 1993; Shapiro & Levine, 1990) who used a cross-modal decision task to probe real-time access to verb argument structure. In this task, participants listened to sentences and had to determine whether a visual probe immediately following a verb was a word or nonword. RT to the probe reflects processing load, where verbs with multiple arguments are hypothesized to result in slower RTs. The results showed that individuals with Broca’s aphasia responded more slowly to verbs with more arguments relative to verbs with fewer arguments. The same pattern was observed in neurotypical adults. The researchers concluded that the slowed RT in individuals with Broca’s aphasia and neurotypical controls indicated that they allocated more processing time to activating verbs' argument structure in real time reflecting preserved verb processing in the aphasic group.

In contrast to these behavioural findings, Kotz, et al., (2003) found electrophysiological evidence that individuals with aphasia showed atypical verb processing, as determined by an absence of P600 in response to verb argument structure violations (e.g. **Das Zimmer wurde gearbeitet* / *The room was worked*). Further evidence of impaired verb processing comes from a series of studies by Hagoort and colleagues (Hagoort et al., 2003a; Wassenaar et al., 2004) who also report an absence of a P600 in response number-verb agreement violations (e.g. **The girls pay the baker and <u>takes</u> the bread home*) in individuals with Broca's aphasia. Overall, ERP evidence indicates that verb processing is atypical in aphasia. However, it is important to note that the ERP studies were underpowered with small sizes. Small sample sizes are especially problematic when conducting ERP studies with clinical groups as they tend to have larger inter-individual differences, reducing the signal to noise ratio.

The data from online input processing studies expands on the findings from offline studies, pointing to a more contradictory and complex picture of preservation and impairment than initially believed. Evidence from ERP studies, in particular, challenges offline findings of preserved verb processing. However, only few studies to date have measured electrophysiological responses to nouns and verbs in individuals with aphasia and further investigations are needed to examine the differential findings between behavioural and electrophysiological studies. The current thesis explores noun and verb processing in aphasia and healthy older adults by utilizing the online measures of WMT and ERP.

2.2 Content/function word dissociation

Investigations into noun/verb dissociations in aphasia highlight the importance of sentential contexts during language processing. Sentence context is particularly important in facilitating verb processing (Cho-Reyes & Thompson, 2012; Shapiro et al., 1993; Wayland et al., 1996). Even more than verbs, function words are inherently relational in that they express relationships between content words. For example, function words in the form of premodifiers, precede and therefore signal upcoming head nouns and verbs (e.g. noun premodifiers: *<u>These</u> shoes are very comfortable*; verb premodifiers: *Peter <u>could have</u> visited the cathedral while he was in town*). They often occur at the beginning of phrases (e.g. *<u>The</u> woman <u>in the</u> library yawned*) and so support parsing routines. As such, they are essential for facilitating syntactic analysis and understanding of sentences. As a class, function words are a small set of highly frequent words. They include auxiliary verbs (e.g., *will have*, *must be*), determiners (e.g., *the, those, my*) conjunctions (e.g., *and, or*), pronouns (e.g., *she, him*), prepositions (e.g., *before, under*). They tend to be semantically light in that they generally do not convey much of the meaning of the the sentence, and instead mainly serve grammatical functions. Despite their importance, experiments with neurotypical adults show that function words are often skipped and overlooked during sentence processing (Angele & Rayner, 2013; Foucambert & Zuniga, 2012; Moravcsik & Healy, 1995; Rosenberg et al., 1985; Staub et al., 2018). For example, most neurotypical individuals do not notice repetitions of function words, such as in "*convey much of the meaning of the the sentence* " from two sentences ago.

Observations of difficulties in retrieving function words during sentence production in aphasia are common (Biassou, Obler, Nespoulous, Dordain, & Harris, 1997; Friederici, 1982; Ishkhanyan, Sahraoui, Harder, Mogensen, & Boye, 2017; Stavrakaki & Kouvava, 2003). Impaired function word production is typically associated with agrammatic aphasia (Andreewsky & Seron, 1975; Gardner & Zurif, 1975; Gordon & Caramazza, 1983; Miceli et al., 1983). Function words are frequently omitted in agrammatic speech, also referred to as "telegraphic speech" (see excerpt 2 in Section 2.1). Individuals with fluent Wernicke's aphasia, on the other hand, produce function words but have difficulties producing content words. Although their speech contains function words, they are frequently incorrect (see excerpt 1 in section 2.1). Erroneous use of function words in Wernicke's aphasia has not received the same attention as function word omissions in Broca's aphasia, and is sometimes attributed to lexical retrieval difficulties associated with Wernicke's aphasia (Edwards, 2005). Researchers have suggested that impaired function word processing is not specific to production but is also evident in perception (Bates et al., 1987; Friederici, 1985; Friederici & Schoenle, 1980; Mätzig et al., 2010; Neville et al., 1992; Rosenberg et al., 1985; Swinney et al., 1980). For example, Rosenberg et al. (1985) used a letter cancellation task in which participants had to detect target letters embedded in content and function words. Consistent with other studies, neurotypical adults (and individuals with Wernicke's aphasia) allocated less attention to function words as they detected more target letters embedded in content compared to function words. In contrast, individuals with Broca's aphasia detected equal number of targets across word classes, indicating that the way they processed function words was atypical.

One attempt to explain lack of function words in agrammatic speech has focused on their phonological properties. In speech, stress is usually placed on content words, whereas function words are mostly short and unstressed (Bell et al., 2009; Kean, 1977, 1979). Kean (1977, 1979) suggested that function word impairments in aphasia result from an inability to process phonological elements with low salience. However, phonological lightness alone does not appear to account for difficulties in function word processing as demonstrated by Swinney, Zurif, & Cutler (1980). They employed a WMT to measure RT to content and function words embedded in sentences, while controlling for stress. Their results showed that neurotypical adults were faster in recognizing stressed target words, regardless of word class, highlighting the importance of stress in neurotypical sentence processing. Neurotypical listeners used stress cues to parse the sentence, increasing their attention to function words only when they were stressed. By contrast, individuals with aphasia responded faster to content relative to function words regardless of stress. To support Kean's phonological hypothesis, an advantage of stressed over unstressed function words would have been expected. The researchers conclude that the selective difficulties in recognizing and processing function words do not lie in their phonological properties.

Rather than a phonological deficit, Bradley (Bradley 1978; Bradley, Garrett, & Zurif, 1980) suggested that selective function word impairments occurred at the stage of accessing or processing lexical items. In a series of experiments using a lexical decision task, Bradley observed that neurotypical adults displayed a speed advantage in recognizing high compared to low frequency content words, but that this frequency effect was absent for function words. In contrast to neurotypical adults, individuals with Broca's aphasia showed frequency effects for both content and function words. Based on these observations, Bradley concluded that the differential effects of frequency in neurotypical processing indicated that function words are processed via a separate, frequency-insensitive processing system. The separate processing route was hypothesized to enable quick access to function words during sentence production and comprehension. Furthermore, the presence of a frequency effect in both content and function words in individuals with Broca's aphasia suggested that their access to function words was damaged and relied on the processing system specialized for content words. However, as Kolk & Blomert (1985) noted, the hypothesis does not explain or specify why function word processing impairments persist given they are accessible through the content word specific processing route.

The separate processing route hypothesis has been challenged on several fronts. Numerous studies have failed to replicate the reaction time results for content and function words (Gordon & Caramazza, 1982, 1983, 1985; Kolk & Blomert, 1985; Segalowitz & Lane, 2000; Segui et al., 1982, 1987). In a series of experiments, Gordon & Caramazza (1982, 1983, 1985) observed RT to both content and function words was modulated by frequency in neurotypical adults. However, it appeared that the relationship between RT and frequency might be more complex for very high frequency items. Content words, but not function words, of very high frequency, (log frequency above 2.5/2.6, e.g. *the*), showed a negative correlation with reaction time. However, Gordon and Caramazza argue that this difference should be treated with caution due to the limited number of content words of such high frequency. Overall, they suggested that both word groups are modulated by frequency, but that this relationship may be nonlinear in that reaction times for very high frequency items may reach ceiling. Further, Gordon and Caramazza (1983) observed similar RT patterns in individuals with agrammatic and non-agrammatic aphasia, with both aphasic groups showing sensitivity to frequency in content and function words. These findings undermine the claim that the impact of frequency in function word processing observed in agrammatic aphasia is atypical. They also cast doubt on the claim that a separate, frequency-insensitive system is responsible for the processing of function words.

A further challenge to the separate processing hypothesis is that not all function word types are equally impaired. For example, Friederici probed production and comprehension of prepositions that differed in their semantic and syntactic role (1982, 1985; Kolk & Friederici, 1985). In a series of experiments, Friederici reported that function words serving primarily a syntactic role (e.g. *Peter ruft den Schüler auf. / Peter calls upon the student*) were recognized more slowly and produced less often than when the same function word carried a semantic function in the form of a preposition (e.g. *Peter steht auf dem Stuhl / Peter stands on the chair*). She concluded that individuals with Broca's aphasia were specifically impaired in processing syntactic items, but had residual capacity to process semantic items. According to Friederici, these observations provide evidence that processing differences occur between lexical and grammatical items rather than between word classes. She further characterized the deficit as a loss of automaticity or speed of processing syntactic information rather than a loss of knowledge. Similar observations were made by Martinez-Ferreiro et al. (2019) who compared production of lexical and grammatical function words in connected discourse in nine Spanish-speaking individuals with aphasia. Speakers with non-fluent aphasia were more impaired in producing grammatical prepositions (e.g. Spanish: *a*, English: *to*), whereas individuals with fluent aphasia had greater difficulties with lexical prepositions (e.g. "Spanish: *bajo*, English: *under*). In contrast, Mätzig et al., (2010) found that perception and production of syntactic prepositions was not impaired to a greater extent when assessed via grammaticality judgment and sentence completion tasks. A consequence of these investigations, rather than treating function words as a homogenous group, researchers have begun to distinguish between subsets based on their semantic and syntactic roles (Franco et al., 2013; Froud, 2001; Ishkhanyan et al., 2017; Kemmerer, 2005; Kemmerer & Tranel, 2003; Mätzig et al., 2010). This thesis will explore online processing of function words with mainly syntactic roles. This subtype is particularly difficult to measure with conventional methods, such as picture-sentence matching task, as they are not easily depicted via pictures. By contrast, online tasks such as ERP and WMT allow probing of listeners' sensitivity to such linguistic information.

2.3 Usage-based approach in language processing in aphasia

Noun/verb dissociations and selective function word impairments have largely been viewed through a generativist lens. Generative theory adopts a 'words and rules' approach (e.g. Pinker, 1999). The grammar is an abstract system of algorithms or rules that operate on equally abstract variables. The rules generate a syntactic frame and lexical items are assigned to the terminal nodes of syntactic representations. Studies grounded in generative frameworks have been prominent in attempting to explain aphasic sentence processing impairments (e.g. Grodzinsky & Friederici, 2006; Thompson & Choy, 2009). However, generative models are currently under challenge by more contemporary usage-based models. These models have considerable potential in exploring aphasic language phenomena (Bruns et al., 2019; DeDe, 2013b; Gahl & Garnsey, 2004; Zimmerer et al., 2018). Usage-based models do not have sharp boundaries between lexicon and syntax and so break away from the 'words and rules' model of generativist theory. Instead, the structure and meaning of language emerge from language use

(Beckner et al., 2009; Goldberg, 2003; Tomasello, 2001). Representations of linguistic units that are frequently encountered become more strongly entrenched in memory and therefore are more easily accessed (Bybee, 2006; Bybee & McClelland, 2005). A language system driven by usage can form single representations for whole strings if they co-occur frequently such as "*I don't know*" (Bruns et al., 2019). Thus, individuals are sensitive to the frequencies and distributional properties of words, phrases and syntactic structures (Jurafsky, 2002; Romberg & Saffran, 2013; Saffran & Thiessen, 2008). Individuals' sensitivity to word frequencies remains important in language processing after acquisition. Lexical frequency is strongly correlated with chronometric measures, such as reaction time and eye-movement, as well as electrophysiological markers. Highly frequent words are recognised more quickly and accurately and are fixated on for less time during reading than less frequent words (Balota et al., 2004; Balota & Chumbley, 1984; Ellis, 2002; Rayner et al., 2004; Rayner, Reichle, et al., 2006). Individuals are also sensitive to the context in which words occur most often (Tremblay & Tucker, 2011). Words (e.g. *palms*) that are highly predictable given a certain context (e.g. *They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of …*) elicit a reduced N400, an electrophysiological marker associated with a word's expectancy, compared to less predictable words (e.g. *tulips*) (Federmeier & Kutas, 1999). The syntactic context in which verbs occur most frequently, referred to as verb bias, has been shown to influence the speed of processing and ease of comprehension (Clifton et al., 1984; Garnsey et al., 1997; Macdonald et al., 1994). For example, Clifton, Frazier and Connine (1984) found that verbs which are more often encountered as transitive verbs (e.g. *read*), were easier to process when placed in a transitive context (e.g. *The babysitter read the story to the sick child*.) than when placed in an intransitive context (e.g. *The babysitter read to the sick child*). Frequency effects have also been shown to occur beyond the word-level (Bannard & Matthews, 2008; Shaoul et al., 2015; Siyanova-Chanturia et al., 2017; Tremblay & Baayen, 2010). For instance, Arnon & Snider (2010) measured processing latencies of high and low frequency four-word combinations in a phrasal-decision task. In their design, high frequency and low frequency combinations differed only in the final word (e.g. *don't have to worry* vs *don't have to wait*). Speed of recognition was faster for high frequency phrases compared to low frequency phrases. Importantly, facilitation by frequency was observed in both noun and verb phrases.

Language processing in aphasia has only recently been investigated within a usage-based framework (Bruns et al., 2019; DeDe, 2013a, 2013b; Gahl & Garnsey, 2004; Huck et al., 2017a; Knilans & DeDe, 2015; Zimmerer et al., 2018). For instance, using a plausibility judgment task, Gahl (2002) presented individuals with aphasia and age-matched controls sentences containing verbs within their preferred syntactic structure and in mismatched structure (preferred structure: *The teacher opened the box*.; mismatched structure: *The box opened after a short while*.). Both neurotypical and aphasic individuals made more errors in sentence plausibility judgments when the verb appeared in its less preferred structure, although individuals with aphasia made more errors. In a further experiment, Gahl et al.

(2003), reported similar effects in comprehension of passive sentences. Comprehension was better when passive-bias verbs (e.g. *denied*) were presented in their preferred syntactic frame. These findings seem to suggest that individuals with aphasia are sensitive to verb bias and presenting verbs in their most frequent syntactic structure aids comprehension. Importantly, it shows that claims of general non-canonical sentence comprehension difficulty in aphasia are not valid. These findings were corroborated and expanded in a study using an online sentence processing task. DeDe (2013b) used a self-paced reading task to investigate whether individuals with aphasia show real-time sensitivity to verb argument structure. Individuals with aphasia were slower in reading transitively biased verbs (e.g. *called*) in an intransitive context (e.g. *The agent called from overseas to make an offer*.) than when used in transitive context (e.g. *The agent called the writer from overseas to make an offer*.). Prolonged reading times were also found for intransitively biased verbs (e.g. *swam*) in mismatched transitive sentence contexts (e.g. *The athlete swam the lake every day before the race*). These investigations represent initial and promising attempts at re-examining language processing, and in particular verb processing in aphasia within a usage-based framework.

2.4 Summary

This chapter provided an overview of selective word class impairments in aphasia, with a focus on noun/verb dissociation and selective function word impairments. Findings of selective word class impairments have informed theoretical models of the organization of the mental lexicon and of sentence processing. While noun/verb dissociations are frequently observed in production, the majority of studies probing input processing have not reported selective word class impairments. One explanation for modality-specific noun/verb dissociations may be differences in task demands. The second part of the overview focused on selective function word impairments. Function word impairments are claimed to result from disruption of specific function word processing system. This view has come under challenge from findings that have shown that not all function word types are equally impaired, and function words with mainly syntactic roles are more impaired. Finally, the chapter introduced a usage-based framework to language, with a particular emphasis on verb processing. In the following chapters, selective word class impairments (nouns versus verbs and function words) are explored using online behavioural (Experiment 1 and 2) and electrophysiological methods (Experiment 4). Furthermore, given the potential insights from usage-based approaches, the impact of frequency of processing is examined. Experiments include both aphasic listeners and neurotypical controls. As the experiments involve novel contrasts, performance is explored in both younger and older neurotypical adults in order to establish the influence of normal ageing on processing. The following chapter, reviews the empirical evidence for changes in syntactic processing in healthy aging and describes the theoretical accounts that have attempted to explain the patterns of syntactic preservation or impairment.

3. Language processing and healthy aging

This chapter is divided into three main sections that address age-related changes in language processing, with a focus on sentence processing. Section 3.1 evaluates the empirical evidence for changes in syntactic processing in healthy aging and outlines the three theoretical accounts that have been put forward to explain the patterns of syntactic preservation or impairment. The following section (Section 3.2) describes research that has applied usage-based principles to investigate changes in language processing older adults, with a specific focus on the role of frequency. The last section (3.3) provides a short chapter summary.

Aphasia is an acquired language impairment most commonly caused by a stroke. Approximately a third of stroke patients are diagnosed with aphasia. The risk of stroke increases with age, with most strokes occurring after the age of 55. The average age of stroke in men and women is 72 and 78 years respectively (Stroke Association, 2018[1]). A key feature in assessing and understanding the patterns of language processing in individuals with aphasia is the comparison to a normative sample of non-brain damaged and age-matched individuals. The experiments reported in this thesis explore claims of selective damage to word classes in aphasia (Berndt & Haendiges, 2000; Miceli et al., 1984). Individuals with aphasia may have greater difficulties processing verbs relative to nouns – or vice versa. A further dissociation is reported between content (e.g. nouns and verbs) and function words. In contrast to the reliance of existing reports on methods involving single word production and offline comprehension tasks, the experiments in this thesis applied the innovative online methods of word monitoring (WMT) and event-related potentials (ERP), to re-examine these claims. The experiments were designed to probe processing of nouns, verbs and function words embedded in sentences. As the experiments involved novel contrasts, particularly the WMT design, performance in these tasks was first explored in younger and older healthy adults.

Verbs and function words, in particular, are important factors in determining the syntactic complexity and structure of a sentence. For example, the argument structure of a verb determines the number and type of obligatory and optional arguments in a sentence. A two-argument verb (e.g. *watched*) usually requires a subject and a direct object to construct a grammatical sentence (e.g. *John watched a movie*.). Sentences containing verbs that require multiple arguments are considered more complex (Thompson, 2003). Function words are often encountered at start of phrases in English or mark the junction between clauses and so support parsing routines. Syntactic complexity also depends on the clausal structure of a sentence. For example, sentences with centre embedded subject-relative clauses (e.g. *The dog that*

[1] Stroke Association 'State of the Nation' report, 2018

chased the man jumped over the fence) are considered simpler to process than those with centre embedded object-relative clauses (e.g. *The dog that the man chased jumped over the fence*). One element that increases the complexity of embedded object-relative sentences, is that the noun phrase "*the dog"* is the subject of the main clause, but it also functions as the object of the embedded clause (e.g. *that the man chased*). By contrast, in the case of subject relative clauses, the subject of the main clause is also the subject of the centre-embedded clause. The difficulties in determining the relationship between agents and themes often lead to parsing difficulties and result in reparsing of the input string. Another source of difficulty is that the embedded clause interrupts processing of the main clause. Similarly, left-branching sentences (e.g. *When it finally stops raining, I will walk the dog*) are considered more difficult to process than right-branching sentences (e.g. *I will walk the dog when it finally stops raining*), as the sentence begins by providing information before the subject. Thus listeners need to hold additional information in memory before assigning thematic roles. The most commonly used method to investigate syntactic processing in healthy aging has explored processing of such complex structures.

To date, only a limited number of studies have used the WMT to examine age-related changes in language (Baum, 1991; Waldstein & Baum, 1992; Wayland et al., 1996). The monitoring latency and error rate data from these studies suggest that older adults show very similar patterns of sensitivity to syntactic information as younger adults. Although ERPs have been widely used to investigate age-related changes in language processing, few have focused on syntactic processing. The initial study by Kemmer et al. (2004) indicates that online syntactic processing, as indexed by the amplitude and latency of the P600 component, is preserved in older adults. However, a substantial body of work on syntactic processing in healthy aging suggests a more complicated pattern of preservation and decline.

3.1 Syntactic processing in healthy aging

Language processing in healthy aging has been examined in the context of sensory-perceptual, cognitive and neurobiological changes (Shafto et al., 2012; Wingfield et al., 2003). Older adults can experience a decline in their visual and auditory acuity, motor performance, and some domains of cognition. At the neural level, there is loss of grey and white matter (Raz et al., 2010; Sowell et al., 2003; Tyler et al., 2010). The loss of neural tissue results in complex patterns of change in cognitive processes. Aging is related to reductions in (working) memory resources and executive function (Craik & Salthouse, 2008; Dennis & Cabeza, 2015; Hoyer & Verhaeghen, 2006). These changes can affect language processing. In the case of spoken language comprehension, input signals may be degraded because of age-related sensory-perceptual changes and multiple decoding processes need to occur rapidly as the signal is transient. Age-related changes in language may also occur in production. Older adults are more likely to experience word-finding difficulties (Burke et al., 1991), leading to dysfluencies in speech and tip of the tongue phenomena. Older adults are also more likely to use lexical and non-lexical fillers (e.g. *you know*, *ehm*), pauses and repetitions (Thornton & Light, 2006). They also tend to produce syntactically complex structures less frequently than younger adults (Bates et al., 1995; Bromley, 1991; Kemper, 1987; Kemper et al., 2001; Kemper & Sumner, 2001). For example, Kemper & Sumner (2001) reported that older adults used fewer syntactically complex sentences, measured by the number of embedded clauses, in spoken responses relative to younger adults. This decline in syntactic complexity was also observed in written language and in constrained production tasks where speakers were given sentence stems, containing a subject and verb, and were required to produce complete sentences (Kemper et al., 2001; Kemper, Herman, et al., 2004).

The most widely used approach in probing syntactic processing in healthy aging, contrasts comprehension of simple with complex syntactic structures. Several studies have reported age-related difficulties in processing and understanding syntactically complex sentences (Kemper, 1987; Kemper & Kemtes, 1999; Obler et al, 1991; Poulisse, Wheeldon, & Segaert, 2018). For example, Kemper (1987) found that older adults (in their 70s and 80s) recalled less information about written passages when they contained syntactically complex left-branching sentences (e.g. *Safety bottles which the law requires are hard to open*) relative to more simple texts (e.g. *Your pharmacist can dispense your medicine in easy-open bottles*). In contrast, middle-aged adults (in their 40s and 50s) recalled similar amounts of information regardless of the syntactic complexity of the passages. Similarly, Obler et al. (1991) tested auditory comprehension of six syntactic structures of varying complexity in middle- and older-aged individuals (30 to 79 years). The results revealed that older age was related to increased errors in judging the plausibility of syntactically complex sentences that contained double embeddings and double negatives (e.g. double embedded: *The doctor who helped the patient who was sick was healthy*.; double negative: *The bureaucrat who was not dishonest refused the bribe*.). Although older adults took longer to judge the plausibility of sentences, response time was independent of syntactic complexity, suggesting that slowed responses were related to a general slowing of task performance, rather than to sentence type. These age effects were also observed at the discourse level. Salis (2011), who probed comprehension of auditory discourse containing active (simple) and non-canonical (complex) sentences, found that increasing age was associated with more errors to comprehension probes to passages containing complex sentences. However, the age-related decline reported in this study was modest to small, indicating intact comprehension across the three age groups (young = average 25 years, old = average 73 years, older = 86 years).

Several researchers have attributed difficulties in processing syntactically-complex sentences to limitations in working memory, rather than to a decline in linguistic processing per se (Fedorenko, Gibson & Rohde, 2006; Just & Carpenter, 1992; Norman et al., 1991; Kemper & Kliegl, 1999; Kemper 1987; Kemper, Crow & Kemtes, 2004; Kemper & Sumner, 2001; Norman, Kemper, & Kynette, 1992; Payne et al., 2014; Salis, 2011; Van der Linden et al., 1999). Working memory is a limited capacity storage system, its primary function is to retain information for brief periods of time during which mental processes operate on and integrate it with information in long-term memory (Baddeley, 1986, 2000; Just & Carpenter, 1992; Daneman & Carpenter, 1980). According to the capacity-constraint theory of Just and Carpenter (Just & Carpenter, 1992; Just & Varma, 2002; King & Just, 1991), limitations in working memory constrains the comprehension of sentences. Difficulties in comprehension are claimed to arise when the processing demands of a sentence is greater than an individual's capacity. For example, left branching or sentences with centre-embedded object relative clauses are claimed to be more difficult to process as they make greater working memory demands than right-branching or centre-embedded subject relative clause sentences. In the case of sentences with centre-embedded object-relative clauses, parsing of the main clause is disrupted by the centre-embedded clause. This requires, listeners to maintain the subject of the main clause in memory, while it also functions as the object in the embedded clause. Applying capacity-constraint theory to healthy aging, Just and Carpenter proposed that due to age-related decline in working memory, sentences that make greater demands on working memory result in comprehension impairments in older adults.

However, contrary to the capacity-constraint theory, numerous studies have found that working memory span correlates poorly with online sentence processing (DeDe et al., 2004; Wingfield & Stine, 1990). In a series of experiments using various working memory span tests, Waters and Caplan (1996a, 1996b, 2001, 2005) found no significant difference between individuals with low and high memory span in their online comprehension of syntactically complex sentences. Although older adults were less accurate and slower in reading and response times, these measures were unrelated to their working memory span. To accommodate for different age-effects depending on whether processing was probed via offline or online tasks, Waters and Caplan have argued that working memory includes a language-specific component that is unaffected by aging (Caplan et al., 2007, 2011; Caplan & Waters, 1999; DeDe et al., 2004). According to their working memory model, online sentence processing is automatic and unconscious. It is subserved by a separate sentence-interpretation working memory resource (SSIR) that is resistant to aging. On the other hand, post-interpretative (offline) processes that encompass conscious and reflective processes, engage domain-general working memory resources that are affected by aging. Water and Caplan's account of syntactic processing in healthy aging is supported by several online studies that report an absence of age effects. These studies have shown that reading and processing times in younger and adults are slowed in a similar fashion by increased syntactic complexity or violations (Kemtes & Kemper, 1997; Tyler et al., 2010; Waters & Caplan, 2001; Wingfield et al., 2003). For example, Baum and colleague (Baum, 1991; Waldstein & Baum, 1992) used the word-monitoring task (WMT) to probe age-related differences in sensitivity to different types of syntactic violations. In one experiment (1992) they measured recognition of target words in syntactically anomalous sentences (e.g. *His the checked beginning man work the before WATER supply*) and grammatically correct sentences (e.g. *Before beginning his work the man checked the WATER supply*).

The results demonstrated that older adults showed similar delays in recognizing target words in syntactically anomalous sentences as younger adults. This finding is supported by observations in a further study (1991) that measured reaction time (RT) to sentences containing more subtle syntactic errors (e.g. *The children were hoping for SNOW/*The children were hoping SNOW*). Although older adults were overall slower in responding, they showed similar delays in responses to grammatical violations as younger adults. The data revealed a decrease in accuracy in the oldest adult group (80 to 89 year olds) that was unrelated to sentence type (grammatical vs ungrammatical), indicating a general decrease in task performance rather than a specific syntactic decline. Using the same WMT paradigm, Tyler et al. (2010), replicated these earlier findings and reported preserved sensitivity to syntactic violations in older adults when using an online method.

Beyond reaction time studies, preserved syntactic processing has also been observed in studies using reading times as a measure of processing ease. For example, in Kemtes & Kemper (1997), younger (18 to 25 years) and older adults (63 to 84 year olds) read ambiguous and unambiguous sentences in a self-paced reading task. They found that both younger and older adults devoted more time to reading the part of the sentence that disambiguates the main verb of the sentence (e.g. *Several angry workers warned about low wages <u>decided to file</u> complaints*). An important further source of evidence for preserved syntactic processing in healthy aging comes from an ERP study by Kemmer et al. (2004). Although electrophysiological markers, such as the P600, have been widely used to examine neurotypical syntactic processing, few have applied this method to probe age-related differences. Kemmer and colleagues investigated age-related changes in syntactic processing by probing sensitivity to subject-verb agreement violations (e.g. *Industrial scientists develop many new consumer products/*Industrial scientists develops many new consumer products*). The data showed that the amplitude and latency of the P600 component was remarkably similar in older (60 to 80 years) and younger adults (18 to 24 years). This indicated that older adults resembled younger adults both in terms of the size of the disruption and the time course. This finding stands in contrast with most behavioural findings that have found preserved but slowed behavioural response. The difference in the time course of syntactic processing between reaction time and the ERP studies may reflect a difference in sensory-motor demands. Whereas ERPs are recorded during passive listening, behavioural tasks require an overt motor response, the speed of which declines in age.

However, a number of studies have reported subtle but important differences beyond speed of processing, between older and younger adults during online sentence processing (Kemper, Crow, et al., 2004; Stine-Morrow et al., 2000; Waters & Caplan, 2005). For instance, Stine-Morrow, Ryan, and Leonard (2000) recorded self-paced reading times of sentences with embedded subject- and object-relative clauses (e.g. subject-relative: *The pilot that admired the nurse dominated the conversation*; object-relative: *The pilot that the nurse admired dominated the conversation*). They found that the reading times of younger adults (19 to 27 years old) slowed in critical regions such as the junction at end of the embedded constituent and the matrix clause (e.g. at *nurse* in the subject-relative and at *admired* in the object-relative) and when encountering the second verb (e.g. *dominated*). Reading times were slowest at the end of the object-relative clause, indicating that increased resources were needed to assign thematic roles and parse the complex sentence. While older adults (59 to 80 years) slowed down at the end of embedded clauses, reading times did not differ between subject-relative and object-relative clauses. This suggested that older adults did not allocate additional resources needed to efficiently parse the complex sentence, resulting in lower accuracy when answering the comprehension probes. Using eye movements as a measure of syntactic processing, Kemper, Crow & Kemtes (2004) found that older (average age = 75) and younger adults (average age = 19) had similar first-pass eye fixation times when reading ambiguous sentences, however older adults made more regressive eye movements to earlier parts of the sentence (e.g. *The experienced soldiers warned about the dangers conducted the midnight raid*). The increased regressive eye movements in older adults reflects additional efforts to reparse and solve the ambiguity in the sentence. These findings of age-related differences in online processing are challenging for Water and Caplan's account of an age-resistant online processing stream.

With a few exceptions, most studies described above have observed an increase in reading or response time in older adults in response to syntactically complex relative to simple sentences, irrespective of whether they have reported preserved or impaired syntactic processing. Observations of slower perceptual, motor and cognitive responses in older age are ubiquitous. As the name implies, general slowing theory proposes that decreased speed in many cognitive processes, including those that support language, impacts on functioning in older age (Salthouse, 1996). One assumption is that slowed processing speed restricts the amount of information that can be processed at a given time. This limitation particularly affects processing when there are external time restrictions (e.g. timed task) and when the incoming signal is transient, like in spoken language. Another assumption is that when processing speed is slowed, earlier information is no longer available by the time later information is processed. Thus, processing deficits arise due to a discrepancy between the speed at which information can be accessed and integrated, and how long it is available. Applying these assumptions to sentence processing, impairments can arise because the parser is too slow to process incoming information or because the loss in speed reduces the amount of information that is available for processing, because resources are still allocated to earlier information (Salthouse, 1996). According to this theory, slowed processing may particularly affect speech comprehension as it depends on rapidly processing transient auditory signals. Sentences which require reparsing, such as centre-embedded clauses, may be particularly challenging as earlier information may no longer be available for reanalysis.

Consistent with general slowing theory, Wingfield, Pelle & Grossman (2003) observed age-related difficulties in processing complex sentences only when they were presented at a very high speech rate (e.g. centre embedded object-relative: *Women that men assist are helpful*). When listening to rapid speech, older adults (61 to 80 years) produced slower responses, but were equally accurate as younger adults (18 to 27 years). The researchers concluded that the effect of speech rate pointed to a loss of perceptual processing speed, influencing syntactic processing, but only when demands on processing time were extremely high. Although comprehension was preserved even under rapid speech conditions, perceptual decline could lead to difficulties in interpretative processes when older adults listen to longer spoken sentences or discourse. Similarly, Norman, Kemper & Kynette, (1992) found that difficulties in comprehension of complex sentences (with left-branching clauses) arose when older adults read under time constraints. A problem with applying a general theory of cognitive aging, such as the general slowing theory, to specific language processes, is that the theories do not make specific predictions about language per se. A more common finding among studies investigating healthy aging and syntactic processing is that, although older adults are generally slower, they are similarly delayed by syntactic violations, ambiguities or complexity. It is unclear whether the general slowing theory predicts and can account for both types of observations.

The complex picture between decline and preservation of syntactic processing in older adults can partly be explained by whether online or offline processing of sentences is probed. Findings from online measures suggests syntactic processing remains preserved. However, age-related changes do appear when syntactic processing is assessed through offline tasks that measure processing after the sentence or phrase. However, evidence for age-related decline is largely absent when probed via online tasks, indicating that that online syntactic processing remains preserved.

3.2 Usage-based approach to language and aging

The majority of studies investigating syntactic change in aging employ complex sentences that are rarely encountered in natural language settings and few studies give insight into how healthy older adults perform under more typical listening conditions. Moreover, explorations of these issues under more contemporary usage-based frameworks are comparatively rare. The usage-based models, introduced in Section 2.3 in Chapter 2, place a strong emphasis on the role of language experience and use in shaping the structure of a language. Furthermore, language experience is believed to have a direct effect in individuals' knowledge and mental representation of language. The frequency with which linguistic units are encountered determines how strongly their memory representations are entrenched and how easily and quickly they are activated and accessed (Bybee & McClelland, 2005; Jurafsky, 1996). Processing advantages for high frequency words are reported across studies employing online behavioural measures such as response time, eye movements and electrophysiological markers (ERPs). Individuals are quicker at retrieving, identifying and recalling higher relative to lower frequency words (Balota & Chumbley, 1984; Jescheniak & Levelt, 1994). Importantly, processing advantages are not restricted to single words (Bannard & Matthews, 2008; Shaoul et al., 2015; Siyanova-Chanturia et al., 2017; Tremblay & Baayen, 2010). In an eye-tracking study, Siyanova-Chanturia, Conklin and van Heuven (2011) found that high frequency phrases (e.g. *bride and groom*) embedded in sentences were read more quickly than their low frequency cognates (e.g. groom and bride) which were identical in terms of syntax and semantics but lower in frequency.

The notion of entrenchment suggests that language knowledge is not a static and innate ability, but instead is continuously updated and reorganized through experiences (Ramscar et al., 2014). This is seen as a life-long process, making usage-based models relevant to investigations into language processing in healthy aging. Older adults have accumulated extensive experiences in their native language, leading to greater knowledge of its distributional properties. One reasonable assumption is that older adults' greater experience with language relative to younger adults, results in stronger frequency effects. There is some evidence that validates this assumption (Kliegl et al., 2004; Rayner, Reichle, et al., 2006). For example, Kliegl et al., (2004) compared eye movements of older and younger adults during silent reading. It is well-established that lexical frequency affects eye movements during silent reading tasks, whereby highly frequent words are fixated on for less time and skipped more often than less frequent words. The results showed that, although older adults were overall slower readers than younger adults, they were more sensitive to lexical frequency, indicated by shorter fixations and more frequent skipping of higher frequency words. In a further eye-tracking study, Rayner et al. (2006) reported that older, but not younger adults, skipped high frequency words more often compared to low frequency words (e.g. high frequency: *I took a tour of a famous* <u>*building*</u> *while I was on holiday*., low frequency: *I took a tour of a famous* <u>*catacomb*</u> *while I was on holiday*). The mechanism that is claimed to be driving this greater frequency effect in older adults is not exactly clear. Some have suggested that the difference between older and younger adults lies in the impact of lexical competitors on the activation of higher and lower frequency words (Balota & Ferraro, 1996; Spieler & Balota, 2000). In an activation-based model, access and activation of words with fewer lexical competitors is claimed to be faster. Greater language experience in older adults typically involves more exposure with lower frequency items. Thus, lower frequency items have more lexical competitors, leading to slower activation of low frequency words. In older adults, this factor leads to greater processing differences between higher and lower frequency items, resulting in a larger frequency effects relative to younger adults. In line with this view, Sommers (1996) found that older adults had more difficulties recognizing low frequency words that had many phonologically similar words as competitors (e.g. *dame – same, fame, claim*) than younger adults, but both groups were equally accurate in identifying high frequency words with few competitors (e.g. *ship).* However, this explanation has been challenged by findings where older adults showed better, rather than worse performance, for lower frequency items (Gomez, 2002; Ramscar et al., 2013). For example, in a lexical decision task, Ramscar et al. (2013) reported that older and younger adults were equally accurate in recognizing higher frequency items and that the advantage of language experience mainly had an effect on low frequency words, where older adults were 80% accurate, while younger adults were at chance.

Overall, the evidence demonstrating greater frequency effects in healthy older adults is inconsistent. In a series of studies, Spieler and Balota (2000; Balota et al., 2004) investigated the roles of lexical frequency, phonological and semantic features (length and orthographic neighbourhood density, imageability) in lexical access using single word recognition and naming tasks. They key finding was that, while older adults showed a greater frequency effect in the naming task relative to younger adults, younger adults produced larger frequency effects when recognizing words. However, more often, studies have reported comparable frequency effects across age groups (Allen et al., 1991; Allen et al., 1993; Badham et al., 2017; Balota & Ferraro, 1996; Tainturier et al., 1989; Whiting et al., 2003). For example, Allen and colleagues (Allen et al., 1991; Allen et al., 1993) reported that younger and older adults were both facilitated by frequency when probed via a lexical decision task. Similarly, Tainturier, Tremblay and Lecours (1989) reported that, although older adults were generally slower in responding in a lexical decision task, they showed a similar reaction time difference between higher and lower frequency words as younger adults. Some researchers have attempted to explain the underlying mechanisms that can lead to comparable frequency effects despite the increased experience and knowledge of older adults. Baayen, Milin and Ramscar (2016) suggested that such findings point to a trade-off between knowledge and speed. They hypothesized that older adults accrue more knowledge about language, together with increasing associations to other information, resulting in an increase in processing load and thus a decrease in speed. They note that this trade-off is evident in the patterns between accuracy and reaction time, where older adults respond more slowly but with similar accuracy as younger adults in tasks probing frequency effects (Ramscar et al., 2013). To date, frequency effects at the phrasal level has gone largely unexplored in healthy aging, and it is unknown whether older adults show comparable or greater frequency effects beyond the word level. Initial evidence by Bruns et al. (in prep) indicates that older and younger adults are similarly facilitated by phrasal frequency, confirming findings at the single-word level. The work in this thesis further explores frequency effects at the phrasal level, providing novel evidence.

3.3 Summary

This chapter provided an overview of syntactic processing in healthy aging. The evidence for preserved syntactic processing is mixed. Results from offline studies show that older adults find syntactically complex sentences, such as those containing object-relative clauses or syntactic ambiguities, more difficult to process. Decline in syntactic processing has largely been attributed to age-related reductions in working memory capacity. However, this account has been challenged by findings that age-related declines are largely absent when syntactic processing is probed using online tasks. These findings suggests that online build-up of syntactic representations are resilient to normal ageing process, however age-related differences may occur later in the processing stream. In the previous section, the chapter reviewed the application of usage-based principles to investigate language processing in healthy aging. A reasonable assumption is that lexical frequency effects are larger in adults as a result of their greater experience and knowledge of language and its distributional properties. However, the evidence demonstrating greater frequency effects in healthy older adults is weak. The next chapter describes the first experiment, an online word-monitoring experiment (WMT), that explores age-related changes in noun phrase (NP) and verb phrase (VP) processing as a proxy for syntactic processing.

4. Experiment 1: Exploring noun phrase and verb phrase sensitivity in healthy aging

This chapter describes an online word-monitoring experiment (WMT) that probed noun phrase (NP) and verb phrase (VP) processing across three conditions: 1) phrase structure violations, 2) premodifiers (function words) and 3) phrase frequency. As the WMT has rarely been utilized to investigate aphasic processing and included novel conditions, performance in this task was first explored in younger and older neurotypical adults. In addition to establishing normative patterns, the inclusion of younger adults provided an opportunity to investigate age-related differences in sentence processing.

4.1 Introduction

Healthy aging is accompanied by changes to perceptual, sensory-motor and cognitive processing systems which can affect language production or comprehension (Li & Dinse, 2002; Salthouse, 2000; Shafto et al., 2012; Wingfield et al., 2003). Of particular interest to the current experiment are studies that have explored syntactic processing and effects of frequency in healthy aging. Several studies have applied the WMT paradigm to probe syntactic processing in healthy aging (Baum, 1991; Tyler et al., 2010; Waldstein & Baum, 1992). For example, Baum (1991) probed age-related changes in syntactic processing across three groups of older adults (60 to 69, 70 to 79 years, and 80 to 89 years old), by comparing reaction times (RTs) to target words embedded in grammatical and ungrammatical contexts (e.g. *The children were hoping for* <u>*snow*</u> / **The children were hoping* <u>*snow*</u>**)**. Slower RTs for words in ungrammatical contexts compared to grammatical contexts indicated sensitivity to syntactic information. The results showed that all three older groups were slower in recognizing words in ungrammatical sentences. Further, RT difference between grammatical and ungrammatical sentences were not correlated with age, demonstrating that adults in their 80s were similarly slowed down by violations as adults in their 60s and 70s. In addition to RTs, error rates were compared across groups, which showed that the oldest individuals had a higher error rate (11%), compared to those in their 70s (6.5%) and 60s (3.75%). Overall, the results indicate that online syntactic processing is largely preserved in older age, although the oldest group made more errors and showed greater RT variability. In a second WMT study probing syntactic processing, Waldstein & Baum (1992) included a younger adult group (20s) in addition to three older groups (60 to 69, 70 to 79, and 80 to 89 years). Younger and older adult groups were slower in recognizing words in syntactically anomalous contexts compared to grammatically correct sentences (e.g. grammatical: *Before beginning his work the man checked the WATER supply*; syntactically anomalous: *His the checked beginning man work the before WATER supply*). Although older adults responded more slowly to target words overall, they were not significantly slower than younger adults. Similar to the previous WMT studies, Tyler et al. (2010) measured reaction time to target words in grammatical and ungrammatical sentences (e.g. normal: *Jane didn't enjoy herself very much. Her neck was stiff because she had a bad cold and she couldn't lift anything properly*; random word order: *Very Stephen catch much himself didn't. Her nose because properly had anyone couldn't he and nail weak a heat driven was*). Consistent with the initial WMT studies, Tyler and colleagues reported similar response patterns in older (49 to 86 years) and younger adults (19 to 34 years), with slower RTs to targets in sentences with random word order. These response latency and error rate data suggest older adults are similarly sensitive to syntactic violations.

While research probing syntactic processing via violation paradigms suggest sentence processing remains preserved in older age, several studies probing offline processing have reported age-related decline when contrasting simple and complex sentences (Kemper, 1987; Kemper & Kemtes, 1999; Obler, Fein, Nicholas, & Albert, 1991; Poulisse, Wheeldon, & Segaert, 2018). Older adults are reported to find it more difficult to remember and understand information when presented in syntactically more complex sentences (Kemper, 1986; Norman et al., 1991). For example, Salis (2011) compared comprehension of complex passages, containing non-canonical sentences, to simple passages consisting of active sentences. The results demonstrated that older adults were less accurate than younger adults in understanding syntactically complex passages. Similar comprehension differences have been reported when probing single sentences (Kemper, 1987; Kemper & McDowd, 2006; Obler et al., 1991). Obler et al. (1991) investigated age-related differences in auditory comprehension of sentences varying in complexity, from actives, to passives and sentences with embedded clauses across four groups of adults (30 to 39, 50 to 59, 60 to 69, and 70 to79 year old). Differences in comprehension were primarily found in more complex sentences, where increasing age was related to increased number of errors in judging the plausibility of complex sentences (e.g. double embedded: *The doctor who helped the patient who was sick was healthy*; double negative: *The bureaucrat who was not dishonest refused the bribe*).

Decline in parsing and interpretive processes in healthy older adults has most commonly been attributed to working memory limitations (Kemper & Kliegl, 1999; Kemtes & Kemper, 1997; Waters & Caplan, 2005). Just and Carpenter's capacity constraint theory proposes that comprehension difficulties in older age primarily arise when processing sentences with complex hierarchical structures or temporary syntactic ambiguities as a result of age-related decline in working memory capacity (Just & Carpenter, 1992; Just & Varma, 2007; King & Just, 1991). For example, sentences containing centre embedded object-relative clauses (e.g. *The dog that the man chased jumped over the fence*) are considered computationally more complex in regards of assigning thematic roles, as the subject of the matrix clause also functions as the object of the relative clause. An additional complexity is that the object-relative clause interrupts processing of the main clause. According to Just and Carpenter, processing sentences with these complexities places a demand on working memory that exceeds capacity in older adults, leading to impaired comprehension.

However, working memory limitations accounts are challenged by findings that demonstrate that older adults exhibit similar patterns as younger adults in response to syntactic ambiguities and complexities (Caplan & Waters, 2003; Stine-Morrow, Loveless, & Soederberg, 1996; Waters & Caplan, 2001; Wingfield et al., 2003). For example, Wingfield, Pelle and Grossman (2003) compared comprehension of complex sentences (centre embedded object-relative: *Women that men assist are helpful*) to simple sentences containing subject-relative clauses (e.g. *Men that assist women are helpful*) in a group of older (61 to 80 years) and younger adults (18 to 27 years). Instead of a plausibility judgment task, individuals had to indicate whether the agent of the sentence was male or female. Although older adults were slower in responding overall, both groups had more difficulties understanding syntactically complex sentences relative to simple sentences. Older adults only exhibited comprehension difficulties when the sentences were presented at a very high speech rate. This suggests that some of differences between younger and older adults might be due sensory-perceptual rather than linguistic challenges. Inconsistent findings across studies appear to be partly due to the use of different tasks. Older adults tend to do worse in offline tasks that probe comprehension, judgements of plausibility, or measure reaction time after presenting the sentences, but perform similarly to younger adults when sentence processing is measured online.

The most widely used approach to examine syntactic processing in healthy aging involves probing comprehension of complex sentences that are rarely encountered in everyday language, such as sentences with centre-embedded object relative clauses (e.g. *The doctor who helped the patient who was sick was healthy)*. It is well-established that the frequencies with which words and phrases are encountered affects the speed and ease at which they are processed. High frequency words are recognized quicker, fixated on for less time, and more likely to be skipped during reading (Balota et al., 1985; Balota & Chumbley, 1984; Drieghe et al., 2005; Inhoff & Rayner, 1986; Rayner et al., 1996, 2004). Frequency effects have also been observed at the phrasal level (Arnon & Snider, 2010; Conklin & Schmitt, 2008, 2012). For example, Conklin & Schmitt (2008) compared processing of high frequency phrases (e.g. *hit the nail on the head*) to control phrases that contained (nearly) identical but rearranged words (e.g. *hit his head on the nail*) when embedded in passages. As predicted, reading times were faster for high compared to low frequency phrases in a group of younger adults. One reasonable assumption is that continued exposure to language across the life span results in stronger frequency effects. However, evidence for stronger frequency in older adults is relatively limited. Several behavioural studies have found older adults are more facilitated by lexical frequency compared to younger adults (Balota et al., 2004; Kliegl et al., 2004; Revill & Spieler, 2012; Spieler & Balota, 2000). For example, Rayner et al. (2006) measured fixation time and eye movements as younger and older adults read sentences containing high frequency and low frequency nouns embedded in neutral sentences (e.g. high frequency: *I took a tour of a famous* <u>*building*</u> *while I was on holiday*; low frequency: *I took a tour of a famous* <u>*catacomb*</u> *while I was on holiday*). The results showed that older adults were more likely to skip high frequency words compared to low frequency words. More often, however, studies have found no age-related differences in the recognition of high and low frequency words (Allen, Madden, & Crozier, 1991; Allen, Madden, Weber, & Groth, 1993; Tainturier, Tremblay, & Lecours, 1989). Allen et al., (1993) examined age-related sensitivity to low and high frequency words using a lexical decision task. Older and younger adults showed similar facilitation by word frequency, with faster reaction times for high frequency than low frequency words. In a further lexical decision study, Whiting et al. (2003) found comparable frequency effects between older and younger adults in response to high and low frequency words.

Overall, these findings suggest that investigations probing frequency effects at the single word level do not find age-related differences, whereas studies examining processing of high and low frequency words embedded in sentences are more likely to find an age effect in favour of older adults. Whether older adults show a comparable or greater frequency effects beyond the single word level has gone largely unexplored. Initial evidence by Bruns et al. (in prep) suggests that both older and younger adults are similarly facilitated in recognizing target words embedded in high compared to low frequency phrases (e.g. high frequency: *The salesman luckily offered me a great DEAL to replace the engine*; low frequency: *The salesman luckily offered me a fair DEAL to replace the engine*).

4.1.1 Present study

The primary aim of the current experiment was to establish the normative behavioural pattern in a WMT task that was designed to probe sensitivity across NP and VP structures. There were three conditions: 1) phrase structure violations; 2) premodifiers), 3) phrasal frequency. A further aim was to investigate age-related differences in sentence processing using the WMT paradigm.

The experiment addressed four main research questions:

1) Do neurotypical older and younger adults show differential processing of NP and VP structures?
2) Are younger and older adults similarly sensitive to NP and VP phrase structure violations?
3) Does premodification facilitate recognition of head nouns and head verbs in younger and older adults?
4) Do older adults show a greater facilitation effects to frequency manipulation than younger adults

The majority of research questions posed in this experiment have not been addressed within the aging literature. As a result, there were few or no previous studies to guide predictions. This is the case for three of the four main research questions stated above, specifically questions 1, 2, and 3. Based on past research on the relationship between age and sensitivity to lexical frequency, it was predicted that younger and older adults would show similar frequency effects.

4.2 Method

4.2.1 Participants

The experiment was approved by the Research Ethics Committee at University College London (approval number LC/2013/05). All participants gave informed written consent.

4.2.1.1 Neurotypical older adults

Twenty-two older adults were recruited through an adult educational organisation and a research volunteer list. Two participants were excluded from analysis because of incomplete data or a pre-consisting neurological condition. The final group consisted of 20 participants (12 women) between 41 and 80 years old (M = 64.65 SD = 11.52). All were neurotypical, had no history of speech/language impairments, with unimpaired, or impaired-to-corrected vision and hearing, and spoke English as their native language. Table 1 provides demographic information for each participant. Most participants had achieved a college/university level degree (60%), or higher (35%). Older adults received an hourly rate of £7.50 for participating

4.2.1.2 Neurotypical younger adults

Thirty-one younger adults were recruited through an online subject pool. Four participants were subsequently excluded because they did not speak English since birth. The final group consisted of 27 participants (19 women) with a mean age of 20.63 years (SD = 3.03). Table 2 provides information regarding their age and language background. Fifteen participants were monolingual and 12 were bilingual native speakers of English. All younger adults were undergraduate or postgraduate students at UCL and received course credit for participating.

Table 1 Demographic information of neurotypical older adults in the WMT experiment

Participant	*Age*	*Gender*	*Education*		*Language*
			Level	*Years*	
1	72	M	Graduate studies	11	M
2	66	F	Postgraduate	19	M
3	62	M	Graduate studies	16	M
4	72	F	Graduate studies	14	M
5	64	F	Graduate studies	17	M
6	68	F	Graduate studies	12	M
7	75	F	Graduate studies	16	M
8	68	F	Graduate studies	15	M
9	80	F	Postgraduate	13	M
10	77	F	Graduate studies	14	M
11	78	F	Graduate studies	16	M
12	70	F	Graduate studies	14	M
13	74	M	Postgraduate	20	M
14	62	F	Sixth form	13	M
15	66	F	Graduate studies	16	M
16	42	M	Postgraduate	21	M
17	52	M	Postgraduate	15	M
18	41	M	Postgraduate	18	M
19	56	M	Postgraduate	18	M
20	48	M	Graduate studies	13	M

Note: M = Monolingual

Table 2 Demographic information of younger adults in the WMT experiment

Participant	Age	Gender	Language
1	20	F	B
2	26	F	M
3	27	F	B
4	20	M	M
5	21	M	B
6	23	M	B
7	21	F	M
8	23	M	B
9	21	F	M
10	18	F	M
11	19	F	M
12	20	F	M
13	22	F	M
14	18	F	B
15	20	F	M
16	18	F	M
17	22	M	M
18	18	M	M
19	20	M	B
20	18	F	B
21	19	F	B
22	19	F	M
23	18	F	M

24	20	M	B
25	30	F	M
26	18	F	B
27	18	F	B

Note: M = Monolingual, B = Bilingual

4.2.2 Materials

4.2.2.1 Word Monitoring stimuli

The total stimulus set consisted of 120 sentence pairs (240 trials), half of which probed NP and half probed VP processing. Within each NP/VP phrase type, 20 sentence pairs were constructed for each sub-condition: phrase structure violation, premodification, and phrasal frequency. A list of the full stimulus set can be found in Appendix A.1. The sections below describe the experimental conditions, followed by the criteria for constructing the stimuli.

To minimise fatigue, the stimuli were divided into four blocks, each containing 60 sentences. Table 3 illustrates how conditions were allocated to blocks. Each block contained equal numbers of sentences from each condition and phrase type. Half of the sentences were from facilitation conditions (non-violated, high frequency, premodified) and half were from non-facilitation conditions (violated, low frequency, bare) sentences. Members of a pair did not appear in the same block.

Table 3 WMT stimuli allocation per block

Phrase type (N=30)	Condition (N = 10)	Manipulation (N = 5)	Example items
NP	Phrase structure violation	Violated	Mary sprayed a few PERFUME on her wrist
		Non-violated	Mary sprayed a little PERFUME on her wrist
	Premodification	Bare	Paul was afraid of SNAKES
		Premodified	John was afraid of the young SNAKES
	Phrase frequency	Low frequency	Alice visited the SCHOOL she went to as a child
		High frequency	Emma entered the SCHOOL where she had left her books
VP	Phrase structure violation	Violated	John is looking FILMS
		Non-violated	John is watching FILMS
	Premodification	Bare	Rose BOUGHT the tickets in advance in order to save money
		Premodified	Claire must have BOUGHT the tickets weeks ago
	Phrase frequency	Low frequency	When I hear music I need to DANCE until I am exhausted.
		High frequency	When I hear music I like to DANCE until my feet get tired.

Note: target words are capitalized

4. 2.2.1.1 Phrase structure violation

One approach to probe processing of syntactic information, is to measure sensitivity to violations within NP and VP phrase structures. In this condition, target words were placed in the same position across sentence pairs.

Verb phrase structure violation

Verb phrases containing transitive verbs require arguments in the position of a direct object (e.g. *Kate is telling a JOKE*) to form syntactically correct sentences. Intransitive verbs, on the other hand, do not require an object argument (e.g. *John is sleeping*). Sentences with transitive or intransitive verbs were constructed to examine sensitivity to verb argument structure (Table 3). In the violation condition, target words were placed in the object position following an intransitive verb (e.g. *Rose slept CUSHIONS in the evening*). In the corresponding non-violation sentence, target nouns were preceded by transitive verbs to form grammatically correct sentences (e.g. *Rose sewed CUSHIONS in the evening*). Target words were identical across violated and non-violated conditions, thus controlling for factors such as lexical frequency, word length and imageability. Intransitive verbs in the violated condition, were semantically-related to the target word or to the transitive verb in the paired sentence to minimize semantic violation. It was not possible to exactly match transitive and non-transitive verbs on lexical frequency, but they were roughly matched for syllable length.

Noun phrase structure violation

Unlike verbs, noun phrases in English do not require arguments to form syntactically correct sentences, with the exceptions of nominalizations (nouns derived from verbs or adjectives such as *decision* - *decide, fear* - *afraid*). Therefore, to construct NP violations we exploited the distinction between mass and count nouns. Countable nouns refer to concepts that can be individually enumerated (e.g. *one book*), while mass nouns refer to objects which cannot (e.g. **one progress*). The noun type governs the use of determiners, verbs and quantifiers (*Mary made little PROGRESS in class* vs. **Mary made three PROGRESS in class*). Speed of recognition of mass nouns was recorded when they were preceded either by matching or mismatched quantifiers. For each paired item, matched and mismatched quantifiers were roughly matched for syllable length and semantics when possible (e.g. *a little* dust vs **a few dust).*

4. 2.2.1.2 Premodification

In order to examine sensitivity to premodification and, in particularly in the case of the VP condition, function words, we exploited the positional relationship between premodifiers and head nouns and verbs. Premodifiers generally directly precede head nouns or verbs and as such serve as markers for the upcoming head nouns and verbs. Sentence pairs were constructed which included either bare or premodified verb or noun phrases. Position of the target word between the sentence pairs differed in the presence or absence of premodifiers.

Verb phrase premodification

To probe sensitivity to premodification by function words, we examined processing of bare VPs and pre-modified VPs (see previous Table 3). VP premodifiers consist of function words such as auxiliary (e.g. *have, do, be*) and modal (e.g. *would, should, could*) verbs. In the premodified condition, target verbs were preceded by an auxiliary and modal verb. In contrast, target verbs in the bare condition were preceded by the subject or by a phrase boundary.

Noun phrase premodification

Unlike verb premodifiers, noun premodifiers consist mostly adjectives and numerals rather than solely function words. To construct a comparable NP premodification condition, combinations of determiner plus adjectives were chosen (see previous Table 3). The News of the World (NOW - Davis, 2016) corpus was used to identify adjectives which were semantically congruent to the head noun, but were not the most frequently associated with the target noun. This selection procedure ensured that adjectives with lower semantic association to target words were selected in order to weight them as much as possible as syntactic primes rather than lexical-semantic ones. Sentence pairs contained a premodified or a bare NP. Targets in the premodified condition were preceded by a determiner and adjective. Sentences for the bare NP condition contained target nouns, preceded by the subject, head verb or by a phrase boundary.

4. 2.2.1.3 Frequency-based conditions

To examine sensitivity to frequency across NPs and VPs, sentence pairs were constructed which included either high or low frequency trigrams, with the target word being the final unit in the trigram. The News of the World (NOW – Davis, 2016) corpus was used to identify high and low frequency trigrams. The NOW corpus contains 3.7 billion words, with approximately 4 million new tokens added daily. The collection comprises online newspapers and magazines written in English. The data search was limited to online sources published in Great Britain before 31 December 2016. Applying these restrictions, the corpus consisted of 550,849,905 words. Trigram pairs were selected and categorized based on raw frequency scores derived from the NOW corpus. Target words were in same position for sentence pairs.

Verb phrase frequency

Processing of verb targets in high frequency trigrams (e.g. *time to TURN*) was compared to the same verb in a lower frequency trigram (e.g. *space to TURN*). High and low frequency trigrams were constructed which only differed in the initial word (see previous Table 3). The word class of initial words varied across the stimuli set, however, within each paired item, word category and tense were the same. The mean frequency for high frequency trigrams was 2494 (SD= 8163.68), ranging from 26 to 37024. The trigram "don't know" was substantially higher in frequency than the rest of the high frequency trigrams. When excluding "*don't know*" and its low frequency pair "*shall not know*", the mean for the remaining high frequency trigrams was 676.63 (SD = 788.58), and 135.95 (SD = 159.47) for the low frequency trigrams. After exclusion of the very high frequency pair, the frequency difference between high and low frequency trigrams was significant as indicated by the one-tailed independent t test, t(36) = 2.92, p =.003.

Noun phrase frequency

To investigate frequency-based effects in NPs, processing of noun targets in high frequency trigrams (e.g. *entered the SCHOOL*) was compared to the same noun in a lower frequency trigram (e.g. *visited the SCHOOL*). Table 3 summarizes the type of NP trigrams tested in this condition. High and low frequency trigram pairs only differed in the initial word. The word category of initial words varied across the stimuli set, however, within each paired item, word class and tense were the same. The mean frequency for high frequency trigrams was 1860.4 (SD = 7090.95), ranging from 23 to 31869. The mean for low frequency trigrams was 274.85 (SD = 1092.02) ranging between 1 and 4912. The high frequency trigram "on the table" and its low frequency pair "off the table" are both substantially higher in frequency than the rest of the items/trigrams in their respective conditions. When this pair is excluded, the mean frequency for the remaining high frequency trigrams was 281 (SD = 642.85) and 30.79 (SD = 35.7) for the low frequency trigrams (see Appendix A.2 for the stimuli list and their frequency values). When excluding the "on/off the table" pair, the frequency difference between high and low frequency trigrams was significant as indicated by the one-tailed t test, t(36) = 1.69, p = .05.

4. 2.2.1.4 Target words

In a WMT, it is critical to accurately identify the onset of the target word as RTs are measured from that onset. This creates phonological constraints on the selection of target words. Target words beginning with plosives (/p/, /t/, /k/, /b/, /d/, /g/, or affricates /tʃ/, /dʒ/) are easiest for determining word onset and most of the targets began with these phonemes (Cruttenden, Gimson, & Gimson, 2008). For a minority of target words where initial sounds were fricatives, nasals, approximants or vowels, the preceding sound of the previous word was taken into account to ensure that onset times could be determined accurately. Conventions for determining word onset in audio recordings were compiled in the Phonetics for Word Monitoring manual (Brekelmans & Meitanis, 2016 unpublished manuscript, see Appendix A.3).

For each sentence pair, the context prior to the target word was nearly identical except for minor lexical changes that maintained the syllabic structure and semantic content of the sentence (*every Friday morning* vs. *every Monday morning*). The post-target context was more varied (*Alice decided to take the TRAIN to travel to the seaside* vs. *Mary decided to catch the TRAIN into town to go to the movie*). These changes aimed to maintain comparability of the pre-target context, while introducing variability into the post-target context in order to decrease participants' awareness of the paired nature of the sentences.

Target word locations varied within and across conditions in order to prevent participants developing expectations regarding target position. The position of the target words in NP conditions ranged between 4 and 16, and between 2 and 16 in VP conditions. Figure 4 shows the position of the target words across all three NP and VP conditions. The position of target words did not differ significantly between NP and VP conditions, t(238) = 1.81, p>.05.

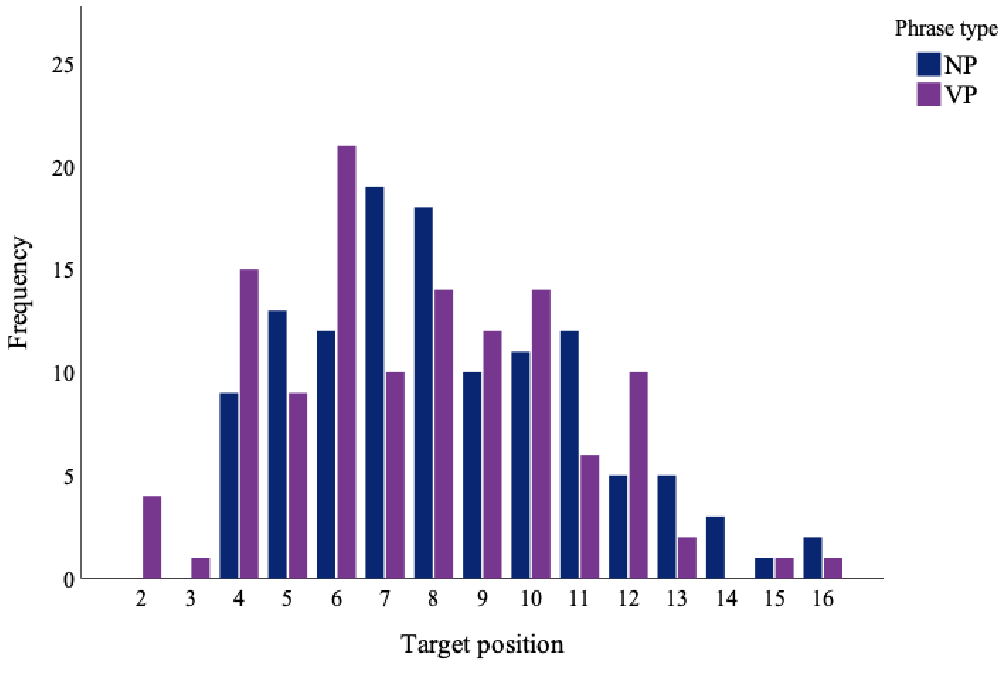


Figure 4 The distributions of target word positions in the word-monitoring task across noun and verb phrase conditions

The target words and sentences were recorded in a sound-attenuated booth, using ProRec recording software version 2.2 (Huckvale, 2016). The stimuli were recorded by a female native speaker of British English. All recordings were then downsampled to 22050 sampling rate, and had amplitudes equalized to 70 dB. Extraneous noise at the beginning or end of the recording were cut.

To ensure accuracy and consistency of marking of target word onset times, onset times measured by two different raters were compared for 17% of stimuli sentences (N = 40). Inter-rater reliability (IRR) was assessed using a two-way mixed, average measures absolute agreement intra-class correlation (ICC) (McGraw & Wong, 1996). The resulting ICC was high, ICC = 1.0, which is in the excellent range (Cicchetti, 1994).

4.2.3 Procedure

The WMT was presented using DMDX software (Forster & Forster, 2003) on a DELL Latitude E5540 laptop. Participants were tested individually in a quiet room, with external DELL speakers at a volume comfortable to the participant. Instructions were presented visually. In order to support a subsequent experiment with aphasic participants, instructions were presented in short sentences to minimise aphasic processing difficulty (Figure 5). In addition to presentation on the screen, the examiner read aloud the following instructions:

You will first hear and see a word on screen. Keep that word in mind. Next you will hear that word in a sentence. Press the button when you hear the word in the sentence. Be quick and accurate.

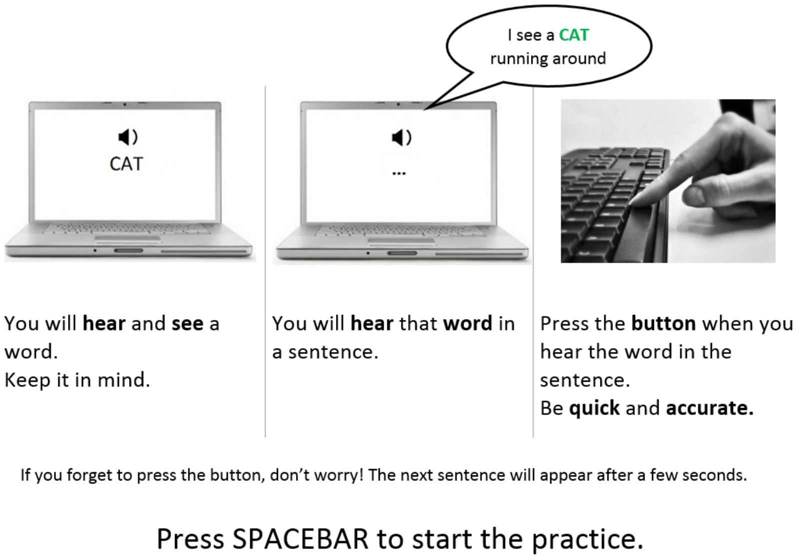


Figure 5 Word Monitoring task instructions

Figure 6 illustrates the WMT stimuli presentation paradigm. At the start of each trial, a fixation cross was presented for 3000ms centrally on the computer screen. Next, a target word (e.g. *cat*) was presented aurally and orthographically on the screen to avoid lexical ambiguity. A blank screen followed for 2000ms. Participants then heard a sentence containing the target word (*I see a CAT running around*). They were required to press a key on the keyboard as quickly as possible on detecting the target using their preferred hand. Reaction times were measured in milliseconds from the onset of the sentence. A new trial started 3000ms after the button press or 10 seconds after the start of the trial if no button press occurred.

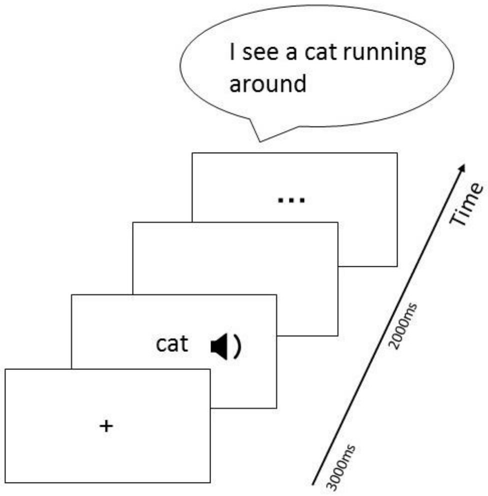


Figure 6 Scheme of stimulus paradigm in WMT

Prior to each block, participants completed two practice items. These were repeated if the participant did not appear to understand the task. In the main task, presentation of blocks was randomized for each individual. Table 4 shows the number of sessions and task order for both groups separately. Neurotypical older adults completed two sessions as they were also assessed on linguistic and non-linguistic measures (reported in Chapter 5).

Table 4 WMT experimental protocol/task list[2]

Group	Session 1	Session 2
Younger adults	1. Information sheet 2. Consent forms 3. Background information (via interview) 4. WMT Block 1 5. Jogging narrative 6. WMT Block 2 7. WMT Block 3 8. Cookie Theft 9. WMT Block 4 (60 minutes)	
Older adults	1. Information sheet 2. Consent forms 3. Background questionnaire 4. WMT Block 1 5. Dinner Party narrative 6. WMT Block 2 7. WMT Block 3 8. Cookie Theft narrative 9. WMT Block 4 (80 mins)	1. BNT 2. PALPA13 3. TROG-2 4. WASI-II: MR 5. Debrief (45 mins)

4.3 Results

4.3.1 Pre-processing of reaction time data

To measure individuals' sensitivity to the NP and VP manipulations, z-score difference values were computed for each sentence pair (N = 120). First, individual RTs to target words were calculated by subtracting RTs from target word onset times. Responses to targets before the onset of target words and no responses were excluded from further analysis. Next, individual mean RT and standard deviations (SD) were calculated across all items. Responses which were above or below 2 SDs from the individuals' mean reaction time were excluded. Mean RTs and SDs were then recalculated for each individual. Individuals' RTs were normalized by computing z-scores. Z-scores for non-facilitated sentences (bare heads, low frequency, or violated structures) were subtracted from their paired

[2] Note: The linguistic and cognitive assessment battery that the older adults completed in session 2 is described in Chapter 5 Section 5.2.2.1

facilitated sentence (pre-modified, high frequency, or non-violated structures). This resulted in a z-score difference value for each sentence pair, henceforth referred to as z-score difference. Subsequent statistical analysis was performed on mean z-score difference scores for complete pairs. Z-scores allow comparisons between scores from samples which have different means and standard deviations. The mean z-score difference represents how many standard deviations a score is away from the mean.

4.3.2 Missing trials

During pre-processing, three types of responses were categorized as missing trials and were excluded from individuals' average reaction times. These were early button presses, time outs (no button presses) and outliers (button presses 2SD from individual's mean). Table 5 presents the number of missing trials per group per error type. In the older adult group, the majority of excluded trials were due to outliers. Approximately half the missing trials in the younger adult group consisted of early button presses and the other half of outliers. Both groups had few missing trials due to time outs. There seems to be a small trend, in both groups, for more excluded VP trials relative to NP. After removing these missing trials, 89% of completed pairs were used in the analysis of the younger group, and 87% in older adult group. The minimal data loss indicates that both groups were attending and understanding the task.[3]

Table 5 Type and number of missing trials in the WMT – younger and older adults

Group	Early		Time out		Outlier		Total	
	NP	VP	NP	VP	NP	VP	NP	VP
Older adults	7	12	2	2	80	94	89	108
Younger adults	61	91	20	23	79	109	160	223

4.3.3 Reaction time data

Overall, older adults responded significantly more slowly (M = 447.82, SD = 71.29) to targets than younger adults (M = 334.08, SD = 61.34), $t(45) = 5.86$, $p<.001$, $r= .657$, indicating a large effect. Figure 7 presents the mean z-score difference for each condition by age group. Positive mean z-score differences indicate faster RTs for facilitated and slower RTs for non-facilitated sentences. Larger mean z-score difference values represent larger reaction time differences between facilitated and non-

[3] One older adult was excluded from the error analysis because she experienced technical difficulties which resulted in several missed trials.

facilitated paired sentences. Overall, younger and older adults showed remarkably similar patterns across conditions. In both groups, z-score differences were the greatest for NP and VP structure violations, indicating that grammatical violations had the greatest impact on processing. In comparison to grammatical violations, facilitation effects of frequency and premodification were more subtle, resulting in smaller z-score differences. Both groups show similar facilitation effects for NP and VP phrase frequency, however, age-related differences appeared in the premodification conditions. While older and younger adults showed similar facilitation effects to VP premodifiers, older adults do not show evidence that processing of nouns was facilitated by the presence of premodifiers.

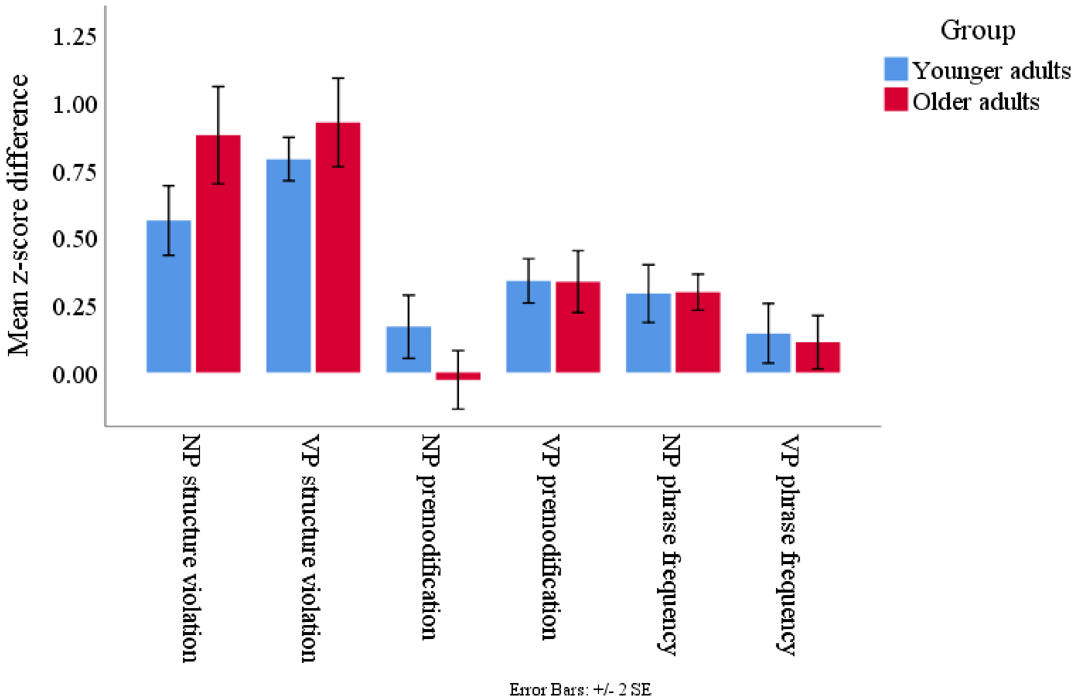


Figure 7 Mean z-score differences for Younger and older adults across all conditions in Experiment 1- Word Monitoring task

A 3 (condition) x 2 (phrase type) x 2 (group) mixed factorial ANOVA was conducted to statistically examine whether older and younger adults differ in their sensitivity to phrase structure violation, premodification, and phrase frequency across NPs and VPs. Partial η^2 was used as a measure of effect size for significant F values (small = .01, medium = .06, large = .14 - Cohen, 1988) and r for significant t values (small = .1, medium = .3, large =.5 – Field, 2009). The Shapiro-Wilk test showed that the distribution for each sub-condition (NP phrase structure violation D(47) = .99, VP phrase structure violation D(47) = .98, NP premodification, .98, VP premodification D(47) = .97, NP phrase frequency D(47) = .97, VP phrase frequency D(47) = .98), did not deviate from normal, p>.05. The Mauchly's test of sphericity was performed for each within-subject factor that had more than two levels. The test showed that the assumption of sphericity was violated for condition, $\chi^2(2)=7.05$, $p<.05$. Greenhouse-

Geisser corrected F values are reported for analyses involving condition as a factor. Homogeneity of variance was assessed via Levene's test of equality of error variance. Variances were unequal for VP phrase structure violation, $F(1, 45) = 5.1$, $p<.05$, and for NP phrase frequency, $F(1, 45) = 6.36$, $p<.05$. Results of ANOVAs are robust against violations of variance, thus the analysis proceeded without transforming these variables.

Results from the ANOVA are presented in Table 6. There were significant main effects for condition and phrase type but not for group. There were two significant two-way interactions, the condition x group and the condition x phrase type interaction, as well as a significant three-way interaction between condition, phrase type and group. The significant main effects were not interpreted as several interactions were also significant. To further investigate the significant three-way interaction, separate 2 (phrase type) x 2(group) mixed ANOVAs were conducted for each condition.

Table 6 F-values for the 3(condition) by 2 (phrase type) by 2 (group) ANOVA in Experiment 1 word monitoring task

Effects	df	F	p
Phrase type	1, 45	5.78	p<.05
Condition	2, 45	126.38	p<.001
Group	1, 45	.88	p>.05
Condition x group	2, 45	7.78	P = .001
Phrase type x group	1, 45	.01	p>.05
Condition x phrase type	2, 45	17.7	p<.001
Condition x phrase type x group	2, 45	3.2	p = .046

4. 3.3.1 Phrase structure violation post hoc analysis

Figure 8 shows mean z- score difference scores for younger and older adult by phrase type. The post-hoc 2 (phrase type) x 2 (group) mixed ANOVA for phrase structure violations revealed a significant main effect for phrase type, $F(1, 45) = 6.52$, $p = .014$, $\eta^2 = .13$, with violations in VPs ($M = .84$, $SD = .29$) resulting in greater processing disruption than in NPs ($M = .69$, $SD = .39$). There was also an age-related difference in the sensitivity to phrase structure violations. Older adults ($M = .9$, $SD = .06$) were more disrupted by violations than younger adults ($M = .68$, $SD = .05$), $F(1, 45) = 7.58$, $p<.05$, $\eta^2 = .14$. The phrase type x group interaction was non-significant, $F(1, 45) = 2.77$, $p = .061$.

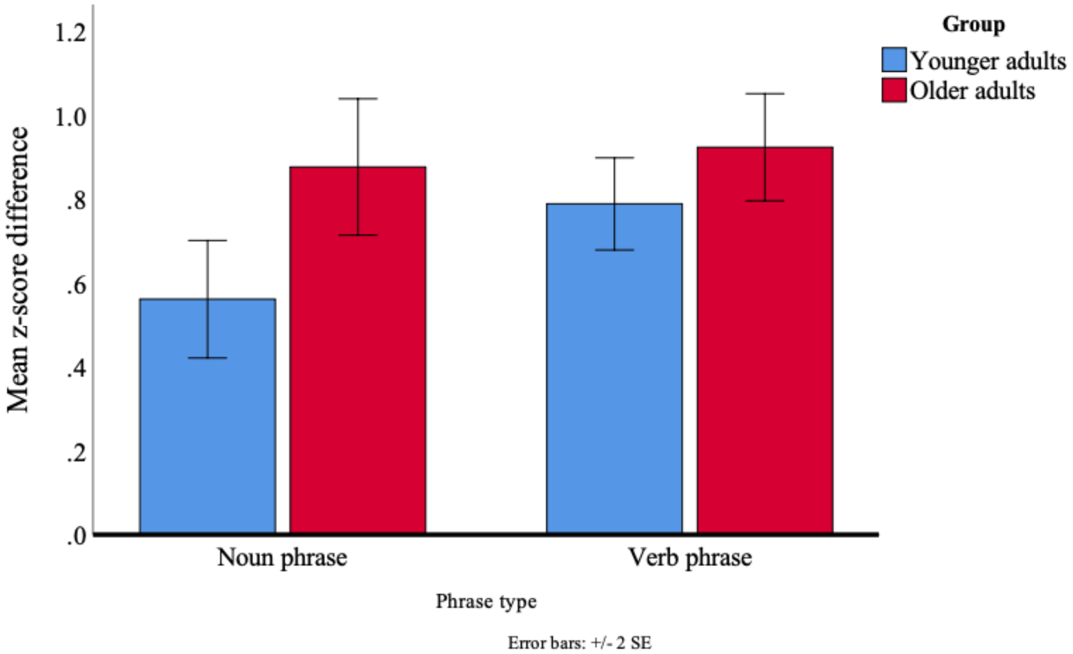


Figure 8 Mean z-score difference in NP and VP phrase structure violation for older (red) and younger (blue) adults in the word monitoring task

4.3.3.2 N/V premodification post hoc analysis

The post-hoc analysis on the facilitation of premodifiers showed a significant main effect for phrase type, $F(1, 45) = 29.34$, $p<.001$, $\eta^2 = .39$, and a marginally significant interaction between phrase type and group $F(1, 45) = 3.97$, $p =.052$, $\eta^2 = .08$. The main effect for group was non-significant, $F(1, 45) = 2.95$, $p>.05$. Mean z- score difference scores for NP and VPs by age group are presented in Figure 9. The marginal interaction was driven by group differences in the facilitation effects of NP premodifiers. While younger adults showed a slight facilitation effect for premodified nouns (M = .17, SD = .3), older adults did not show any facilitation in recognizing nouns preceded by premodifiers (M = -.02, SD = .24), $t(45) = 2.39$, $p<.05$, $r = .3$. On the other hand, older adults (M = .34, SD = .21) and younger adults (M = .33, SD = .25) were similarly facilitated by verb premodifiers, $t(45) = .02$, $p>.05$

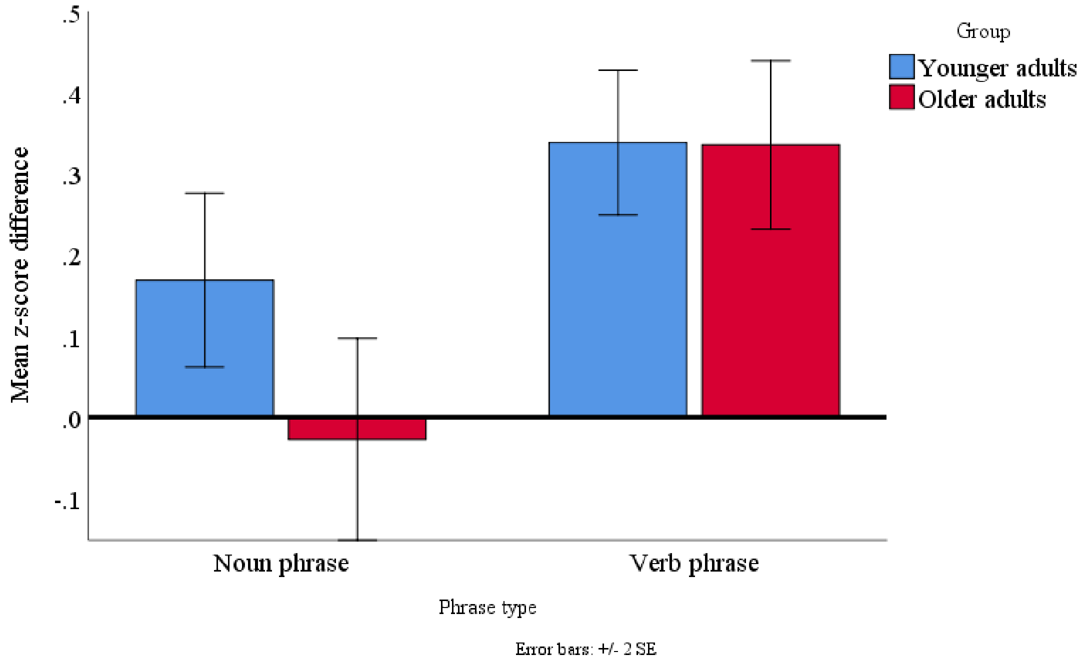


Figure 9 Mean z-score difference in NP and VP premodification for older (red) and younger (blue) adults in the word monitoring task

4.3.3.3 Phrase frequency post hoc analysis

The post-hoc ANOVA revealed a significant main effect for phrase type, with individuals showing stronger facilitation effects of frequency when recognizing nouns (M = .29, SD = .22) compared to verbs (M = .13, SD = .25), F(1, 45) = 7.89, p<.05, η^2 = .15. Further, there was no main effect group, indicating that phrase frequency had a similar facilitatory effect in older (M = .2, SD = .11) and younger adults (M = .22, SD = .16), F(1, 45)= .1, p>.05. The phrase type by group interaction was also non-significant, F(1, 45) = .1, p>.05. Figure 10 shows younger and older adults' mean z- score difference scores for NP and VPs.

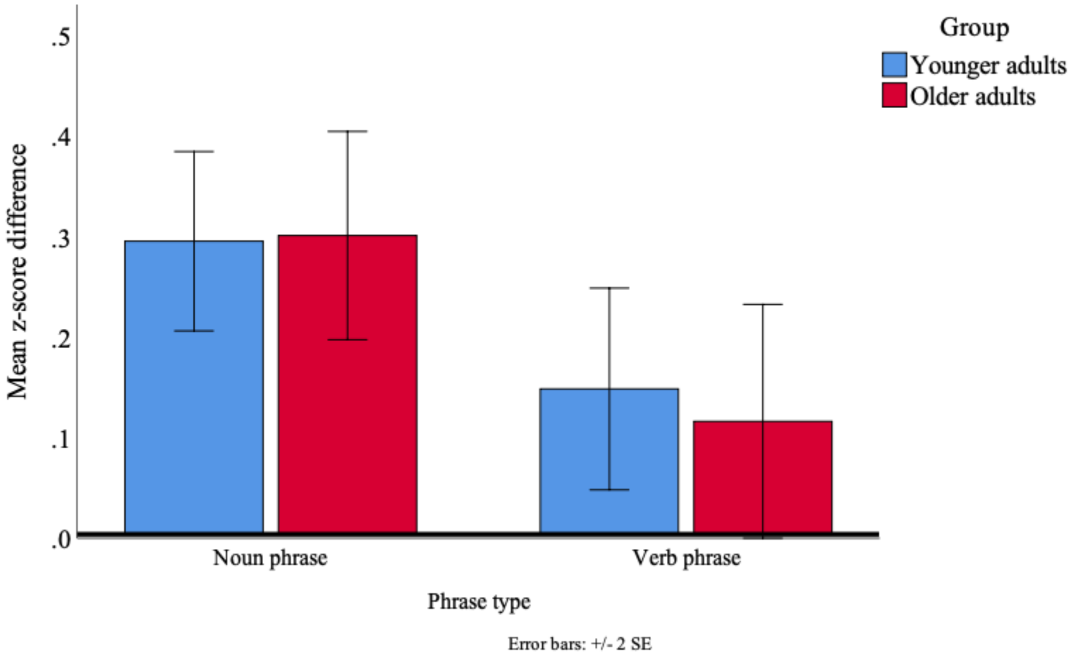


Figure 10 Mean z-score difference in noun and verb phrase frequency for older (red) and younger (blue) adults in the word monitoring task

4.4 Discussion

The current experiment used the word-monitoring (WMT) paradigm involving novel contrasts to investigate differential processing of nouns and verbs across three different conditions: 1) phrase structure violations, 2) premodification (function words) and 3) phrase frequency. One aim was to establish normative WMT patterns prior to investigating participants with aphasia. The results showed that nouns and verbs were not equally facilitated or disrupted across condition. The pattern indicates that frequency was more facilitative in the recognition of nouns relative to verbs, whereas premodifiers aided anticipation of upcoming verbs, but not necessarily nouns. In addition, violations to noun phrase structure were less disruptive than verb phrase structure violations, however, this normative NP/VP pattern differed between age groups and is discussed in more detail in the sections below. It should be noted that these normative patterns are based on a group of highly educated neurotypical adults as the majority of both younger and older adults had gone through higher education. Individual differences in linguistic knowledge, such as inflectional morphology and quantifiers, are related to education (Dąbrowska, 2012). Thus, it is possible that the education level of the neurotypical sample heightened the degree of sensitivity to phrase structure violation, frequency and premodifiers. This raises the question whether these normative patterns serve as a suitable comparison for the aphasic group (reported in Chapter 5). For future research, recruitment of neurotypical adults with more varied educational backgrounds would contribute to establishing robust normative data for the online tasks.

As an alternative, the effects of educational level on language processing could be controlled by including it as a covariate in the analysis.

A further aim of the study was to examine age-related differences in sentence processing. Although older adults were slower overall, they showed similar response patterns to phrase structure violations, premodification and phrase frequency as younger adults, albeit with a few subtle differences. Although the age-related differences were relatively small, they were unexpected given that previous online studies have reported an absence of differences in syntactic processing in healthy older adults (Baum, 1991; Kemtes & Kemper, 1997; Tyler et al., 2010; Waldstein & Baum, 1992; Waters & Caplan, 2001; Wingfield, Peelle, & Grossman, 2003). The current findings appear to be more in line with findings from studies that have employed offline comprehension or acceptability tasks and consistently report age-related changes in syntactic processing in older adults (Kemper, 1987; Kemper & Kemtes, 1999; Obler, Fein, Nicholas, & Albert, 1991; Poulisse, Wheeldon, & Segaert, 2018). The current findings suggest that aging affects interpretative processes, as measured by online tasks, as well as post-interpretative (offline) processes. However, it is likely that these processes are differentially affected by aging, with post-interpretative processes more vulnerable to age-related decline. The following sections below discuss the behavioural patterns of younger and older adults across the three experimental conditions.

4.4.1 Sensitivity to phrasal structure violation

Sensitivity to noun and verb phrase structure was probed by comparing the speed at which words are recognized in grammatical and ungrammatical phrases (e.g. violated NP: *many courage*; VP: *slept cushions;* non-violated NP: *much courage*; VP: *sewed cushions*). Contrary to expectations, older and younger adults were differently affected by phrase structure violations. Taking into account that older adults responded more slowly overall, the results showed that they were more delayed by phrase structure violations than younger adults. This finding challenges previous studies that have reported similar delays between younger and older adults when processing violated or complex sentences (Baum, 1991; Kemmer et al., 2004; Kemtes & Kemper, 1997; Rayner, Chace, et al., 2006; Tyler et al., 2010; Waldstein & Baum, 1992). For example, in a WMT study by Tyler et al. (2010), older adults were similarly delayed in recognizing target words in syntactically anomalous sentences (e.g. *Very Stephen catch much himself didn't. Her NOSE because properly had anyone couldn't he and nail weak a heat driven was*) relative to grammatically correct sentences (e.g. *Jane didn't enjoy herself very much. Her NECK was stiff because she had a bad cold and she couldn't lift anything properly*). An absence of an age effect was also observed in a WMT by Baum (1991) when probing sensitivity to more subtle syntactic violations (e.g. *The children were hoping for SNOW/*The children were hoping SNOW*). Another important source advocating for the preservation of syntactic processing in healthy aging comes from an ERP study by Kemmer et al. (2004) who examined age-related changes to the P600 component in response to subject-verb agreement violations (e.g. *Industrial scientists develop many new consumer products/*Industrial scientists develops many new consumer products*). The results showed that the P600 response in older adults resembled younger adults not only in the size of the effect but also in the time course.

A possible reason for the presence of an age effect in the current experiment is that younger and older adults responded differently to NP and VP structure violations. Although the interaction between phrase type and age did not reach statistical significance, there was a clear trend that younger adults were less disrupted by NP structure violations compared to VPs. In comparison, older adults were similarly delayed in recognizing nouns and verbs in violated contexts. It is not clear whether the younger or the older adults are exhibiting unusual processing as noun phrase structure violations have largely gone untested in healthy aging. However, there is some evidence that syntactic violations in NPs results disrupts sentence processing to a lesser degree than in VPs. Using a WMT, Wayland, Berndt and Sandson, (1996) found that younger and older adults were more delayed when syntactic violations involved verbs (e.g. *The woman warned herself not to fall asleep while bathing. She was relaxing in the <u>starve</u> and was afraid she might doze off*) than nouns (e.g. *The woman warned herself not to fall asleep while bathing. She did not want to <u>meal</u> in the bathroom).* The syntactic violations involved presenting verbs in noun contexts and vice versa. The researchers suggested that the difference in the size of the delay reflects a difference in syntactic restrictions between nouns and verbs. They argue that the position of verbs in sentences is less flexible compared to nouns, and encountering them in an incorrect position leads to greater difficulties in interpreting the sentence. Another possibility for the greater delay in response to verb violations, is the importance of verb argument structure in determining the syntactic structure of the sentence. Listeners predict a noun phrase in the direct object slot upon encountering transitive verbs, but not following intransitive verbs. Processing a direct object following an intransitive verb is likely to derail predictive processing mechanisms resulting in delayed parsing. In contrast, listeners would still expect a noun when encountering a count quantifier. Thus, the prediction error may be reduced or less disruptive in the case of noun violations. However, considering the scarcity of studies probing noun violations, it is difficult to draw conclusion whether this difference between older or younger adults reflects a decline in aging or actually greater sensitivity to grammatical violations. Further research is needed to investigate the impact of syntactic violations of nouns. However, because nouns carry few syntactic cues and restrictions, in English, languages in which nouns have overt case or gender markings could be more suitable to shed more light on this question.

4.4.2 Facilitation of premodifiers

The WMT included a novel contrast that exploited the positional relationship between premodifiers and head nouns and verbs. In particular, the VP condition allowed subsequent evaluation as to whether individuals with aphasia exhibit atypical processing of function words as suggested by previous studies. In contrast to previous studies probing function word processing, the current experiment measured the degree to which function words facilitate recognition of upcoming nouns and verbs, rather than recognition of the function word itself. To this end, we compared the speed at which nouns and verbs are recognized when preceded by premodifiers and in neutral contexts (e.g. premodified verb: *Claire must have bought the tickets weeks ago*; neutral verb: *Claire bought the tickets weeks ago*; premodified noun: *Jane hit the tiny balls with a golf club*; neutral noun: *Jane hit balls with a golf club*). This question has not been addressed in relation to healthy aging and the current experiment presents novel findings. The results showed that younger and older adults responded differently to premodifiers across the two phrase types. While both younger and older adults were equally facilitated by premodifiers in recognizing verbs, group differences were observed in the facilitation of nouns. Younger adults were able to make use of NP premodifiers and reacted faster to premodified nouns relative to bare nouns. In contrast, older adults did not show this facilitation effect.

One possible reason for the dissimilar facilitation of premodifiers is the difference in the transitional probability between premodifiers across noun and verb phrases. In the VP condition, premodifiers consisted of modal and auxiliary verbs that consistently precede the head verb, resulting in a high transitional probability. In contrast, the adjectival NP premodifiers have more flexibility in terms of the position and number in a sentence and thus do not consistently precede the head noun (e.g. *Mary bought the sweet apples from the farmer vs Mary bought the sweet and juicy apples from the farmer)*. The difference in transitional probability between premodifiers and head verbs would explain a greater facilitation effect in VPs over NPs. It is likely that older adults are more entrained to the patterns in which words co-occur as they have accumulated more knowledge about the statistical distribution within their native language.

4.4.3 Facilitation of phrasal frequency

Investigations into the effects of healthy aging on language processing commonly involves probing complex sentences that are rarely encountered in natural settings. Studies which have adopted a usage-based approach have shown that the frequency with which words and phrases occur affects language processing. One aim of the current experiment was to explore frequency effects beyond the single word level in older and younger adults. To this end, we compared the speed at which nouns and verbs were recognized when embedded in high and low frequency phrases (e.g. NP high: *write a letter* vs NP low: *send a letter*; VP high: *trying to catch* vs VP low: *hoping to catch*). One reasonable assumption is that older adults exhibit a larger facilitation effects for high frequency phrases because they are likely to be more entrained to distributional properties of words and phrases. However, contrary to this hypothesis, the results revealed that, although older adults were overall slower in their responses, they were similarly facilitated by phrasal frequency as younger adults. This finding expands previous studies that have found comparable frequency effects across age groups at the single word level (Allen et al., 1991; Allen et al., 1993; Badham et al., 2017; Balota & Ferraro, 1996; Tainturier et al., 1989; Whiting et al., 2003 but also see Rayner et al., 2006). For example, Allen and colleagues (Allen et al., 1991; Allen et al., 1993) found that both younger and older adults were quicker at recognizing high frequency than low frequency words in a lexical decision task. It is not entirely clear why older adults do not show a greater frequency difference, given their greater experience with language. Baayen, Milin and Ramscar (2016) have suggested that there is a processing cost associated with greater knowledge, whereby accumulation of knowledge comes with increasing associations to other information, resulting in increase in processing load which leads to a decrease in speed.

With regard to noun/verb dissociations, the results also revealed that frequency effects were modulated by phrase type. Both age groups were more facilitated by frequency when monitoring for nouns compared to verbs. Rather than representing a true noun/verb dissociation, it is possible that the dissimilar frequency effects are a result of differences in the critical word that was manipulated to create low and high frequency phrases. In the case of nouns, high and low frequency phrases differed in pre-target words which were usually verbs (e.g. ***writing*** *a letter* vs ***sending*** *a letter*) or, in a few cases, nouns (e.g. ***pint*** *of beer* vs ***mug*** *of beer*). In addition to frequent co-occurrence, the critical words in NPs also carried stronger semantic associations with the target words. By contrast, the critical words in VPs mainly consisted of adverbs (e.g. ***able*** *to grab* vs ***likely*** *to grab*) and semantically light verbs (e.g. ***need*** *to talk vs* **have** *to talk),* which tended to have a looser semantical association with the target verb. It is possible that the larger frequency effect in the NP condition is due to an additional semantic facilitation that was absent in the VP condition. Future research should further explore phrasal frequency effects in both nouns and verbs, while taking semantic associations within phrases into account.

Although the results indicate only subtle changes between younger and older adults in online processing of sentences, it should be noted that the older adult group comprised individuals from a broad age range (41 to 80 years). This age band was selected in order to achieve a match to the ages of the sample of aphasic participants. However, it is possible that the inclusion of adults aged 45 to 60 in the older group may have masked more age-related differences that might emerge in later old age. For example, in a WMT study by Baum (1991) age effects were largely observed in the older old adults (aged 80-89), who made more errors and showed less consistent evidence for sensitivity to syntactic violations, compared to younger older adults aged between 60 and 79. Future investigations could sample older adults across these age bands in order to establish processing patterns between younger adults and different sub-group of older adults.

Rather than an effect of healthy aging, a possible explanation for the differences observed in younger and older adults' sentence processing is the difference in English proficiency. While the older adult group consisted exclusively of monolinguals, the younger adult group included several bilingual individuals (12 of 27). The present study addressed this confound by excluding bilingual individuals who did not acquire English during childhood, however, the influence of bilingualism on online processing cannot be completely discounted. Evidence from behavioural, electrophysiological and neuroimaging studies has shown that that bilinguals activate both languages even in contexts where only one language is used (Kroll et al., 2006, 2012; Kroll & Bialystok, 2013; Marian & Spivey, 2003; Sanoudaki & Thierry, 2015). This parallel activation might have influenced younger adults' online processing of phrase structure violations, premodifiers and phrase frequency. It is also possible that monolingual and bilingual adults did not experience the same level of exposure to English, which may result in differences in the sensitivity to the distributional properties in language. However, the current data do not support that view as indicated by similar frequency effects for younger and older adults. To address this possible confound, future studies on sentence processing in healthy aging may want to include only monolingual younger and older adults.

4.5 Conclusion

This study used a word-monitoring task to investigate age-related differences in the recognition of nouns and verbs embedded in three different contexts, phrase structure violations, premodification, and phrase frequency. Although nouns and verbs were not equally facilitated and disrupted, both age groups showed sensitivity to NP and VP information, indicating an absence of differential processing. Although older adults were generally similar to younger adults in reaction time patterns, there were subtle differences that suggest that some aspects of sentence processing change as a result of healthy aging. For example, noun phrase structure violation resulted in greater delay in response in older adults compared to younger adults. Yet, older adults were clearly sensitive to both NP and VP violations. Furthermore, while both groups were able to make use of VP premodifiers to anticipate the upcoming verb, only younger adults also showed this facilitation in response to NP premodifiers. In the case of frequency effects, younger and older adults were similarly facilitated by phrasal frequency. What the normative results reveal is the importance of comparing aphasic performances to age matched controls rather than forming processing predictions based on patterns described in research on younger adults.

The following chapter will describe the second experiment which used the same WMT paradigm to probe noun and verb phrase processing in aphasia.

5. Experiment 2: Noun phrase and verb phrase sensitivity in individuals with aphasia

5.1 Introduction

Differential impairment of word classes, such as nouns versus verbs, and content versus function words, has been a central issue in the study of aphasia. Patterns of selective word class impairments have been used to classify individuals with aphasia into subtypes, such as fluent and non-fluent. Findings of selective word class impairments have also been essential in informing neuroanatomical models on language processing (Aggujaro et al., 2006; Bedny & Thompson-Schill, 2006; Cappa & Perani, 2003). The behavioural evidence for selective word class impairment relies heavily on studies using single word production tasks (Chen & Bates, 1998; Lu et al., 2002). They found that some individuals could produce nouns but had difficulties producing verbs, and vice versa (Berndt, Mitchum, et al., 1997; Miceli et al., 1984, 1988; Zingeser & Berndt, 1990). More recently, studies have emphasized the increased occurrences of verb deficits over noun impairments in both fluent and non-fluent aphasia (Bastiaanse & Jonkers, 1998; Berndt et al., 2002; Jonkers & Bastiaanse, 1998; Luzzatti et al., 2002; Mätzig et al., 2009).

While noun/verb dissociations are consistently observed in production, there is mixed evidence that differential word class impairments occur in comprehension. In an early study, Miceli et al. (1988), probed noun/verb dissociations in seven individuals with aphasia using a word-picture matching comprehension task. In the individual case analysis, three of the seven individuals presented with selective word class difficulties. Two individuals made more errors in selecting pictures to the spoken verbs, while one showed greater difficulty with nouns. Three further individuals showed no comprehension impairments and one was equally impaired in both word classes. The authors suggested that these findings demonstrate that comprehension of nouns and verbs can be selectively impaired. More recently, Soloukhina & Ivanova (2018) used a computerized version of the word-picture matching task to measure reaction times (RT) to nouns and verbs in a group of 32 individuals with aphasia. They found that individuals with aphasia were slower and made more errors when responding to verbs relative to nouns. However, when examining RT differences to nouns and verbs in relation to aphasia subtypes, slower RT to verbs was not associated with agrammatic aphasia but was observed across subtype. Further, slowed response times to verbs was also observed in neurotypical controls. The researchers concluded that the similar patterns across neurotypical and aphasic populations suggests that verbs are inherently more difficult to process.

In contrast, Alyahya et al. (2018) showed that noun/verb dissociations in single word comprehension tasks disappeared when items were matched for psycholinguistic variables such as frequency, age of acquisition, and imageability. These findings are more in line with the majority of studies that have found evidence that comprehension of nouns and verbs is not selectively impaired (Bates et al., 1991; Berndt, Mitchum, et al., 1997). In a series of studies using single word and offline sentence level tasks, Thompson and colleagues (Cho-Reyes & Thompson, 2012; Kim & Thompson, 2000; Thompson et al., 2012) probed noun/verb dissociations in comprehension. None of the 101 agrammatic and 42 anomic aphasic individuals, combined across all studies, displayed selective word class impairments in comprehension, showing near-normal comprehension of both nouns and verbs. They investigated whether comprehension of verbs is affected by their complexity by examining comprehension to verbs with simple and complex argument structures. For example, one grammaticality judgment task compared processing of sentences with verbs with one (e.g. *The dog is barking*) or more arguments (e.g. *The boy is catching the ball*) to ungrammatical sentences with unnecessary additional arguments (e.g. *The dog is barking the girl*) or deleted obligatory arguments (e.g. *The woman is giving the sandwich*). The results showed that sentences containing more complex verbs did not result in more errors. In fact, individuals with aphasia made very few errors in this task overall. Combined, the findings provide strong evidence that noun/verb dissociations are absent in comprehension and that verbs were not more frequently impaired. However, while these studies provide some evidence against noun/verb dissociations in comprehension, it is important to note that the cohort of participants consisted mainly of mild and mild to moderately impaired individuals whose performance might not represent the full spectrum of aphasic impairment.

Unlike previously mentioned studies, Wayland, Berndt and Sandson (1996) probed processing of nouns and verbs in sentences in real-time in eight individuals with mild or mild-to-moderate impairments. Using the word-monitoring task, they compared reaction times to target nouns and verbs embedded within congruent or incongruent semantic and syntactic contexts. Individuals with aphasia were most sensitive to, and more delayed in recognizing verbs in syntactically incongruent contexts (e.g. *The woman warned herself not to fall asleep while bathing. She was relaxing in the <u>starve</u> and was afraid she might doze off*.), and less sensitive to semantically incongruent contexts (e.g. *The woman warned herself not to fall asleep while bathing. She did not want to <u>starve</u> in the bathroom*.). Overall, they were more delayed by verbs in incongruent contexts compared to nouns (e.g. semantic incongruent: *The woman warned herself not to fall asleep while bathing. She was relaxing in the <u>meal</u> and was afraid she might doze off*; syntactic incongruent: *The woman warned herself not to fall asleep while bathing. She did not want to <u>meal</u> in the bathroom*.). Similar to individuals with aphasia, older adults also showed greater disruption in syntactically incongruous sentences when monitoring for a verb. This suggests individuals with aphasia and neurotypical controls showed similar patterns of noun/verb processing. In a further step, they investigated whether noun/verb patterns differed in individuals with more impaired comprehension. Individuals who had difficulties understanding reversible passive sentences (e.g. *The boy is kicked by the girl*) in an offline picture-sentence matching task were categorized as having impaired comprehension. The results revealed that individuals with impaired offline comprehension displayed the same noun/verb patterns as individuals with intact comprehension. This indicated that despite their offline comprehension difficulties, they had residual access to verbs' syntactic information when probed in real-time. The inconsistency between offline and online findings further highlights the difficulties of using offline measures of language comprehension to predict or discriminate divergent noun/verb patterns probed in real time.

Further evidence for intact verb argument structure knowledge comes from a series of online reaction time experiments by Shapiro and colleagues (Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro & Levine, 1990). Using a cross-modal decision task, they compared reaction time to probes immediately following verbs embedded in sentences. The embedded verbs differed in the number of obligatory arguments (e.g. two-argument verb: *regret*; three-argument verb: *put*). RT to the probe reflected processing load, so that verbs with multiple obligatory arguments were hypothesized to result in slower RTs. The results showed that both neurotypical and individuals with agrammatic Broca's aphasia (but not fluent aphasia) displayed the predicted pattern, with increased RTs to probes following verbs requiring more arguments. They concluded that the observed increased reaction time to verbs with multiple arguments in individuals with aphasia reflected their residual ability to activate multiple arguments in real time. Initial evidence from online sentence studies are consistent with previous offline findings that have reported an absence of noun/verb dissociation during input processing. The current experiment aimed to expand the evidence base of online studies by using a word-monitoring task to systematically probe noun/verb dissociations at the sentence level.

Sentence-level investigations also provide the opportunity to examine other linguistic elements such as function words, which are claimed to be impaired in some forms of aphasia. Function words are central to processing sentences as they signal the relationship between content words. For example, prepositions provide spatial and temporal cues (e.g. *under the bed, on Monday*), while conjunctions (e.g. *and, but, because*) are used to connect phrases and clauses. Others, in the case of quantifiers (e.g. *much, many*) or premodifiers (e.g. *will have, could have*), modify head nouns and verbs. Individuals with non-fluent aphasia subtypes, in particular, are reported to be selectively impaired in producing function words (Friederici, 1982; Ishkhanyan et al., 2017; Miceli et al., 1983; Stavrakaki & Kouvava, 2003). In non-fluent agrammatic speech, function words are frequently omitted or used incorrectly, although they are rarely missing entirely (see extract 2 in Chapter 2, Section 2.1 for an example of agrammatic speech). Researchers have suggested that individuals with non-fluent agrammatic aphasia also show differences when reading or recognizing function words (Bradley, Garrett, & Zurif, 1980; Friederici, 1985; Neville, Mills, & Lawson, 1992; Swinney, Zurif, & Cutler, 1980). Although function words are important for sentence processing, initial evidence for differential processing of function words in aphasia largely comes from studies probing at the single word level. In a seminal study, Bradley (1978) found that while neurotypical adults made faster decisions in a lexical decision task for high frequency content words compared to low frequency ones, this frequency effect was absent for function words. Unlike neurotypical adults, individuals with aphasia showed a frequency effect for both content and function words, which seemed to indicate that they processed function words differently. Bradley concluded that individuals with aphasia processed function words as if they were content words, whereas neurotypical adults showed differential processing of the word classes. Based on these findings, Bradley proposed that content and function words utilize neurally separate and distinct processing systems and function word impairments in individuals with aphasia were due to damage to the function word specific processing system.

However, most subsequent lexical decision experiments failed to replicate this finding (Gordon & Caramazza, 1982, 1985; Kolk & Blomert, 1985; Segalowitz & Lane, 2000; Segui et al., 1982, 1987). Rather than a true word class effect, Bird, Franklin and Howard (2002) suggested that differences in imageability accounted for content/function word dissociations. They drew parallels to noun/verb dissociations, where lower imageability of verbs was a factor that could explain differential processing of the two word classes. They suggested that the low imageability of function words, like verbs, could explain impaired processing. In a lexical decision task, they compared accuracy between a set of function and content words matched for imageability, frequency and word length. None of their five patients showed differences in accuracy between function and content words, when they were matched for imageability, frequency and word length.

Several studies that have examined processing of content and function words embedded in sentences have found evidence for differential processing (Biassou et al., 1997; Friederici, 1985; Friederici & Schoenle, 1980; Rosenberg et al., 1985). Using a WMT, Swinney, Zurif, & Cutler (1980) reported slower reaction times to function word targets than content word targets in individuals with aphasia regardless of whether target words were stressed or unstressed. In contrast, neurotypical adults showed faster reaction times to stressed target words, regardless of word class, again suggesting that individuals with aphasia and neurotypical adults process function words differently. Similarly, Friederici (1985) employed an auditory WMT in which individuals with aphasia monitored for function or content words embedded in sentences. Individuals with aphasia were slower in recognizing function words (e.g. *Der Besitzer vermietet <u>nur</u> an ältere Ehepaare/The owner <u>only</u> rents to older couples*) than content words (e.g. *Der Mann hoffte, <u>Geld</u> zu gewinnen/The man hoped to win <u>money</u>*). In contrast, healthy younger adults, who served as the control group, responded faster to function words than to content words. Both studies concluded that the different response patterns between neurotypical adults and individuals with aphasia to content and function words provided further support for Bradley's proposal of a word-class specific processing system. However, this interpretation of the results should be viewed with caution as neither study matched the word class stimuli sets on psycholinguistic variables, such as frequency or imageability that are known to influence processing (Bird et al., 2002). Additionally, Friederici (1985) compared response patterns of individuals with aphasia to younger adults, introducing a further age confound.

The current study expands on previous sentence level studies, while addressing some of the experimental difficulties. It examined the facilitative role of function words in sentence processing. Function words in the form of premodifiers precede, and therefore signal, upcoming head nouns and verbs in noun or verb phrases. Head verbs are often premodified by auxiliary and modal verbs (e.g. *Frank should have kicked the ball to his team mate*). Similarly, NPs premodifiers include determiners as well as content words such as adjectives (e.g. *The red apples are sweet and crunchy*). VP premodifiers, in particular, mainly serve a syntactic role. The high transitional probability between premodifiers and head verbs and nouns enable listeners to anticipate the upcoming head when encountering a premodifier. Thus, failure to process function words in the form of premodifiers could result in delayed recognition of noun and verb heads. Processing of premodifiers has largely gone untested in aphasia. Measuring processing of premodified versus bare verbs, allows for an experimental design that avoids the requirement of matching content and function words on psycholinguistic factors such as imageability and frequency.

More recently, researchers have applied usage-based approaches to re-examine language profiles in aphasia (Bruns et al., 2019; DeDe, 2013a, 2013b; Gahl & Garnsey, 2004; Huck, Thompson, Cruice, & Marshall, 2017a; Knilans & DeDe, 2015; Zimmerer, Newman, Thomson, Coleman, & Varley, 2018). In contrast to generativist theories, usage-based models do not have sharp boundaries between lexicon and syntax and break away from the 'words and rules' model of generativist theory. An important aspect in language processing in usage-based approaches is the role of frequency. Research on adult language processing has shown that more frequent words are processed more rapidly than less frequent words (Baayen et al., 2007; Balota et al., 2004; Balota & Chumbley, 1984; Ellis, 2002). Frequency effects have also been observed beyond the single-word level (Conklin & Schmitt, 2008; Jacobs et al., 2017; Janssen & Barber, 2012; Tremblay & Baayen, 2010). For example, Arnon & Snider (2010) compared processing speed of high frequency (e.g. *don't have to worry*) and low frequency phrases (e.g. *don't have to wait*) in a phrasal-decision task. High-frequency noun and verb phrases were recognized quicker than low-frequency noun and verb phrases. A growing number of studies have applied usage-based principles to investigate aphasic language processing (Bruns et al. in prep; DeDe, 2013b; Gahl, 2002; Gahl et al., 2003; Huck et al., 2017; Knilans & DeDe, 2015; Zimmerer, Wibrow, & Varley, 2016). These studies have demonstrated that more frequent lexical units have advantages in processing and comprehension over less frequent items. Using a plausibility judgment, Gahl (2002) found that individuals with aphasia made fewer errors in sentences that contained verbs in their most frequent syntactic structure (e.g. *The teacher opened the box*) compared to sentences in which verbs were in less frequent syntactic structures (e.g. *The box opened after a short while*). These results show that individuals with aphasia are sensitive to the frequency beyond the single word level. More recently, Bruns et al. (2019) investigated the frequencies of grammatically correct residual multi-word utterances in individuals with non-fluent aphasia. They found that residual speech consisted largely of high frequency word combinations (e.g. *it's alright)*, suggesting that such strings present reduced processing demand and are therefore less vulnerable to damage. However, it remains unclear whether similar processing advantages are found when recognising high frequency phrases embedded in spoken sentences.

Our current knowledge on differential processing of noun and verbs and selective impairment of function words in individuals with aphasia largely comes from single word or offline studies. In offline tasks, such as the sentence-picture matching, lexical decision or grammaticality judgment tasks, the complete stimulus sentence is presented before participants respond. These tasks are more suited when probing meta-linguistic knowledge of language but are not particularly sensitive to the real-time construction and processing of linguistic input. In contrast to offline studies, online tasks such as WMT measure implicit cognitive processes that are automatic and capture the temporal aspect of language processing (Marinis, 2010; Schmitt & Miller, 2010). A further advantage of the WMT is that it can be applied to different populations such children (Tyler & Marslen-Wilson, 1981), neurotypical older adults (Baum, 1991), and individuals with aphasia (Baum, 1989; Friederici, 1983, 1985; Swinney, Zurif, & Cutler, 1980; Tyler, 1988, 1989; Wayland, Berndt, & Sandson, 1996). In studies with people with aphasia, the WMT has been used to probe recognition of words in contexts that differ in syntactic or semantic complexity and violations (Marslen-Wilson et al., 1988; Marslen-Wilson & Tyler, 1980).

The present experiment aims to examine aphasic and age-matched neurotypical language profiles using an online WMT. The task probed differential processing of noun phrase (NP) and verb phrase (VP) structures across three conditions: sensitivity to phrase structure violation; function words (premodifiers); and phrasal frequency. A secondary aim was to examine the relationship between performance in standard tests of comprehension and production and the online WMT task.

The WMT experiment aimed to answer five main research questions:

1) Do aphasic and neurotypical groups show differential processing of NP and VP?
2) Are participants with aphasia sensitive to NP and VP phrase structure violations?
3) Do premodifiers facilitate recognition of head nouns and head verbs in participants with aphasia and neurotypical older adults?
4) Do participants with aphasia show more rapid response to high frequency phrases relative to low frequency phrases?
5) Do online measures of sentence processing (WMT conditions) correlate with standard measures of sentence comprehension (TROG-2) and lexical retrieval (BNT)

Firstly, aphasic and neurotypical individuals were not expected to process NP and VPs differently. Further, it was predicted that the neurotypical and aphasic groups would show sensitivity to both NP and VP structure violations, however, the aphasic group was expected to exhibit reduced sensitivity to phrase violations compared to the neurotypical group. There was no previous literature to guide predictions about whether premodifiers facilitate recognition of head nouns and verbs. In the case that they did facilitate processing of head nouns and verbs, individuals with aphasia were expected to show a reduced facilitation effect. With regards to phrasal frequency, it was predicted that frequency would facilitate recognition of noun and verb phrases for both aphasic and neurotypical individuals. Lastly, sensitivity to conditions in the online task was not expected to correlate with performance in the standard offline measures (TROG-2 and BNT).

5.2 Method

5.2.1 Participants

The experiment was approved by the Research Ethics Committee at University College London (approval number LC/2013/05). All participants gave informed written consent.

5.2 1.1 Neurotypical age-matched control group

Twenty neurotypical older adults were included in this experiment. Background information of the neurotypical older adults have been previously described in Chapter 4. Table 1, containing demographic information, can be found in Section 4.2.1.2. The neurotypical group consisted of 20 participants (12 women) between 41 and 80 years old (M = 64.65, SD = 11.52). There was no significant difference in age with the aphasic group, $t(39) = 1.15$, $p>.05$.

5.2 1.2 Participants with aphasia

Twenty-one participants (three women) with aphasia were recruited from a university clinic. Table 7 provides demographic information for each participant. The mean age was 60.76 years (SD = 10.18) and all were in the chronic stage of aphasia recovery (M = 76.8 months post-onset, SD = 43.18). All except two participants suffered a single stroke. Based on standardized language assessments, aphasia profiles were mixed with regard to expressive and receptive difficulties and both non-fluent and fluent aphasic individuals were included. Fluency was determined by an experienced speech and language therapist based on spontaneous speech samples. Non-fluent aphasia was characterized by grammatical errors and non-fluent speech, whereas fluent speakers had longer phrases, with normal intonational contours, although output was disrupted by lexical retrieval errors. All, except two participants, were right-handed prior to their stroke.

While the aphasic and older adult groups were matched in age, they differed in level and years of education, $t(39) = 2.85$, $p<.05$. In the aphasic group, 52.4% of individuals indicated they had completed graduate studies, 33.3% reported finishing secondary school and a further 14.3% completed postgraduate studies. In contrast, the majority of neurotypical older adults had completed a university level degree (60%), or higher (35%), indicating that the older adult group had higher educational attainment.

Table 7 Aphasic group demographic information

Participant	*Age*	*Gender*	*TPO*	*Fluency*	*Education*	
					Level	*Years*
1	54	M	45	Mild non-fluent	Graduate studies	14
2	76	M	102	Global	Secondary	11
3	63	M	77	Moderate non-fluent	Secondary	11
4	57	M	80	Mild mixed - simplified language	Graduate studies	14
5	37	M	43	Mild non-fluent	Graduate studies	14
6	51	M	89	Moderate non-fluent	Graduate studies	14
7	64	M	127	Mild to moderate non-fluent	Graduate studies	14
8	48	F	40	Moderate non-fluent - agrammatic	Secondary	11
9	61	M	18	Moderate non-fluent	Secondary	11
10	67	M	56	Moderate non-fluent	Graduate studies	14
11	55	M	51	Moderate non-fluent	Secondary	11
12	84	M	174	Moderate fluent	Graduate studies	14
13	67	M	80	Mild to moderate non-fluent	Graduate studies	14

14	58	F	100	Moderate non-fluent	Postgraduate	17
15	68	M	76	Moderate non-fluent	Postgraduate	17
16	59	M	122	Moderate to severe non-fluent – agrammatic	Postgraduate	17
17	71	F	164	Mild fluent	Graduate studies	14
18	57	M	59	Mild non-fluent	Graduate studies	14
19	56	M	21	Mild to moderate fluent - anomic	Graduate studies	14
20	55	M	25	Mild mixed - simplified language	Secondary	11
21	68	M	64	Global	Secondary	11

Note: TPO = Time post-onset in months

5.2.2 Materials

5.2.2.1 Language & cognitive assessment battery

Individuals with aphasia and older neurotypical controls completed background profiling which included linguistic and cognitive assessments. The linguistic battery included an offline sentence comprehension task (TROG-2), lexical retrieval (BNT), as well as two spontaneous speech tasks that involved description of pictured narratives. The recordings were used to determine speech fluency in individuals with aphasia. In addition, individuals with aphasia were also assessed in their comprehension of single words through the Comprehensive Aphasia Test (CAT) comprehension of spoken words subtest. Older adults were likely to be at ceiling on this task and were not tested. The cognitive measures probed phonological working memory (PALPA 13) and non-verbal reasoning (WASI-II Matrix Reasoning). Detailed procedures and scoring of these assessments are outlined below.

5.2.2.1.1 Offline sentence comprehension Offline sentence processing was assessed using Test for Reception of Grammar 2nd edition (TROG-2 – Bishop, 2003). TROG-2 is an 80 item, auditory sentence picture-matching comprehension task. It is designed to assess comprehension of 20 different sentence constructions, such as reversible passives, as well as testing function words such as pronouns. Participants heard a sentence read by the examiner and were presented with four pictures. Participants selected the picture that best matched the sentence. Testing was discontinued when five consecutive blocks contained one or more wrong answers. Individuals' scores reflect number of correct blocks. The maximum score was 20.

5.2.2.1.2 Single word comprehension Single word comprehension was assessed using the Comprehensive Aphasia Test (CAT – Swinburn, Porter & Howard, 2004) comprehension of spoken words subtest. Participants heard a word and were presented with four pictures. Participants selected the picture that best matched the word. Testing was discontinued after four consecutive errors. The assessment consists of 15 items. Correct answers without assistance or delay were awarded two points, but one point if the participant asked for the word to be repeated, self-corrected or answered after a significant delay (over 5 seconds). The maximum score was 30.

5.2.2.1.3 Lexical retrieval The Boston Naming Test (BNT) 2nd Edition (Kaplan, Goodglass & Weintraub, 2001) was used to measure spoken noun retrieval. The assessment consists of 60 line drawn pictures. Participants named each picture, and were allowed approximately 20 seconds to respond. Stimulus cues were provided by the examiner if the participant misperceived the drawing and subsequent correct responses counted towards the total score. All participants were tested using the aphasia protocol and criteria, starting with the first item and testing was discontinued after eight consecutive wrong responses. Individuals' scores represent the total number of correct items.

5.2.2.1.4 Spontaneous speech To determine speech fluency, participants were asked to describe two picture cartoon series. The 'Jogging' (Fletcher & Birt, 1983) narrative consists of eight pictures that together constitute a story. Participants received the following instructions prior to completing the task: *Please take a look at the pictures. Together they make a story. In your own words, tell me what is happening in the pictures.* The Cookie Theft (Boston Diagnostic Aphasia Examination - Third Edition (BDAE-3) - Goodglass & Kaplan, 1983) picture is a single black and white line drawing of a complex scene. Participants received the following instructions: *I will show you a picture of a scene. Please describe to me what is happening in the picture.* Narratives were audio recorded.

5.2.2.1.5 Non-verbal intelligence The Matrix-Reasoning (MR) subtest of the Wechsler Abbreviated Scale of Intelligence 2nd edition Matrix Reasoning (WASI-II MR) (Wechsler, 1999) was used to measure non-verbal intelligence. The subtest consists of 30 items that progressively increase in difficulty. Participants viewed an incomplete matrix and were presented with five possible choices to complete the matrix. They had 30 seconds to select an answer. Testing was discontinued after three consecutive errors. Standardized scoring procedures involve transforming raw scores into t-scores as indexed by age. As this procedure is not appropriate to use with individuals with aphasia, raw scores were used for all participants. Thus, individuals' scores reflect total number of correct responses.

5.2.2.1.6 Phonological working memory Phonological working memory capacity was assessed with the Psycholinguistic Assessments of Language Processing in Aphasia – subtest 13 Auditory Digit matching span (PALPA 13) (Kay, Lesser, & Coltheart, 1992). This test avoids the requirement for spoken responses and thus contamination by word retrieval difficulties in aphasic participants. The examiner presented an auditory string of numbers and then presented a second string that was either identical or in which two adjacent digits were reversed. Participants indicated whether the strings were the same or different. Items increased in difficulty as the length of the digit span increased. Individuals' span length corresponds to the digit span at which most trials were correct.

5.2.2.2 Word Monitoring stimuli

The word monitoring stimuli were identical to those reported in Experiment 1 (Chapter 4 Section 4.2.2.1). See Appendix A1 for the full stimuli list.

5.2.3 Procedure

The word monitoring procedures were identical to those in Experiment 1 WMT Chapter 4 Section 4.2.3.

Table 8 shows the number of sessions and task order for individuals with aphasia and older adults. Individuals with aphasia completed three and neurotypical older adults two testing sessions.[4]

Table 8 Session and task order for individuals with aphasia and neurotypical older adults in the WMT experiment

Group	Session 1	Session 2	Session 3
Individuals with aphasia	1. Information sheet 2. Consent forms 3. Background information (via interview) 4. WMT Block 1 5. Jogging narrative 6. WMT Block 2 (60 minutes)	1. WMT Block 3 2. Cookie Theft 3. WMT Block 4 (45 - 60 minutes)	1. CAT 2. BNT 3. PALPA 13 4. TROG-2 5. WASI-II: MR 6. Debrief (45 - 60 minutes)
Older adults	1. Information sheet 2. Consent forms 3. Background questionnaire 4. WMT Block 1 5. Dinner Party narrative 6. WMT Block 2	1. BNT 2. PALPA 13 3. TROG-2 4. WASI-II: MR 5. Debrief	

[4] Some individuals with aphasia, where recent scores on background language and cognitive assessments were available through the research register, completed two instead of three sessions, and PALPA 13 and TROG-2 took place in session 1 and 2 respectively.

	7. WMT Block 3 8. Cookie Theft narrative 9. WMT Block 4 (80 minutes)	(45 mins)

5.3 Results

The section first describes the data pre-processing steps for the word monitoring task and analysis of missing trials, followed by the group analyses of the reaction time data using a 3 (condition) x 2 (phrase type) x 2 (group) mixed factorial ANOVA. Lastly, Section 5.3.4. describes the correlational analysis between online and offline measures for the aphasic group.

5.3.1 Pre-processing of reaction time data

Pre-processing of the data involved converting reaction times (RTs) to z-scores and computing z-score difference values for each sentence pair. The data was pre-processed using the same procedure reported in Experiment 1 (Chapter 4 Section 4.3.1), with the exception of how initial means and standard deviations (SD) of RT were calculated in the aphasic group. Individuals with aphasia completed the WMT experiment in two separate sessions. Therefore, mean RT and SD were calculated separately per session due to possible learning effects.

5.3.2 Missing trials

During pre-processing, three types of responses resulted in excluded trials and did not count towards the RT mean of an individual: early button presses (before the target was presented), time outs (no button presses) and outliers (above 2 SD from individual’s mean RT). The total number of missing trials per error type by group is shown in Table 9. In both groups, the majority of excluded trials consisted of outliers. The highest number of outliers was recorded in the aphasic group in the VP condition (sum = 111), which accounts for half of the group’s missing trials. The older adult group had few early button presses (sum = 19) and even fewer time outs (sum = 4). Upon removing these trials, 84% of completed pairs were used in the group analyses in the aphasic group, and 87% in older adult group.[5]

[5] One older adult was excluded from the error analysis because she experienced technical difficulties which resulted in several missed trials.

Table 9 Type and number of missing trials in the WMT – older and aphasic groups

Group	Early		Time out		Outlier		Total	
	NP	VP	NP	VP	NP	VP	NP	VP
Older adults	7	12	2	2	80	94	89	108
Individuals with aphasia	59	49	30	64	80	111	169	222

5.3.2 Reaction time data

Overall, participants with aphasia responded significantly slower (mean RT = 608.87, SD = 142.61) to targets than neurotypical controls (M = 447.82, SD = 71.29), $t(39) = 4.54$, $p<.001$, $r = .58$. Subsequent statistical analyses report mean z-score difference scores, which were calculated by subtracting z scores for non-facilitated sentences (violated phrase structure, non-premodified heads, low frequency phrases) from their paired facilitated sentence (non-violated phrase structures, pre-modified heads, high frequency phrases). Positive mean z-score difference values indicate faster RTs for facilitated conditions and slower RTs for non-facilitated sentences. Larger mean z-score difference values represent larger reaction time differences between facilitated and non-facilitated paired sentences. Table 10 shows mean z-score differences for aphasic and age-matched control groups for each condition. Overall, the aphasic and neurotypical groups showed remarkably similar patterns across NP and VP conditions. In both groups, noun and verb phrase structure violations resulted in the largest z-score difference. This suggests that grammatical violations, which disrupted sentence processing, resulted in the largest RT difference. Relative to phrase structure violations, the facilitative conditions, premodification and phrase frequency, resulted in smaller z-score differences. Both groups showed nearly identical NP/VP patterns of facilitative effects across premodification and phrase frequency. Individuals with aphasia and neurotypical adults were more facilitated by VP relative to NP premodifiers. Conversely, both groups showed a greater frequency effect in NPs than in VPs.

Table 10 illustrates the behavioural patterns across conditions in aphasic and neurotypical older adults that are remarkably similar to the patterns observed in the younger adults with the exception of noun premodification (see Experiment 1, Chapter 4). Younger adults showed minimal facilitation to NP premodification, similarly neither individuals with aphasia nor older adults showed a facilitation effect.

Table 10 Mean z-score differences for aphasic and older adult groups across all NP/VP conditions in Experiment 2- Word Monitoring task

Phrase type	*Conditions*	*Mean z-score difference (SD)*		*95% Confidence interval*	
		Aphasia	Older	Aphasia	Older
NP	Premodification	-.04 (.31)	-.03 (.24)	-.18-.1	-.14-.09
	Phrase frequency	.25 (.31)	.3 (.15)	.1-.39	.23-.37
	Phrase structure violation	.57 (.38)	.88 (.4)	.39-.74	.69-1.06
VP	Premodification	.28 (.31)	.34 (.26)	.14-.42	.22-.46
	Phrase frequency	.11 (.23)	.11 (.22)	.01-.22	.01-.22
	Phrase structure violation	.53 (.24)	.92 (.37)	.43-.64	.75-1.09

A 3 (condition) x 2 (phrase type) x 2 (group) mixed factorial ANOVA, using Bonferroni adjusted alpha levels, was conducted to examine whether individuals with aphasia and neurotypical older adults differ in their sensitivity to phrase structure violation, premodification and phrase frequency across NPs and VPs. Partial η^2 was used as a measure of effect size for significant F values (small = .01, medium = .06, large = .14 - Cohen, 1988) and r for significant t values (small = .1, medium = .3, large =.5 – Field, 2009). The Shapiro-Wilk test showed that the distribution for each subcondition (NP phrase structure violation D(41) = .98, VP phrase structure violation D(41) = .97, NP premodification, D(41) = .97, VP premodification D(41) = .99, NP phrase frequency D(41) = .95, VP phrase frequency D(41) = .97), did not deviate from normal, p>.05. Assumption of sphericity and homogeneity of variance was assessed via Mauchly's test of sphericity and Levene's test of equality of error variance, respectively. Assumption of sphericity was violated for condition $\chi^2(2) = 9.52$, p<.05, and Greenhouse-Geisser corrected F values were reported for tests including that variable. NP phrase frequency violated the test of equal variance, F (1, 39) = 7.73, p<.05. Results of ANOVAs are robust against violations of variance when sample sizes between groups are equal or close to equal. (Stevens, 1996). As the sample sizes in the aphasic (N = 21) and older adults (N = 20) are almost equal, analysis of results proceeded without transforming this variable.

Results from the 3 (condition) x 2 (phrase type) x 2 (group) mixed factorial ANOVA are presented in Table 11. There were significant main effects for condition and group but not for phrase type. Significant main effects were not interpreted due to the significant interactions. There was a significant condition x group interaction, indicating that individuals with aphasia and older adults differed in their response across conditions. The significant interaction between condition and phrase type revealed that the effects of disruption and facilitation was not equal across NP and VPs. No further interactions were significant. Post-hoc analyses were performed for the significant interactions.

Table 11 Mixed factorial ANOVA F-values for noun phrase and verb phrase conditions in the WMT task – older and aphasic groups

Effects	df	F	p
Phrase type	1, 39	2.66	p>.05
Condition	2, 39	88.2	p<.001
Group	1, 39	10.46	p=.002
Condition x group	2, 39	7.28	p=.003
Phrase type x group	1, 39	. 08	p>.05
Condition x phrase type	2, 39	22.28	p<.001
Condition x phrase type x group	2, 39	.37	p>.05

5.3.2.1. Condition by group post hoc analysis

The significant condition x group interaction indicated that individuals with aphasia and neurotypical controls did not respond in a similar manner across conditions. This analysis combines averages across NP and VP sub-conditions. To further analyse the significant interaction, independent t tests were performed for each condition separately. Figure 11 shows z-score differences for each condition by group. In both groups, mean z-score differences were greatest for phrase structure violation, suggesting sentence processing was strongly disrupted by violations.

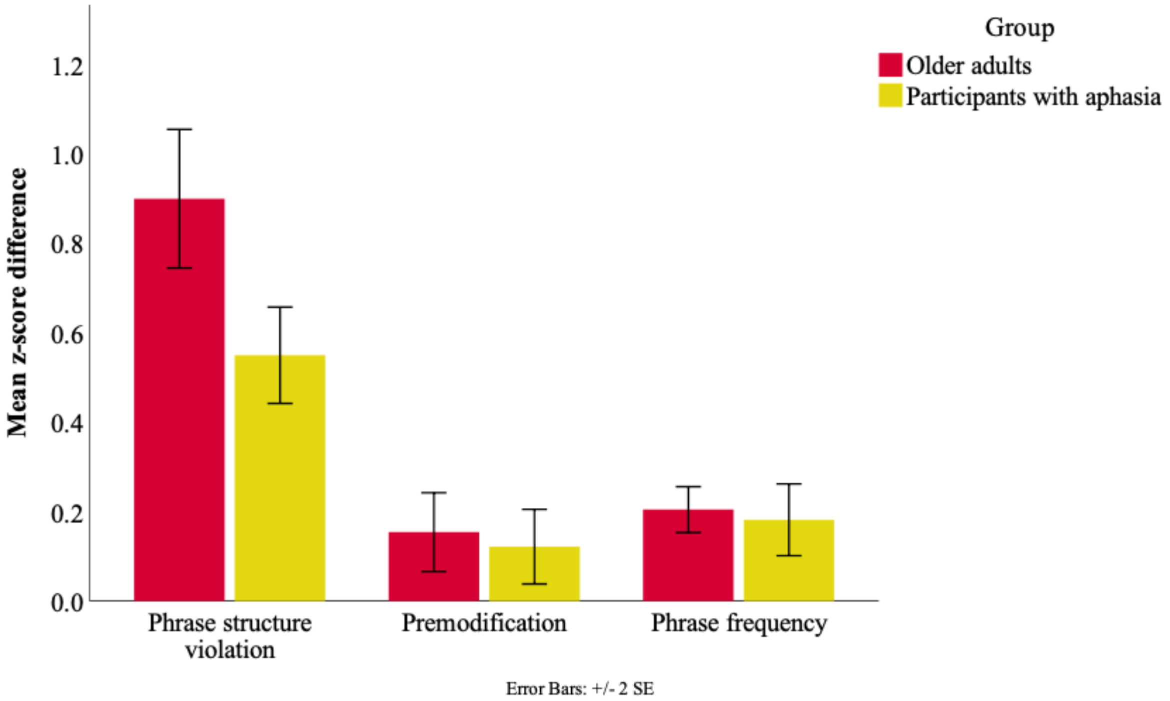


Figure 11 Mean z-score difference for phrase structure violation, premodification and phrase frequency in older adult and aphasic groups

The aphasic group had a lower mean z-score differences (M = .55, SD = .25) compared to older adults (M = .9, SD = .35), revealing they were less sensitive to phrase structure violations, $t(39) = 3.74.$, $p = .001$, $r = .51$. Premodification and frequency conditions resulted in smaller z-score differences and more modest effects in comparison to the disruption to online processing created by violations. Older adults (M = .15, SD = .2) and individuals with aphasia (M = .12, SD = .19) were similarly facilitated by premodifiers, $t(39) = .53$, $p>.05$. This pattern was also observed in phrase frequency, where individuals with aphasia (M = .18, SD = .18) and older adults (M = .2, SD = .11) were similarly facilitated by high frequency phrases, $t(39) = .47$, $p > .05$. Thus, the only group difference was observed in phrase structure violation, where participants with aphasia were less sensitive to grammatical violations than older adults.

5.3.2.2. Condition by phrase structure post hoc analysis

The significant condition x phrase type interaction indicated that there were different patterns of NP/VP sensitivity across the conditions. To further analyse this interaction, independent t-tests were conducted for each condition separately. This analysis groups together neurotypical and individuals with aphasia together as the two way (phrase type x group) and three-way (condition x phrase type x group) was non-significant, indicating that the two groups showed the same response patterns across phrase type and conditions.

5.3.2.2.1 Phrase structure post hoc analysis

Figure 12 shows the mean z-score difference values for the two phrase types in the phrase structure condition. Overall, participants showed no dissociation between NP (M = .72, SD = .42) and VP (M = .72, SD = .36) structure violations, t(40) = -.12, p>.05. That indicates that the aphasic group and neurotypical adults showed similar disruptions across VP and NP phrase structure violations. At the group level, there was no evidence of differential NP/VP effects in sensitivity to violations.

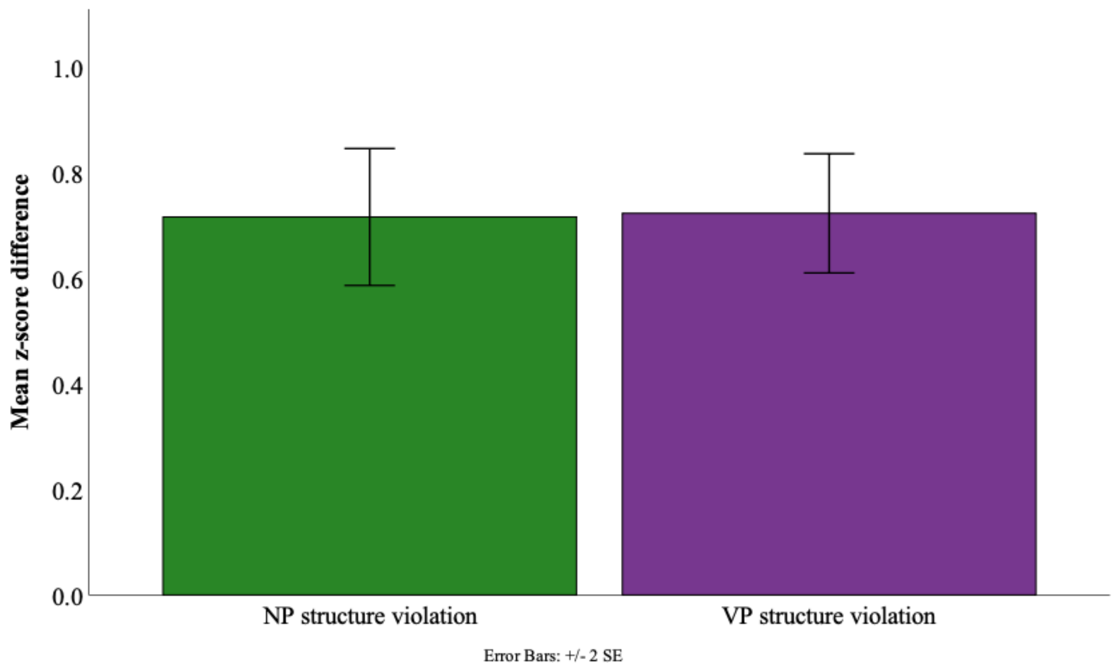


Figure 12 Mean z-score difference values for NP and VP structure violation in Experiment 2 - word monitoring task

5.3.2.2.2. Premodification post hoc analysis

Figure 13 shows mean z-score difference for NP and VP premodifier conditions. There was a dissociation between phrase types, with both the neurotypical and aphasic group showing greater facilitation by premodifers preceding verbs (M = .31, SD = .28) compared to nouns (M = -.03, SD = .27), t(40) = -5.45, p <.001, r = .65. Further, there was no evidence that premodifiers preceding nouns resulted in a facilitatory effect. Thus, at the group level, there was evidence of differential NP/VP effects in sensitivity to premodifiers, with stronger facilitative effects for verbal premodifiers, consisting entirely of function words, relative to noun premodifiers which also contained content words.

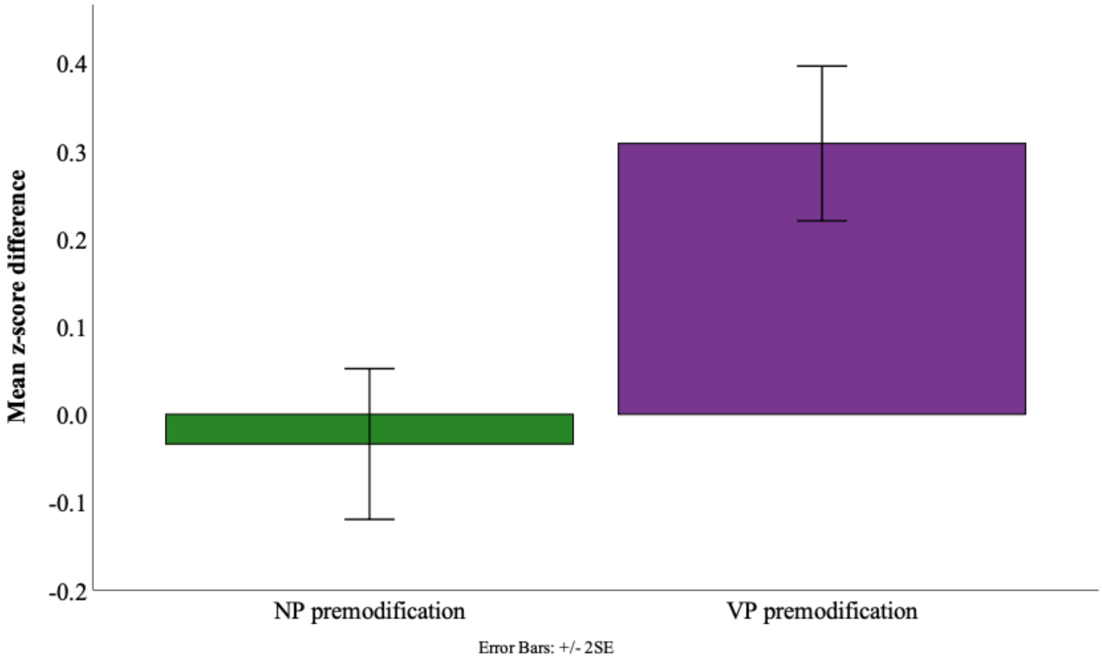


Figure 13 Mean z-score difference values for NP and VP premodification in Experiment 2 - word monitoring task

5.3.2.2.3. Phrase frequency post hoc analysis

Lastly, the facilitation effect of frequency was compared across noun-ending and verb-ending phrases (see Figure 14). Both groups showed a dissociation between NP and VP, with more facilitation by frequency for phrases ending in nouns (M = .27, SD = .24) compared to verbs (M = .11, SD = .22), t(40) = 2.86, p < .05, r = .41. At the group level, there was evidence of differential NP/VP effects in sensitivity to phrase frequency, with stronger frequency effects in NPs compared to VPs.

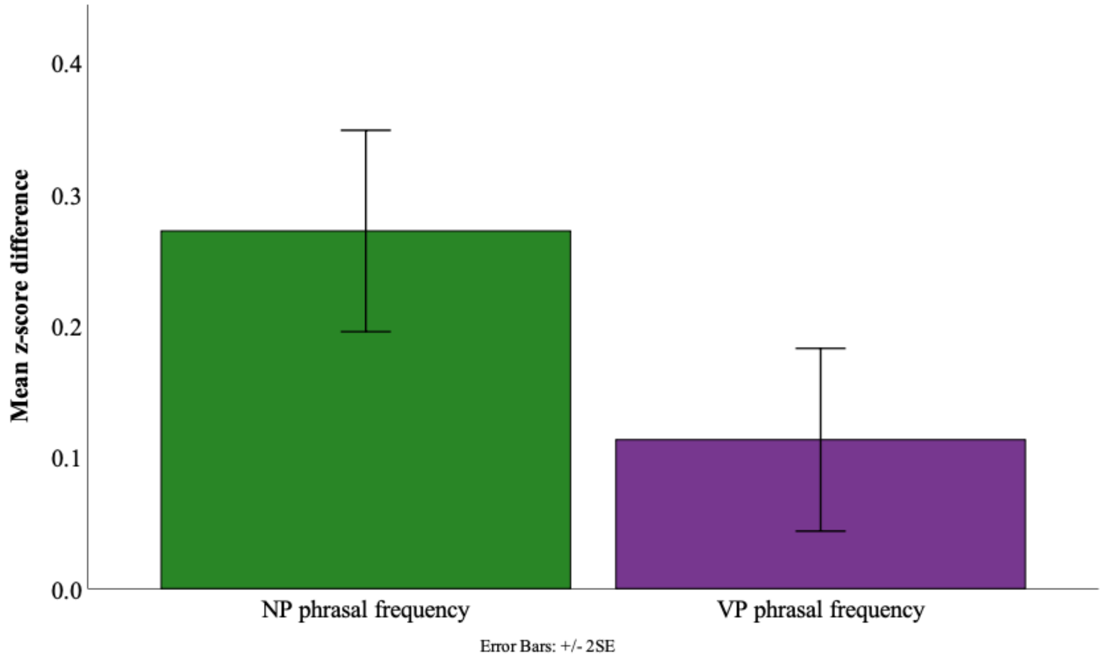


Figure 14 Mean z-score difference values for noun and verb phrase frequency in Experiment 2 - word monitoring task

5.3.4. Comparisons between offline and online measures

In the final stage of the analysis, correlations between online measures and offline tasks were explored. These included language probes (sentence comprehension – TROG-2, lexical retrieval - BNT) as well as cognitive measures including phonological working memory (PALPA13 – digit span) and non-verbal reasoning (WASI-II MR). Table 12 shows individual scores on the background measures for the aphasic group, as well as group means for neurotypical older adults. Neurotypical older adults performed at or near ceiling on the BNT, digit span and TROG-2. They were expected to be at ceiling in the CAT single word comprehension and therefore did not complete that measure. Older adults performed in the average range on the WASI-II Matrix Reasoning task, where the raw score group mean was 17.9 (SD = 2.6). All individuals with aphasia with the exception of one (A24), showed relatively preserved comprehension of single words as indexed by the CAT spoken word subtest. The result of the TROG-2, however, suggests heterogeneity of impairment in comprehension at the sentence level, with 15 of 21 individuals scoring two standard deviations below the neurotypical average. The remaining six individuals performed within the neurotypical range, indicating they had mild comprehension impairments. Similarly, for the BNT, 16 individuals with aphasia had scores at two standard deviations below the neurotypical average, while the remaining five individuals performed within the neurotypical range. Across these two language measures, three individuals showed mild impairments in both comprehension and lexical retrieval. The group showed greater variability in regards to the two cognitive measures, non-verbal reasoning (WASI-II MR) and digit span (PALPA13). For the digit span task, the aphasia group mean (M = 5.6) was slightly below the neurotypical average, despite ten individuals performing at ceiling. The range of scores (7 – 22) in the non-verbal reasoning task indicates greater variability in performance relative to the neurotypical norm, with six individuals performing two standard deviations below the neurotypical mean. On the other hand, nine individuals scored at or above the neurotypical mean.

Table 12 Scores on language and cognitive assessments for individual with aphasia in the word monitoring experiment

Participant	*CAT*	*BNT*	*TROG-2*	*WASI-II MR*	*PALPA13*
1	28	25	3	21	4
2	24	11	6	19	4
3	27	17	2	9	7
4	29	39	19	21	7
5	29	39	18	20	7
6	28	32	7	14	7
7	29	52	15	16	7
8	26	27	11	18	7
9	24	22	9	8	3
10	27	52	11	19	7
11	26	52	18	22	5
12	30	14	5	7	4
13	24	41	6	14	4
14	28	33	12	11	7
15	28	52	17	21	5
16	24	35	18	18	4
17	29	48	13	12	7
18	26	48	14	17	5
19	27	43	1	10	4
20	29	56	16	11	7
21	14	9	2	16	*NA*[6]
Mean score (SD)	26.5 (3.4)	35.6 (14.9)	10.6 (6)	15.4 (4.7)	*5.6 (1.5)*
Older adults mean (SD)	NA	56.7 (2.3)	19.1 (1.4)	17.9 (2.6)	*6.8 (.5)*

Note: CAT = CAT spoken word comprehension, BNT = Boston Naming Test, TROG-2 = Test for Reception of Grammar 2nd Edition, WASI-II MR = Wechsler Abbreviated Scale of Intelligence 2nd Edition Matrix Reasoning, PALPA13 = Digit span by recognition

[6] One participant (21) showed difficulties understanding the instructions and procedures of the PALPA13 and therefore did not complete that assessment. He was excluded from the analyses which included the digit span measure.

The Shapiro-Wilk test was used to assess normality of offline variables. Scores for CAT spoken word comprehension, $W(21) = .73$, $p<.001$, and digit span, $W(20) = .76$, $p<.001$ were not normally distributed. In addition, scatterplots of PALPA13 and CAT scores in relation to other measures showed the scores were non-linear. Thus, they were not explored further in the correlational analyses. The Shapiro-Wilk test showed that the number of missing trials from the WMT (early button presses, time outs, and outliers) was also not normally distributed $W(20) = .83$, $p<.05$, but relationships with other measures showed a linear relationship. Therefore, missing values was included as a variable in the correlational analyses and the non-parametric Spearman's rho value was reported.

Table 13 shows the correlation matrix between online WMT reaction time data and linguistic and cognitive measures for the aphasic group.

Table 13 Correlations between WMT conditions and background assessments for aphasic group

Measure	NP premodification	VP premodification	N phrase frequency	V phrase frequency	NP structure violation	VP structure	Errors^	BNT	TROG-2
NP premodification	-								
VP premodification	-.23	-							
N phrase frequency	.19	-.04	-						
V phrase frequency	.02	-.25	-.11	-					
NP structure violation	.006	-.21	.43	-.32	-				
VP structure violation	-.25	-.005	.03	.07	.24	-			
Errors^	-.34	.14	-.21	.27	-.23	-.16	-		
BNT	.36	-.31	.57**	-.01	.39	.26	-.57*	-	
TROG-2	.32	-.12	.17	.1	.26	.16	-.79**	.65**	-
WASI-II MR	-.13	.3	.07	-.14	.03	.19	-.3	.26	.47*

Note: not significant p>.05, * p<.05, ** p<.01, ^ Spearman's rho is reported due to non-normality of variable, Errors = number of missing trial

First, the relationship between online experimental measures and the standard language measures (TROG-2, BNT) in the aphasic group was explored. Of the online measures, two NP conditions but none of the VP conditions were correlated with offline language measures. There was a significant relationship between lexical retrieval (BNT) and sensitivity to noun phrase frequency, r = .57, p<.001. This relationship indicates that individuals with aphasia who could produce less frequent words were more sensitive to frequency differences in noun-ending phrases (Figure 15).

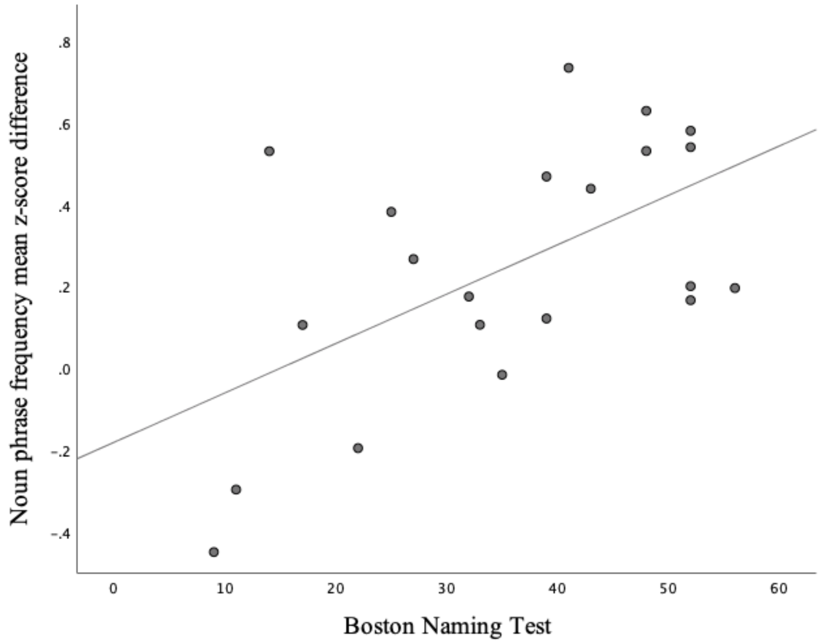


Figure 15 Correlation between z-score difference values for noun phrase frequency and BNT scores in individuals with aphasia

The BNT that probes production of nouns did not correlate with any verb phrase conditions. Further, sentence comprehension (TROG-2) was not correlated with any NP or VP conditions, indicating that there was a dissociation in performance between online and offline measures of sentence processing. However, TROG-2 scores were related to numbers of missing trials across all conditions, showing that individuals who had better offline sentence comprehension also made fewer errors in the WMT, r = -.79, p<.001 (Figure 16).

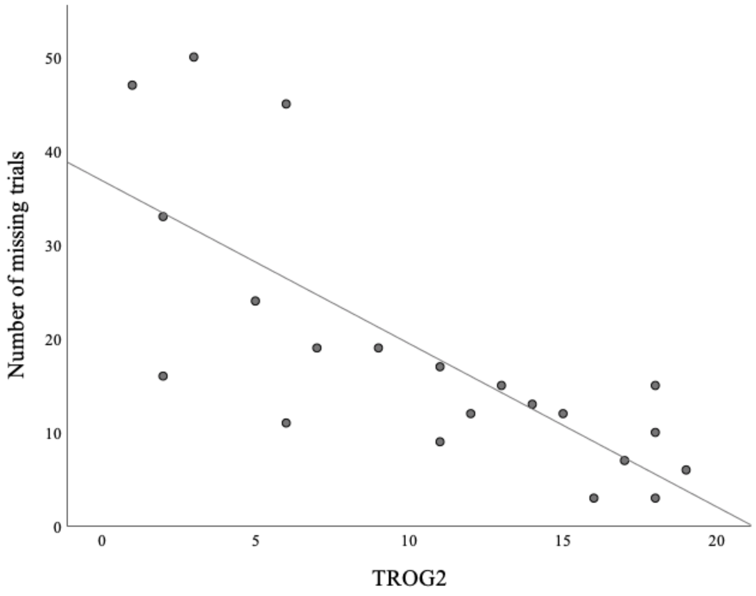


Figure 16 Correlation between number of missing trials in the WMT and TROG-2 scores in individuals with aphasia

Number of missing trials was also related to lexical retrieval (BNT), showing that individuals who made more errors in the WMT had lower naming performance, r = -.57, p<.001 (Figure 17).

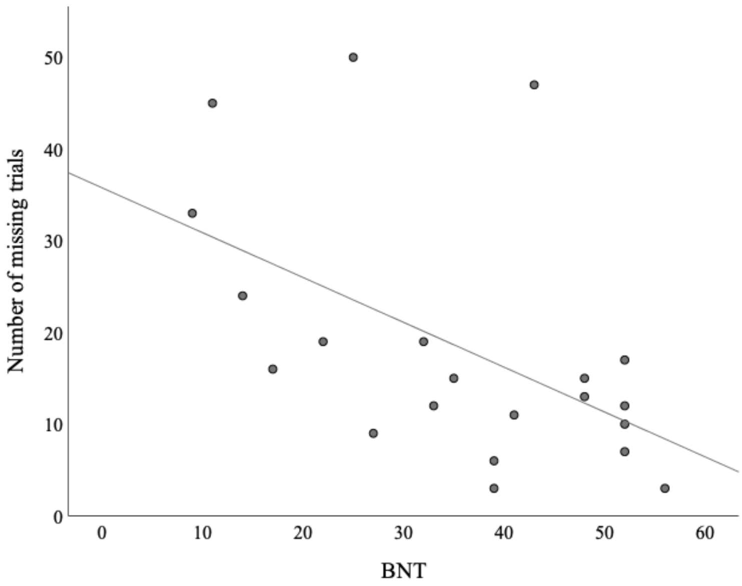


Figure 17 Correlation between number of missing trials in the WMT and BNT scores in individuals with aphasia

Notably, errors in the WMT, as measured by the number of missing trials, instead of RT performance were related to standard language measures. These correlations suggest that number of errors reflects a more general measure of sentence processing difficulty, similar to offline measures.

Next, the relationship between online WMT conditions and non-verbal reasoning, as indexed by the WASI-II MR, was examined. Non-verbal reasoning was not related to any WMT conditions, indicating that online language processing as measured by the WMT was independent from general cognitive functioning. Lastly, correlations between offline measures were examined. The scatterplots (see Figures 18 and 19) demonstrate that better comprehension of sentences (TROG-2) was related to higher naming performance (BNT), r = .65, p>.05, and higher non-verbal reasoning (WASI-II MR), r = . 47, p<.05.

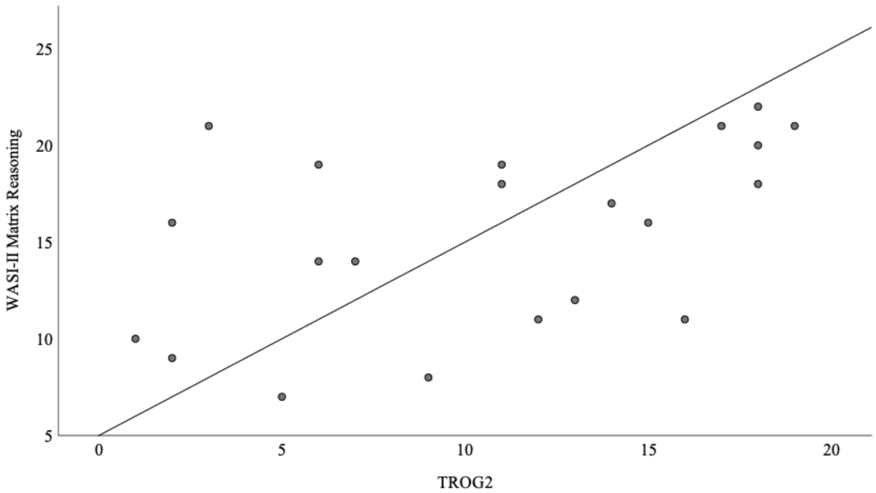


Figure 18 Correlation between TROG2 and non-verbal reasoning in individuals with aphasia – Experiment 2

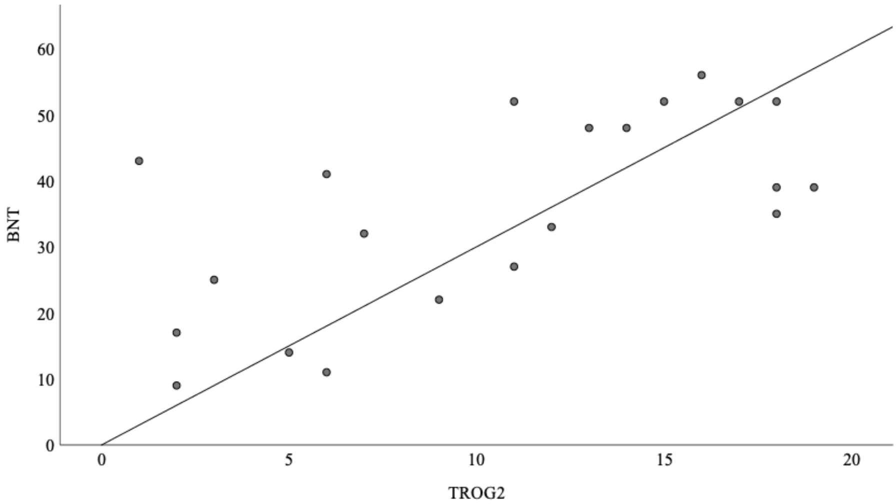


Figure 19 Correlation between TROG2 and lexical retrieval (BNT) in individuals with aphasia – Experiment 2

5.4 Discussion

The word-monitoring task (WMT) is a sentence processing task that measures in real time the recognition of words in sentence contexts. Online methods such as the WMT are particularly useful for exploring processing of function words and verbs in relational contexts. The current experiment applied the WMT to investigate differential processing of noun phrases (NP) and verb phrases (VP) in three different conditions, 1) phrase structure violations, 2) premodification, and 3) phrase frequency. Unlike the majority of previous studies probing noun/verb dissociation, this experiment probed selective word class impairments at sentence level. In addition, the use of the WMT paradigm allowed the opportunity to examine function words in a sentential context. Overall, the aphasic group was slower in responding to target words across conditions and had more timed out responses than neurotypical adults. This might reflect slowed automatic lexical activation or real-time construction of sentences. It is also possible that reaction times were slower as a result of sensory-motor impairments, as half of the group had right-sided hemiparesis and used their non-dominant hand for responses. Data analysis employed in this study examined reaction time differences, which are a more sensitive measure to capture processing difficulties as it takes into account the slower baseline in the aphasic group. With regard to reaction time differences, the data suggest that the aphasic group was sensitive to both NP and VP information, showing remarkably similar patterns across phrase type as neurotypical older adults. In light of these general findings, verbs – at a group level – do not appear to be more difficult to process than nouns when embedded in sentences. This observation challenges previous individual case and group studies that have found selective word class impairments in input processing (e.g. Laiacona & Caramazza, 2004; Miceli et al., 1988; Zingeser & Berndt, 1990). The significant interaction between condition and phrase type indicates that nouns and verbs were not equally facilitated or disrupted across conditions. The following sections discuss the specific NP/VP patterns for each condition in more detail.

5.4.1. Phrase structure violation

One way to investigate noun/verb dissociations was to examine sensitivity to noun and verb phrase structure violation. This was probed by measuring recognition of words in grammatically violated (e.g. *NP: *many courage*; * VP: *slept cushions*) and paired non-violated phrases (e.g. NP: *much courage*; VP: *sewed cushions*). This approach exploits the fact that grammatical violations disrupt sentence processing, delaying word recognition in ungrammatical contexts. The results revealed that both groups showed delayed word recognition in grammatically violated phrases compared to non-violated phrases, indicating a sensitivity to both NP and VP structure. There was an absence of NP/VP dissociation, with similar delays to both types of phrase structure violations in both groups, which is in line with previous findings of preserved noun and verb input processing (Alyahya et al., 2018; Haarmann & Kolk, 1994;

Kim & Thompson, 2000; Wayland et al., 1996). With regard to VP structure violations, the delayed recognition of target nouns in violated contexts suggests that aphasic listeners had difficulties integrating the noun into the sentence, suggesting they were sensitive to the syntactic restrictions. These patterns suggest that the aphasic listeners had residual sensitivity to argument structure of verbs and utilized that knowledge implicitly and automatically. This finding expands previous research that found preserved offline (Kim & Thompson, 2000) and online sensitivity to verb-argument structure (Shapiro et al., 1993; Shapiro & Levine, 1990). Similar to the current experiment, Kim and Thompson (2000) showed that individuals with agrammatic aphasia exhibited offline sensitivity to verb-argument structure by probing the grammaticality of sentences that contained unnecessary arguments (e.g. **The dog is barking the girl*). Using a cross-modal lexical decision task, Shapiro and colleagues (Shapiro et al., 1993; Shapiro & Levine, 1990) found that both aphasic and neurotypical listeners were slower in responding to visual probes that followed verbs with multiple arguments compared to one argument structure verbs. This pattern indicated that verbs with multiple arguments required more processing time to activating the verb's argument structure in real time. Together these results suggest that individuals with aphasia appear to have more difficulties understanding verbs when they are presented in isolation, indicating that elements which scaffold their form and function are important (Miceli et al., 1988; Soloukhina & Ivanova, 2018).

Furthermore, the current results also support and expand findings of preserved noun comprehension. Studies have generally assessed noun comprehension at the single word level by asking participants to match pictures of objects to words, or through metalinguistic tasks that assess a noun's semantic properties (e.g. Berndt, Haendiges, & Wozniak, 1997; Kim & Thompson, 2000; Tyler, Bright, Fletcher, & Stamatakis, 2004). For example, Tyler et al. (2004) assessed comprehension of nouns in a task where individuals had to determine whether or not a target word (e.g. *wrens*) was semantically related to cue words (e.g. *sparrows, thrushes*). Rarely, however, have nouns been assessed when embedded in sentences and with a task that assessed semantic as well as syntactic features. The delayed target word recognition in violated NP structures indicates that aphasic listeners were sensitive to the mismatch between the types of quantifier preceding a count noun. This finding provides novel evidence and a unique approach to noun processing.

One interpretation of this pattern of delayed response to phrase structure violations might suggest that basic knowledge of nouns and verbs and their syntactic structures is preserved in individuals with aphasia. However, aside from the generally slower responses of individuals with aphasia, there was a difference in the magnitude, with older adults showing a greater reaction time difference between normal and violated sentences compared to the aphasic group. The reduced response to violation might point to inefficiencies in the sentence processing system. However, it should be noted that the aphasia group was biased towards mild to moderately impaired individuals. Thus the level of residual sensitivity to noun and verb phrase structure violation may not reflect residual language abilities in individuals with more severe impairments.

5.4.2. Premodification

Unlike previous single word studies, the WMT paradigm is particularly well suited to examine function word processing as it evaluates these forms in a sentence context in which they fulfil their syntactic role. The current experiment probed the facilitatory effects of premodifiers in recognizing head nouns or verbs. The findings showed that verbs preceded by premodifers (e.g. *Tom will have PLAYED*) were recognized faster than verbs in bare contexts (e.g. *Tom PLAYED)*. This suggests that at the group level aphasic participants used function words to anticipate the upcoming verb in real time. This requires recognition of the lexical forms and their positional relationship to the head. The results provide online evidence for preserved function word processing in this group of mild to moderately impaired aphasic individuals. This is consistent with the findings in Shankweiler et al. (1989) where individuals with aphasia were equally accurate as neurotypical controls in judging the grammaticality of sentences containing function words errors (e.g. *Picking the birthday present on would be nice for Susan*). The current result is in stark contrast with the majority of previous findings which have found delayed or lack of recognition of function words (Friederici, 1985; Rosenberg et al., 1985; Swinney et al., 1980) and increased errors in reading function words aloud (Biassou et al., 1997; Friederici & Schoenle, 1980). For example, in a WMT, Friederici (1985) found faster RTs to content compared to function words in seven agrammatic individuals, but observed the opposite in non-age matched younger neurotypical adults. She interpreted this group difference as indicative of atypical processing in agrammatic individuals. In her analysis, she directly compared RT to function words with content words. However, the word classes were not matched in terms of frequency, syllable length, or imageability, factors that contribute to differences in recognition speed. Several studies have shown that differences in content and function word processing can at least in part be explained by differences in frequency between word class, with function words being of very high frequency (e.g. Gordon & Caramazza, 1985; Kolk & Blomert, 1985; Segalowitz & Lane, 2000). More importantly, function words in spoken sentences are often short and unstressed which could delay their recognition. Reaction time differences between function and content words might be due to differences in stress and prosody rather than true word class effects. Unlike the previous WMT studies, the current experiment measured the degree to which function words facilitate anticipation or recognition of upcoming words rather than recognition of the function word itself. An advantage of this design is that it avoids the problems of comparing content and function words that may not be matched in phonological saliency, stress, frequency and imageability. The current observations revealed that when these factors are taken into account, as a group, individuals with aphasia show more preservation of function word processing than indicated by previous studies. Furthermore, the results of the verb premodification condition are particularly important as the premodifiers consisted entirely of function words (while in the NP condition consisted of determiners followed by adjectives). The results revealed similar patterns between the neurotypical and the aphasic groups. This observation is not compatible with Bradley's (Bradley 1878; Bradley, Garrett, & Zurif, 1980) separate processing route hypothesis that proposes that individuals with aphasia process function words differently than neurotypical adults because of damage to the function word specific processing route. Thus, reports of difficulties with function words in recognition appear not to be due to factors specific the word class, but are likely to arise due to differences in psycholinguistic factors.

Although our findings showed there was a clear processing advantage for verbs that followed premodifiers (compared to bare verbs), the same pattern of facilitation was not found for nouns in both groups. The results show that NP premodifiers (e.g. *Mary bought <u>the sweet apples</u> from the farmer*) did not facilitate the recognition of nouns. The difference in facilitation between VP and NP premodifiers may be due to differences in transitional probabilities between premodifiers and heads. In the case of NPs, the adjectival premodifiers used in this experiment do not always necessarily directly precede the head noun (e.g. *<u>The sweet</u> and juicy <u>apple</u>*) resulting in a lower transitional probability compared to VP premodifiers, where premodifiers consistently directly precede head verbs (e.g. *John <u>should have kicked</u> the ball to his team mates*). The unequal sensitivity between NP and VP premodifiers is therefore most likely a consequence of differing transitional probabilities in the items preceding the head.

5.4.3. Phrase frequency

The facilitation by phrase frequency was probed by comparing the recognition of nouns and verbs as the final element of high and low frequency phrases (e.g. NP high frequency: *asked for directions* vs NP low frequency: *looked for directions*; VP high frequency: *trying to catch* vs VP low frequency: *hoping to catch*). Overall, both groups were similarly facilitated by frequency, supporting earlier findings that have found frequency-facilitated sentence comprehension (DeDe, 2013a; Gahl, 2002; Huck et al., 2017b) and production (Bruns et al., 2019; Zimmerer et al., 2018). The current results revealed that both groups showed faster recognition of nouns in high frequency phrases in comparison to low frequency cognates. Moreover, the frequency effect was not limited to input processing. Individuals who showed greater sensitivity to frequency differences between high and low NPs also displayed an advantage in naming lower frequency items in the BNT. This is in line with evidence from healthy aging that suggests that greater frequency sensitivity leads to processing advantages for low frequency items. For example, in a lexical decision task, Ramscar et al. (2013) observed that older adults were similarly sensitive to high frequency lexical items, but that greater language experience in older adults resulted in greater accuracy in low frequency items.

The data from the current experiment provides further evidence that frequency effects occur beyond the single word level, supporting a previous finding by Bruns et al. (in prep), where words in high frequency phrases (e.g. *a great deal*) were more rapidly recognized than in low frequency phrases (e.g. *a fair deal*). The stimuli in the Bruns et al. study almost exclusively noun-ending trigrams, whereas the current study also investigated verb-ending phrases. The frequency effect was reduced in the recognition of verbs. Verbs in high frequency phrases were recognized only minimally faster than verbs in low frequency phrases. The facilitation effect for NPs and reduced facilitation for VPs was observed in both groups, suggesting that unequal facilitation effects across phrase type is not a feature of aphasia or due to impaired verb processing.

Nevertheless, this result is in contrast with most findings that have found strong frequency effects for verbs (DeDe, 2013a; Gahl, 2002; Gahl et al., 2003). For example, Gahl et al. (2003) found individuals with aphasia made fewer errors in a plausibility judgment task when verbs, which are most frequently encountered in transitive frames, were presented in their preferred frame (e.g. *The researchers dissolved the crystals*) compared to when they were presented in less frequent syntactic frames (e.g. *The crystals dissolved in the solution*). Unlike these previous studies, the structure of the syntactic frames was kept constant across phrase pairs in the current experiment (e.g. high frequency: *The plants continued to grow strong and tall* vs low frequency: *The plants started to grow in the spring*). A potential explanation for the different frequency effects across NPs and VPs may lie in the word class of the critical words. For example, the critical word manipulated in NPs was almost exclusively a verb, (e.g. *closing the door*) and in a few cases nouns (e.g. *pint of beer*). By contrast, critical words in the VP condition were more varied, including adverbs (e.g. *able to grab*), verbs (e.g. *decided to try*) and nouns (e.g. *time to cook*). In particular, the pre-head verbs (e.g. *want, try, need*) and adverbs (e.g. *able, likely*) were semantically light. The semantic association between the critical word and the target word was more salient in the NP condition than in the VP condition, allowing semantic priming to cumulatively facilitate access to the noun head.

5.4.4. Relationship between WMT conditions and offline measures

One aim of the current experiment was to examine the relationship between standard offline measures of language and non-linguistic processing to online WMT conditions. The results showed that performance on offline measures was a poor predictor of sensitivity to NP/VP phrase structure violations, premodifcation and frequency. The lack of association between performance on offline sentence comprehension and online WMT tasks mirrors previous findings. For example, Tyler, (1985,

1988) reported divergent performances across task type. In a single case study, Tyler (1988) found evidence of intact syntactic processing in a WMT but poor offline syntactic comprehension as measured both by the TROG-2 and a grammaticality judgment task assessing the same stimuli used in the online WMT. The striking difference between online NP/VP patterns and offline measures has implications for clinical evaluations of selective word class impairments. Clinical evaluation largely relies on offline and single word tasks. Given that natural language processing occurs online, performance on standard clinical tests might not reflect individual's residual language abilities. One explanation for dissimilar findings between online and standard tasks is that the latter involves additional cognitive components that may overlay linguistic processing. For example, standard measures of sentence comprehension, such as sentence picture matching tasks, require simultaneous processing of multiple pictures as well as auditory information and, as a result, place greater demand on working memory. By contrast, the WMT allows for assessment of finer grained linguistic processing as it is not dependent on picturable sentences, at the same time placing low demands on meta-linguistic processes. Its great advantage is that it measures online language processing which more closely reflects how individuals process language in everyday life. However, there are several limiting factors to the use of the WMT that might explain the restricted use so far. In comparison to standard offline sentence measures, such as the TROG-2, the WMT paradigm requires more complex stimulus design and more effort in processing and analysing response time. Furthermore, the WMT measures recognition rather than comprehension as is the case in the TROG-2. Thus, the WMT could be performed without necessarily understanding or constructing the meaning of the complete sentence.

One aspect of the WMT that did correlate with offline measures was the error rate. Although the overall error rate was relatively low in the aphasic group, individuals who made more errors in the task also had more difficulties in retrieving single words (BNT) and understanding sentences (TROG-2). Based on that finding, one would predict that individuals with more severe impairments have greater difficulties completing WMT. The individual case series presented in the next chapter (Chapter 6) addressed the question of severity by examining WMT performance in two individuals with severe impairments.

5.5 Conclusions

The findings reported in this study provide evidence that, at a group level, individuals with mild to moderate aphasia are sensitive to NP and VP information. The findings challenge the view that verbs are generally more difficult to process and vulnerable to damage. Individuals with aphasia were similarly delayed by both noun and verb phrase structure violations, indicating residual sensitivity. The results also showed that processing of function words, in the form of premodifiers, was preserved in this group of individuals with aphasia. This contradicts the majority of previous studies that have found impaired function word processing and does not support the view that function words and content words are accessed and processed through separate mechanisms. This suggests that individuals with mild to moderate aphasia retain sensitivity to low imageability function words that primarily hold a syntactic role. It is important to note however, that the NP premodifiers did not facilitate recognition of the head noun in the same degree as VP premodifiers. In addition, the findings of the current study also provide novel evidence that sensitivity to statistical probabilities in language is preserved beyond the word level and plays a role in real time language processing. Performance on standard sentence comprehension and lexical retrieval tasks were poor predictors for online language processing. The differential findings between online and offline tasks suggests that they make different demands on cognitive processes and are likely to tap into different processes. Standard offline behavioural data are not sufficient to elucidate residual language processing in individuals with aphasia. It is essential that performance on online tasks that probe real-time processing, complement offline profiles.

Overall, the results provide further evidence of a lack of NP/VP dissociation at a group level in aphasia, however, a degree of caution is needed when interpreting these results. First, the current sample included a subset of individuals with mild aphasia, leaving the question open whether more severely impaired individuals show similar facilitation effects for function words and lack of NP/VP dissociation. Further, the group result might mask specific word class difficulties that are associated with aphasia subtypes. Agrammatic individuals, in particular, are claimed to show verb-specific impairments, while anomic individuals are reported to have greater difficulties with nouns. The individual case analysis in the following chapter (Chapter 6), which includes two individuals with severe impairments, will be able to provide further answers to these questions.

6. Experiment 3: Individual case series analysis of noun phrase and verb phrase sensitivity in individuals with agrammatic, anomic or severe aphasia

6.1 Introduction

Nouns and verbs can be selectively impaired in aphasia. Noun/verb dissociations have been mainly observed in production. In contrast, the majority of studies that have examined noun/verb dissociations in comprehension have not reported selective word class impairments (e.g. Cho-Reyes & Thompson, 2012; Wayland, Berndt, & Sandson, 1996). Experiment 2 (Chapter 5) examined differential processing of noun phrases (NP) and verb phrases (VP) across three different conditions: 1) phrase structure violations, 2) premodification (function words), and 3) phrase frequency in a group of 21 individuals with aphasia. Within the aphasic group, individuals displayed mixed profiles with regard to receptive and expressive impairments. In line with previous comprehension studies, the findings indicated that. at the group level, individuals with aphasia were sensitive to both NP and VP information, showing slowed but otherwise remarkably similar RT patterns across conditions and phrase type as neurotypical age-matched adults. The findings in Experiment 2 provide evidence for an absence of an NP/VP dissociation, as well as preserved function word processing and sensitivity to frequency. However, a degree of caution is needed when interpreting these results as the group was heterogeneous in terms of severity and aphasia subtype. One possible reason for not finding NP/VP dissociations is that group patterns masked individual differences. In particular, the sample included a subset of individuals with mild aphasia and NP/VP dissociations might be evident in individuals with more severe impairments or with prominent grammatical symptoms, typical of agrammatic-type aphasia.

Studies investigating noun/verb dissociations in comprehension have based their findings on samples that, to a large extent, included individuals with mild or mild to moderate impairments (e.g. Shapiro & Levine, 1990; Wayland, Berndt, & Sandson, 1996). For example, Kim & Thompson (2000) reported an absence of noun/verb dissociations in their sample of seven agrammatic individuals in a grammaticality judgment task. However, the profiles of the seven individuals reveal that they had mild auditory comprehension impairments, ranging between 7.9 and 9.9 out of a maximum of 10 on the auditory comprehension subtest of the Western Aphasia Battery (WAB – Kertesz, 2007).[7] Similarly, Wayland, Berndt and Sandson (1996) reported preserved online noun and verb processing in a sample of eight

[7] The aphasia quotients (AQ) for the seven agrammatic individuals based on the completed WAB ranged between 64.5 and 77.8 with a mean of 73.06, which corresponds to mild or mild-moderately impairment

individuals who were mildly impaired, ranging between 73rd and 97th percentile on the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan, 1982) auditory comprehension subtest.

However, if verbs, relative to nouns, require additional processing resources due to their complexity, it is likely that noun/verb dissociations may be more pronounced in individuals with more severe impairments. Using a computerized version of the word-picture matching task, Soloukhina & Ivanova (2018) found that individuals with aphasia were slower and made more errors when responding to verbs relative to nouns. Their study included a more mixed sample of 32 aphasic participants, including a number of individuals with more severe impairments. Although the study did not directly investigate the role of severity in noun/verb dissociations, the pattern of selective word class impairments suggests there is a possible link. It is important to point out, however, that many of the individuals with severe impairments were still in the subacute phase (three to six months post-onset) when symptoms are usually more severe and language recovery is still ongoing. It is possible that the residual language abilities of these more severe cases may not reflect abilities of individuals with chronic severe impairments.

Very few studies have directly explored and analysed whether noun/verb patterns differ with regard to aphasia severity. Alyahya et al. (2018) included a diverse participant group in terms of severity (and subtype) in assessing comprehension of nouns and verbs. Overall, their sample of 48 individuals with aphasia was moderately impaired scoring 2.83 (out of 5) as measured by the Boston Diagnostic Aphasia Examination (BDAE[8]), including ten severely impaired individuals (score of 1). At the group level, Alyahya et al. report no difference between nouns and verbs in a picture-word matching task. The same finding was mirrored in their individual case analysis where only one out of 48 participants showed a noun/verb dissociation. This participant was classified as severely impaired. Notably, he was more accurate in identifying verbs compared to nouns. Overall, however, the individual patterns suggested that noun/verb dissociations are not more frequent even in individuals with more severe impairments. Although there is some evidence regarding the relationship between severity and occurrence of noun/verb dissociations, there is limited research and further investigations are needed.

A second issue is whether individuals with agrammatic aphasia are more likely to display selective difficulties with verbs and function words. Some studies have demonstrated that the features of agrammatic production also manifest in comprehension (Goodenough, Zurif, & Weintraub, 1977; McCarthy & Warrington, 1985; Schwartz, Saffran, & Marin, 1980; Zurif & Blumstein, 1978; Zurif, Caramazza, & Myerson, 1972; Zurif, Green, Caramazza, & Goodenough, 1976). These researchers argue that agrammatism represents a general impairment in syntactic processing, resulting in cross-modal deficits. Further, Bradley, Garrett, and Zurif (1980) suggested that the underlying syntactic deficit in agrammatism is expressed as difficulties in processing verbs as well as function words. By

[8] BDAE aphasia severity rating is based on a 5-point scale where 1 indicates severe aphasia

contrast, individuals with anomia are often reported to have disproportionate difficulty with nouns, particularly in production (Chen & Bates, 1998; Hillis & Caramazza, 1995; Laiacona & Caramazza, 2004). While individuals with anomia (and other forms of fluent aphasia) produce function words in sentences, they can contain errors – a feature that is labelled paragrammatism (see excerpt 1 in Chapter 2). Individuals with Wernicke's/fluent aphasia are claimed to process function words more similarly to neurotypical adults, and errors in production are due to underlying word selection difficulties. In support of this hypothesis, Friederici (1981, 1982, 1985) conducted a series of experiments in German, comparing processing of content words to prepositions in individuals with Wernicke's or Broca's aphasia. In a WMT, neurotypical adults reacted faster to function words compared to content words. However, the opposite pattern was observed in individuals with Broca's aphasia, indicating atypical function words processing. Further, she reported differences between individuals with Broca's and Wernicke's aphasia in a grammaticality task and picture-word matching task. The response pattern showed that individuals with Broca's aphasia, but not Wernicke's, made more errors in processing prepositions that served mainly a syntactic compared to a semantic role (e.g. semantic: *Peter stands <u>on</u> the chair*/*Peter steht <u>auf</u> dem Stuhl*; syntactic: *Peter hopes <u>for</u> summer*/*Peter hofft <u>auf</u> den Sommer*). Taken together, Friederici concluded that processing of function words in individuals with Broca's aphasia is mediated by the role they take in a sentence, providing further evidence for a general syntactic deficit account of agrammatism. However, there are a number of possible explanations for the findings of previous experiments. Importantly, content and function words were not matched on psycholinguistic variables such as imageability or frequency, that influence the speed and ease of processing (Bird et al., 2002).

The general syntactic deficit hypothesis has been challenged by several studies that have reported dissociations across modalities, such that individuals with agrammatic production and difficulties producing verbs and function words did not show the same difficulties in comprehension (Alario & Cohen, 2004; Goodglass et al., 1970). In an early case study analysis of four agrammatic and three anomic individuals, Miceli et al. (1988) found that aphasia subtype did not predict selective word class impairment in comprehension. In fact, two of the four agrammatic individuals showed only a slight impairment in understanding verbs and preserved noun comprehension, while comprehension in the other two agrammatic individuals was preserved for both word classes. Similarly, two of the three anomic individuals had intact verb and noun comprehension and only one individual showed superior verb comprehension. Rather than confirming the hypothesis that agrammatic and anomic individuals have cross-modality deficits, the findings revealed heterogeneous comprehension profiles in both agrammatic and anomic subtypes.

A lack of association between aphasia subtype and selective noun/verbs impairment in comprehension has also been reported at a group level in several studies by Thompson and colleagues (Cho-Reyes & Thompson, 2012; Kim & Thompson, 2000; Thompson et al., 2012). In addition to investigating the link between noun/verb dissociations and severity, Alyahya et al., (2018) carried out analyses examining whether individuals with non-fluent (global, mixed non-fluent, Broca's and transcortical mixed) and fluent aphasia (anomic, conduction and transcortical sensory) displayed different word class effects. Their results showed that, although individuals with fluent aphasia had overall higher scores in the word-picture matching comprehension task compared to non-fluent individuals, comprehension accuracy was not mediated by word class. Thus, agrammatic and anomic individuals comprehended nouns and verbs equally well. Overall, these findings challenge the view that aphasia subtype is linked to selective word class impairment in comprehension. However, so far none of the studies have used an online sentence level task to investigate the association between aphasia subtype and noun/verb dissociations.

6.1.2 Present study

The individual profiles of three subgroups of participants from Experiment 2 were examined. The sub-groups were: agrammatic aphasia, anomic aphasia, and individuals with severe impairments. One aim of the case analysis was to examine whether sensitivity to NP/VP conditions differ in individuals with more severe impairments compared to the sample mean in Experiment 2, in which individuals with mild to moderate impairments predominated. In individuals with severe impairments, all aspects of language are greatly impaired, with limited speech output and reduced comprehension. Standard profiles of severity are mostly established via explicit tasks. It is unclear whether tasks that probe implicit language processing will show the same patterns and degree of impairment. A further aim was to examine the association between aphasia subtype and selective NP/VP impairment. Past studies have used single word or offline tasks to probe noun/verb dissociations in agrammatic and anomic individuals, however, none have utilized online sentence level tasks to investigate the association between aphasia subtype and noun/verb dissociations. Lastly, the WMT profiles are also discussed in reference to individual’s performance on standard language measures. Individuals with agrammatic, anomic aphasia and severe impairments were identified based on their speech output in two narrative speech samples as well as their scores on the Boston Naming Test (BNT) and Test for Reception of Grammar (TROG-2). The group mean of 20 neurotypical older adults (reported in Experiment 2, Chapter 5), are included in the figures and tables as a reference to the neurotypical profile. Table 1 in Chapter 4, Section 4.2.1.2 and Table 12 in Chapter 5, Section 5.3.4 show demographic information, as well as mean neurotypical group performance on background assessment, respectively.

The individual case analysis was based on participants’ data from the WMT experiment (Chapter 5) to answer the following research questions:

1. Do individuals with severe impairments show similar NP/VP patterns as the aphasic group mean?
2. In comparison to the aphasic group, do agrammatic individuals show greater verb and function word impairment in the WMT?
3. In comparison the aphasic group, does the individual with anomia show greater noun impairments?
4. Do individuals show dissociations between online and standard offline tasks?

In line with the limited evidence that currently exists, it was expected that aphasic individuals with severe language impairments show similar NP/VP patterns as the aphasic group mean. Based on a lack of association between aphasia subtype and selective noun/verbs impairment in offline comprehension, agrammatic individuals were not expected to exhibit reduced sensitivity to VPs and premodifiers relative to the aphasic group mean. Similarly, individuals with anomia were predicted to not show reduced sensitivity to NPs compared to the aphasic mean. Lastly, consistent with group results in Chapter 5, it was expected that individuals' online sensitivity to NP and VPs would not be related to their performance on standard offline tasks (TROG-2 and BNT).

6.2 Individual case analysis

The present analysis focused on comparing single cases to the aphasia group mean to determine if dissociations could be identified in relation to NP vs. VP profile, or online vs. offline performance. Table 14 shows the background assessment and demographic information for the four single cases. Speech fluency was determined by an experienced SLT. The section below provides, first, a brief summary of the group level findings (for the full group analysis see Section 5.3 in Chapter 5). Next, it describes the individual profiles on the standard language and cognitive assessments, as well as providing an excerpt from each individual's spontaneous speech sample. Finally, reaction time (RT) patterns in the WMT are analysed in relation to the aphasic group mean and to individuals' scores on the standard language and cognitive assessments.

6.2.1 Group NP/VP pattern

Patterns of NP/VP dissociation were investigated across three conditions: 1) phrase structure violations, 2) premodification (function words), and 3) phrase frequency. Processing of noun and verb phrase structure was assessed by measuring the speed at which nouns or verbs were recognized in grammatical and ungrammatical phrases (e.g. NP non-violated: *much courage*; NP violated *many courage*; VP non-violated *sewed cushions*; VP violated: *slept cushions*). Recognition was faster for nouns and verbs in non-violated phrases relative to violated phrases, indicating that at the group level, processing was preserved across phrase types. In addition, recognition of verbs and nouns was similarly delayed in violated phrases, demonstrating that individuals were equally sensitive to verb (verb argument structure) as to noun syntactic information (mass/count status). The preservation of phrase structure information suggests that the aphasic group had real time access to lexical-syntactic information for nouns and verbs. With regard to function word processing, the data showed that individuals with aphasia showed sensitivity to verb premodifiers by recognizing premodified verbs faster (e.g. *Frank should have kicked the ball*) than bare verbs (e.g. *Frank kicked the ball*), however this effect was absent in noun premodifiers (and also in neurotypical controls). The opposite NP/VP pattern was observed when examining effects of frequency. Nouns in high frequency phrases were recognized more quickly in comparison to the same noun embedded in a lower frequency phrase (e.g. NP high frequency: *asked for directions*, NP low frequency: *looked for directions*). This frequency effect was absent in verbs, in both the aphasic group and neurotypical controls. Finally, WMT patterns were examined in relation to performance on standard language and cognitive assessments. Offline sentence comprehension, as determined by the TROG-2, did not correlate to any online NP or VP conditions.

Table 14 Background information of individuals in the single case WMT analysis

ID	*Age*	*Gender*	*TPO*	*Fluency*	*Education*	*CAT*	*BNT*	*TROG2*	*WASI-II MR*	*Digit span*	*WMT Mean RT (ms)*
21	68	M	64	Severe	Secondary	14	9	2	16	*NA*	746.29
2	76	M	102	Severe	Secondary	24	11	6	19	4	449.93
8	48	F	40	Moderate non-fluent agrammatic	Secondary	26	27	11	18	7	573.45
16	59	M	122	Moderate to severe non-fluent agrammatic	Postgraduate	24	35	18	18	4	616.25
19	56	M	21	Anomic	Graduate studies	27	43	1	10	4	793.95
Aphasia group mean (SD)	60.7 (10.2)		76.8 (43.2)			26.5 (3.4)	35.6 (14.9)	10.6 (6)	15.4 (4.7)	5.6 (1.5)	608.8 (142.6)
Neurotypical mean (SD)	64.6 (11.5)					NA	56.7 (2.3)	19.1 (1.4)	17.9 (2.6)	6.8 (.5)	447.8 (71.2)

Note: TPO = time post onset (months), BNT = Boston Naming Test, CAT = Comprehensive Aphasia test spoken word subtest, TROG-2 = Test for Reception of Grammar 2nd edition, WASI-II MR = Wechsler Abbreviated Scale of Intelligence Matrix Reasoning subtest, Digit span = PALPA13 subtest, WMT = word-monitoring task

6.2.2 Aphasia severity analysis

6.2.2.1 Background profiles

Participant A21 was a 68-year old man who had suffered a single stroke. On the basis of his Cookie theft narrative and his CAT, BNT and TROG scores he was classified as having severe aphasia. Excerpt 10 was his entire response to the cookie theft task.

[10] *Ehm (pause) yeah (pause) cookin' ehm (pause) ehm (pause) no. Alright good lovely (ehm). Washing. Pool. (pause) Three three (pause). Lovely.*

A21 struggled to name the agents in the picture (e.g. *mother, daughter*), but did produce low imageability, but high frequency forms such as "*lovely*". However, they did not function as adjectives but rather served pragmatic conversational functions. A21 did not incorporate these forms into phrasal structures, suggesting that they are stereotyped utterances or conversational fillers. The absence of phrasal structure is a characteristic of his narrative.

His performance on the offline background measures suggested he had severe production as well as receptive difficulties (see Table 14). In addition to difficulties in connected speech, his production difficulties were also apparent in the BNT, where he correctly named nine items. With regard to comprehension, he was severely impaired at both the single word (CAT = 14) and sentence level (TROG-2 = 2). This indicates he had difficulties understanding simple active sentences (e.g. *The girl pushes the box*) and stimuli that probed function words (e.g. *The duck is on the ball*). A21 also had difficulties in understanding the verbal instructions and procedures of the digit span task (PALPA13) and was unable to complete it. In contrast, his nonverbal reasoning appeared intact, scoring 16 versus the neurotypical group mean 17.9 in the WASI Matrices, pointing to a dissociation between his language and non-verbal reasoning abilities. Based on the comprehension difficulties, one would expect atypical performance in the WMT relative to the aphasic group and neurotypical group mean.

The second participant with severe impairments was A2, a 76-year old man. The participant declined recording of the Cookie Theft narrative. In his second testing session, he consented to the researcher taking notes while describing the Dinner Party story. Excerpt 11 is the transcription of the entire Dinner Party narrative.

[11] A2:	*Right (approx. 25 seconds, scans through story, laughs). Oh dear. Oh dear. (25 seconds pause) (points to picture 2) One is there and two, no two. (points at picture 3) (approximately 15 seconds) (scratched his head) No.*
Researcher:	*Can you try to describe what you see?*
A2:	*Oh dear. No.*

A2 struggled to name any items in the pictures and his output was limited to social speech, a few two to three word utterances (*one is there*) and stereotypical utterances (*oh dear*). From the limited output, it is difficult to make conclusions regarding preservation of nouns or verbs, but his impairment appeared to cross word categories.

His performance on the offline background measures suggested he had moderate to severe production and comprehension impairments. His single word retrieval difficulties (BNT = 11) mirrored those observed in his speech. His understanding of single words was superior to his sentence comprehension which appeared to be severely impaired (CAT = 24, TROG-2 = 6). Similar to A21, his non-verbal reasoning was within the neurotypical range, scoring 19 on the WASI-II MR (neurotypical M = 17.9, SD = 1.4), providing further evidence for preserved reasoning abilities despite severe impairments of expressive and receptive language (Varley, 2014; Varley & Siegal, 2000). In the phonological working memory task (digit span) he scored 4 (out of 7) and was one SD below the aphasia group mean (M = 5.6, SD= 1.5). Based on the offline profile, in particular when considering the TROG-2 score, one would expect poor performance in the WMT.

6.2.2.2 Word Monitoring task patterns

Pre-processing of the reaction time data resulted in exclusion of: early button presses (before the target was presented), time outs (no button presses), and outliers (2 SD above individual's mean RT). Table 15 illustrates the total number of missing trials per error type for each individual in reference to the aphasia group mean. Overall, both A21 and A2 had a markedly greater number of missing trials relative to the group mean. Approximately half of A2's rejected trials were due to early button presses, similarly divided between NP and VP conditions. In comparison, A21 made fewer errors, the majority of which were time outs. After excluding missing trials, A2 and A21 had 67.5% and 75.83% of complete pairs, respectively. The data loss for the two individuals was greater compared to the group average, where 84% of completed pairs were retained, indicating that they had more difficulties with the online task than less impaired individuals.

Table 15 Number of missing trials in the word monitoring task of the two severely impaired individuals in relation to the aphasia group mean

Participant	Early		Time out		Outlier		Total	
	NP	VP	NP	VP	NP	VP	NP	VP
A2	14	16	3	5	4	1	21	22
A21	3	1	8	11	3	7	14	19
Aphasia group mean (SD)	2.81 (4.23)	2.33 (4.73)	1.43 (2.25)	3.05 (6.43)	3.81 (2.32)	5.29 (2.33)	8 (5.68)	10.67 (8.46)

Differences between the two severely impaired individuals were also observed in relation to their reaction time. Overall, A2 reacted more quickly to targets (mean RT = 449.93ms), than the group mean (mean RT = 608.87, SD = 142.61), whereas A21 was approximately one standard deviation slower than the mean (mean RT = 746.28ms).

Pre-processing of the data involved converting reaction times (RTs) to z-scores and computing z-score difference values for each sentence pair. Figure 20 depicts z-score difference values for A2 (purple) and A21 (grey), in relation to the aphasic group mean (yellow). A2's NP/VP pattern across the conditions roughly resembles the group mean, whereas A21 deviated from it to a greater degree. When examining conditions separately, A2 was equally delayed by VP and NP structure violations and the size of the effect was comparable to the aphasia group mean. In contrast, A21's response to phrase structure violations was atypical in relation to the aphasia group and indicated considerable difficulties in processing syntactic information. Contrary to expectation, he responded more quickly to nouns in violated phrases (e.g. *few progress*) than in non-violated phrases (e.g. *little progress*), as evident by the negative mean z-score difference (z = -.28). However, he did show a slight delay (z = .13), in recognizing target words in violated VP structures compared to non-violated structures, but this effect was more modest relative to the aphasia group.

With regard to premodification, the aphasic and neurotypical groups showed a NP/VP dissociation, where premodifiers facilitated recognition of verbs but not nouns. Relative to the group, both individuals with severe impairments exhibited atypical NP/VP responses to premodifiers. Although A2 showed comparable facilitation from VP premodifiers as the group, he displayed a clear processing advantage for bare (e.g. *Paul was afraid of SNAKES*) relative to premodified nouns (e.g. *John was afraid of the young SNAKES*). A21 was facilitated by both NP and VP premodifiers (NP z = .2; VP z = .22). His online sensitivity to premodifiers is unexpected in light of his severe comprehension difficulties as indexed by the TROG-2, which showed that he had difficulties understanding sentences that probed prepositions (e.g. item C2: *The duck is on the ball*), and his limited speech output (Excerpt 10) that lacked any function words, including premodifiers.

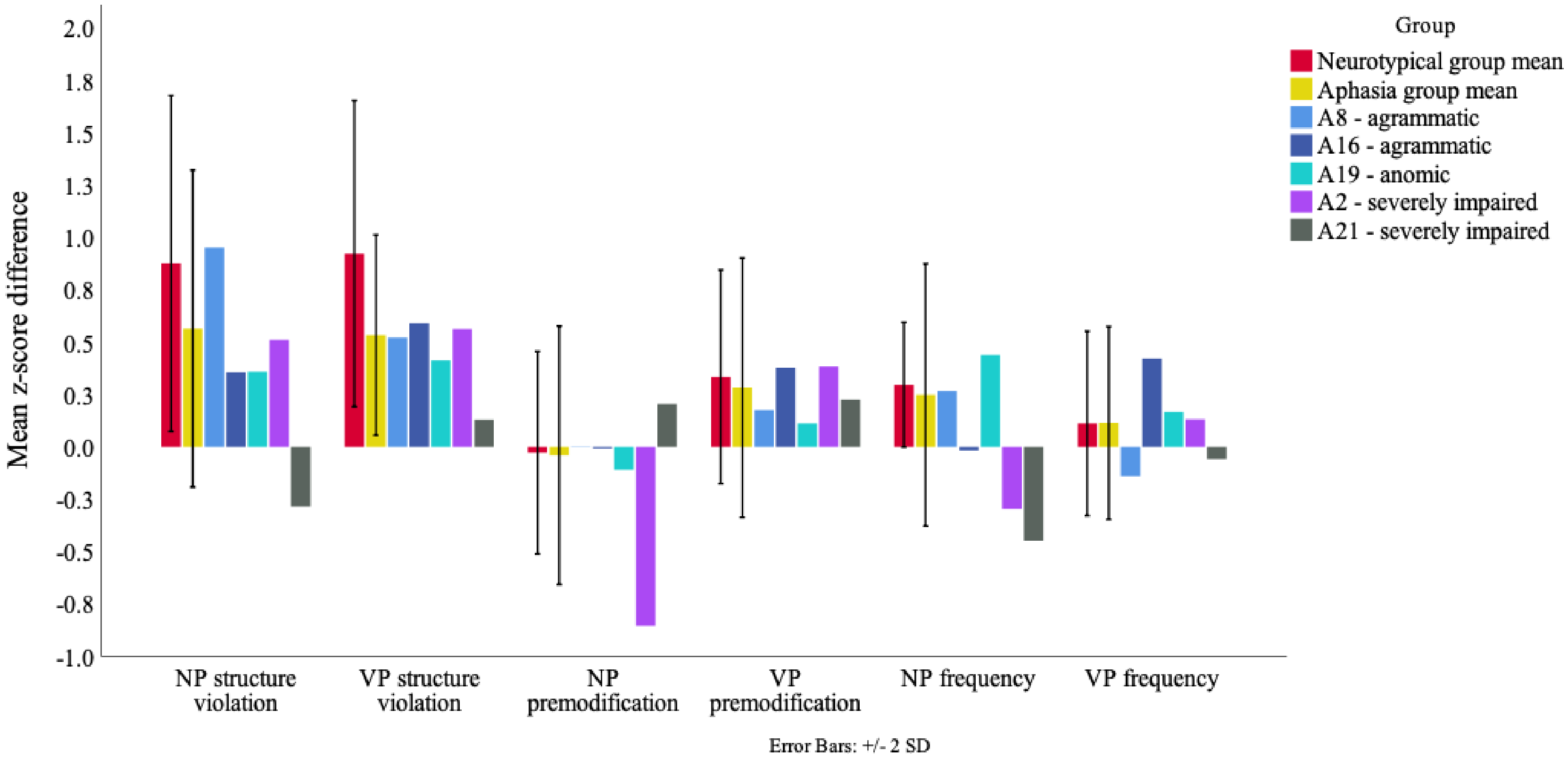


Figure 20 WMT Mean z-score difference scores for individuals included in the case analysis as well as aphasia and neurotypical group mean

The WMT assessed sensitivity to phrase frequency by measuring the speed at which nouns and verbs are recognized when embedded in high and low frequency phrases (e.g. NP high frequency: *Emma entered the SCHOOL where she had left her books*; NP low frequency: *Alice visited the SCHOOL she went to as a child*; VP high frequency: *There is not a lot of time to TURN if you miss your exit*; VP low frequency: *There is not a lot of space to TURN in case you drive wrong*). Neurotypical and aphasic groups displayed processing speed advantages for nouns when embedded in high relative to low frequency phrases, but weak frequency effects for verbs. Contrary to the group, both A2 and A21 were faster at recognizing nouns in low frequency phrases than high, but were similar to the group in their response to verbs.

Finally, the WMT patterns were examined in relation to performance on standard language and cognitive assessments. A2 and A21's difficulties in offline single word and sentence comprehension mirror to some extent their difficulties in the WMT task, as evidenced by their deviations from the group pattern and increased errors in the WMT task. Based on their TROG-2 and BNT scores, A2 was expected to perform slightly better on the WMT task than A21. This is somewhat substantiated given that A2 deviated less from the group WMT pattern, in particular when considering his preserved sensitivity to phrase structure violations. On the other hand, A21 showed a more complex response pattern that suggests greater difficulties in forming syntactic representations in real time. His performance in the online task was consistent with impairments in the offline measures.

In summary, both individuals with severe impairments exhibited atypical NP processing while their responses to VP conditions more closely resembled the group mean. A2's response to NP frequency (preference for low frequency phrases) and NP premodifiers (preference for bare phrases) indicate he displayed more atypicality in processing nouns. Similarly, A21 exhibited atypical noun processing as evidenced by his unexpected facilitation to NP premodifiers, and processing speed advantage for nouns in low frequency phrases.

6.2.3 Aphasia subtype analysis

6.2.3.1 Background profiles

Of the 21 participants in Experiment 2, two individuals were classified as agrammatic and one individual as anomic. Participant A8 was a 48-year old woman. She had effortful non-fluent speech and with agrammatic features based on the Cookie Theft narrative. Excerpt 12 is an example of her speech:

[12] *The woman is washing the dishes, but because like thinking about it. This is ehm, ehm, this is too too ti- too loose, and this is all over the - all over the (pause) - ehm, this (pause) yeah sorry. I can't remember. Ehm and then the boy is (pause) up on the (pause) the table (pause) his cookie jar, so his - his girl is all over- all over like this (sound). But cookie jar is, not cookie jar, is ehm his slip over the (pause) can't remember this one. That's all (laughs).*

Her speech was effortful and contained several long pauses rendering her narrative non-fluent. She produced fewer verbs compared to nouns, however, the verbs she did produce were semantically rich and differed in syntactic complexity (e.g. *slip, remember*). Her speech also contained grammatical morphemes (inflections and function words). While she produced several function words, some of these contained errors (e.g. *his slip over*) and omissions (e.g. *But cookie jar is*). A few of the function words were in the form of VP premodifiers, and these occurred within formulas (e.g. *I <u>can't</u> remember*). Her use of fixed expressions (e.g. *That's all, I can't remember*) enabled her to produce islands of fluent and error-free speech.

Her single word retrieval (27), as measured by the BNT, indicated moderate difficulties, and was within one standard deviation below the aphasic group mean (M = 35.6, SD = 14.9). Her understanding of single words was superior to her comprehension of sentences, which indicated she had moderate impairments (CAT = 26, TROG-2 = 11) and falling within the aphasia group average (M = 10.6, SD = 6). In contrast to her language abilities, her non-verbal reasoning and working memory span were intact (WASI-II MR = 18, digit span = 7 out of 7). Overall, her performance on the background assessment and the connected speech sample did not completely conform to the standard profile of agrammatism, as her speech was more connected than expected. However, she exhibited impaired comprehension and production, confirming the classic agrammatic patterns of cross-modal deficits (Zurif et al., 1972, 1976).

A16 was the second individual who was classified as having agrammatic aphasia. He was a 59-year old participant who had a single stroke. His speech was categorized as moderately to severely non-fluent agrammatic. Excerpt 13 is a sample of his Cookie Theft narrative.

[13] *Ehm, ehm the mother and two children, a boy and a girl. Ehm ehm ehm mother, washing up and ehm sink ehm ehm ehm sink flows down s- ehm ehm cupboard and floor and ehm mother very angry (laughs). Ehm ehm ehm plate ehm ehm plate and ehm washing ehm ehm drying a plate and ehm ehm p- ehm ehm and ehm a plate and two cups. ehm dry.*

Most of his utterances were limited to single words, however, there were a few islands of speech containing three to five words (e.g. *a boy and a girl*). His speech contained mostly nouns and a limited number of verbs. Many of the words or phrases he produced were not grammatically linked, as he often omitted function words and verbs that typically signal the relationship between other content words (e.g. *washing up and ehm sink*). His speech did contain a few grammatical morphemes in the form of noun and verb inflections (e.g. nouns: *flows*, *cups*, verbs: *drying a plate*). His use of function words was restricted to a few prepositions and articles, and lacking copulas and auxiliary verbs.

In addition to his non-fluent speech, his single word retrieval was moderately impaired, scoring 35 on the BNT. On the CAT spoken word subtest he scored 24 (out of 32) suggesting a mild comprehension impairment of single words. In contrast to his single word difficulties, his offline sentence comprehension appeared intact, attaining 18 blocks on the TROG-2 assessment. On the non-verbal intelligence measure (WASI-II), the participant was within the neurotypical range, scoring 18 (neurotypical M = 17.9, SD = 1.4).

His performance on the background assessments and the connected speech task do not conform to the classic agrammatic profiles of cross-modal deficits. Instead, he presented with impaired production of single words and connected speech, but preserved sentence comprehension. His characterisation more closely resembles agrammatic cases reported by Miceli et al. (1988) and Cararamazza, et al. (2001) where agrammatic production occurred independently from asyntactic comprehension.

A19 is a 56 year old man who was categorized as mild to moderately fluent anomic. Excerpt [14] is a sample of his Cookie Theft narrative.

[14] *Right, okay, it's like (unclear) a couple of kids. There's the ehm the little daughter and her son. And ehm he's been, he wants a lots of ehm jars full of ehm c- ehm ehm cookies aren't they, no - because the ah god knows the jam things, (unclear) be ehm nah they're called ehm ehm (pause) well ehm as the Americans call them cookies and it's easy. And the kids there's, that's where, is there, and ehm one of the kids about to eat everything.*

In contrast to the agrammatic speech described earlier, A19 produced prosodically normal sentences. While his speech output was fluent and appeared grammatically correct, it contained pauses and hesitations that indicate he had difficulties retrieving the names of items and sometimes used circumlocutions in place of names (e.g. *the jam things*). His sentences contained different types of function words, including premodifiers (e.g. *he's been*).

His single word retrieval and comprehension was mildly impaired, scoring 43 on the BNT and 27 on the CAT spoken word subtest. However, he had great difficulties understanding sentences (TROG-2 = 1). On non-linguistic measures, he was more impaired than the group, scoring one standard deviation below the aphasic mean on the non-verbal reasoning (WASI-II MR = 10) and working memory task (4 out of 7). Overall, his performance on the connected speech task indicated an anomic profile, and he additionally exhibited severe impairments in sentence comprehension (Caramazza & Berndt, 1978; Varley & Zimmerer, 2018).

6.2.3.2 Word monitoring task patterns

First, missing trials for the two agrammatic and one anomic individual were examined (Table 16). Overall, both agrammatic individuals (A16 and A8) had few missing trials. All except one of A16's rejected trials were in VP conditions, whereas A8 made an equal number of errors across the two phrase types. By contrast, the anomic individual (A19) made substantially more errors than the agrammatic individuals and the group mean. The majority of A19's missing trials occurred in VP trials, mostly due to timeouts (no button presses). After excluding missing trials, A16 and A8 had 90% and 93.33% of completed pairs, respectively. The data loss for the anomic individual (A19) was greater compared to the agrammatic individuals, and 65% of completed pairs were retained. His level of difficulty with the WMT, in terms of missing pairs, is comparable to the severely impaired individuals described above.

Differences between aphasia subtypes were also observed in relation to their mean raw reaction time. The mean RTs of both agrammatic individuals (A8 = 573.45ms, A16 = 616.25ms) were similar to the group mean (mean RT = 608.87, SD = 142.61), whereas the anomic individual, A19, was approximately on average one standard deviation slower (M = 793.95ms).

Table 16 Number of missing trials in the word monitoring task of the two agrammatic and one anomic individual in relation to the aphasia group mean

Participant	Early		Time out		Outlier		Total	
	NP	VP	NP	VP	NP	VP	NP	VP
A16	1	3	0	3	0	8	1	15
A8	2	0	1	0	1	4	4	4
A19	3	1	6	28	4	5	13	34
Aphasia group mean (SD)	2.81 (4.23)	2.33 (4.73)	1.43 (2.25)	3.05 (6.43)	3.81 (2.32)	5.29 (2.33)	8.0(5.6 8)5	10.6 7 (8.4 6)

Note: A16 = agrammatic, A8 = agrammatic, A19 = anomic

Next, NP/VP patterns were compared between the two agrammatic individuals (A8 and A16) and the anomic individual (A19). As can be seen in the earlier Figure 20, all three individuals exhibited similar NP/VP patterns as the aphasia group (yellow) and the neurotypical group (red), although each individual deviated from the norm in different conditions. NP and VP structure violations resulted in delayed word recognition in all three individuals. Similar to the aphasia group mean, the anomic individual A19 (turquoise) showed no dissociation between NP and VP structure violations. The two non-fluent individuals displayed opposite NP/VP patterns from each other. A16 (dark blue) was less sensitive to NP structure violations compared to VPs, while A8 (light blue) was more sensitive to NP compared to VP structure violations. Further, A8's NP sensitivity was at the level of neurotypical adults, suggesting her noun processing may be more preserved than verbs. Overall, the latencies to phrase structure violations indicate that all three individuals had accessed and processed syntactic information relating to verbs and nouns in real time.

With regard to processing NP/VP premodifiers, slightly different patterns were observed between the two aphasia subtypes. The NP/VP pattern for both agrammatic individuals mirrored that of the aphasia and neurotypical groups. Both A16 and A8 were faster at recognizing premodified verbs (e.g. *Frank should have kicked the ball*) compared to verbs in bare contexts (e.g. *Rob kicked the ball*). Similar to the neurotypical group, neither A16 nor A8 were facilitated by NP premodifiers. In comparison, A19 was minimally facilitated by VP premodifiers and displayed a slight processing advantage for bare relative to premodified nouns.

The WMT also assessed sensitivity to phrase frequency. Neurotypical and aphasic groups showed a frequency effect in NPs but not in VPs. This NP/VP pattern was observed in two of three individuals, but was not specific to aphasia subtype. A8 (agrammatic) and A19 (anomic) both showed the same NP/VP pattern as the aphasia group, whereas A16 (agrammatic) displayed the opposite pattern, reacting faster to verbs in high frequency phrases (e.g. *There is not a lot of time to turn if you miss your exit*) compared to low frequency phrases (e.g. *There is not a lot of space to turn in case you drive wrong*), but did not show a frequency advantage for noun-ending phrases.

Lastly, the WMT patterns of the two agrammatic and one anomic individual were examined in relation to their performance on standard language assessments. The three were heterogeneous with regards to offline sentence comprehension. Although A19 (anomic) exhibited greater impairments (TROG-2 = 1), compared to two agrammatic individuals (A8 = 11, A16 = 18), their WMT patterns were remarkably similar. One would have expected greater differences in WMT patterns between individuals with markedly different TROG-2 scores if the online and offline tasks were tapping into the same processes. This suggests that offline sentence comprehension, as measured by the TROG-2, was not related to performance on the WMT.

In summary, the two agrammatic individuals did not show a greater impairment in processing verbs or premodifiers. The lack of verb and function word impairment is supported by their sensitivity to VP structure violation and VP premodifiers, both of which were close to the aphasia and neurotypical group means. Similarly, A16 (anomic) resembled the group mean profile and did not exhibit greater difficulties in processing nouns, as shown by his sensitivity to NP structure violation and noun phrase frequency. He did make more errors in sentences probing verbs, (18%) relative to NP conditions (2%), which was the only indication that he experienced verb difficulties. In comparison to the agrammatic individuals, A19 did not show contrasting NP/VP patterns which might indicate greater difficulties with nouns compared to verbs. In fact, his responses closely resembled the group mean with the exception of the premodification condition, where he was not sensitive to either NP or VP premodifiers.

6.3 Discussion

In Experiment 2 (Chapter 5) the word-monitoring task (WMT) was used to explore differential processing of noun phrases (NP) and verb phrases (VP) in three different conditions, 1) phrase structure violations, 2) premodification and 3) phrase frequency. The aphasia group results revealed an absence of noun/verb dissociations by showing a sensitivity to NP/VP structure violations, VP premodifiers and NP frequency. However, it is likely that these findings, which are based on mainly mild to moderately impaired individuals, do not represent noun/verb processing in more severely impaired individuals. The group result may have also masked individual cases of noun/verb dissociations, especially in individuals with agrammatic or anomic aphasia that have, in past research, been associated with specific word class impairments. The aim of this investigation was to examine whether severity of impairment or aphasia subtype was associated with selective word class impairments.

The WMT patterns of the two agrammatic and the anomic individual were largely indistinguishable from the aphasic group mean and from each other, whereas the severely impaired individuals exhibited more marked deviations and a-typicalities, but also islands of residual processing. Consistent across individuals, with the exception of A21, the responses indicated sensitivity to NP and VP structure violations, as well as VP premodifiers, indicating that they had successfully constructed syntactic representations in real time. The observations of the individual case analysis challenge the view that aphasia subtype is linked to selective word class impairment in comprehension, but also highlights the differences between mild/moderate impaired and more severely impaired individuals. The following sections will discuss the findings of the WMT in severely impaired and in the agrammatic and anomic individuals in more detail.

6.3.1 Aphasia severity

The analysis of NP/VP patterns in more severely impaired individuals suggests that they deviated from the aphasic mean and revealed unexpected results. While the aphasia group mean showed no consistent word class impairment, both severely impaired individuals displayed atypical processing in response to NPs. Although A2 was sensitive to NP violated structures, he exhibited a clear preference for bare as opposed to premodified NPs and was faster at recognizing target nouns when they were embedded in low frequency phrases. A21 on the other hand, deviated from the group to a greater degree and exhibited atypical noun processing patterns as well. He was faster at recognizing target nouns in violated and low frequency phrases. The inverse frequency effect for NPs in both A2 and A21 is particularly difficult to explain, given that it implies that processing speed advantages for high frequency items are reversed following brain damage. Although, there is some evidence from single case studies that have described individuals who are more likely to produce low frequency items (e.g. *salamander*) than high frequency items (e.g. *cow*) (Hoffman, Jeffries, & Lambon Ralph, 2011; Marshall, Pring, Chiat, & Robson, 2001), this has mainly been observed in individuals whose speech is marked by semantic jargon. The inverse frequency effect in A2 and A21 is likely to reflect a more general difficulty in processing nouns.

Observations of greater anomalies on nouns was unexpected, given that previous research has emphasized greater verb difficulties in both fluent and non-fluent subtypes (Berndt et al., 2002; Jonkers & Bastiaanse, 1998; Luzzatti et al., 2002; Mätzig et al., 2009). Many of the theoretical accounts on selective word class impairments in aphasia claim that verbs are more difficult to process as they are either more semantically (Bird, Howard, et al., 2000), syntactically (Thompson, 2003) or morphologically complex (Tsapkini et al., 2002). However, these accounts fail to explain findings of selective noun impairments in severely impaired individuals. The greater anomaly in nouns also is different from the group findings from Experiment 2 which indicated a lack of noun/verb dissociations. It also contradicts previous results by Alyahya et al. (2018) who examined noun/verb dissociations in individuals with a range of impairment levels and reported an absence of noun/verb dissociations in all individuals but one. Interestingly, the one participant who did show a selective word class deficit was more severely impaired and had greater difficulties in identifying nouns compared to verbs, mirroring the current finding. The link between noun impairments and severe aphasia is still only tentative given the lack of noun/verb dissociations in the fairly large sample (N = 48) reported by Alyahya et al. (2018), including several individuals with severe impairments.

Rather than a true word class effect, a more simple explanation for atypical noun processing exhibited by A2 and A21, is that nouns and verbs differed on psycholinguistic or usage-based factors that had a greater impact in severely impaired individuals. While the stimuli were designed so that psycholinguistic and semantic variables were matched within contrasts (e.g. violated NP structure vs non-violated NP structure), it was difficult to ensure materials were matched in frequency across phrase type. The frequency of target nouns may have been lower than verbs, as verbs tend to be generally more frequent. This may have resulted in a general processing disadvantage for nouns. Further research and analyses are needed to investigate the link between severity and noun impairments while controlling for psycholinguistic variables and frequency.

Difficulties with input processing were reflected in the number of missed trials. In comparison to the group mean reported for Experiment 2, both severely impaired participants (32% and 24%) and also the anomic individual (35%) had more errors, indicating that they had greater difficulties with the task. Despite the number of errors, the WMT pattern of the anomic individual resembled the group mean, suggesting that sufficient data remained to draw valid conclusions. Considering that the two individuals with severe impairments had similar or lower error rates, their behavioural patterns seem to reflect genuine difficulties in sentence processing rather than artifacts from insufficient or noisy data, suggesting that the WMT is a suitable task to probe sentence processing in severely impaired individuals. One difference to previous WMT studies that have reported less data loss, is that the current analyses are based on reaction time differences between sentence pairs (e.g. high – low frequency) rather than comparing raw reaction time per sentence type (e.g. mean high frequency RT vs mean low frequency RT). The paired design leads to greater data loss as incomplete pairs get excluded from analysis. To retain as many responses as possible, it could be beneficial to reanalyse the data based on mean reaction times per sentence type rather than reaction time difference values. Another suitable method for probing noun and verb processing in individuals with severe impairments is EEG and ERP. An advantage of that method is that it does not require any behavioural responses, beyond listening or reading, greatly reducing task-induced confounds.

6.3.2 Aphasia subtype

Another aim of the case analysis was to examine whether agrammatism and anomia were associated with selective word class impairments. The agrammatic individuals, A16 and A8, were predicted to show greater verb and function word difficulties, whereas the anomic individual, A19, was predicted to have difficulties with noun processing. The in-depth analysis of their WMT responses did not reveal consistent and selective word class difficulties in either aphasia subtype. The WMT profiles of the two agrammatic and one anomic individuals were largely indistinguishable from the whole aphasic group. The lack of association between aphasia subtype and selective word class impairment is in line with previous studies at the group (Cho-Reyes & Thompson, 2012; Kim & Thompson, 2000; Thompson et al., 2012) and individual level (Alyahya et al., 2018). The latencies of all three individuals indicated that they accessed and processed syntactic information relating to verbs and nouns in real time. The anomic individual did not show the expected pattern of noun difficulties. In fact, he was strongly facilitated by frequency in noun-ending phrases. Both agrammatic individuals did not have greater verb or function word impairment compared to the whole aphasic group. The lack of verb and function word impairment is supported by their sensitivity to VP structure violations and VP premodifiers, both of which were within the aphasia and neurotypical group mean. The delay in recognizing nouns in the direct object slot following a transitive verb suggests that they had difficulties integrating the noun into the sentence, indicating that they were sensitive to the syntactic restrictions imposed by the verb. This finding is consistent with previous group studies that have reported online (Baum, 1989; Haarmann & Kolk, 1994) and offline (Kim & Thompson, 2000) sensitivity to syntactic restrictions of verbs in individuals with agrammatism. For example, using a WMT, Baum (1989) found that individuals with Broca's aphasia were delayed in recognizing nouns in a position that violated argument structure of verbs (grammatical: *The little boy waved at his FATHER on the corner*; violated: *The little boy waved his FATHER on the corner*). Moreover, Haarmann & Kolk (1994) reported preserved sensitivity to subject-verb agreement violations in a task that required individuals to build up long-distance dependencies (grammatical: *De vrouwen dragen het kind en eaten IJS / The women carry the child and eat ICE CREAM*; violated: *De vrouwen dragen het kind en eet IJS / The women carry the child and eats ICE CREAM*). Together, these findings challenge the view that individuals with aphasia, particularly of the agrammatic type, have selective damage to verb processing.

Another important finding was the relationship between sensitivity to premodifiers and aphasia subtype. Unexpectedly, the individual case analysis revealed that both agrammatic individuals, but not the anomic individual, were sensitive to function words. This residual ability processing implies that the function word impairments observed in production are not due to damage to a specialized function word processing system, but may be more specific to processes involved in language production. Further, the finding of residual function word processing in the anomic and particularly in the two agrammatic individuals is contrary to the majority of findings from previous studies. Notably, difficulties with function word processing are frequently reported in non-fluent aphasia subtypes (Bradley, Garrett, & Zurif, 1980; Friederici, 1985; Rosenberg et al., 1985; Grodzinsky, 1988; Swinney, Zurif, & Cutler, 1980). Further, the current finding of sensitivity to function words in the agrammatic individuals challenges the view that atypical function word processing is part of the symptom complex of agrammatism. Future research is needed to further explore online processing of function words in agrammatic as well as anomic individuals. It is also important to note that neither A8 nor A16 completely fit the classically agrammatic profile as described by Zurif and colleagues (e.g. Zurif et al., 1976). A8's speech output was more connected than typically observed in individuals with agrammatism, while A16 did not exhibit cross-modal deficits. Thus, further studies with classic agrammatic individuals are needed to explore the relationship between aphasia subtype and noun/verb dissociations.

The current individual case analysis also revealed a dissociation between production and input processing. Despite selective difficulties with producing verbs during spontaneous speech, the agrammatic individuals did not exhibit a similar impairment in input processing. Similarly, the anomic individual exhibited difficulties in retrieving nouns but did not show a comparable deficit during input processing. These deficit patterns show that selective word class impairments in production do not predict or necessitate corresponding deficits in input processing. The theoretical implications of these results are not straightforward. Most deficit accounts do not directly address and incorporate modality specific impairments into their model of the mental lexicon, with exception of lexical-based accounts. According to lexical-based accounts, the modality specific word class impairment exhibited by the anomic and agrammatic individuals points to damaged lexeme representations, while their intact lemma representation allows for residual input processing. Modality specific impairments pose a greater challenge to the semantic and syntactic accounts. Semantic accounts propose that verb impairments arise as a result of their greater semantic complexity relative to nouns. However, it is unclear how differences in semantic factors, such as imageability, between nouns and verbs, lead to difficulties in retrieval but not in comprehension. One explanation is that processes involved in comprehension make fewer demands on the semantic network compared to production, which enables residual functioning (Marshall, 2003).

6.3.3 Comparisons between standard and online measures

A further aim of the individual case series was to examine the relationship between WMT profiles and performance on standard clinical assessments such as the TROG-2. Offline sentence comprehension as measured by TROG-2 was not a reliable indicator of how well a person performed in the WMT, substantiating the group findings in Experiment 2. For example, the agrammatic individuals differed in their severity in the offline measure, but displayed similar patterns in the WMT. Based on his severe offline comprehension difficulties, the anomic individual was not expected to show sensitivity to the finer grained linguistic manipulations in the WMT. However, his response patterns exhibited strong similarities to the aphasic group mean, which suggests that the offline measure underestimated his residual language abilities. In addition, although both individuals with severe impairments did similarly poorly on the offline task, the online profiles revealed important processing differences between A2 and A21, especially in terms of their sensitivity to phrase structure violation, where A2 but not A21 exhibited residual sensitivity to both NP and VP structure violations. These differences would not have been apparent by standard offline profile.

One possible reason for the low agreement between the measures is that they did not probe the same sentence constructions. The current experiment was not designed compare the same sentences in offline and online tasks, rather the aim was to examine the relationship between commonly used and standardized offline measures of sentence comprehension and the WMT. However, it has been shown that differences in performance between online and offline measures persist even when identical stimuli are probed (Tyler, 1985). In comparison to online tasks, standard offline tasks may make additional demands on cognitive processes such as visual perception, increased working memory load and inhibitory control (Marinis, 2010). For example, the TROG-2 requires individuals to listen to sentences while simultaneously scanning and matching it to one of four pictures. In comparison to offline tasks, online tasks, such as the WMT, capture language processing in real time, which might be better at representing a person's language abilities in functional listening situations.

6. 4 Conclusion

Complementary to the group result in Experiment 2, the in-depth analysis of individual WMT patterns provided further insight into the residual abilities of individuals with severe impairments that would have been difficult to assess with standard measures. More severely impaired individuals showed different NP/VP patterns compared to individuals with milder impairments, providing initial evidence that severity may play a role in noun/verb dissociations, however, further analysis into psycholinguistic differences between the phrase types is needed to rule out confounds in the current design. Although the current study focused on comparing mild to severe impairments, it remains unclear whether NP/VP atypicalities occur only in severe cases or whether already moderately impaired individuals deviate from the NP/VP patterns. The individual case analysis further revealed that aphasia subtype is not associated with a clear NP/VP pattern and expanded previous offline and single word studies by providing online evidence against subtype specific word class impairments. Rather than selective word class impairments, the WMT patterns point to heterogeneous processing profiles that do not respect aphasia subtype boundaries and challenges accounts of agrammatism that emphasize cross modal deficits. Lastly, performance on standard offline tasks were poor indicators of residual online language abilities.

7. Experiment 4: Online verb processing in neurotypical younger and older adults: An ERP study

7.1 Introduction

Processing of nouns and verbs can appear differentially impaired in individuals with aphasia. While researchers have initially focused on occurrences of double dissociations (i.e. impaired processing of verbs but intact knowledge of nouns – or vice versa), more recently, studies have found greater impairment of verbs compared to nouns (Luzzatti et al., 2002; Mätzig et al., 2009). Verb impairments were generally found in individuals with fluent and non-fluent forms of aphasia (Bastiaanse & Jonkers, 1998; Berndt et al., 2002; Berndt & Haendiges, 2000; Jonkers & Bastiaanse, 1998; Luzzatti et al., 2002; Mätzig et al., 2009). However, verb impairments are not consistently found when probed across modality (production vs comprehension) or level (words vs sentences), suggesting that specific processes involved in production, perception or comprehension of verbs are damaged rather than the underlying structural knowledge of verbs. For example, verbs are more consistently found to be impaired when probed with single word production tasks (Chen & Bates, 1998; Lu et al., 2002; Luzzatti et al., 2002; Mätzig et al., 2009). In contrast, the extent of the impairments are diminished when probing verbs in offline and online sentences tasks (Cho-Reyes & Thompson, 2012; Kim & Thompson, 2000; Shapiro & Levine, 1990; Thompson et al., 2012; Wayland et al., 1996). For example, Wayland, Berndt & Sandson (1996), measured the reaction time (RT) to nouns and verbs embedded in congruent or incongruent semantic and syntactic contexts and found intact sensitivity to verbs (and nouns) in eight individuals with aphasia. In line with previous findings from sentence-level tasks, the group results of the online word monitoring task (WMT) reported in Experiment 2 Chapter 5, showed that the recognition of verbs was not consistently more impaired than nouns in individuals with aphasia. Together, these findings demonstrate that processing of verbs is aided when placed in sentential context. One explanation for this effect emphasises the syntactic nature of verbs. Verbs are inherently relational and usually require a subject (and a direct object) and are therefore "at home" in sentences which provide richer syntactic information and thus, facilitate processing of verbs. Probing verbs in isolation may at least partially contribute to the observation that verbs are more impaired.

Thus, sentence-level experiments are essential to better understand verb processing in aphasia. A methodology that is well suited to studying real-time processing of verbs embedded in sentences is measuring event-related potentials (ERPs). ERPs are small voltage changes in electrical brain potentials that are time-locked to specific events. The temporal resolution of ERPs make it possible to investigate differences in language processing in the order of hundreds of milliseconds. This resolution provides an insight into the time course of cognitive processes involved in language processing. One relevant ERP component, when probing grammatical aspects of verbs in sentences, is the P600. The P600 is a positive-going component which is most prominent over centro-parietal scalp sites. Some researchers have proposed that the P600 is divided into an early component, starting approximately 500ms after a syntactically incongruous word, and a late component starting after around 900ms, and persisting for several hundreds of milliseconds (Hagoort & Brown, 2000; Molinaro et al., 2008). The early P600 is equally prominent over anterior and posterior regions, whereas the late P600 is largest in posterior scalp regions (Hagoort et al., 2000). The P600 has been recorded in response to numerous types of syntactic violations (Hagoort et al., 1993; Osterhout & Mobley, 1995; Vos et al., 2001). It has been consistently observed in subject-verb number agreement violation, where a singular subject is mismatched with a plural verb form or vice versa (e.g. *The bird builds a nest in the tree/ *The birds builds a nest in the tree*). Similarly, the P600 has been observed in sentences with verb-argument structure violations (e.g. *The tired young man elapsed the book on the floor*) (Ainsworth-Darnell et al., 1998; Hagoort et al., 1993; Osterhout & Holcomb, 1992), and word category violations (e.g. *La prueba ocultada por el <u>apareció</u>* / *The proof (that was) hidden by the <u>appeared</u>*) (Hinojosa et al., 2003). However, the P600 does not only occur when there are obvious syntactic violations but also for sentences which are syntactically ambiguous and require re-parsing, such as garden path sentences (e.g. *The broker persuaded to sell the stock was tall*) (Kaan & Swaab, 2003; Osterhout & Holcomb, 1992). The P600 has been proposed to reflect reanalysis processes, reprocessing costs or difficulties in syntactically integrating upcoming words (Friederici, 2002; Kaan et al., 2000; Osterhout et al., 1994). It is important to mention that the P600 is not a syntax-specific component, as non-syntactic anomalies, such as semantic incongruencies and spelling errors, as well as violations in non-language contexts such as music and mathematics, also elicit a P600 response (Martín-Loeches et al., 2006; Patel et al., 1998). For a non-syntactic interpretation, consider the results by Coulson, King and Kutas (1998) which suggest that the P600 is part of an earlier component, the P3b, that is associated with unexpected or surprising stimuli.

A growing number of researchers have conducted ERP studies to examine verb processing in aphasia (Hagoort et al., 2003a; Kielar et al., 2012; Kotz et al., 2003; Wassenaar et al., 2004). Initial evidence suggests that the electrophysiological responses to verb violations are atypical in aphasic individuals compared to healthy older adults. For example, Hagoort, Wassenaar & Brown (2003) and Wassenaar, Brown & Hagoort (2004) examined sensitivity to subject-verb agreement violations by measuring the modulation of the P600 response in individuals with aphasia and healthy older adults (e.g. *The women pay the baker and <u>take/takes</u> the bread home*. In Dutch: *De vrouwen betalen de bakker en <u>nemen/neemt</u> het brood mee naar huis*). In both studies, older adults showed a P600 effect with an onset of approximately 500ms after the violation point. However, the ERP response from the aphasic group was distinctly different from that of the neurotypical older adults. Unlike healthy older adults, individuals with aphasia did not show a P600 effect in response to violated verbs. The researchers argued that the absence of the P600 effect was most likely due to an insensitivity to verb morphology. Although the aphasic groups overall did not show a significant P600 effect, the size of the ERP response was modulated by the severity of syntactic impairment in comprehension. In other words, a sub-group of individuals with milder impairments in syntactic processing, as measured by an offline task, showed a more typical P600 response to the verb violations compared to a sub-group with severe syntactic impairment. However, caution is needed when interpreting this finding as the sample sizes of the sub-groups used to compare the relationship between severity and size of ERP component were very small (five individuals in each group). Nevertheless, initial ERP evidence suggests that some individuals with aphasia do not show the same P600 in response to verb violations in sentences. Sensitivity to the violations required processing of number marking on verbs. It is possible that the lack of P600 reflects impaired processing of bound inflectional morphology, while other aspects of verb processing remained intact. While these are important initial findings, studies with larger sample sizes are essential to provide further evidence whether individuals with aphasia show atypical responses during verb processing and to distinguish between impairments of verb stems and their attached inflections.

Although the current study does not report patient data, measuring modulations of P600 responses is a promising avenue for investigating verb processing in sentences. An initial and important step in understanding ERP data from individuals with aphasia is to compare them against non-brain damaged and age-matched individuals. The current knowledge on the P600 effect of subject-verb agreement violations relies almost exclusively on reading studies conducted with younger healthy adults (Coulson, King, & Kutas, 1998; Kaan et al., 2000; Osterhout & Mobley, 1995 and see Molinaro, Barber, Carreiras, 2011 for a review). In younger adults, subject-verb agreement errors typically elicit a P600 effect with a centro-parietal distribution. The latency of the P600 in younger adults varies, with some studies reporting onsets after 500ms (Hagoort et al., 1993; Kemmer et al., 2004; Molinaro et al., 2008; Osterhout & Mobley, 1995) or after 700ms (Hagoort & Brown, 2000; Kaan et al., 2000; Kaan & Swaab, 2003). To date, only one study has examined whether healthy aging affects the P600 response to subject verb-agreement violations. Kemmer, et al. (2004) compared the P600 response in a group of younger and older neurotypical adults while reading sentences containing subject-verb number agreement errors and judging whether they were well-formed (e.g. *Industrial scientists <u>develop</u> many new consumer products/*Industrial scientists <u>develops</u> many new consumer products*). Their results showed that the P600 of older adults was similar in terms of latency and amplitude to that of the younger adults, indicating an absence of an age-effect in verb processing. Notably, older adults were less accurate than younger adults in judging whether the sentences were grammatical, suggesting that age-related differences arise during a later stage in processing. A possible explanation for the dissociation between the offline and online findings, is that the tasks make different demands on cognitive processes such as working memory. Offline tasks, such as a grammaticality judgment task, measure how an individual processes a sentence *after* hearing the complete sentence. This places a demand on working memory as the listener needs to process the sentence, keep it in working memory, and then make a judgment on it.

In contrast, online methods, such as EEG, measure individuals' language processing as it unfolds over time, and thus place less demand on working memory. As working memory is known to decline with age, older adults may show greater difficulties with offline tasks compared to online measures, underestimating their language abilities (Braver & West, 2008; Just & Carpenter, 1992). The absence of an age-related difference in online processing is surprising, given that older adults have been found to show reduced amplitudes and delayed peaks of other components such as the N400 (Federmeier et al., 2002; Federmeier & Kutas, 2005).

Another approach to investigate verb processing is to examine linguistic elements that facilitate processing of verbs. Premodifiers, for example, serve an important role in processing verbs. In comparison to verb inflection violations (e.g. *The toddler bounces/*bounce on the bed*), premodifiers are free morphemes and thus perceptually more salient. Verb premodifiers consist of modal (e.g. *can, could, will*) and auxiliary verbs (e.g. *be, do have*) and, while syntactically important, they are semantically light. They precede, and therefore signal, upcoming head verbs (e.g. *Rose should have tipped the waiter*). The result of the word monitoring task in Experiment 1 Chapter 4 has provided initial evidence that premodifiers facilitated verb processing in healthy older and younger adults, as verbs which were preceded by premodifiers (e.g. "Frank should have kicked the ball to his team mate"), were recognised more rapidly than in non-facilitated contexts where premodifiers were absent (e.g. "Frank kicked the ball to his team mate"). Although older adults were generally slower in their response time, the size of the facilitation was similar to that of younger adults. A likely explanation for this effect is that the conditional relationship between premodifiers and head verbs allowed listeners to anticipate upcoming verbs upon encountering a premodifier such as an auxiliary verb. However, it remains unclear whether the facilitation effect of premodifiers is associated with electrophysiological markers. Evidence from electrophysiological studies suggests that individuals use many different types of cues in sentential contexts to predict semantic (Federmeier et al., 2002; Federmeier & Kutas, 1999), as well as morphosyntactic (Van Berkum et al., 2005; Wicha et al., 2004) features of upcoming words. When making semantic predictions of upcoming words, research has shown that individuals are more likely to predict the word "*bread*" than "*cream*" after hearing "*The kids fed the ducks some stale…*" (Bloom & Fischler, 1980). The N400, a negative going component which peaks around 400 ms after stimulus onset, is linked to the semantic expectancy of a word within a context. The size of the N400 component is inversely correlated with the expectancy of a word, whereby words that are more predictable tend to elicit a smaller N400 (i.e. less negative) response (Federmeier, 2007). In a series of studies, Federmeier and colleagues observed age-related differences in how individuals use contextual information to predict the semantics of upcoming words (DeLong et al., 2012; Federmeier et al., 2003, 2010; Federmeier & Kutas, 2005; Wlotko et al., 2012). For example, in younger adults, the N400 amplitude is known to be reduced for target words that are highly predictable due to strongly constraining sentences compared to when the same target words are less predictable due to a weakly constraining sentence (e.g. strongly constraining: *The cold drink was served with a slice of lemon*; weakly constraining: *The only food left in the barren refrigerator was a mouldy lemon*). While older adults had a qualitatively similar N400 response to younger adults, it was not modulated by context to the same degree and amplitudes in strongly constraining sentences were not as reduced as in younger adults. Federmeier and colleagues suggested that these age-related differences in strongly constraining sentences indicate that older adults are less efficient in using information from sentence context to predict upcoming words.

While the current investigation draws on the knowledge from previous research which assessed age-related differences in the influence of contextual information on predictive processes, there are important differences. In contrast to previous studies which have focussed on measuring the extent to which individuals can predict the semantics of a given word, the current study probes whether a specific syntactic category (verb) can be anticipated. For example, the meaning of the word "*kicked*" is not necessarily more predictable than the word "*cut*" after hearing "*Frank should have…*". However, in this context, the occurrence of a verb is more predictable than that of a noun. Therefore, it is not expected that the premodified verb will result in a reduced N400 compared to the non-premodified verb. It is still unclear, whether the facilitation effect of premodifiers to anticipate upcoming verbs is associated with an electrophysiological response.

7.1.1 Present study

This experiment expands the findings from the word monitoring experiments reported in Chapter 4 and 5 by further exploring the more unexpected and intriguing behavioural results, in particular verb and function word processing. The electrophysiological investigation of verb and function word processing was adapted due to differences in methodological constraints. One main methodological constraint in ERP research is the need for identical pre-target words across paired sentences, as different pre-target words result in unequal baselines. Since the VP structure violation (e.g. VP: **looking/watching FILMS*) and premodification conditions (e.g. VP: *Tom should have KICKED/ Tom KICKED*) of the behavioural experiments had different pre-target words, the stimuli were adapted. Thus, the ERP experiment probed a more subtle but well-established morphosyntactic violation (e.g. The toddler *BOUNCE/BOUNCES the ball) to complement an ERP-adapted and exploratory investigation of function word processing (e.g. Rose *must have* finally TRAVELLED/ Rose finally TRAVELLED).

The aim of the current study was to investigate age-related changes in neurotypical adults in online processing of verbs embedded in sentences. Two distinct types of experimental materials were developed to measure electrophysiological responses to verbs in different contexts. The first condition examined age-related changes in the P600 response to subject-verb agreement violations. The second condition explored the facilitative effect of pre-verbal modifiers on participants' brain response to verbs, by comparing their ERP response to bare and premodified verbs. A further aim of the study was to establish normative ERP responses and assess the suitability of the task for a future study with individuals with aphasia.

The ERP experiment aimed to answer three main research questions:

1) Do younger and older adults differ in the latency, amplitude or topographical distribution of the P600 in response to subject-verb agreement violations?
2) Are there electrophysiological responses that are associated to facilitated verbs?
3) Do older and younger adults show the same electrophysiological responses to facilitated verbs?

In response to subject-verb agreement violations, younger and older adults were not expected to differ in terms of latency and amplitude of the P600. It was likely, however, that the age groups may show differences in the topographical distribution of the P600. Further, it was predicted facilitated verbs would be associated with an electrophysiological marker. This marker was expected to be similar across age groups.

7.2 Method

The experiment was approved by the Research Ethics Committee at University College London (approval number SHaPS-2014-JT-008). All participants gave informed written consent. Participants were paid £20 to attend a single experimental session.

7.2.2 Participants

Two groups of neurotypical adults were recruited: older and younger adults. All had no previous history of speech, language or cognitive impairment. They had unimpaired or impaired-to-corrected vision and were monolingual or bilingual native speakers of English.

7.2.2.1 Older adults

Twenty five older adults were recruited through charity organisations, social media, online subject pool and a lab internal research volunteer list. Two participants were excluded from all further data analysis because of severe hearing impairment or due to a technical fault during the EEG recording. The final group consisted of 23 adults (3 men) and ranged in age between 45 and 80 years (mean 62.83, SD = 9.97). Table 17 provides demographic information and scores on background measures. All older adults scored 25 or above on the Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005) which was used to screen for mild cognitive impairment and dementia. All except two participants had normal hearing as defined by pure-tone threshold of 25dB hearing loss (HL) or better, calculated as a mean over octave frequencies 250Hz to 4000Hz in the better ear.[9] All individuals except two were right handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). In a phonological working memory task (Wechsler Adult Intelligence Scale – 4th edition digit span forward; Wechsler, 2008) the mean score was 9.39 (SD = 2.53) (of 14). They had a mean of 16.2 (SD = 2.35) years of formal education, with nine participants achieving post-graduate level.

7.2.2.2 Younger adults

Twenty younger adults (13 women) were recruited through an online subject pool. Data from one participant had to be excluded due to excessive blinking or motion artefacts and a further participant was excluded after reporting a head injury following a road traffic accident. The final group consisted of 18 participants with a mean age of 25.72 years (SD = 4.75, range = 20 to 35). Table 18 provides information regarding their demographic and background measures. The audiometry measurements indicated all had normal or near normal hearing. The same audiometry criteria were applied as for older adults. They had a mean of 16.58 (SD = 2.17) years of formal education, with nine participants achieving post-graduate level and thus matched with the older adult group, $t(39) = .51$, $p>.05$. In the phonological working memory task (WAIS – IV) the group mean score was 8.78 (SD = 2.39) (of 14), which was similar to older adults, $t(39) = .79$, $p>.05$. All except four individuals were right handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971).

[9] The stimuli were presented through in-ear headphones at a comfortable listening level, which was adjusted to the participant's preference, if needed. All participants reported hearing the stimuli well.

Table 17 Demographic information and background assessments of older adults

Participant	*Age*	*Gender*	*TROG*	*Handedness*	*Digit span*	*Education*		*MoCA*	*Hearing (mean dB)*	
						Level	*Years*		*Right*	*Left*
1	45	F	19	R	12	Postgraduate	17	30	8	10
2	69	M	20	R	10	University	16	30	15	9
3	64	F	19	R	11	Sixth form	13	29	23	32
4	66	F	17	R	11	Postgraduate	17	28	17	21
5	66	F	19	R	4	University	17	29	21	12
6	68	F	18	R	6	Postgraduate	18	28	14	16
7	71	F	17	R	8	University	14	29	14	14
8	58	M	19	R	8	Postgraduate	18	30	15	18
9	66	F	17	R	12	University	17	29	13	12
10	68	F	18	L	11	University	16	30	16	18
11	65	F	19	R	14	Postgraduate	18	29	13	15
12	51	M	18	R	11	Postgraduate	18	30	12	14
13	19	F	17	R	8	University	15	29	6	5
14	71	F	16	R	10	University	11	29	7	6
15	51	F	18	R	12	University	13	26	10	15
16	80	F	20	R	6	Postgraduate	19	27	24	34

17	61	F	20	R	10	Postgraduate	18	29	10	14
18	78	F	19	R	13	University	14	25	15	16
19	50	F	17	L	9	University	18	27	14	19
20	63	F	19	R	8	University	16	29	7	9
21	69	F	18	R	6	Sixth form	13	28	28	26
22	45	F	18	R	8	Postgraduate	21	25	4	7
23	71	F	18	R	8	University	16	28	28	28
Group mean (SD)	61.52(13.28)		18.26(1.1)		9.39(2.53)		16.22(2.35)	28.39(1.5)	14.52(6.63)	16.09(7.82)

Note: TROG = Test for Reception of Grammar 2nd edition, Digit span = Wechsler Adult Intelligence Scale 4th edition, MoCA = Montreal Cognitive Assessment

Table 18 Demographic information and background assessment of younger adults

Participant	*Age*	*Gender*	*TROG*	*Handedness*	*Digit span*	*Education*		*Hearing (mean dB)*	
						Level	*Years*	*Right*	*Left*
1	35	F	18	L	10	University	17	2	3
2	26	M	20	L	12	Postgraduate	19	3	1
3	34	M	16	R	11	Postgraduate	17	10	10
4	26	M	17	R	7	University	16	11	12
5	33	M	19	L	11	Sixth form	12	7	6
6	20	F	20	R	12	University	14.5	3	1
7	22	F	19	R	19	University	17	9	10
8	21	F	16	R	8	Sixth form	14	5	2
9	29	M	17	R	6	University	16	11	0
10	21	M	15	R	6	University	16	11	7
11	29	F	18	R	7	Postgraduate	20	10	8
12	25	F	19	R	11	Postgraduate	17	4	3
13	26	F	19	R	8	University	14	9	10
14	23	F	20	R	12	Postgraduate	18	4	4
15	21	F	19	R	7	Postgraduate	17	11	9
16	20	F	20	R	6	University	15	6	7.8

17	26	F	19	R	6	Postgraduate	20	2	0
18	26	F	18	L	7	Postgraduate	19	11	1
Group mean (SD)	25.73(4.75)		18.28(1.53)		8.78(2.39)		16.58 (2.17)	7.17 (3.52)	5.27 (4.03)

Note: TROG = Test for Reception of Grammar 2nd edition, Digit span = Wechsler Adult Intelligence Scale – 4th edition

7.2.3 Language & cognitive assessment battery

Older and younger participants completed background profiling that also included linguistic, nonlinguistic, and general cognitive assessments. Younger adults did not complete the cognitive impairment assessment (MoCA) as they were expected to be at ceiling. All participants also completed a hearing test and a handedness questionnaire.

7.2.3.1 Offline sentence comprehension Offline sentence processing was assessed using *Test for Reception of Grammar 2nd edition* (TROG-2*;* Bishop, 2003). TROG-2 is an 80 item, auditory sentence picture-matching comprehension task. It is designed to assess individuals' comprehension of 20 different sentence constructions such as reversible passives and constructions involving contrasts on function words and pronouns. Participants heard a sentence and were presented with four pictures. Participants selected the picture that best matched the sentence. Blocks increase in difficulty. Testing was discontinued when 5 consecutive blocks contained one or more wrong answers. Individuals' score reflects number of correct blocks.

7.2.3.2 Cognitive screening test The presence of mild cognitive impairment was assessed using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The test assesses visuospatial abilities, executive functioning, short-term memory, and several language related skills such as naming, verbal fluency and sentence repetition. The maximum test score is 30, and a score of 22 indicates mild cognitive impairment.

7.2.3.3 Phonological working memory Phonological working memory capacity was assessed with the Digit span forward subtest of the Wechsler Adult Intelligence Scale 4th edition (WAIS – IV; Wechsler, 2008). The subtest consisted of 14 items with each item representing 1 point. The examiner presented a string of numbers which the participant had to repeat in the same sequence. Items increased in difficulty as the length of the sequence of digits increased.

7.2.3.4 Handedness The Edinburgh Handedness Inventory (Oldfield, 1971) was used to assess participant's handedness. The questionnaire consists of ten activities or objects for which participants indicate their hand preference.

7. 3 Materials

The total stimulus set consisted of 210 sentences of which 150 were experimental sentences and 60 filler sentences (see Appendices B.1, B.2 and B.3 for full stimuli list). Among the experimental stimuli, 80 sentence quartets were created to probe subject-verb agreement (see Table 19 for an example). In the non-violation conditions, the verb had the same number feature as the subject, while in the ungrammatical conditions the verb mismatched the subject in its number feature. In order to counterbalance the verb's number feature and its grammaticality, a singular subject was used in half of the sentences, while a plural subject was present in the other half. The critical word (the verb) was in same position for each sentence quartet.

Table 19 Subject-verb agreement conditions and example items - Experiment 4 ERP experiment

Subject number	**Sample material**	
	Grammatical	**Ungrammatical**
3rd person singular	The toddler bounces on the bed	The toddler BOUNCE on the bed
3rd person plural	The toddlers bounce on the bed	The toddlers BOUNCES on the bed

A further 70 sentence pairs were designed to examine the effects of verb premodification. As shown in Table 20, the critical word (verb) was preceded by premodifiers (e.g., *must have*) in the premodification condition but not in the neutral condition. An adverb immediately preceded the target word, in order to create an identical baseline across conditions. The critical words (verbs) were in the same position for sentence pairs.

Table 20 Verb premodification conditions and example items - Experiment 4 ERP experiment

Type of manipulation	**Sample material**
Neutral	On Saturday Rose finally TRAVELLED to Scotland to visit her friends
Premodified	Rose *must have* finally TRAVELLED to Scotland to visit her relatives

The experiment also contained 60 filler sentence pairs. The filler items were derived from a previous experiment by Chow et al. (2014) that probed the effect of cloze probability on the N400. Minor lexical adaptations were made to reflect native British wording. The cloze probability of a word refers to proportion of participants who respond with that word in a sentence completion task (Taylor, 1953). The filler items consisted of sentence pairs that contained a high or low cloze critical word (Table 21).

Each critical word appeared in a sentence frame where it had a high cloze probability and in a sentence frame where it had a low cloze probability.

Table 21 Filler conditions and example items - Experiment 4 ERP experiment

Sentence type	Sample material
High cloze	They drank champagne to celebrate their twelfth wedding ANNIVERSARY with friends and family
Low cloze	They ate ice cream and cake at his birthday ANNIVERSARY last Sunday afternoon

7. 3.1 Critical word

There were phonological constraints on the selection of critical words (CW) as it is crucial to accurately identify the onset of the target word as ERP components are measured from that onset. The criteria outlined in the "Phonetics for word monitoring" manual were applied to construct the stimuli (Brekelmans & Meitanis, 2016 unpublished manuscript, see Appendix A.3). Praat software (Boersma & Weenink, 2015) was used for determining target onset and extracting onset times. To ensure accuracy and consistency of target word onset times, onset times of target words for 20% (N = 116) of randomly selected sentences were compared between two different raters. To determine interrater reliability, a two-way mixed absolute agreement intra-class correlation (ICC) (McGraw & Wong, 1996) was conducted. The ICC between the two raters was high, ICC = 1.0, which indicates excellent reliability (Cicchetti, 1994).

7.3.2 Pre-processing of auditory stimuli

Auditory stimuli were recorded in an anechoic chamber, using ProRec recording software version 2.2 (Huckvale, 2016). The stimuli were recorded by a female native speaker of British English. All recordings were first high pass filtered at 50Hz to filter out DC offset. They were then downsampled to 22050 sampling rate, and had their amplitudes equalized to 70 dB. Extraneous noise at the beginning and end of the recording were cut.

7.3.3 Procedure

All participants gave informed written consent. Participants were tested in a single session lasting approximately 120 minutes. Table 22 shows the task order. In the first part of the session, individuals completed the background language and cognitive assessments. Younger adults did not complete the cognitive screening test (MoCA) as they were expected to be unimpaired. Next, participants completed the EEG experiment that lasted approximately 90 minutes, including the application of electrodes. Participants were seated comfortably approximately 100 cm from a computer screen in a dimly lit, sound-proof and electrically shielded booth. Participants were asked to listen to aurally presented sentences over ear-insert phones. Each sentence was preceded by a fixation cross that appeared in the centre of the screen for three seconds. Participants were instructed to avoid blinking or moving their eyes while the sentence was presented auditorily. To familiarize participants to the task, participants completed a practice block consisting of ten trials before the experimental session. The experimental session consisted of a total of 210 stimulus sentences, including 60 filler sentences. Sentences were quasi-randomly distributed across 5 blocks to ensure that participants only heard one sentence of the verb premodification and filler pairs or one sentence from the subject-verb agreement stimuli quartet. Per individual, sentences were randomized within blocks, while the order of the blocks was randomized across participants. In order to ensure listeners were paying attention to the sentences, they were asked to make a Yes/No plausibility judgment after each filler sentence, via button press.

Table 22 Session order for the ERP experiment

Session order
1. Information sheet
2. Consent forms
3. Background information (via interview)
4. Hearing test (Pure-tone audiometry)
5. MoCA
6. TROG-2
7. Edinburgh Handedness Inventory
8. WAIS -IV Digit span forward
9. EEG recording
Total time = approximately 120 minutes

Note: MoCA = Montreal Cognitive Assessment, TROG-2 = Test for Receptive Grammar 2nd edition

7.3.4 EEG recording

The electroencephalogram (EEG) was continuously recorded from 32 electrodes mounted in an electrode cap each referenced online to the left mastoid and re-referenced offline to the average activity recorded from the right and left mastoids. Scalp recording sites included: midline: Fz, FCz, Cz, CPz, Pz, Oz; left hemisphere/lateral (FP1, F3, F7, FC3, FT7, C3, T7, CP3, TP7, P3, P7 and O1) and right hemisphere (FP2, F4, F8, F4, FT8. C4, T8, CP4, TP8, P4, P8 and O2). The electro-oculogram (EOG) was recorded at two sites. Horizontal eye movement was recorded from an electrode placed at the outer canthus of the left eye, and vertical eye movement was recorded from an electrode placed below the right eye. Electrical impedances were kept below 25 KΩ. The data were digitized at 2048 Hz and downsampled offline at 512Hz. The EEG and EOG were filtered using an IIR (Butterworth) bandpass filter of 0.1-40Hz.

7.3.5 EEG data processing and analysis

Prior to analysis, the continuous data were epoched and decomposed by Independent Component Analysis (ICA). Components whose time course and scalp distribution matched eyeblinks or, eye movements, or muscle tension artefacts, were excluded using visual inspection. The epoched data was further inspected visually to exclude remaining artefacts. Data from a participant was only included for conditions if they had a minimum of 15 complete sentence pairs. Following artefact rejection, the subject-verb agreement analysis included 16 younger and 23 older adults, and the filler condition comprised data from seven younger and 19 older adults. Due to technical difficulties during the verb premodification condition, six younger and 12 older adults remained with sufficient trials to be included in the analysis.

ERPs were extracted from each trial for 1200ms after target critical word onset and with a 200ms pre-stimulus baseline. The analysis included nine electrodes which were of topographical interest: left-anterior; F3, midline-anterior: Fz; right-anterior F4; left-central: C3; midline-central: Cz; right-central: C4; left-posterior: P3; midline-posterior Pz; and right-posterior: P4. In accordance with previous studies which have examined subject-verb agreement processing, statistical analyses on mean voltage amplitudes were conducted for the following three time windows: 300 – 500ms for the LAN (left anterior negativity), 600 – 800ms and 800 – 1200ms for the P600/late positivity. In the verb premodification condition, the following time windows, based on visual inspection of the waveform, were chosen for analysis: 200 – 400ms, 400 – 600ms, and 600 – 1000ms post-verb onset. Last, the statistical analyses for the filler sentences were conducted for two time windows: 300 – 500ms and 700 – 1100ms corresponding to N400 and P600 effects, respectively. The Greenhouse-Geisser corrected F values are reported in univariate tests with more than one degree of freedom (Greenhouse & Geisser, 1959).

7.4 Results

The section first describes the accuracy of the plausibility judgment task. This is followed by the analyses of the ERP data from the experimental conditions (subject-verb agreement condition, verb premodification) and filler items, using mixed factorial ANOVAs.

7.4.1 Behavioural response

The groups' accuracy in the plausibility task was calculated by taking the mean correct responses for the filler sentences for each participant separately, and then averaging across the groups (Table 23). Accuracy in the plausibility judgment task was high and not significantly different across older and younger adults, $t(39) = 1.42$, $p>.05$. The two groups were also similar in the types of errors, with small numbers of false positives (responding "yes" to implausible sentences), and a slightly higher false alarm rate (responding "no" to sentences which were plausible).

Table 23 Accuracy in the plausibility judgment task in Experiment 4

Group	Mean accuracy % (SD)	False positives % (SD)	False alarm % (SD)
Older adults	85% (5.42)	2.17 (2.68)	12.32 (4.32)
Younger adults	82% (9.65)	4 (2.95)	13.86 (8.88)

7.4.2 Subject verb agreement results

Figure 21 shows the grand average ERPs for the nine regions of interest for older and younger adults for the target verbs in grammatical and ungrammatical contexts. Visual inspection of the ERP waveforms suggests both younger and older show a P600-like effect from 800 ms onwards, as evidenced by a more positive going wave (red line) in the ungrammatical relative to the grammatical condition (black line). As can be seen in Figure 22, the grammaticality effect (ungrammatical minus grammatical) appears largest in the midline region during the 800-1200ms time window.

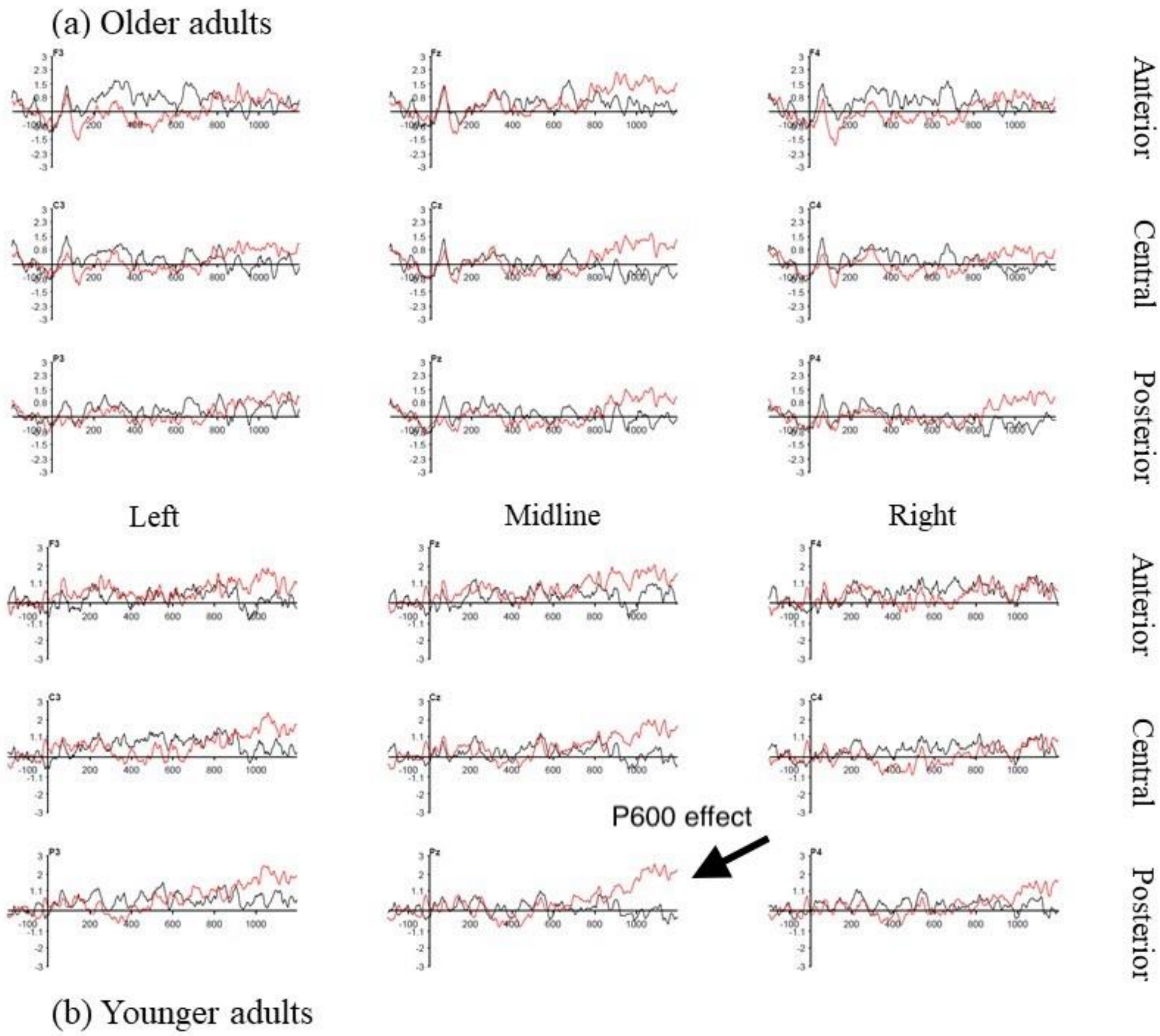


Figure 21 Grand average ERPs for nine electrodes of interest for older (a) and younger adults (b) for verbs that (matched black line) and mismatched the subject in its number feature (red line). Positive voltage plotted up.

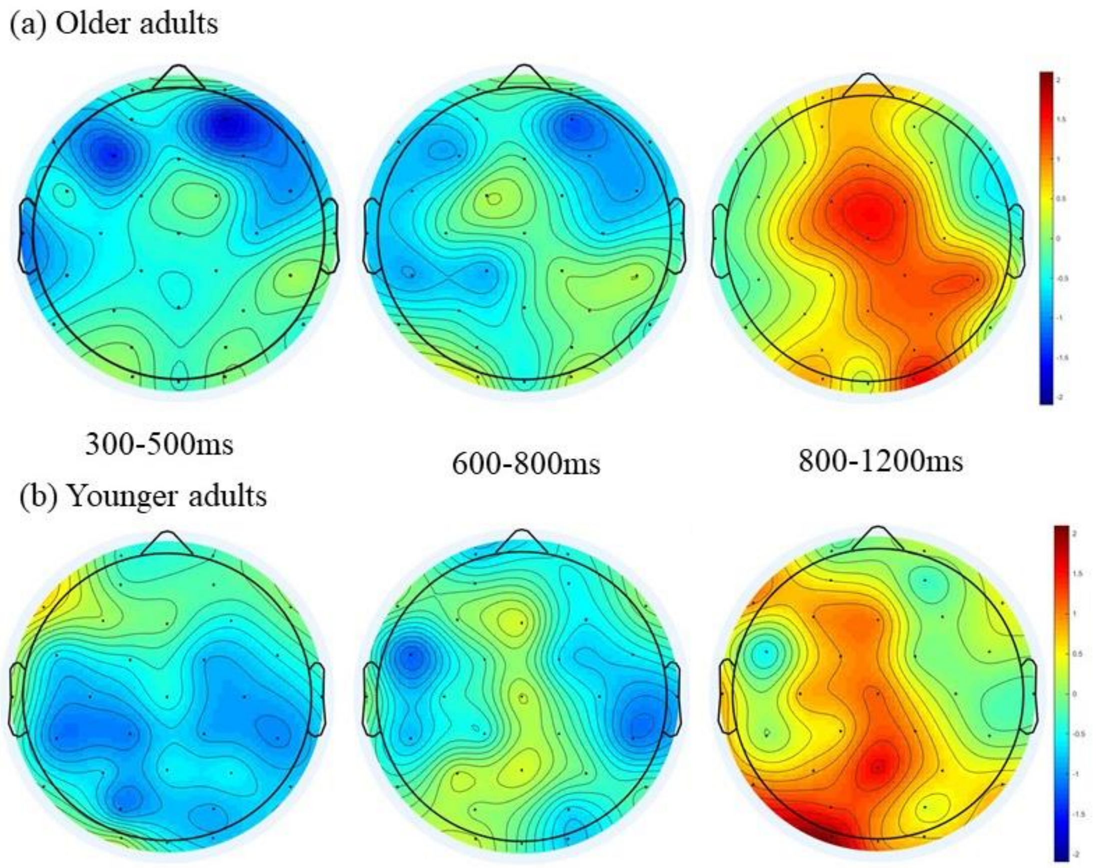


Figure 22 Topographic distribution of ERP effects in the 300-500ms, 600-800ms and 800-1200ms time windows with a scale of +/- 2mV (ungrammatical minus grammatical sentences) in the subject-verb agreement condition.

These observations were supported by the statistical analyses. Results from a 2 (grammaticality) x 3 (anteriority) x 3 (laterality) x 2 (group) mixed ANOVA for each time window are presented in Table 24. In the 300 – 500ms time window, there was a marginal main effect of grammaticality, as well as a marginally significant three way interaction of grammaticality x anteriority x group. To investigate the marginal three-way interaction, a 2 (grammaticality) x 3 (anteriority) repeated measures ANOVA was conducted separately for the younger and older groups. Although the initial three-way interaction was significant, neither follow-up analyses resulted in a significant two-way interaction, therefore no further tests were conducted. The topographic maps show that the positivity in younger adults was more posterior compared to older adults.

In the 600 – 800ms time window, there were no significant main effects or interactions, however there was a trend towards significance in the grammaticality x laterality interaction. In the 800 – 1200ms time window, there was a main effect of grammaticality, as well as a grammaticality x laterality interaction. Post-hoc dependent t-tests for each level of laterality (left, midline, right) showed a significant effect of grammaticality in midline electrodes ($t(38)$ = 2.98, p = .005), indicating a larger positivity for the ungrammatical than grammatical verbs, but not in right or left electrode clusters. This grammaticality x laterality interaction effect was also observed in the 600 – 800ms time window, however it did not reach significance. There were no significant differences between age groups.

Table 24 ANOVA F-values for the subject-verb agreement condition

	df	300 - 500ms	600 - 800ms	800 - 1200ms
Grammaticality	1, 37	3.91 (p=.055)	<1	4.11*
Grammaticality x group	1,37	<1	<1	<1
Grammaticality x anteriority	2, 74	<1	1.08	<1
Grammaticality x laterality	2, 74	1.07	2.68 (p =.08)	4.36*
Grammaticality x laterality x group	2, 74	<1	<1	1.26
Grammaticality x anteriority x group	2, 74	3.53 (p=.051)	<1	<1
Grammaticality x anteriority x laterality	4, 148	<1	<1	<1
Grammaticality x anteriority x laterality x group	4, 148	1.09	<1	<1

** p< .01, * p <.05 (Greenhouse-Geisser corrected values reported)

7.4.3 Verb premodification results

Figure 23 shows the grand average ERPs across all the electrodes for older and younger adults for the target verbs in facilitated and non-facilitated contexts. Visual inspection of the data indicated that critical verbs elicited a less positive response in the premodified (black line) than the non-premodified condition (red line) in the younger adults. Figure 24 shows the topographic distribution of the facilitation effect (non-premodified minus premodified) in the 200 – 400ms, 400 – 600ms and 600 – 1000ms respectively.

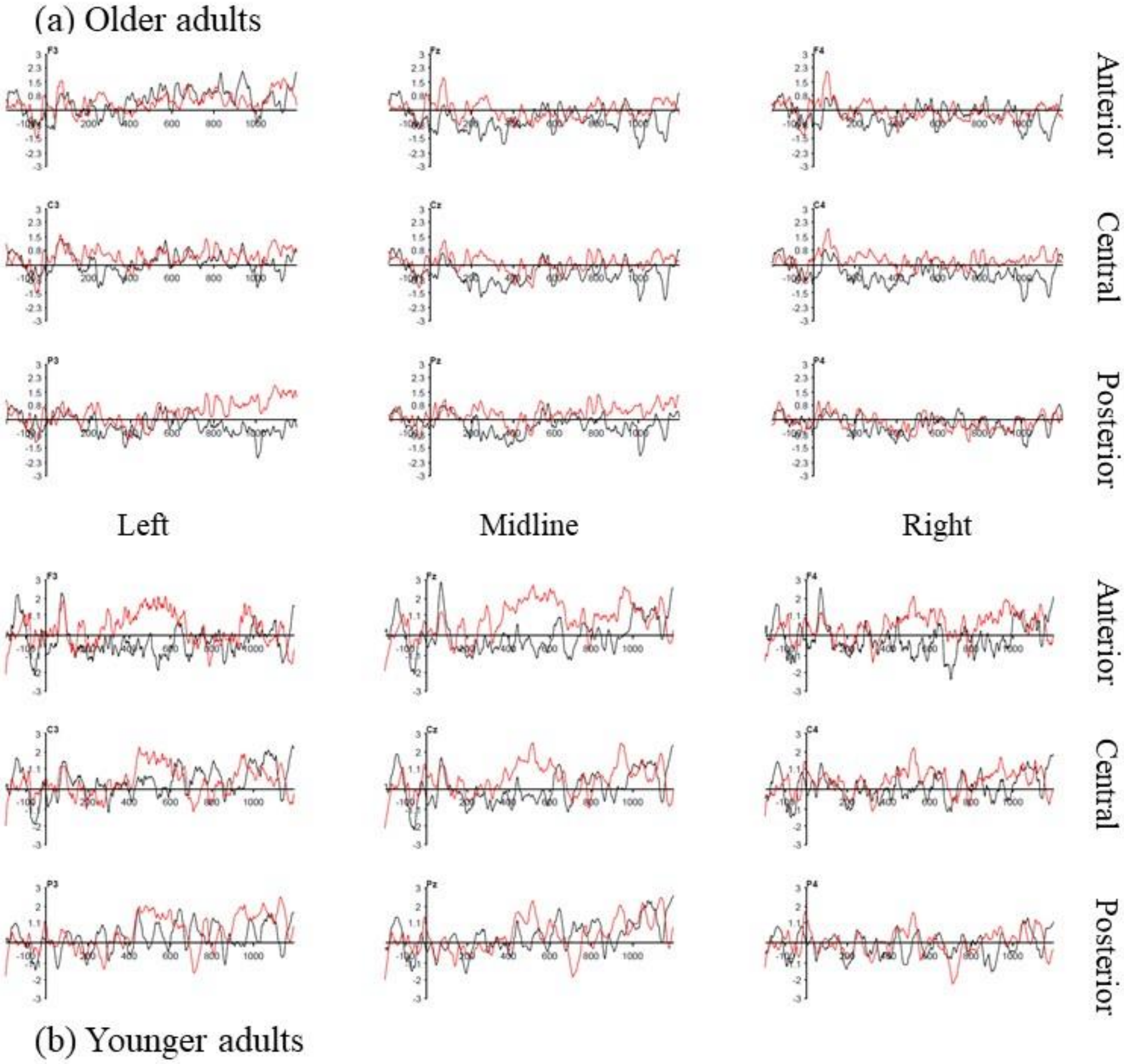


Figure 23 Grand average ERPs across nine electrodes of interest for the premodified (black line) and non-premodified contexts (red line) in the verb premodification condition. Positive voltage plotted up.

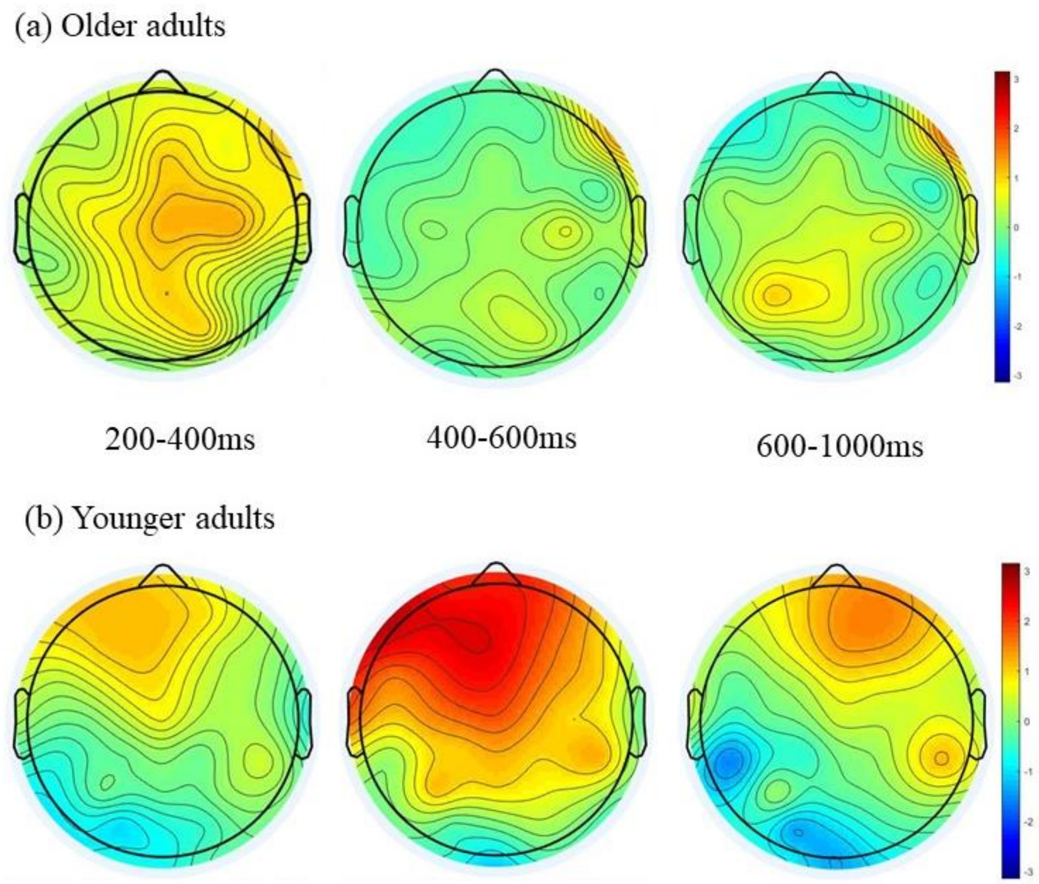


Figure 24 Topographic distribution of ERP effects in the 200-400ms, 400-600ms and 600-1000ms intervals (non-facilitated minus facilitated sentences) with a scale of +/- 3mV in the verb premodification condition

Results from the 2 (premodification) x 3 (anteriority) x 3 (laterality) x 2 (group) mixed ANOVAs for each time window are presented in Table 25. There was no statistically significant main effect or interaction with premodification in any of the time windows. This indicates that there is no evidence that verbs preceded by premodifers are processed differently than non-premodified verbs and there were no differences between older and younger adults. Given the low number of trials (due to technical difficulties), it is likely that there was insufficient statistical power to detect significant differences between premodified and bare verbs.

Table 25 ANOVA F-values for the verb premodification condition

	df	200-400ms	400-600ms	600-1000ms
Premod	1, 16	<1	1.74	<1
Premod x group	1, 16	<1	1.33	<1
Premod x anteriority	2, 32	<1	<1	<1
Premod x laterality	2, 32	1.45	1.29	<1
Premod x laterality x group	2, 32	<1	1.63	<1
Premod x anteriority x group	2, 32	<1	1.19	2.43
Premod x anteriority x laterality	4, 64	<1	<1	1.85
Premod x anteriority x laterality x group	4, 64	1.88	<1	<1

** p< .01, * p <.05

7.4.4 Filler condition results

Figure 25 depicts the grand average ERPs to high (black line) and low cloze (red line) target words for older and younger adults across the nine electrodes of interest. Visual inspection of the data of the older adults revealed a N400 response in central and parietal electrodes. On the other hand, the N400 effect in younger adults appears to be more broadly distributed as can be seen in Figure 26. In addition, a P600 was also evident in centro-parietal electrodes for both older and younger adults.

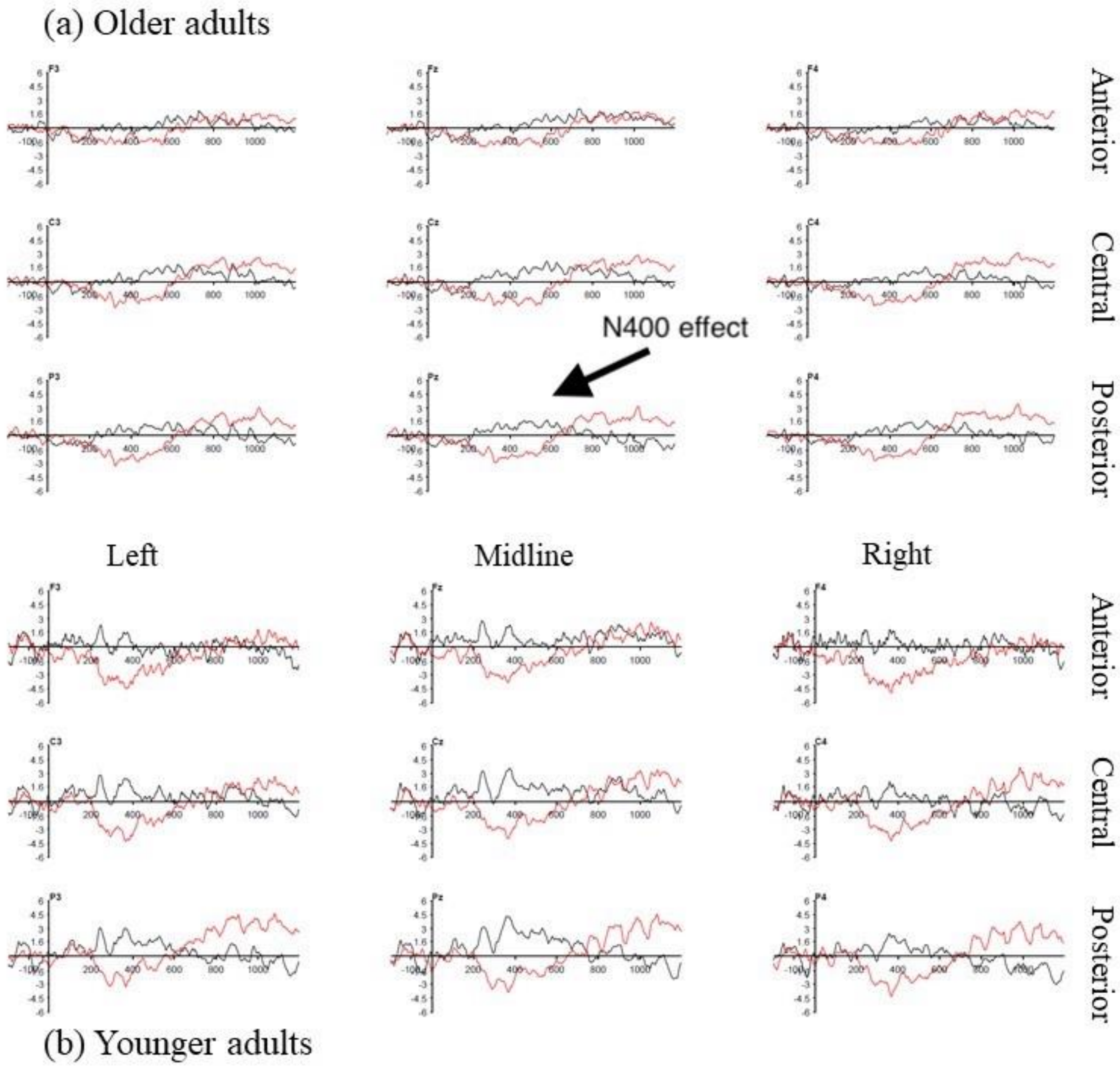


Figure 25 Grand average ERPs for nine electrodes of interest for older (a) and younger adults (b) for high cloze (black line) and low cloze (red line) words in filler sentences. Positive voltage plotted up.

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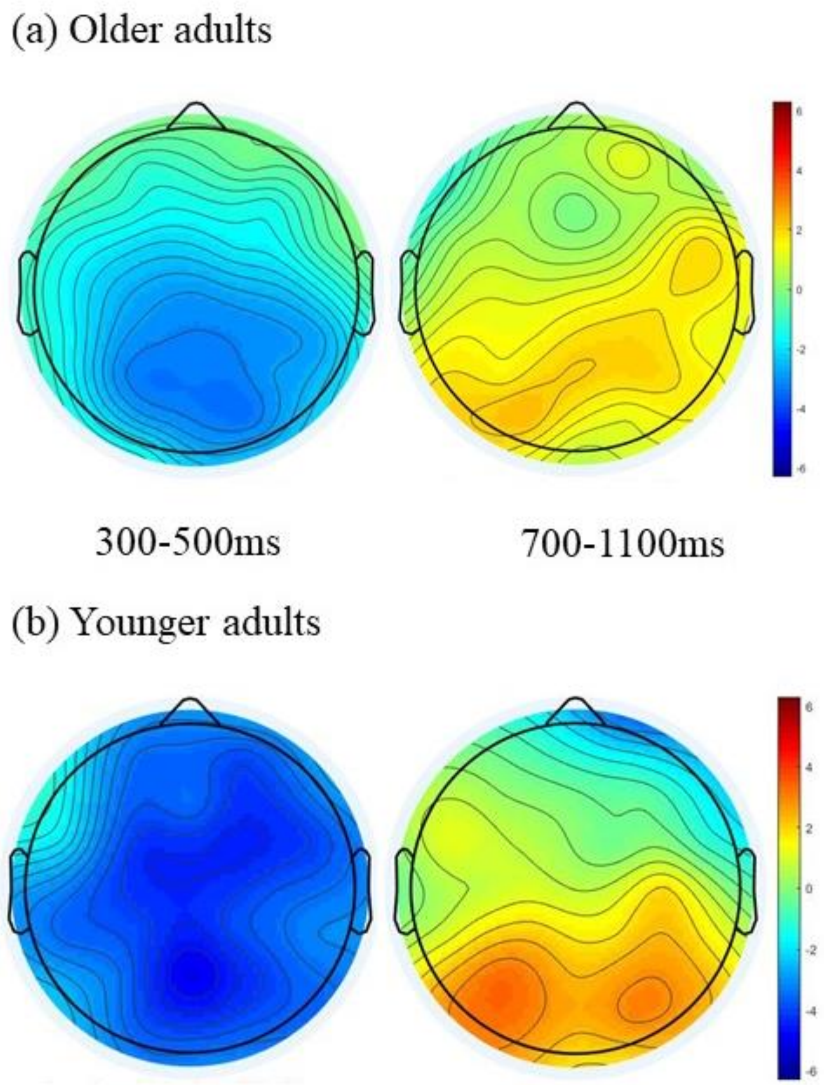

Figure 26 Topographical distribution of ERP effects in 300-500ms and 700-1100ms intervals (low minus high cloze sentences) with a +/- 6mV scale in the filler condition.

These observations were confirmed by the statistical analyses. The results from the 2 (cloze) x 3 (anteriority) x 3 (laterality) x 2 (group) mixed ANOVAs for both time windows are presented in Table 26. In the 300 – 500ms time window there was a significant main effect of cloze probability, as well as cloze probability by anteriority interaction. Dependent t-tests performed post hoc for each level of anteriority (frontal, central, parietal) revealed a significant effect of cloze probability in all three cases (frontal: $t(25) = 4.5$, $p<.001$; central: $t(25) = 6.87$, $p<.001$; posterior: $t(25) = 7.3$, $p<.001$). In the 700 – 1100ms time window, there was a significant cloze probability by anteriority interaction. Separate dependent t-tests were conducted to examine the effect of cloze probability in anterior, central and posterior electrodes. Posterior electrodes, $t(25) = 3.33$, $p = .003$, showed an effect of positivity, while central electrodes showed a trend towards significance $t(25) = 1.93$, $p = .065$. Frontal electrodes, on the other hand, did not show a P600 effect, t(25) = .2, p>.05. There were no significant differences between age groups.

Table 26 ANOVA F-values for filler sentences comparing high and low cloze probability words

	df	300-500ms	700-1100ms
Cloze	1, 24	50.09**	2.84
Cloze x group	1, 24	3.16	.006
Cloze x anteriority	2, 48	5.54*	15.25**
Cloze x laterality	2, 48	2.21	.75
Cloze x laterality x group	2, 48	.49	.31
Cloze x anteriority x group	2, 48	2.01	1.41
Cloze x anteriority x laterality	4, 96	1.11	.64
Cloze x anteriority x laterality x group	4, 96	.94	.65

** p< .01, * p <.05

7.5 Discussion

The aim of the present study was to examine age-related differences in processing of verbs during real-time auditory sentence comprehension. To that end, the electrophysiological responses to verbs in different contexts were measured. One avenue for investigating verb processing in sentences involved recording ERPs to verbs that either matched or mismatched the subject noun phrase in terms of number, resulting in grammatical and ungrammatical sentences. The second avenue examined age-related facilitation effects of premodifiers in verb processing by comparing the ERP response to verbs that are preceded by premodifiers to those which were not. Overall, the data indicated an absence of an age-related difference in processing verbs, with older and younger adults showing remarkably similar electrophysiological responses to verbs across different sentence contexts. The ERP results for the subject-verb agreement and verb premodification conditions are discussed separately in the sections below.

7.5.1 Subject-verb agreement

Effects of healthy aging in the sensitivity to subject-verb agreement was investigated by measuring ERP responses to verbs in context where verbs and subjects were matched or mismatched in number (e.g. *The toddler BOUNCES/*BOUNCE on the bed*). Sensitivity to these violations requires processing of morphosyntactic information, in this case the number marking on the verbs (-s). As predicted, the electrophysiological response to the mismatched verb elicited an increased P600 response, a positive wave most prominent over centro-parietal scalp sites, starting around 800ms post target word onset. The results revealed no age-related effects in terms of the timing or the size of the P600 to subject-verb agreement violations. Although the P600 effect appeared smaller in size in the older adults, the difference between groups was not statistically significant. The absence of age-related differences in verb processing is in line with previous findings by Kemmer et al. (2004) who also observed no age effect in the P600 response to subject-verb agreement violations. Thus, healthy aging appears to have little to no effect on the electrophysiological response to verb violation

The lack of age-related difference can be taken as evidence that processing morphosyntactic violations does not induce greater processing costs or correspond to greater difficulties in reanalysis in older adults, functions that are associated with the P600. These findings have implications for theories of cognitive aging, and in particular challenges general slowing theories which propose that aging is associated with slowing down of cognitive processes, including language (Salthouse, 1996, 2000). As language processing is time sensitive, particularly when listening to speech because the auditory signal is transient, slowed processing in older adults might lead to comprehension difficulties. However, the lack of an age-related difference in the onset of the P600 latency indicates older adults processed the morphosyntactic violations as quickly as younger adults. The absence of any age-related effects is particularly noteworthy considering that differences in timing and amplitude have been observed in other components, such as the N400 (Federmeier et al., 2002, 2003; Kutas & Iragui, 1998). Older adults are reported to be less efficient in using contextual information to predict the meaning of upcoming words, as indexed by a less reduced N400 amplitude to highly predictable words, compared to younger adults.

Although the current experiment did not set out to specifically examine age-related differences in the build-up of semantic expectancy of a word given a sentential context, the analysis of the filler condition revealed older and younger adults were similarly facilitated by the semantic context when anticipating (e.g. *anniversary*) a word in a highly predictable (high cloze) context (e.g. *They drank champagne to celebrate their twelfth wedding ANNIVERSARY with friends and family*) compared to when they were less predictable (low cloze) (e.g. *They ate ice cream and cake at his birthday ANNIVERSARY last Sunday afternoon*) as evidenced by their similar N400 responses. The absence of an age effect opposes numerous previous findings. However, the result has to be interpreted with caution as the sample size of the younger adult group was relatively small due to technical difficulties, and it is likely that the analysis did not have sufficient statistical power to detect a difference between older and younger adults.

7.5.2 Verb premodification

The second condition explored the role of healthy aging in the facilitative effect of pre-verbal modifiers in processing verbs embedded in sentences. Facilitative effects of premodifiers was measured by comparing brain responses to verbs in facilitated contexts, in which verbs were preceded by premodifiers, and in non-premodified contexts (e.g. premodified: *Rose must have finally TRAVELLED to Scotland to visit her relatives*; non-premodified: *On Saturday Rose finally TRAVELLED to Scotland to visit her friends*). In order for premodifiers to facilitate processing of verbs, knowledge of the conditional relationship between premodifiers and head verbs is required. The results revealed that premodified verbs did not elicit specific ERP components and were not associated with voltage changes during specific time windows. Thus, the findings provide no evidence that verbs appearing in syntactically facilitative contexts are processed differently than non-facilitated verbs in either younger or older adults.

Although there is no evidence at this stage for an electrophysiological response that is associated with syntactic facilitation of verbs, there is a substantial body of literature which shows the semantic predictability of a word is associated with a modulation in the N400 component (Federmeier, 2007; Ito et al., 2016; Kutas et al., 2011). For example, in a given sentence context (e.g. *They wanted to make the hotel look like a tropical resort. So, along the driveway, they planted rows of…*) the predicted word (e.g. *palms*) resulted in a reduced N400 compared to a less predictable ending (e.g. *tulips*) (Federmeier et al., 2002). In contrast to previous studies, the current experiment probed whether premodifiers provide cues about the word class category of the upcoming word. The facilitative effects of premodifiers in recognizing verbs was first reported in the online behavioural experiment in Experiment 1 Chapter 4. In the WMT task, both younger and older adults recognized verbs more quickly when they were preceded by premodifiers. However, the current results did not replicate the behavioural findings. There are several differences between the WMT and the current electrophysiological exploration into premodification facilitation effects that might explain the dissimilar findings. Due to technical difficulties, the group sizes were relatively small especially in the younger adult group. The small group size would result in increased variability and decreased signal to noise ratio, making it difficult to interpret the absence of the effects as a true effect. It is likely that the lack of facilitation effect in the current experiment is at least partially due to the insufficient statistical power to detect a significant difference between bare and premodified verbs. A further factor which has to be taken into account when interpreting the absence of electrophysiological markers associated with facilitated verb processing, is the exploratory nature of this investigation. As this was the first electrophysiological study to examine facilitative effects of premodifiers, it was unknown how large the effect would be. Even if effect sizes from subject-verb agreement violations are used as a reference, the sample size for the premodification condition would be insufficient. Furthermore, when taking into account the results from the behavioural experiments in Experiments 1 and 2 (Chapters 4 and 5) which demonstrated that the facilitation effect of premodifiers was small, the ERP effect is likely to be smaller than in violation paradigms. Future further studies with larger sample sizes are needed in order to address the issue of statistical power. Dissimilar findings can also be explained by subtle but important differences in the stimuli material. Unlike the WMT task, an adverb was placed immediately preceding the critical word in the ERP stimuli, in order to have an identical baseline across conditions (e.g. *The teacher will have <u>briefly</u> DISCUSSED*). Similar to premodifiers, adverbs are good indicators of upcoming verbs. Thus, rather than provide a neutral baseline, the adverb itself may facilitate the anticipation of verbs, thereby reducing the facilitative effects of the premodifiers. Future research could address this question by testing the magnitude of the facilitation effect of the ERP stimulus material in the online word monitoring task.

7.5.3 Suitability of ERP methods for conducting research with individuals with aphasia

An aim of the study was to assess the suitability of the task for a future study with neurotypical older adults and individuals with aphasia. One indication of the suitability of the task for older adults is the high accuracy in the behavioural task, which suggests that both younger and older adults were attending to the stimuli and comprehended the filler sentences. Although the current experiment had greater data loss compared to similar ERP studies, this resulted from technical issues and was not an indication of difficulties with the task. With regard to the suitability for individuals with aphasia, an advantage of ERP is that it does not require any behavioural responses beyond listening or reading, greatly reducing task-induced confounds. More importantly, ERP components can be used to measure real-time language processing, potentially differentiating between qualitative and quantitative differences that provide further insight into processing deficits in individuals with aphasia. Several adjustments to the current experimental protocol would make the experiment more suitable for individuals with aphasia and minimize data loss. To ensure optimal data capture, it is essential to minimize mental fatigue as it is associated with increased alpha waves, synchronous neural oscillations with a frequency range between 8-12 Hz (Barwick et al., 2012; Makeig & Jung, 1995). Because alpha waves are in the same frequency band as ERP components, it is not possible to filter them out without distorting the signal of the ERP components. Thus, tiredness tends to result in data loss (Woodman, 2010). One adjustment would be to conduct the background language and cognitive assessments during a separate testing session to shorten the overall session time. Applying only essential electrodes included in the analysis would shorten montage time and prevent potential fatigue before the start of the experimental session and restricting the length of stimuli blocks with breaks in between would ensure sustained attention to the task across blocks.

7.6 Conclusion

The primary aim of the study was to examine whether healthy older adults differ in the way they process verbs and verb-related information in real time relative to younger adults. Age-related differences in verb processing were examined using two different paradigms, sensitivity to violations and facilitation. This study demonstrates that the P600 effect in response to subject-verb agreement violations was similar in terms of onset latency and amplitude in older and younger adults. During the exploratory investigation, no obvious electrophysiological markers were found to be associated with a facilitation effect of pre-verbal modifiers in anticipating upcoming verbs. However, the exploratory investigation lacked statistical power to detect significant differences between bare and premodified verbs due to technical difficulties that affected this condition and further experiments with appropriate sample sizes are needed to fully examine the effects of premodifiers in the ease and speed of integrating head verbs into sentence contexts.

Overall, the findings suggest that verb processing remains stable across the lifespan. Considering the scarcity of ERP investigations into grammatical processing in older age, future research is needed to corroborate and expand the evidence presented in this study. Advancing the evidence base of ERPs in healthy aging also has the potential to contribute to our understanding of language processing in individuals with aphasia, in particular in providing normative data for comparisons.

8. General discussion

Nouns and verbs, as well as function words, have been reported to be selectively impaired in aphasia. However, the degree to which selective word class impairments occur in individuals with aphasia is still the subject of debate. While observations from speech production consistently report noun/verb dissociations, often finding verbs more impaired than nouns, evidence from input studies suggests that processing of both verbs and nouns remains intact. Similar differences across modalities are reported when probing function word processing. Observations of function word errors or omissions in speech are common, whereas findings of comparable function word difficulties in input processing are inconsistent. The aim of this thesis was to investigate selective word class impairments in input processing in individuals with aphasia. This aim was explored through a series of three experiments that applied online behavioural and electrophysiological methods to investigate differential processing of nouns and verbs, and sensitivity to function words embedded in sentences. The following sections present a summary of the experimental findings, before discussing the methodological and theoretical implications of the results within the wider aphasia and healthy aging literature. Lastly, it outlines several ideas for future research.

Our current knowledge on differential processing of noun and verbs and selective impairment of function words in individuals with aphasia is largely based on evidence from single word or offline studies. While offline tasks, such as the sentence-picture matching or grammaticality judgment tasks, are well-suited to probing meta-linguistic knowledge of language, they are not particularly sensitive to the real-time construction and processing of linguistic input. In contrast to offline studies, online tasks, such as WMT, measure implicit cognitive processes and capture the temporal aspect of language processing in everyday life. To date, little is known about online input processing of nouns and verbs in aphasic listeners. The word-monitoring paradigm (WMT) was used as an online measure to explore processing of nouns and verbs embedded in sentences in individuals with aphasia (Experiment 2). The use of the WMT paradigm also provided the opportunity to examine function word processing, in the form of premodifiers, in sentential contexts. Specifically, the WMT measured the speed at which nouns and verbs are recognized when embedded in three different contexts; 1) phrase structure violations (NP: *more MILK /*many MILK*; VP: watching FILMS/*looking FILMS), premodification (function words) (NP bare: *afraid of SNAKES/* NP premodified: *afraid of <u>the young</u> SNAKES;* VP bare: *Claire BOUGHT/* VP premodified: *Clair <u>must have</u> BOUGHT*) and 3) phrase frequency (NP low: *visited the SCHOOL*; NP high: *entered the SCHOOL*; VP low: *space to TURN*; VP high: *time to TURN*). The reaction time results show that the aphasic group was sensitive to both NP and VP information, exhibiting remarkably similar patterns across phrase type to those of neurotypical older adults. The main difference between neurotypical and aphasic groups was in their sensitivity to phrase structure violations. Although both older adult and aphasic groups were sensitive to NP/VP structure violations, as indicated by slower monitoring latencies for nouns and verb in violated compared to grammatical phrases, aphasic individuals were less delayed by violations. This finding cannot be explained by overall slower responses in individuals with aphasia compared to neurotypical adults, as the data analysis takes into account the slower baseline in the aphasic group through individualised z scores. Rather, this group difference suggests that real-time processing of phrase structure information is slowed or less efficient in individuals with aphasia.

Interestingly, the aphasic group was remarkably similar to neurotypicals in processing sentence contexts which facilitated noun and verb recognition. Both groups were faster at recognizing premodified compared to bare VPs, indicating that aphasic and neurotypical listeners recognised function words and their positional status to anticipate upcoming verbs. The result suggests that mild-to-moderately impaired individuals have residual function word processing capacity. This finding was unexpected given that the majority of previous studies have reported delayed or lack of recognition of function words during input processing (Friederici, 1985; Rosenberg et al., 1985; Swinney et al., 1980) and increased speech errors when reading function words aloud (Biassou et al., 1997; Friederici & Schoenle, 1980). Unlike previous studies, the current work did not assess function word processing by comparing them to content words, rather it measured the degree to which they facilitate noun/verb recognition. This design circumvented the problem of matching content and function words in terms of stress and psycholinguistic variables, which are confounded in the previous studies.

Although there was a clear processing advantage for premodified verbs (compared to bare verbs), a similar facilitation effect was not found for premodified nouns. Unlike VP premodifiers, NP premodifiers did not solely consist of function words but also contained adjectives. One reason for the differential facilitation effects between VP and NP premodifiers may be because of differences in transitional probabilities between premodifiers and heads. Adjectival noun premodifiers do not always directly precede head nouns (e.g. *<u>The sweet</u> and juicy <u>apple</u>*) resulting in a lower transitional probability compared to VP premodifiers, which directly precede head verbs (e.g. *John <u>should have kicked</u> the ball to his team mates*). The unequal transitional probabilities are likely to result in different strengths of facilitation. Future studies could address this issue by exploring function word processing in languages with richer noun phrase morphology.

The results also revealed that neurotypical and aphasic groups were similarly facilitated by phrase frequency, showing faster recognition of nouns embedded in high frequency phrases compared to low frequency phrases. This indicates that individuals with aphasia showed preserved sensitivity to statistical probabilities in language. The current observation confirm earlier findings that have reported preserved sensitivity to frequency during sentence comprehension (DeDe, 2013a; Gahl, 2002; Huck et al., 2017b) and production (Bruns et al., 2019; Zimmerer et al., 2018). Additionally, it supports initial findings by Bruns et al. (in prep) who have reported frequency effects in comprehension beyond the single word level in individuals with aphasia. Extending Bruns and colleagues' work, the current study also investigated frequency effects in verb-ending phrases. In comparison to nouns, frequency effects for verb phrases were reduced in both neurotypical and aphasic groups. This is in contrast with previous findings which have reported frequency effects for verbs (DeDe, 2013a; Gahl, 2002; Gahl et al., 2003). Whereas these previous studies compared processing of verbs embedded in their preferred frame (e.g. *The researchers* <u>*dissolved*</u> *the crystals*) to less frequent syntactic frames (e.g. *The crystals* <u>*dissolved*</u> *in the solution*), in the current experiment the structure of the syntactic frames was kept constant across verb phrase pairs (e.g. high: *The plants* <u>*continued to grow*</u> *strong and tall*; low: *The plants* <u>*started to grow*</u> *in the spring*). It is likely that the current frequency manipulation was more subtle compared with previous verb frequency investigations, and thus resulted in a smaller processing difference between high and low frequency phrases. The unequal facilitation effects across phrase type, however, is unlikely to be an indication that verbs are frequency insensitive, but rather points towards a difference in the word class of the critical words used to differentiate high and low frequency phrases (e.g. NP: <u>*closed/locked*</u> *the DOOR vs* VP: <u>*able/likely*</u> *to GRAB*). The semantic association between the critical word and the target word was more salient for nouns than for verbs, providing additional semantic priming to facilitate access to the noun.

Despite these differences across phrase type, one important conclusion that can be drawn from the response pattern is that the aphasic group was sensitive to both NP and VP information, pointing towards an absence of noun/verb dissociation. The data challenge the view that verbs are more difficult to process than nouns, at least when probed within sentential context. This finding confirms and expands previous offline studies that have argued against noun/verb dissociations during input processing (Alyahya et al., 2018; Bates et al., 1991; Cho-Reyes & Thompson, 2012; Crepaldi et al., 2006; Kim & Thompson, 2000; Marshall et al., 1998).

Some caution should be employed in interpreting these conclusions. The aphasic group largely consisted of mild-to-moderately impaired individuals, and it is possible that individuals with more severe impairments exhibit differential noun/verb processing patterns. The group analysis may have also masked noun/verb dissociations in individuals that have traditionally been associated with selective word class impairments, such as individuals with agrammatic or anomic aphasia. Chapter 6 Experiment 3 addressed these concerns by examining, at the individual level, the relationship between instances of noun/verb dissociations and severity of impairment, as well as aphasia subtype. Severity appeared to play a role in whether noun/verb dissociations occur. Specifically, more severely impaired individuals displayed atypical processing of nouns. Greater difficulties processing nouns was unexpected, given that previous research has emphasized greater verb difficulties in both fluent and non-fluent subtypes (Berndt et al., 2002; Jonkers & Bastiaanse, 1998; Luzzatti et al., 2002; Mätzig et al., 2009). The current finding contradicts initial observations by Alyahya et al. (2018) who reported an absence of noun/verb dissociations across a fairly large sample of individuals (N = 48) with varying levels of impairment. However, Alyahya and colleagues did report one individual with severe impairment who displayed greater difficulties in identifying single nouns relative to verbs. Together, these single-case observations provide an initial but tentative link between selective noun impairment and severity. However, further research with a larger sample of severely impaired individuals is needed to explore the relationship between severity and selective word class impairment. With regard to aphasia subtype, the presence of a selective impairment in production was not associated with a similar impairment of nouns or verbs in input processing. In other words, agrammatic and anomic speech was not associated with corresponding verb and noun deficits in input processing. This implies that difficulties in noun and verb retrieval can be modality specific without a corresponding impairment in input processing. Together, the findings from the group and individual case analyses (Experiment 2 and 3), indicate that noun/verb dissociations are absent in input processing. However, there is some evidence at the individual level that suggests that more severely impaired individuals are more likely to show selective word class impairment which, in the case reported here, disrupted nouns.

The second aim of this thesis was to differentiate pathological processing from changes due to neurotypical aging. To this end, two experiments (Experiment 1 and 4) using online behavioural (WMT) and electrophysiological methods were used to explore age-related changes in syntactic processing in younger and older neurotypical adults. Using the same WMT task as described above, the behavioural findings indicate that, although remarkably similar, older adults exhibit subtle differences in the way they process syntactic information compared to younger adults. These age-related differences suggest that some aspects of online sentence processing change as a result of healthy aging. For example, younger adults were less delayed by phrase structure violations when monitoring nouns (e.g. **many milk*) compared to verbs (e.g. **slept cushions*), whereas violations resulted in similar delays in recognizing nouns and verbs in older adults. Given the scarcity of studies probing noun phrase processing in healthy adults, it is difficult to draw conclusions whether younger or older adults are exhibiting hyper- or hypo-sensitivity to violations. There is some evidence from a study by Wayland, Berndt and Sandson (1996) that suggests that syntactic violations involving nouns (e.g. *She did not want to <u>meal</u> in the bathroom*) are less disruptive to sentence processing than violations involving verbs (e.g. *She was relaxing in the <u>starve</u> and was afraid she might doze off*). An explanation for the current results could be that verbs are more central than nouns in determining the syntactic structure of the sentence. For example, encountering a transitive verb leads to the expectation of a direct object, and in the case of intransitive verbs the absence of it. In contrast, in the NP condition, when encountering a count quantifier, the parser would still predict a noun. It is likely that the parser is derailed to a greater degree when there is a prediction error involving verbs than nouns. According to this hypothesis, younger adults in the current study were able to recover more rapidly from mis-parsing, while older adults were more disrupted by more subtle grammatical violations.

Additional age-related differences were observed in the facilitation provided by premodifiers in anticipating head nouns and verbs. While both neurotypical groups used VP premodifiers (e.g. *should have*) to anticipate upcoming verbs (e.g. *kicked*), only younger adults also showed this facilitation for premodified nouns (e.g. *the thin cats*). This aspect of sentence processing has not yet been investigated in relation to healthy aging and the current experiment presents novel findings. Interestingly, older adults show a similar lack of facilitation of noun premodifiers as individuals with aphasia. One possible reason for the normative age differences is that older adults are more sensitive to differences in the transitional probability between premodifiers as they have accumulated more knowledge about the statistical distribution of language. Furthermore, the only condition that showed a complete absence of an age effect was observed when probing sensitivity to phrase frequency (e.g. NP low: *visited the SCHOOL*; NP high: *entered the SCHOOL*; VP low: *space to TURN*; VP high: *time to TURN*). Older adults were similarly sensitive as younger adults to frequency differences in phrases, showing processing speed advantages for nouns embedded in high compared to low frequency phrases. The current age-effect is particularly noteworthy considering that participants listened to sentences that were not particularly complex and suggest that age-related changes affect online processing of sentences which do not make great demands in terms of computational needs or working memory. However, this conclusion based on the results of the behavioural experiment is complicated by the absence of electrophysiological evidence of differences in the brain responses of younger and older adults during syntactic processing. Both younger and older adults exhibited similar electrophysiological response to subject-verb agreement violations, as evidenced by similar amplitude and onset latency of the P600 response. The patterns across experiments paint a complex picture of preservation and decline of syntactic processing in older adults.

8.1 Theoretical implications

8.1.1 Aphasia

While noun/verb dissociations, and in particular verb impairments, are often observed in production, previous offline evidence and the findings from this thesis (Experiment 2 and 3) show that there is little evidence that they are selectively impaired in input processing. Sensitivity to NP and VP information in the WMT task indicates intact representation of lexical-syntactic information. Thus, the differential findings between production and input processing suggest that the locus of impairment is modality specific, rather than a general loss of noun/verb representations. The three most prominent deficit accounts, (lexical, semantic and syntactic), differ greatly in the degree to which they have addressed and incorporated modality specific noun/verb impairments into their models of the mental lexicon. Of the three accounts, lexical-based accounts have most clearly specified how nouns and verbs can be selectively damaged within specific modalities while remaining intact in others. According to lexical-based accounts, the mental lexicon is organized according to grammatical classes, where nouns and verbs are stored separately. Several proponents of the lexical account (e.g. Caramazza & Hillis, 1991; Hillis & Caramazza, 1991) suggest that residual input processing is enabled by intact lemmas, where conceptual and grammatical information of words is encoded, while damage to lexemes that encode phonological/ orthographic information, allows for selective word class dissociations in speech production. Within the lexical framework, the findings from Experiment 2 and 3 are consistent with the notion that intact lemma allow for residual input processing, while the locus of breakdown occurred at the lexeme level. That is because impairments at speech production were not mirrored by similar impairments in input processing.

It has also been suggested that modality-specific impairments can be explained without invoking a mental lexicon that is organized according to grammatical class. Proponents of the semantic account have suggested that partial activation in a unified semantic lexicon leads to residual input processing but is not sufficient for word retrieval. Processing externally-generated language may be more implicit and automatic for which partial activation may be sufficient, whereas language production, may require more explicit and conscious processes during which access to lexical-syntactic information has to be generated internally. While the current thesis was not designed to differentiate between these two deficits accounts, it is clear that evidence from input processing has not been sufficiently addressed andincorporated into models of the mental lexicon.

Given the sentence-level aspect of the noun/verb investigations, the results in this thesis also have implications for syntactic deficit accounts. A commonality across several accounts is that they claim that the underlying syntactic representations are intact, and that deficits occur as a result of restrictions in processing. These are in contrast to representational theories, for example Trace Deletion Hypothesis (TDH; Grodzinsky, 1995, 2000, 2006) which assume that there is a loss of knowledge or specific syntactic computations, such as Movement. Several processing deficit accounts have suggested that sentence comprehension difficulties are due to temporal changes during language processing. The accounts differ as to the nature of the temporal abnormality that leads to syntactic difficulties. Haarmann and colleagues propose that either activation of syntactic information is either slowed (Haarmann & Kolk, 1991; Kolk & Van Grunsven, 1985), or decays too fast (Haarmann & Kolk, 1994). In the case of the sentences containing verb phrase structure violations, listeners need to access and maintain the verb argument structure information long enough so that when the direct object is encountered it can be integrated into the argument slot. If the information about verb argument structure is slow to activate, or decays too soon, the agreement between arguments and verbs cannot take place. In the case of NP structure violations (e.g. **many milk*), listeners had to extract mass/count noun information from the quantifiers and keep it active until the same information could be extracted from the noun. Considering that both NP and VP structure violations occurred between adjacent items, the demands on working memory were relatively low and unlikely to have compounded the computational demands. The data from the aphasic group showed that they were less disrupted by NP and VP violations than neurotypical controls. This suggests that information regarding verb-argument structure was not simultaneously active when processing the noun in the direct object slot. Similarly, syntactic information of the count quantifier might have decayed before retrieving syntactic information of mass nouns.

Because the current analysis is based on reaction time difference and takes into account the slower baseline in the aphasic group, it may mask processing differences between aphasia and healthy older adults. It is reasonable to assume that overall slowed interpretative processing has significant consequences in post-interpretative processes, particularly in connected discourse. Although slower response times in the aphasic group could suggest slowed activation of syntactic information, it is also likely to reflect slowed sensory-motor processing due to right-sided hemiparesis. One way to distinguish between the temporal dynamics of internal language processing and peripheral sensory motor processes, would be to record electrophysiological responses during sentence listening as this does not require overt behavioural responses and thus eliminates sensory-motor confounds. Slowed processing would be reflected in delayed onset times of the ERP component.

The results in this thesis also contribute to the discussion regarding function word processing in individuals with aphasia. As mentioned in Chapter 2 Section 2.2, there have been several attempts to explain selective function word deficits in individuals with aphasia. Most prominently, Bradley (Bradley 1878; Bradley, Garrett, & Zurif, 1980) proposed that content and function words are represented and accessed by neurally separate processing systems. They claim an advantage of separate processing routes is quick access to function words during sentence production and comprehension. According to this model, impaired or atypical function word processing in aphasia is due to damage to the function word specific processing system, affecting both comprehension and production. The current findings (Experiment 2 and 3) showed that individuals with aphasia were sensitive to function words in the form of premodifiers and used them to anticipate upcoming verbs, indicating that function words facilitated syntactic processing of sentences in neurotypical as well as aphasic individuals. This anticipation effect requires individuals to access the lexical forms in real time and recognize the positional relationship to the head. Impaired sensitivity to function words would result in a lack of facilitation effect. The similar magnitude of the facilitation effect between aphasic and neurotypical processing is not compatible with Bradley’s separate processing route hypothesis which would, at the very least, predict diminished facilitatory effects in individuals with aphasia, as function word processing access would be slowed via the content-word system.

Other explanations of function word impairments focus on the roles they serve in sentence processing. Based on observations that function words that served primarily a syntactic role were recognized more slowly and produced less often than when the same function word served a semantic function, Friederici

(1982, 1985; Kolk & Friederici, 1985) concluded that impaired function word processing was due to difficulties processing syntactic items rather than a selective word class impairment. This hypothesis predicts that syntactic function words (e.g. *will*) are more vulnerable to damage than lexical function words (e.g. *under*) which carry more semantic weight. However, contrary to Friederici's hypothesis, the finding in this thesis shows that individuals with aphasia with mild-to-moderate impairments had residual sensitivity to function words, in the form of verb premodifiers, which mainly served a syntactic function. This suggests that aphasic group's ability to process syntactic items was to some degree preserved. It is possible that processing verb premodifiers was more salient to listeners because they consisted of two consecutive function words (e.g. *should have*). This could have affected the stress and prosody of a sentence and in turn aid their processing. However, using a WMT, Swinney, Zurif, & Cutler (1980) have shown that individuals with aphasia did not show a speed advantage in recognizing stressed over unstressed function words. Thus, stress is unlikely to be the main reason for residual sensitivity to verb premodifiers. Besides the current results, there is little other evidence at this stage that illustrates preserved processing of low imageability function words, as most information regarding (impaired) function word processing is based on prepositions which tend to carry more semantic weight than other types of function words. Clearly, further research which specifically examines processing of syntactic function words is needed to further probe Friederici's claims. The evidence base so far leaves open the question whether different types of function words can be selectively impaired and whether they should not be treated as one homogenous class. It is also likely that function words can be impaired due to a number of different factors and that one deficit account is unlikely to capture and explain the variability in findings.

Lastly, the thesis also applied usage-based principles to explore noun and verb processing. The findings from Experiment 2 and 3 suggest that frequency-based factors play a role in language processing in aphasia. Nouns embedded in high frequency phrases were recognized quicker than when embedded in low frequency phrases, indicating that the phrase frequency affected the speed and ease at which they were processed. This supports earlier studies that have found frequency-facilitated sentence comprehension (DeDe, 2013a; Gahl, 2002; Huck et al., 2017b) and production (Bruns et al., 2019; Zimmerer et al., 2018). Furthermore, the frequency effect was not limited to input processing. Individuals who exhibited greater sensitivity to frequency differences while listening to sentences also displayed an advantage in retrieving lower frequency words in the naming task. This suggests that the frequently encountered phrases are more strongly entrenched in memory and are more easily accessible in individuals with aphasia (Bybee, 2006; Bybee & McClelland, 2005). Frequency-based investigations provide interesting opportunities for clinical applications. Processing advantages for highly frequent phrases (e.g. *I like it*) could be exploited to stimulate access to structurally similar, but lower frequency phrases (e.g. *I like pizza*).

8.1.2 Aging

With regard to comparisons between the neurotypical groups in this thesis, the primary question was whether older adults were similarly disrupted/facilitated by sentential context as younger adults. The electrophysiological evidence indicates that there were no age effects in the brain's response in terms of timing and amplitude to subject-verb number agreement violations. If the P600 is taken as an index reflecting reanalysis processes, reprocessing costs, or difficulties in syntactically integrating upcoming words, the result indicates that aging did not affect the speed of these processes. This suggests that aging did not have a fundamental or even minimal change in how older adults process syntactic information, supporting similar findings by Kemmer, et al. (2004). In particular, the absence of a delay in the onset of the P600 response challenges general aging theories which claim that older adults are slower in processing sentence information. However, the lack of age effect in the P600 response stands against a backdrop of age-related changes in behavioural measures of sentence processing. The behavioural findings indicate that, although remarkably similar, older adults exhibit subtle differences in the way they processed syntactic information. For example, word recognition was more disrupted by phrase structure violations in older compared to younger adults, suggesting that they are slower in reparsing or reanalysing sentences that contain grammatical errors. This findings is in line with general slowing theory and directly contrasts to the electrophysiological findings. It is noteworthy however, that younger and older adults were similarly delayed by verb phrase violations and that the age-related difference in processing speed was only observed in response to noun phrase structure violations, where younger adults were less disrupted.

Behavioural age effects were also observed in facilitated contexts, indicating that older adults were less efficient at using sentence context, in the form of premodifiers, to facilitate processing of upcoming words. Again, this difference was only observed in noun premodifiers, where younger but not older adults showed a facilitation effect. Although the behavioural evidence is partially in line with general slowing theory, it cannot easily account for the uneven patterns of preserved and slowed language processing across phrase types. Given the inherent generality of the theory, it is unclear how general slowing in older adults would affect noun but not verb recognition following phrase structure violations. Indeed, it is more likely that slowed processing would affect verb than noun processing, given their syntactic complexity and lower imageability. One major difficulty with applying general slowing theories when assessing age effects in specific language processes is that they does not make specific predictions about those processes.

There is a possibility that working memory limitations can explain the differential age-effects across electrophysiological and behavioural findings. Working memory limitations theories have proposed that age-related reductions in working memory resources lead to difficulties in syntactic processing when demands exceed capacity. In particular, sentences with greater syntactic complexity, where listeners need to retain information across embedded clauses or left-branching sentences. Although the word-monitoring task measures online sentence processing, it does require listeners to maintain a word in working memory long enough until it occurs in the sentence. In contrast, ERPs do not make any additional working memory demands beyond passive listening. Thus, the slight difference in working memory demands across the tasks might account for the differential findings. However, working memory limitations cannot explain lack of NP premodification effect nor increased delay in noun recognition in phrase structure violations in older adults. In both sentence contexts, facilitators and violations were immediately preceding the monitored words and therefore did not require that memory traces were active for a long time, and thus place relatively low demands on working memory. At this stage, the source of the differences between ERP and behavioural results is unclear and requires further investigations. The theoretical implication is that patterns of language processing revealed by online methods in healthy aging cannot be accounted for by general slowing nor by working memory reductions.

8.2 Methodological contributions

The psycholinguistics literature is dominated by reports of investigations into single word production. In comparison, there are far fewer studies that have probed input processing/comprehension. The majority of input research has also adopted single word tasks or used offline comprehension tasks. As described extensively in Chapter 2, there are several factors inherent in single word and offline comprehension tasks that may have masked or, in the case of speech production, magnified selective word class impairments in previously published studies. A major contribution of the experiments presented in this thesis, is the use of behavioural (Experiment 1 and 2) and electrophysiological methods (Experiment 4) to probe real time processing of nouns, verbs and function words embedded in sentences.

Only few studies have used online sentence level tasks (Baum, 1989; Tyler, 1989; Tyler & Marslen-Wilson, 1977; Tyler & Cobb, 1987), and of these, even fewer have applied the method to probe noun and/or verb processing (Shapiro et al., 1993; Shapiro & Levine, 1990; Wayland et al., 1996). A unique aspect of the behavioural experiment was that it compared noun and verb processing across similar linguistic manipulations. Comparisons between nouns and verbs are often done based on probing different processes and types of knowledge. Verb processing generally involves probing their syntactic structure, for example, sensitivity to verb argument structure or morpho-syntactic information, whereas tasks generally assess nouns by probing their semantic properties. For example, in a single word task by Tyler et al. (2004) noun comprehension was probed by determining whether or not a target word (e.g. *wrens*) is semantically related to cue words (e.g. *sparrows, thrushes*). Rarely, however, do tasks assess nouns' semantic as well as syntactic features, as was done in this thesis. This is probably partly due to the limited overt syntactic cues and restrictions that nouns have in English (e.g. count/mass, regular vs irregular plural marking).

The current work also provides a novel way of probing function words. Previous sentence-level investigations generally compare the speed and ease at which function words are recognized or processed in comparison to content words. For example, Friederici (1985) used an auditory WMT to probe differential processing of content and function words by comparing monitoring latencies to function or content words embedded in sentences (e.g. function word: *Der Besitzer vermietet nur an ältere Ehepaare/The owner only rents to older couples*; content word *Der Mann hoffte, Geld zu gewinnen/The man hoped to win money*). A major confound is introduced when comparing function and content words as they are rarely, if ever, matched on psycholinguistic variables, such as frequency or imageability, which are known to influence processing. The current thesis used an innovative way to circumvent the difficulty of matching content and function words on psycholinguistic variables by examining the facilitative role of function words in sentence processing. Verb premodifiers consist of modal and auxiliary verbs. These precede, and thus signal, upcoming head verbs (e.g. *Rose should have tipped the waiter*). Noun premodifiers, on the other hand, include determiners as well as content words such as adjectives that signal upcoming nouns (e.g. *The red apples are sweet and crunchy*). Thus, it assessed sensitivity to function words by the degree to which they aided the recognition of upcoming head verbs or nouns, rather than measuring recognition of function words themselves. The results of the verb premodification condition are especially important as the premodifiers consisted entirely of function words (while in the NP condition consisted of determiners followed by adjectives). Insensitivity to function words would result in a lack of facilitation, and the speed of recognition of nouns and verbs would be similar between premodified and bare context, Importantly, the novel experimental design enables assessment of function words that mainly serve syntactic roles and are impossible to test with conventional picture-matching tasks and are stripped of their positional context in lexical decision tests.

8.3 Future directions

The work described in this thesis expands the current knowledge on selective word class impairment in aphasia, as well as syntactic processing in healthy aging. The results of the experiments have raised further research questions and a number of potential future studies have already been mentioned in previous chapters.

While the current work presents strong evidence for an absence of noun/verb dissociations in input processing, one important question that arose from the group and individual case analyses, was the role of severity in occurrences of noun/verb dissociations. In contrast to the group results, which included mostly mild to moderately impaired individuals, both severely impaired individuals displayed atypical noun processing. While this result is a tentative indication of a relationship between severity and selective word class impairment, further research is needed to explore it. This could be achieved by exploring occurrences of noun/verb dissociations in samples including more severely impaired individuals.

The WMT and potentially ERPs could be important in characterizing residual abilities of individuals with severe impairments that are difficult to assess with standard measures. Depending on the severity of impairment, assessment materials could be adjusted in terms of syntactic and semantic complexity. An additional advantage of ERPs is that they do not require any overt responses beyond listening or reading, placing low demands on individuals with severe impairments who may not understand the task instructions of other online tasks. Importantly, changes in the amplitude or onset latencies of ERP components could potentially differentiate between qualitative and quantitative differences between neurotypical and aphasic language processing.

The online methods applied in this thesis have been useful to measure real-time processing of nouns and verbs, as well as capture residual sensitivity to function words when embedded in sentences, and thus have potential to enhance clinical practice. So far, clinical evaluations largely rely on offline and single word tasks. Given that natural language processing occurs online, performance on standard clinical tests might not reflect individual’s residual language abilities. The main advantage in using the word-monitoring task and event-related potentials (ERP), is that they capture real-time processing of spoken language and thus reflect how individual with aphasia might process discourse in everyday situations. An additional advantage of the WMT and ERPs, is that they allow for assessments of finer grained linguistic processing that are not dependent on picturable sentences and at the same time place low demands on meta-linguistic and working memory processes. ERP and reaction time methods allow researchers and clinicians to measure degrees of sensitivity to linguistic stimuli, differentiating between levels of intact, reduced and absent sensitivity. In contrast, standard measures typically rely on accuracy or error analysis where responses are either correct or incorrect.

Online measures of language processing could be particularly effective tools to measure changes in online language processing in response to interventions. Such tools are particularly relevant for therapies targeting online as opposed to offline language processing. These methodologies offer great potential to complement and enhance observations and results from offline tasks. A possible benefit of combining offline with online measures is that it could help localize the breakdown in processing and in turn inform clinical intervention. For example, clinical interventions for individuals with residual online processing in the context of impaired offline processing may differ from interventions for individuals displaying impairments in both domains. One approach could be to target and strengthen residual interpretative processes with the aim of generalizing to post-interpretative processes.

Despite the advantages of online measures of language processing, many of them are not easily transferrable and applied in clinical settings in their current form, making them less feasible than commonly used offline assessments. In contrast to standard offline tasks, ERP and WMTs require greater effort in terms of pre and post-processing and analysing the data. They also demand considerable effort in designing and recording audio stimuli. These factors place a greater burden on clinicians than conventional, standard offline tasks, which could explain the limited use of online measures so far.

These limitations, however, also offer an opportunity to develop and adapt the tasks to increase their feasibility for clinical use. For example, a programming script could automatize and thus simplify data processing and analysis, greatly reducing the time and effort involved in producing interpretable results. Similar adaptations could be applied to other online methods such as eye-tracking. A more long-term objective could involve establishing an open source databank of linguistic stimuli that provides researchers and clinicians assessment material to probe various aspects of online sentence processing. Establishing openly accessibly assessment resources and tools to reduced data processing could greatly increase the application of online measures in clinical settings, and expand our understanding of residual language processing in aphasia as well as inform clinical interventions.

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Appendix

Appendix A – Experiment 1 & 2

Appendix A.1 Complete stimuli list of the WMT. Target words bolded and premodifiers underlined

Pair nr	Phrase type	Condition	Non-violated phrase	Violated phrase	Non-violated sentence	Violated sentence
1	NP	Phrase structure violation	a lot of meat	a few meat	I was planning on cooking a lot of MEAT and a big salad for lunch on Sunday	I was planning on cooking a few MEAT and potatoes for dinner on Saturday.
2	NP	Phrase structure violation	a lot of luggage	a few luggage	For her holiday, Claire brought a lot of LUGGAGE to take with her to Spain.	For her trip, Rose brought a few LUGGAGE to take with her to Italy.
3	NP	Phrase structure violation	enough clothing	several clothing	For her business trip, Kate packed enough CLOTHING for two weeks.	For her upcoming holiday, Jane packed several CLOTHING for a week.
4	NP	Phrase structure violation	a little perfume	a few perfume	Mary sprayed a little PERFUME on her wrist before leaving the house.	Alice sprayed a few PERFUME on her wrist before meeting her date.
5	NP	Phrase structure violation	enough courage	each courage	Claire didn't believe she had enough COURAGE to speak up in class.	Kate didn’t believe she had each COURAGE to confront her fears.
6	NP	Phrase structure violation	some petrol	several petrol	Frank filled his car with some PETROL on the way to work.	Paul filled his van with several PETROL before driving to work.

7	NP	Phrase structure violation	little progress	few progress	Mary made little PROGRESS in learning Spanish although she went to all the classes.	Sarah made few PROGRESS in learning French even though she never missed a session.
8	NP	Phrase structure violation	a little food	a few food	Jane saved a little FOOD for the guests who were arriving late.	Rose saved a few FOOD for her friends who were arriving late.
9	NP	Phrase structure violation	some bread	each bread	On his way home, Rob wants to buy some BREAD from the bakery.	For brunch on Sunday, Paul wants to buy each BREAD from the bakery.
10	NP	Phrase structure violation	some toast	few toast	Mark asked Paul: "Would you like some TOAST for breakfast tomorrow?"	Rose asked Kate: "Would you like few TOAST for breakfast on Sunday?"
11	NP	Phrase structure violation	more pasta	several pasta	Jane prepared more PASTA so she could bring it to work tomorrow.	Rose prepared several PASTA so she could have it again for dinner tomorrow.
12	NP	Phrase structure violation	a little dust	a few dust	On the shelf, the books were gathering a little DUST from rarely being used.	On the coffee table, the books were gathering a few DUST from never being read.
13	NP	Phrase structure violation	more furniture	one furniture	When Frank moved into his new house, he considered buying more FURNITURE for the living room.	When Paul moved out of his flat, he considered buying one FURNITURE such as a new TV.

14	NP	Phrase structure violation	lots of butter	a few butter	Claire prefers to have lots of BUTTER on her toast.	Rose prefers to have a few BUTTER on her toast.
15	NP	Phrase structure violation	much dirt	many dirt	There was so much DIRT on our shoes after walking in the forest.	There was so many DIRT on our trousers after working in the garden.
16	NP	Phrase structure violation	enough flour	many flour	Emma wondered whether she had enough FLOUR to bake a cake.	Mary wondered whether she had many FLOUR to make a pie.
17	NP	Phrase structure violation	more milk	many milk	Do you prefer more MILK in your coffee?	Do you prefer many MILK in your tea?
18	NP	Phrase structure violation	some poetry	many poetry	At school the children read some POETRY for their English class.	For class the students read many POETRY as part of the curriculum.
19	NP	Phrase structure violation	more work	few work	Tom is still in his office because he has more WORK to finish for tomorrow.	Paul was still in his office because he had few WORK he needed to finish.
20	NP	Phrase structure violation	a little salt	a few salt	Rose added a little SALT to the sauce before stirring it.	Jane added a few SALT to the pot before cooking the spaghetti.
1	VP	Phrase structure violation	slept cushions	sewed cushions	Mary had a lot of time to herself and she sewed CUSHIONS in the evenings.	Sarah had a lot of time to herself and she slept CUSHIONS in the afternoons.

2	VP	Phrase structure violation	said stories	told stories	John and Mary were very popular and they told STORIES which made people laugh.	Mark and Sarah were very popular and they said STORIES which made friends laugh.
3	VP	Phrase structure violation	hopped frogs	chased frogs	Mary was in the garden and chased FROGS into the pond.	Emma was in the garden and hopped FROGS into the pond.
4	VP	Phrase structure violation	laughs jokes	tells jokes	Claire is a young comedienne and she tells JOKES which are very funny.	Kate is a young comedienne and she laughs JOKES which are very political
5	VP	Phrase structure violation	walk shoes	find shoes	Paul was getting ready to go hiking and he couldn't find SHOES suitable for the mountain.	Rob was getting ready to go hiking and he couldn't walk SHOES suitable for the mountain.
6	VP	Phrase structure violation	falling juice	spilling juice	Kate is spilling JUICE all over her new dress.	Rose is falling JUICE all over her new trousers.
7	VP	Phrase structure violation	happened fish	bought fish	On Friday evening Emma bought FISH and steaks for the barbecue on the weekend.	On Thursday evening Sarah happened FISH and vegetables for dinner on the weekend.
8	VP	Phrase structure violation	travelling bikes	selling bikes	On Friday Alice is selling BIKES to her friend Jane.	On Sunday Sarah is travelling BIKES to the next town.

9	VP	Phrase structure violation	jumping cats	chasing cats	Frank had a naughty dog that enjoyed chasing CATS out of the house.	Tom had a naughty dog that enjoyed jumping CATS out of the cage.
10	VP	Phrase structure violation	trembling arms	waving arms	John was in a nightclub and saw people waving ARMS in time to the music.	Mark was in a nightclub and saw people trembling ARMS in time to the music.
11	VP	Phrase structure violation	talking friends	calling friends	Although it's expensive, Claire likes calling FRIENDS on the phone when she's on holiday abroad.	Although it's expensive, Alice likes talking FRIENDS on the phone from overseas.
12	VP	Phrase structure violation	looking films	watching films	John is happy being back home and watching FILMS with his friends.	Tom is happy being back home and looking FILMS at the new cinema.
13	VP	Phrase structure violation	look photos	show photos	Alice was excited to show PHOTOS from her latest trip to Stockholm.	Emma was excited to look PHOTOS from her holiday to Canada.
14	VP	Phrase structure violation	travel trains	catch trains	We left work five minutes early so we could catch TRAINS home before rush hour.	We left work five minutes early so we could travel TRAINS to the airport.
15	VP	Phrase structure violation	staying courses	taking courses	Emma is taking COURSES at University that are not related to her degree.	Alice is staying COURSES on Saturday mornings even though she likes to sleep in.

16	VP	Phrase structure violation	belong balloons	collect balloons	Every year, I collect BALLOONS at my nephew's birthday party.	Every year, I belong BALLOONS at my niece's birthday party.
17	VP	Phrase structure violation	disappear calories	burn calories	In order to regularly burn CALORIES and get fitter, Mark signed up to a gym.	In order to regularly disappear CALORIES and lose weight, Rob joined a running group.
18	VP	Phrase structure violation	happens tourists	brings tourists	The annual music event brings TOURISTS to the area from all over the globe.	The annual music event happens TOURISTS to the city from far away.
19	VP	Phrase structure violation	come drinks	bring drinks	Paul told John: "Don't forget to bring DRINKS and snacks when you come over later."	Rob told Frank: "Don't forget to come DRINKS and crisps from the shops."
20	VP	Phrase structure violation	disappear money	spend money	Frank prefers not to spend MONEY from his savings account on entertainment.	Paul prefers not to disappear MONEY from his retirement saving to pay for renovations.
			Premodified	**Bare**	**Premodified sentence**	**Bare sentence**
1	NP	Premodification	the thin cats	cats	On her way to the room, Sarah looked and saw the thin CATS running around.	One day about three weeks ago, Alice looked and saw CATS running around.

2	NP	Premodification	the sweet apples	apples	When she went to the market, Mary bought the sweet APPLES from the farmer.	When she went to the market, Mary bought APPLES from the farmer.
3	NP	Premodification	the young snakes	snakes	John was afraid of the young SNAKES although he had never seen them.	Paul was afraid of SNAKES although he had never seen one.
4	NP	Premodification	the unusual music	music	It was a good event and the unusual MUSIC was playing from the loudspeakers.	It was a fun event and there was MUSIC playing from the loudspeakers.
5	NP	Premodification	the lovely flowers	flowers	While waiting for the train, Emma thought about the lovely FLOWERS for the party.	Despite the amount of work, Mary thought about FLOWERS for the party.
6	NP	Premodification	the red onions	onions	Kate was making soup and found the red ONIONS in the cupboard.	Jane was making soup and she found ONIONS in the cupboard.
7	NP	Premodification	the heavy books	books	Claire had to carry around the heavy BOOKS all day because her bag was torn.	Jane had to carry around BOOKS all day because she forgot her bag.
8	NP	Premodification	the fresh water	water	It was very hot outside, and the kids in the pool were tipping the fresh WATER into buckets.	Last Sunday we went to the park, and the kids in the pool were tipping WATER into buckets.

9	NP	Premodification	a fresh juice	juice	Jane offered her friends buttered toast and a fresh JUICE at brunch.	Claire offered her guests buttered toast and JUICE or coffee for breakfast.
10	NP	Premodification	the unfortunate students	students	Although the class had already started, the unfortunate STUDENTS kept walking into the lecture hall.	Although the class had already started, STUDENTS kept walking into the lecture hall.
11	NP	Premodification	his new shoes	shoes	Paul was getting ready to go to work and he couldn't find his new SHOES to match his suit.	John was getting ready to go to the wedding and he couldn't find SHOES to match his suit.
12	NP	Premodification	the young doctors	doctors	Although it was Sunday, the young DOCTORS were busy treating patients.	In the early hours of the day, DOCTORS were busy treating patients.
13	NP	Premodification	the gorgeous trees	trees	The gardener wanted to place the gorgeous TREES along the stream in the forest.	The gardener wanted to place TREES along the road in the park.
14	NP	Premodification	the tiny balls	balls	Although she was young, Jane hit the tiny BALLS with a golf club.	When she was younger, Kate hit BALLS in the park with a cricket bat.
15	NP	Premodification	the tired soldiers	soldiers	In the new town square, the tired SOLDIERS were parading before the mayor.	To mark the Queen's birthday, SOLDIERS were parading in front of the palace.

16	NP	Premodification	the special dinner	dinner	She had been cooking all day, it was clear the special DINNER was soon ready.	From the sounds in the kitchen it was clear DINNER was not yet ready.
17	NP	Premodification	a large coffee	coffee	Do you usually have a large COFFEE or tea at break-time?	Do you usually have COFFEE or tea in the morning?
18	NP	Premodification	a small bread	bread	Kate forgot to buy a small BREAD loaf at the grocery store.	Jane forgot to buy BREAD loaves at the grocery store.
19	NP	Premodification	the best cakes	cakes	The bakery down the road makes the best CAKES in the city.	The bakery down the road makes CAKES with elaborate toppings.
20	NP	Premodification	the local prison	prison	The priest visits the local PRISON once a week to pray with inmates.	The priest visits PRISON once a month to talk to the inmates.
1	VP	Premodification	has been dreaming	dreaming	Emma is buying a lottery ticket and has been DREAMING of a holiday in the Caribbean.	Mary is buying a lottery ticket and DREAMING of winning the jackpot one day.
2	VP	Premodification	had been dancing	dancing	I couldn't believe it when I saw you had been DANCING the waltz at your wedding.	I couldn't believe it when I saw you DANCING to rock music.
3	VP	Premodification	had been looking	looking	All Sunday long, the children had been LOOKING through the window to see if it was raining.	The entire day, the children LOOKING through the window hoped it would snow.

4	VP	Premodification	will be baking	baking	Mary is in the kitchen and will be BAKING muffins this weekend.	Sarah is in the kitchen and BAKING cookies with her children for the party.
5	VP	Premodification	must have cleaned	cleaned	On Saturday morning, Mark must have CLEANED the car before he went for a stroll.	On Sunday evening Tom CLEANED the kitchen and then took a well-deserved break.
6	VP	Premodification	should have travelled	travelled	Last summer Kate should have TRAVELLED to Spain for holiday.	Last summer Claire TRAVELLED to Greece for a holiday.
7	VP	Premodification	can be cooked	cooked	While the salad is freshly prepared, the chicken can be COOKED in advance.	While Sarah prepared the salad, the chicken COOKED in the oven.
8	VP	Premodification	should have kicked	kicked	On the field, Frank should have KICKED the ball to his team mate.	On the pitch, Rob KICKED the ball to his team mate who then scored the winning goal.
9	VP	Premodification	must have knocked over	knocked over	Mark must have KNOCKED OVER the mirror while looking for his scarf.	Rob KNOCKED OVER the glass vase onto the floor while looking for his glove.
10	VP	Premodification	should have poured	poured	At the restaurant, the waiter should have POURED wine for the guests.	At the restaurant, the waiter POURED tea for the guests.

11	VP	Premodification	could have changed	changed	Emma thought it was important that she could have CHANGED the light bulb herself without help.	Alice thought it was important that she CHANGED the tyre herself when she punctured it.
12	VP	Premodification	will be finished	finished	I will be FINISHED writing soon so I can go outside and play.	I FINISHED writing my essay and now I'm reading a book.
13	VP	Premodification	would have dropped	dropped	There was a loud noise and Paul would have DROPPED his glass if he had been holding it.	There was a loud noise and Frank DROPPED the glass he was holding.
14	VP	Premodification	must have bought	bought	Claire must have BOUGHT the tickets weeks ago in order to get good seats.	Rose BOUGHT the tickets in advance in order to save money.
15	VP	Premodification	will have taught	taught	Last winter Rose will have TAUGHT the children how to ice skate.	Last summer Kate TAUGHT the children how to roller skate.
16	VP	Premodification	should have caught	caught	Because Mary woke up on time, she should have CAUGHT the bus for school.	Because Alice woke up on time, she CAUGHT the bus for work.
17	VP	Premodification	must have cost	cost	Frank's new TV must have COST him a lot of money.	Rob's new TV COST a lot more than he had expected.

18	VP	Premodification	must have put	put	Paul <u>must have</u> PUT a lot of old toys in the attic when cleaning up.	John PUT a lot of old photos in the album while cleaning up his desk
19	VP	Premodification	should have paid	paid	The service was excellent and Tom <u>should have</u> PAID the waiter a generous tip.	The service was excellent and Mark PAID the waiter a generous tip.
20	VP	Premodification	must have played	played	The kids <u>must have</u> PLAYED together until they fell asleep.	The kids PLAYED together in the park until it rained.
			High frequency phrase	**Low frequency phrase**	**High frequency phrase sentence**	**Low frequency phrase sentence**
1	NP	Phrase frequency	riding an elephant	touching an elephant	Last time at the zoo I was <u>riding an ELEPHANT</u> for the first time in my life.	Last time at the zoo I was <u>touching an ELEPHANT</u> for the first time in my life.
2	NP	Phrase frequency	range of sports	variety of sports	The local centre offers a <u>range of SPORTS</u> and activity opportunities suitable for everyone.	The community centre offers a <u>variety of SPORTS</u> clubs that anyone can join.
3	NP	Phrase frequency	cup of tea	glass of tea	Frank ordered a <u>cup of TEA</u> and scones at his favourite café.	John ordered a <u>glass of TEA</u> and biscuits and read a newspaper.

4	NP	Phrase frequency	asked for directions	looked for directions	Alice was new to the city so she asked for DIRECTIONS to the nearest museum.	Mary was new to the town so she looked for DIRECTIONS to the nearest library.
5	NP	Phrase frequency	wash my hair	style my hair	Every Monday morning I wash my HAIR at the hairdresser.	Every Friday morning I style my HAIR at the hairdresser.
6	NP	Phrase frequency	pay the bill	get the bill	When she finished her tea Rose asked the waiter: "Can I pay the BILL with my credit card?"	When she finished her coffee Jane asked the waiter: "Can I get the BILL soon, I need to catch the next train."
7	NP	Phrase frequency	loaf of bread	slice of bread	Kate remembered to buy a loaf of BREAD from the bakery on her way home.	Rose remembered to buy a slice of BREAD from the bakery on her way to work.
8	NP	Phrase frequency	take the train	catch the train	Alice decided to take the TRAIN to travel to the sea side.	Mary decided to catch the TRAIN into town to go to the movies.
9	NP	Phrase frequency	visited the school	entered the school	A few years later, Alice visited the SCHOOL she went to as a child.	A few hours later, Emma entered the SCHOOL where she had left her books.
10	NP	Phrase frequency	closed the door	locked the door	Rob closed the DOOR behind him and drove to his office.	Tom locked the DOOR behind him and drove to the airport.
11	NP	Phrase frequency	fly a kite	lose a kite	The wind was so strong that it was easy to fly a KITE in the park.	The breeze was so strong that it was easy to lose a KITE in the park.

12	NP	Phrase frequency	published a book	finished a book	Kate was very happy that she finally published a BOOK about British castles.	Jane was very happy that she finally finished a BOOK about Japanese gardens.
13	NP	Phrase frequency	pint of beer	mug of beer	Rob ordered a pint of BEER and chips while waiting for his friend.	Mark ordered a mug of BEER and a bag of crisps while waiting for his mates.
14	NP	Phrase frequency	wear a coat	get a coat	It was a chilly evening so I decided to wear a COAT before leaving for the party.	It was a frosty morning so I decided to get a COAT before going for my walk.
15	NP	Phrase frequency	won a prize	got a prize	Emma won a PRIZE in the best fiction category for her new novel.	Sarah got a PRIZE in the best pop song category for her new song.
16	NP	Phrase frequency	buy a car	sell a car	Last Friday Alice went to the dealer to buy a CAR big enough to fit a pram.	On Saturday Sarah went to the dealer to sell a CAR she had owned for many years.
17	NP	Phrase frequency	get some food	buy some food	Mark woke up early on Saturday to get some FOOD for dinner that evening.	Rob woke up early on Sunday to buy some FOOD for breakfast that morning.
18	NP	Phrase frequency	write a letter	send a letter	Frank promised to write a LETTER to his grandmother for her 80th birthday.	Mark promised to send a LETTER to his niece from his trip abroad.

19	NP	Phrase frequency	brush your teeth	clean your teeth	Mark reminded his son at bed time: "Don’t forget to <u>brush your TEETH</u> every night.	Paul reminded his son at bed time: "Don’t forget to <u>clean your TEETH</u> before going to bed.
20	NP	Phrase frequency	on the table	off the table	Tom likes to keep the vase with flowers <u>on the TABLE</u> in the kitchen.	John likes to keep the vase with flowers <u>off the TABLE</u> when he cleans the dining room.
1	VP	Phrase frequency	do n't know	shall not know	Mary went to see the Doctor and he said "I <u>don’t KNOW</u> when I'll have time to see you today."	Emma went to see the Doctor and he said: "I <u>shall not KNOW</u> until I get the test results back."
2	VP	Phrase frequency	want to play	need to play	John and Mary sat down and she said: "I <u>want to PLAY</u> cards."	Tom and Alice sat down and she said: "I <u>need to PLAY</u> cards."
3	VP	Phrase frequency	like to dance	need to dance	When I hear music I <u>like to DANCE</u> until my feet get tired.	When I hear music I <u>need to DANCE</u> until I am exhausted.
4	VP	Phrase frequency	want to finish	need to finish	Mark and Emma <u>want to FINISH</u> eating their breakfast before leaving for work.	Tom and Alice <u>need to FINISH</u> packing their suitcases before leaving for their holidays.
5	VP	Phrase frequency	trying to catch	hoping to catch	Rob and Frank were hurrying to the port <u>trying to CATCH</u> the ship to the islands.	Mark and Paul were rushing to the port <u>hoping to CATCH</u> the ferry to France.

6	VP	Phrase frequency	don't forget	won't forget	As he left his house Mark said: "Sarah, don't FORGET our date this evening at seven."	As he left his office Paul thought: "Emma won't FORGET our date this evening."
7	VP	Phrase frequency	continued to grow	started to grow	The plants continued to GROW strong and tall although it hadn't rained almost all year.	The plants started to GROW in the spring although it hadn't rained almost all year.
8	VP	Phrase frequency	able to run	ready to run	Despite recovering from an injury, Mark was able to RUN several miles each day.	Despite leaving late from work, Rob was ready to RUN several miles tonight.
9	VP	Phrase frequency	need to talk	have to talk	Emma said: "We need to TALK about planning our next holiday."	Sarah said: "We have to TALK about Dad's birthday present."
10	VP	Phrase frequency	time to turn	space to turn	It's difficult to drive in Milan. There is not a lot of time to TURN if you miss your exit.	It's not easy to drive in Madrid. There is not a lot of space to TURN in case you drive wrong.
11	VP	Phrase frequency	able to grab	likely to grab	John's daughter is crawling now and able to GRAB toys from shelves.	Rob's daughter is crawling now and likely to GRAB items lying around the floor.
12	VP	Phrase frequency	likely to fall	about to fall	Because he was weary, Tom was likely to FALL and injure himself.	Because he was tired, Frank was about to FALL and injure himself.

13	VP	Phrase frequency	trying to guess	going to guess	Rob received a parcel in the post and was trying to GUESS who had sent it to him.	Frank received a parcel in the post and was going to GUESS what was inside before opening it.
14	VP	Phrase frequency	plans to build	wants to build	John plans to BUILD a doll's house for his daughter Alice this winter.	Tom wants to BUILD a tree house for his daughter Claire this autumn.
15	VP	Phrase frequency	agreed to pay	expected to pay	Mary's parents agreed to PAY half the cost of her new car.	Sarah's parents expected to PAY some of the cost for her university degree.
16	VP	Phrase frequency	time to visit	day to visit	Thursdays are a great time to VISIT the exhibition at the science museum.	Mondays are a great day to VISIT the castle and its parks.
17	VP	Phrase frequency	looking to buy	hoping to buy	Last Saturday, Frank was looking to BUY a suit for his wedding.	Last Friday, Paul was hoping to BUY a bouquet of flowers for his wife.
18	VP	Phrase frequency	likely to drink	ready to drink	When Paul and Jane watch movies together they are likely to DRINK coke and eat popcorn.	When Frank and Claire watch TV together they are ready to DRINK beer and eat pizza.
19	VP	Phrase frequency	time to cook	help to cook	Rose isn't sure that she has enough time to COOK her friends dinner.	Jane isn't sure that she has enough help to COOK Christmas lunch.
20	VP	Phrase frequency	decided to try	planned to try	We decided to TRY the five course menu at our favourite restaurant.	We planned to TRY the new ice cream flavour at our favourite café.

Appendix A.2 Phrase frequency stimuli including frequency values

Pair nr	Phrase type	Phrase frequency (high/low)	High frequency phrase	Low frequency phrase
1	NP	22/0	riding an elephant	touching an elephant
2	NP	135/60	range of sports	variety of sports
3	NP	2897/8	cup of tea	glass of tea
4	NP	28/1	asked for directions	looked for directions
5	NP	28/6	wash my hair	style my HAIR
6	NP	140/27	pay the bill	get the bill
7	NP	307/89	loaf of bread	slice of bread
8	NP	133/45	take the train	catch the train
9	NP	78/26	visited the school	entered the school
10	NP	185/115	closed the door	locked the door
11	NP	23/0	fly a kite	lose a kite
12	NP	314/10	published a book	finished a book
13	NP	361/3	pint of beer	mug of beer
14	NP	17/8	wear a coat	get a coat
15	NP	99/8	won a prize	got a prize
16	NP	180/16	buy a car	sell a car
17	NP	44/10	get some food	buy some food
18	NP	274/94	write a letter	send a letter
19	NP	72/57	brush your teeth	clean your teeth
20	NP	31869/4912	on the table	off the table
1	VP	37024/2	do n't know	shall not know
2	VP	2691/570	want to play	need to play
3	VP	26/7	like to dance	need to dance

4	VP	265/87	want to finish	need to finish
5	VP	352/153	trying to catch	hoping to catch
6	VP	2698/198	do n't forget	wo n't forget
7	VP	522/142	continued to grow	started to grow
8	VP	620/91	able to run	ready to run
9	VP	566/375	need to talk	have to talk
10	VP	221/7	time to turn	space to turn
11	VP	82/25	able to grab	likely to grab
12	VP	404/142	likely to fall	about to fall
13	VP	75/20	trying to guess	going to guess
14	VP	1214/351	plans to build	wants to build
15	VP	1036/311	agree to pay	expected to pay
16	VP	389/11	time to visit	days to visit
17	VP	991/48	looking to buy	hoping to buy
18	VP	105/31	likely to drink	ready to drink
19	VP	78/2	time to cook	help to cook
20	VP	531/12	decided to try	planned to try

Appendix A.3 Word monitoring manual

08.2016

Phonetics for Word Monitoring

Gwen Brekelmans, Vanessa Meitanis
UCL

PHONETICS FOR WORD MONITORING

Types of sound

Plosives: /p/ plant , /t/ tree, /k/ cat, /b/ baby/banana, /d/ dog, /g/ goal

Fricatives: /f/ fun, /v/ very, /th/ think, /th/ the, /s/ sand, /z/ zoo, /sh/ ship, /zj/ measure, /h/ hello

Affricates: /tsh/ chance, /dzj/ judge

Nasals: /m/ money, /n/ nuts, /ng/ sing (does not exist at beginning of word)

Approximants: /l/ lullaby, /r/ ride, /j/ yes, /w/ water

Vowels:

RULES: CONTEXT SPECIFIC

<u>0: Speakers</u>

If the speaker is a British native speaker, they will NOT pronounce most /r/ s in spelling in places after a vowel at the end of a syllable, such as ‘year’, ‘car’, ‘mayor’, ‘Mark’.

<u>1: Same sounds</u>

NEVER use a word that starts with the same **sound (not necessarily spelling)** as the ending of the previous one.

e.g. ‘dolphins swim’, ‘some more’, ‘take courses’

<u>2: Same type of sound</u>

Avoid 2 **nasals** following each other with the target word starting with a nasal (See below)

e.g. ‘some nuts’, ‘baking muffins’

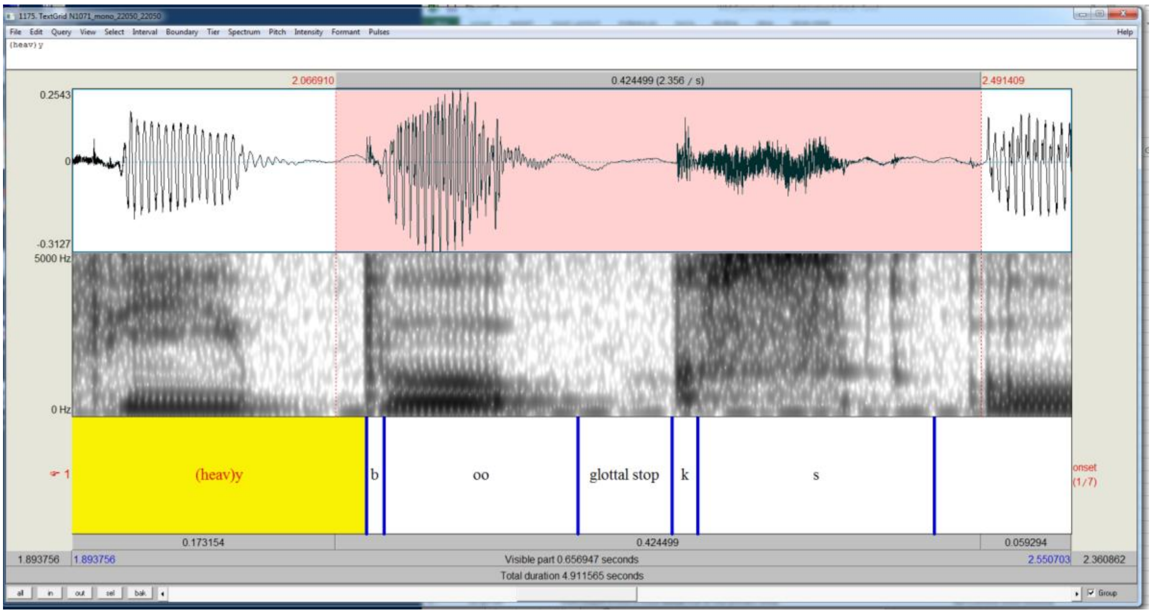
same goes for 2 **fricatives** following each other with the target word starting with a fricative.

e.g. ‘fresh fruit’, ‘boats shipped’.

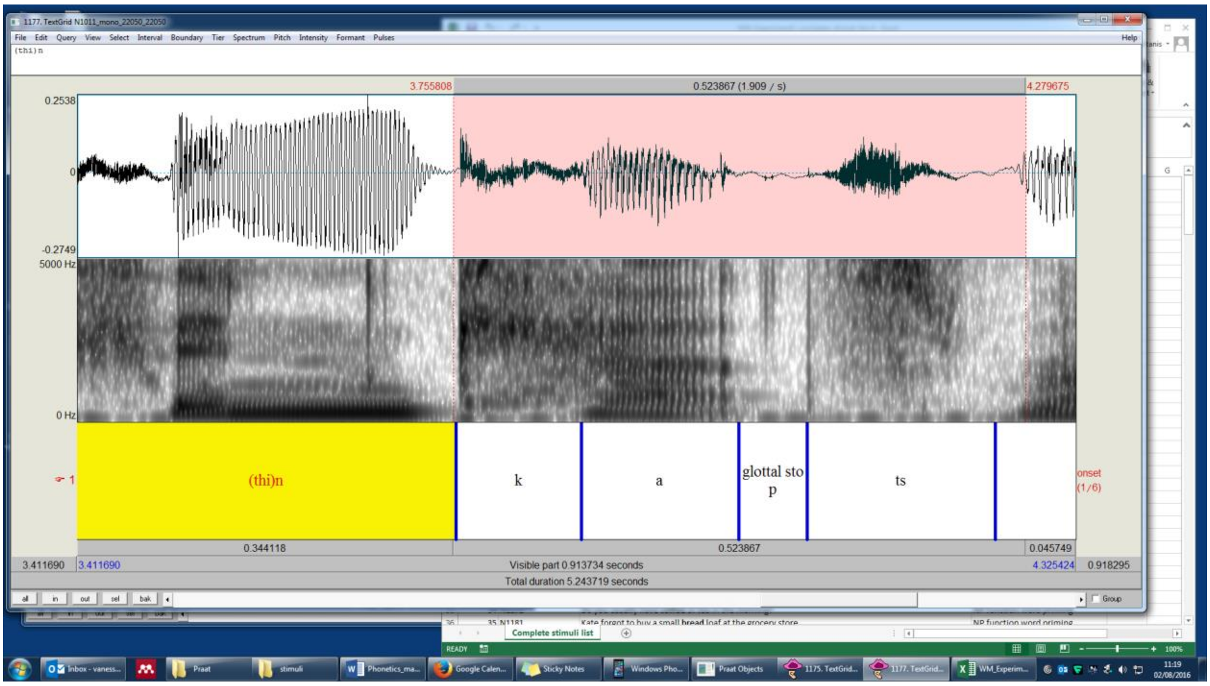
RULES: TARGET WORD SPECIFIC

<u>3 – Plosives:</u>

Use target words that begin with plosives (p,t,k,b,d,g) because this makes determining the onset easier.

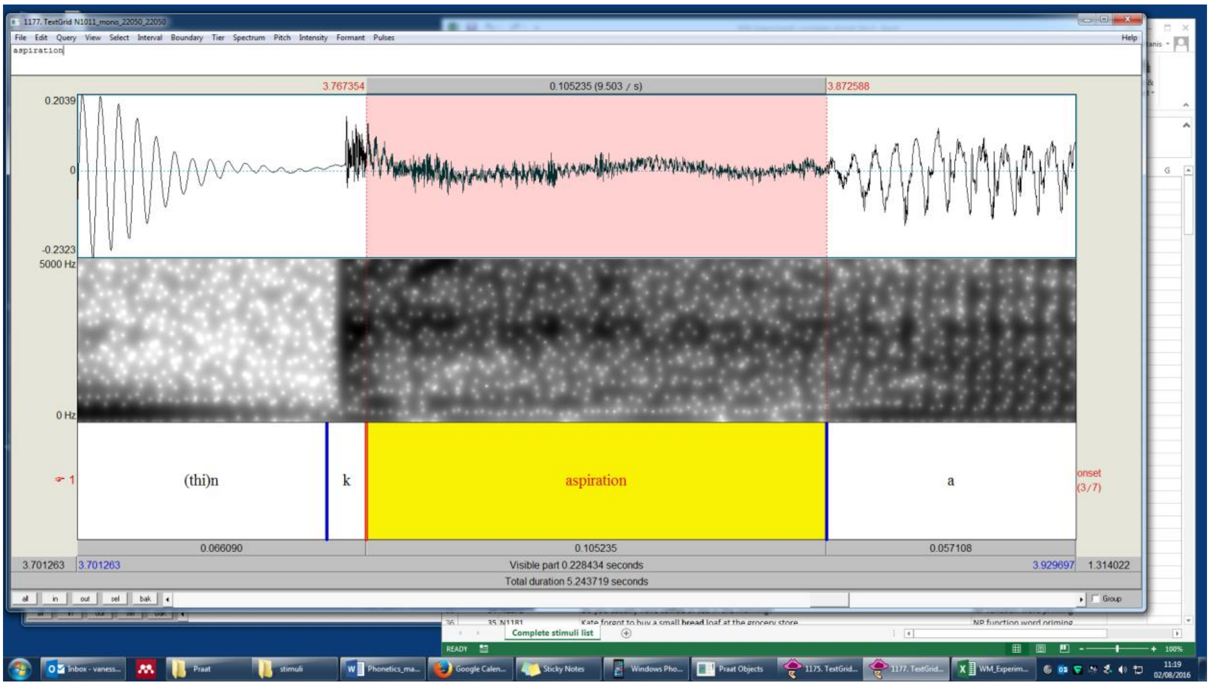


Example: ‘carry heav**y** **b**ooks’

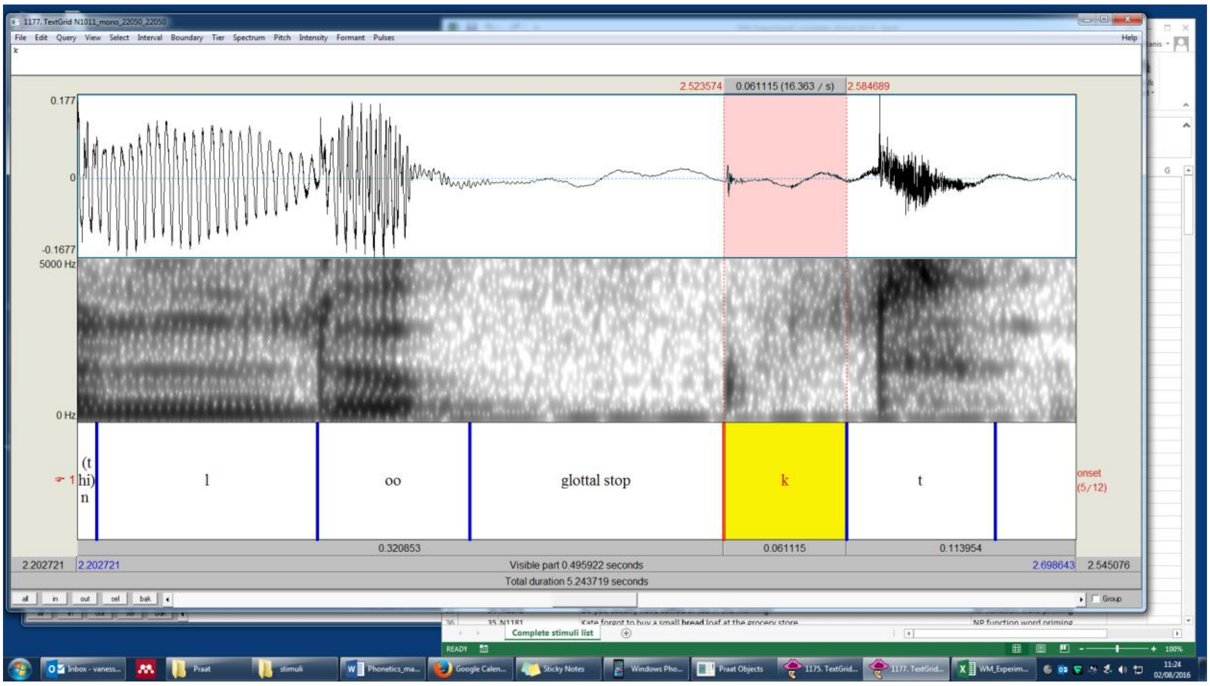


Example: ‘thi**n** **c**ats’

Sounds do not look identical in every position of the word; for example, the /k/ in ‘cats’ has aspiration because it is at the start of a syllable, while the /k/ in ‘ask’ will not have this aspiration there.



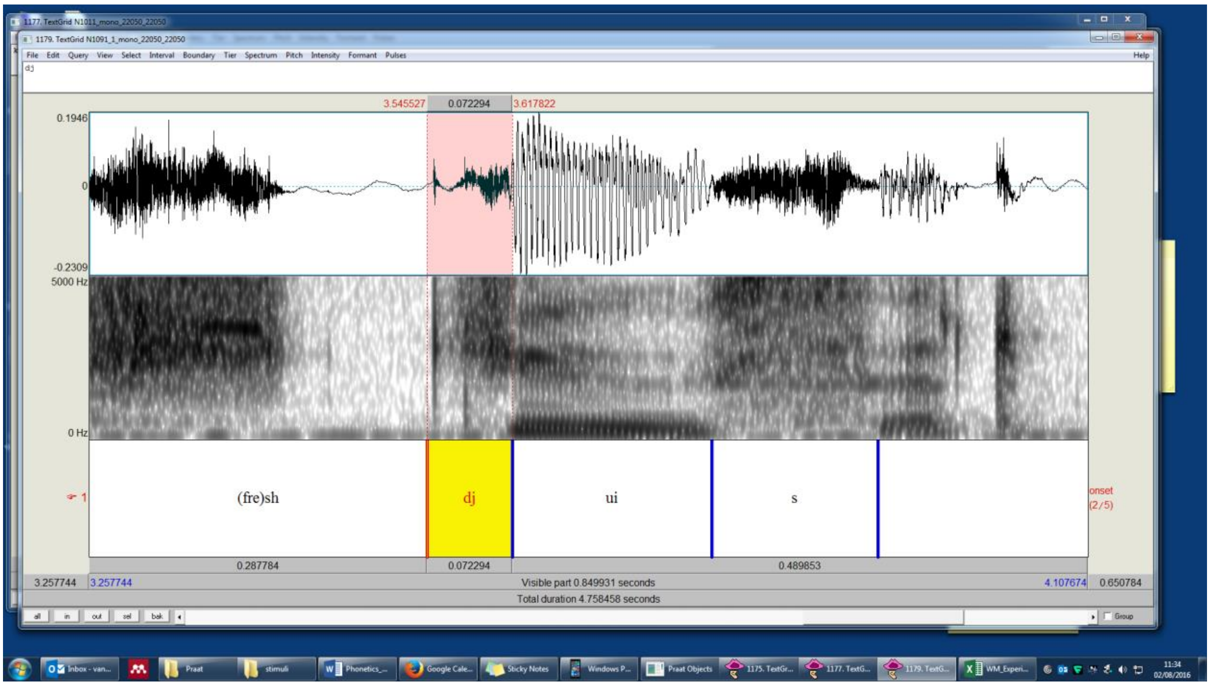
Example: /k/ in '**c**ats'



Example: /k/ in 'looked'

<u>4 - Affricates:</u>

If plosives are not possible, try to use affricates ('dj' like 'juice', 'judge, or 'tsh' like 'chance' or 'choose', 'change'



Example: ‘fre**sh j**uice’

5 – Vowels, fricatives, nasals:

If affricates are not possible either, choose a target word starting with a vowel (any vowel), a fricative (f, v, th, s, z, sh, zj; avoid ‘h’, see rule 6 below), or a nasal (m, n). Which is easiest depends on the previous sound.

5a. Vowels

Easier after plosives, fricatives, affricates, breaks in the sentence.

Difficult after approximants (r, l, j, w), /h/, and nasals (sometimes, mainly if the vowel is u-like).

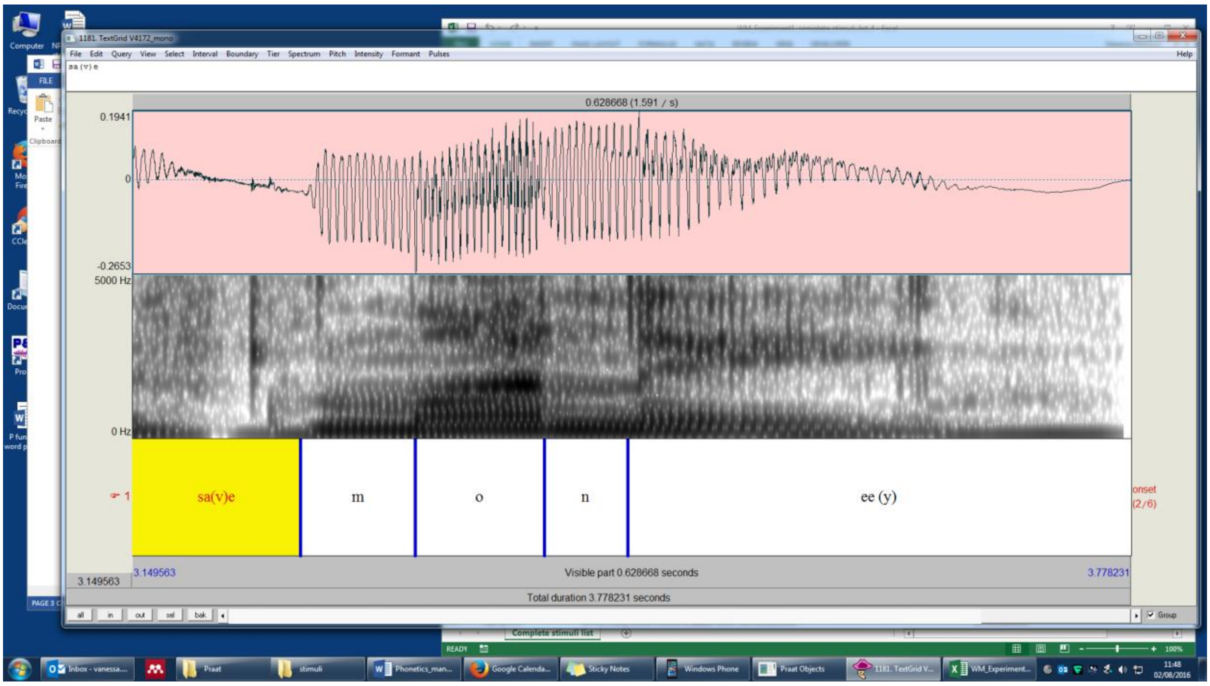
5b. Fricatives

Easier after plosives, vowels, nasals, most approximants.

Difficult after affricates, /h/.

5c. Nasals

Easier after plosives, fricatives, affricates, and most vowels.



Example: 'sa**ve m**oney' (e.g. after fricatives)

More difficult after some vowels (the ones ending in 'u', e.g. 'new money', or in schwa ('uh') such as 'better money' (better ends in 'uh' if you're Rosemary)), all nasals (m, n, ng), **and approximants** (/l/, /r/, /j/, /w/.

<u>Rule 6 - /h/:</u>

If previous rules cannot be followed, choose a target word starting with 'h'.

Only easier after plosives or nasals.

<u>Rule 7 – Approximants:</u>

Only if you have no other options, choose a target word starting with an approximant (e.g. 'l', 'r', 'j', 'w'). The approximants take on the sound quality and formants of surrounding vowels, so this makes it hard to distinguish them.

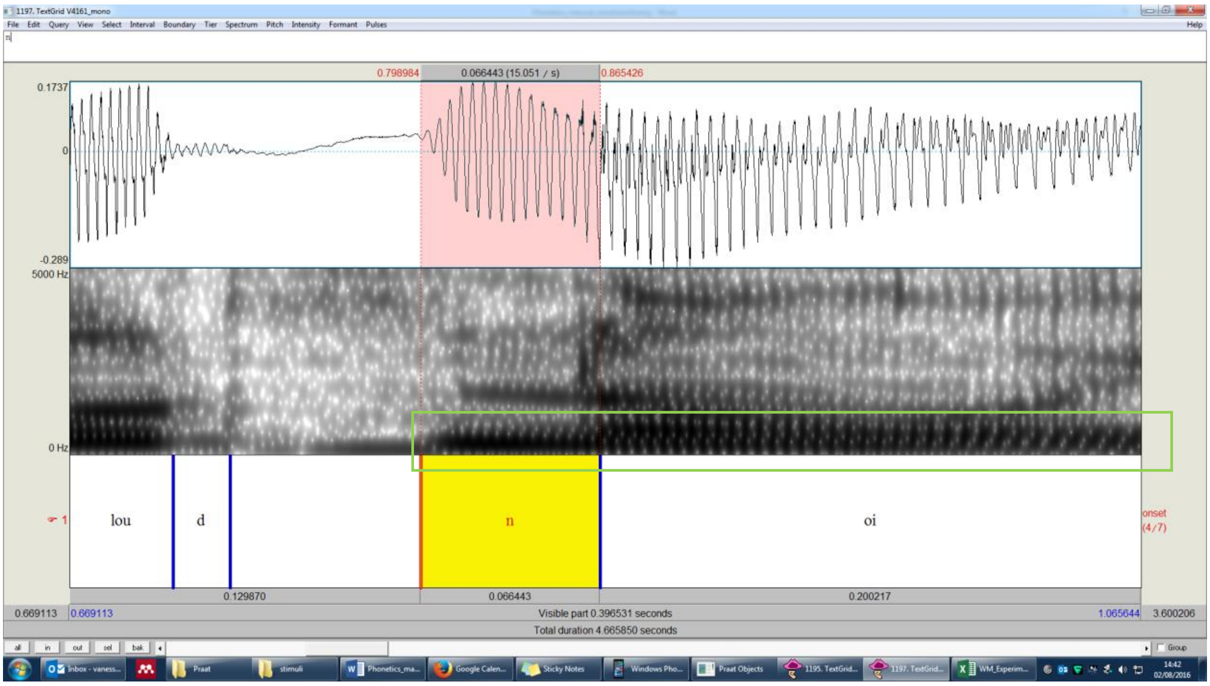
Easier after a plosive, fricative or affricate.

E.g. 'cold water', 'fresh water', 'orange water' but not 'cool water'.

SOUND SPECTRUMS

Voicing

Voiced sounds (e.g. all vowels, nasals, approximants, and voiced fricatives/affricates) should have a ‘voicing bar’ in their spectrum: a dark bar at the bottom of the spectrum. This is the low frequency from the vibrating vocal cords.



NOTE: this does not apply to English plosives, see below.

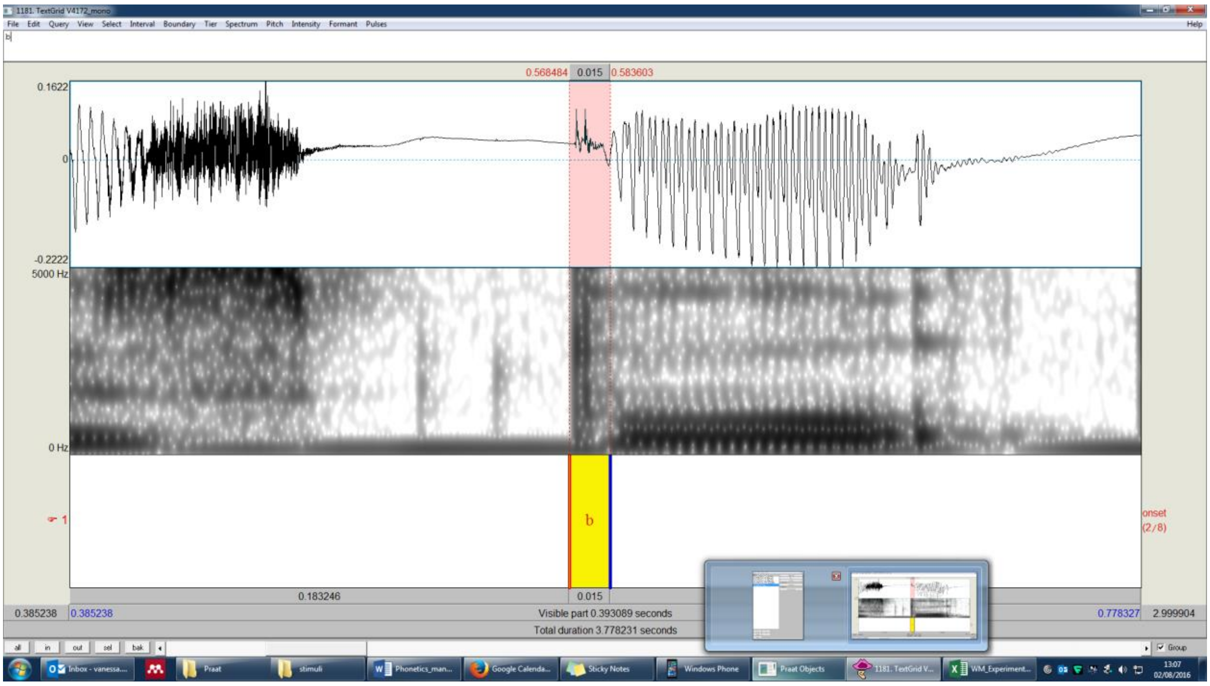
Plosives

Plosives consist of a closure somewhere in the mouth, which results in a dark line on the spectrum along the entire frequency range. After the closure follows a burst, which you can see in the spectrogram as spikey-ness. Depending on the location of the sound and the quality sound, this burst is longer.

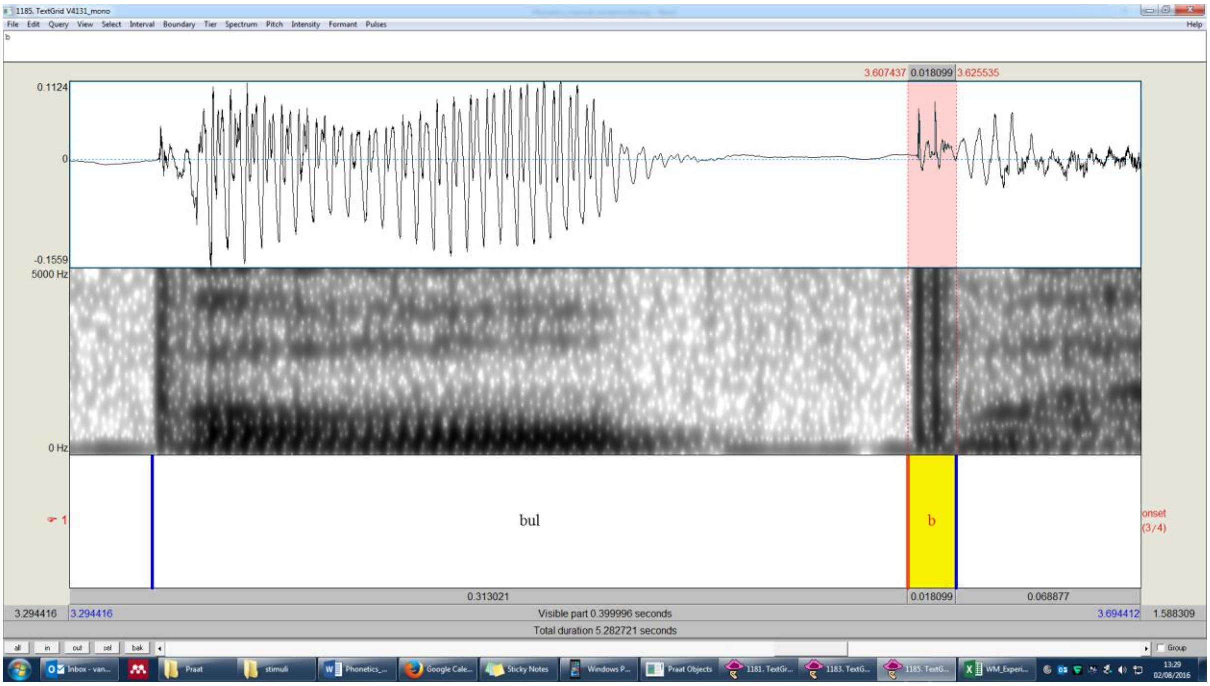
Plosives that are produced in the same location in the mouth, will result in similar spectrograms. The distinction in these is often in the voicing (e.g. /p/ vs /b/, /t/ vs /d/, /k/ vs /g/).

/b/

Voiced, no aspiration at beginning of syllable.



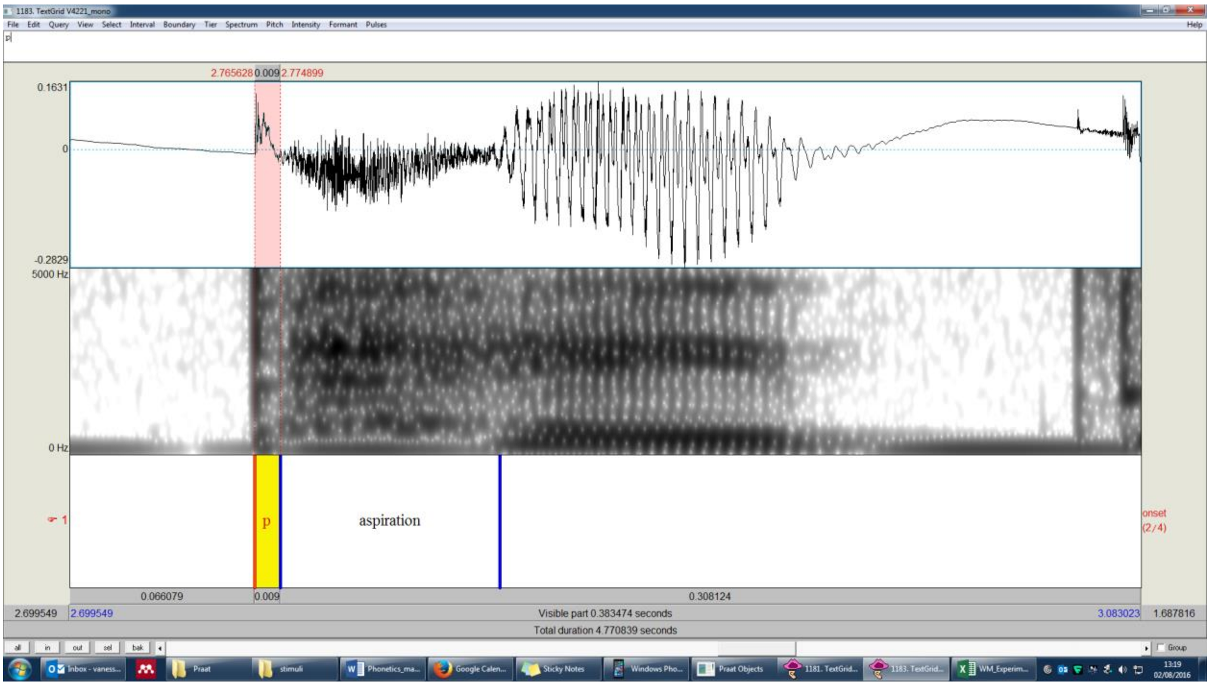
Example: /b/ at beginning of syllable



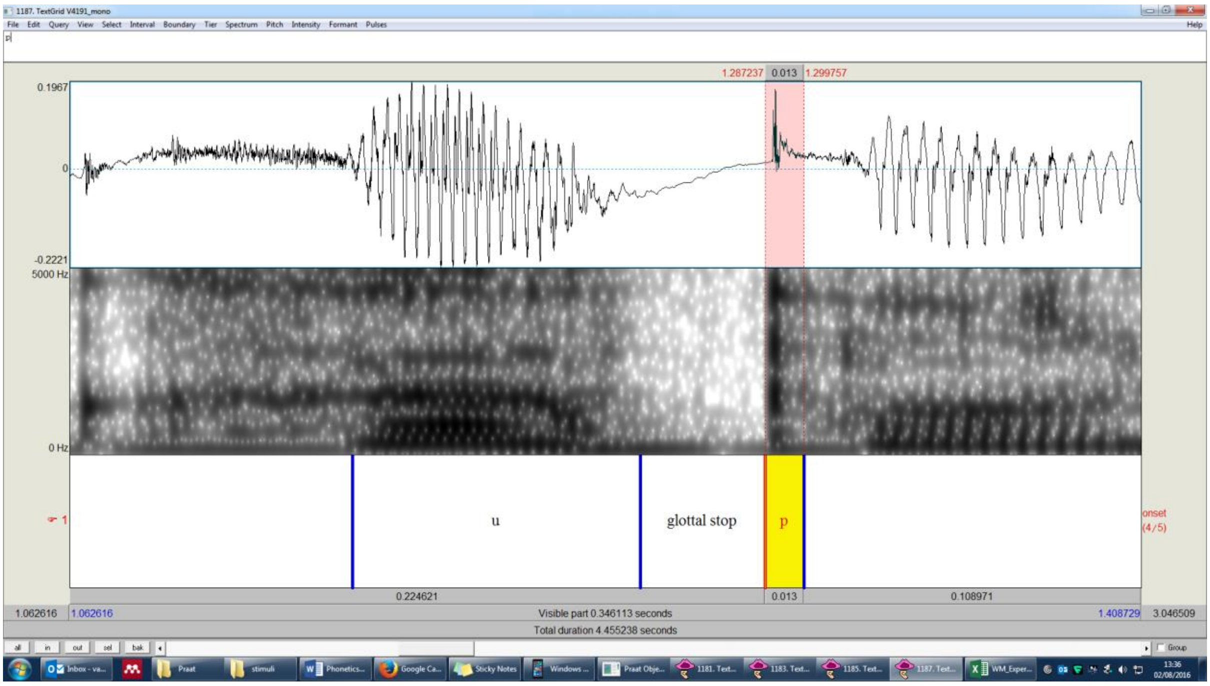
Example: /b/ at the end of ‘bulb’

/p/

Voiceless, aspiration if at the beginning of a syllable and NOT followed by /r/ or /l/, also NOT when in 'sp'.



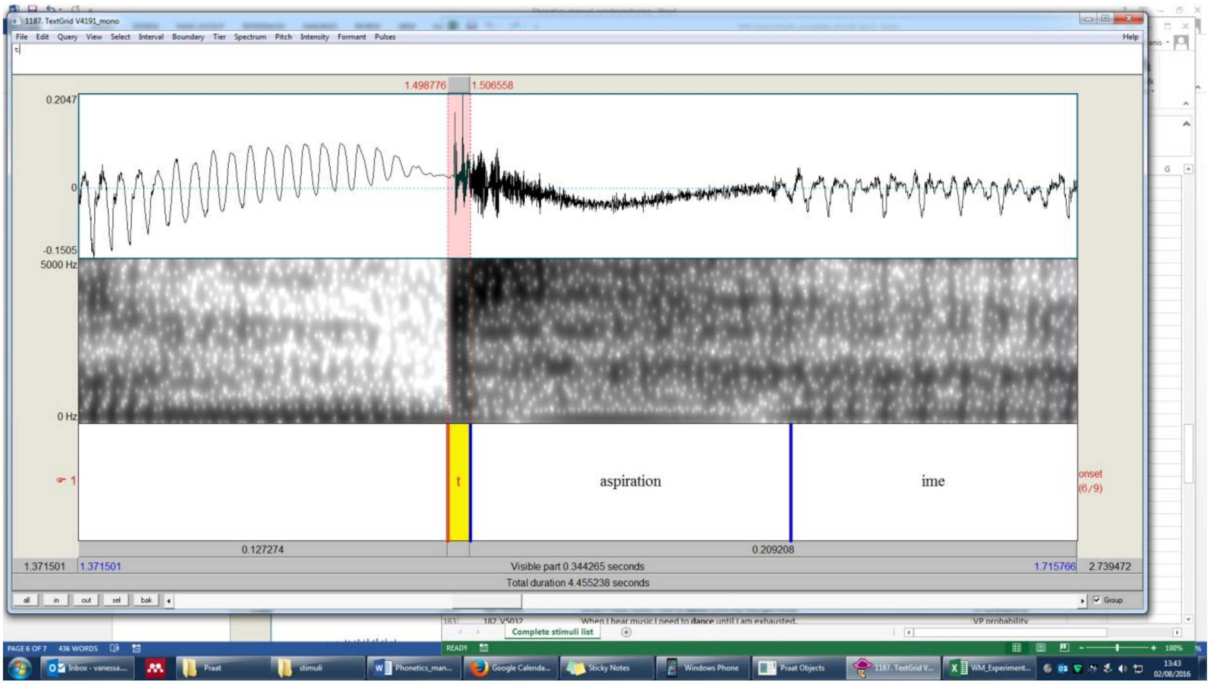
Example: /p/ at the beginning of 'paid'



Example: /p/ at the end of 'up'

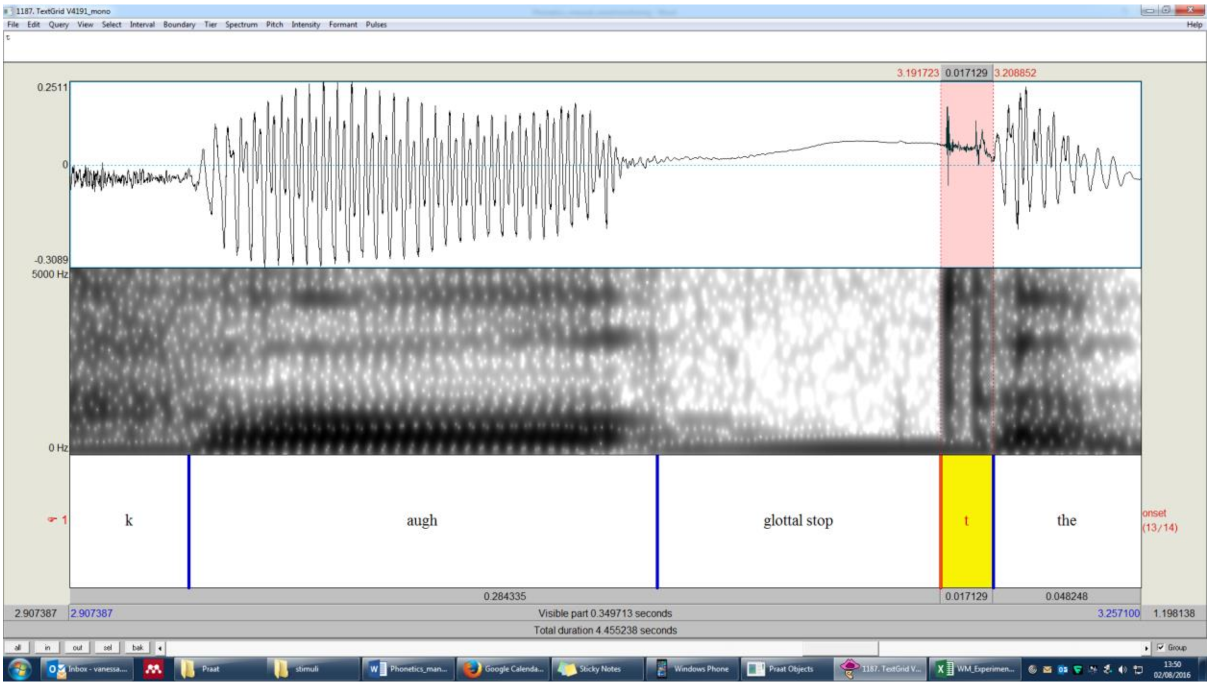
/t/

Voiceless. Aspirated at the beginning of a syllable, unless followed by /r/ (when there is frication instead) or in /st/.



Example: /t/ in 'time'.

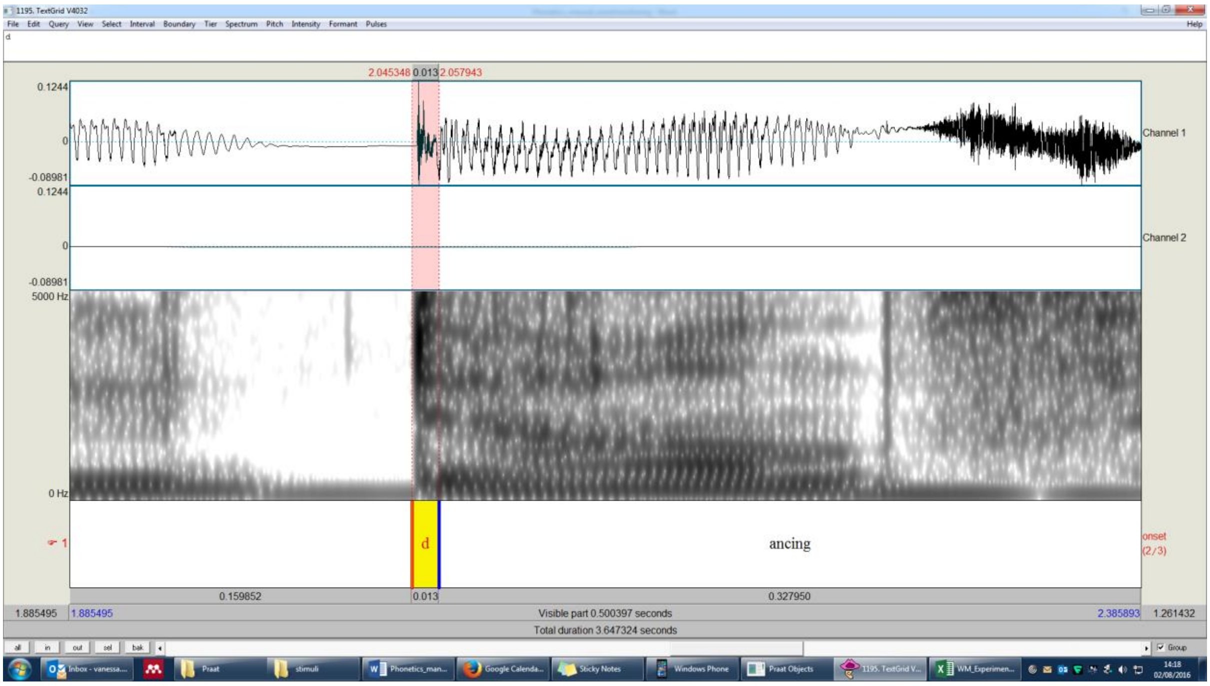
No aspiration when at the end of a syllable, instead preceded by a glottal stop.



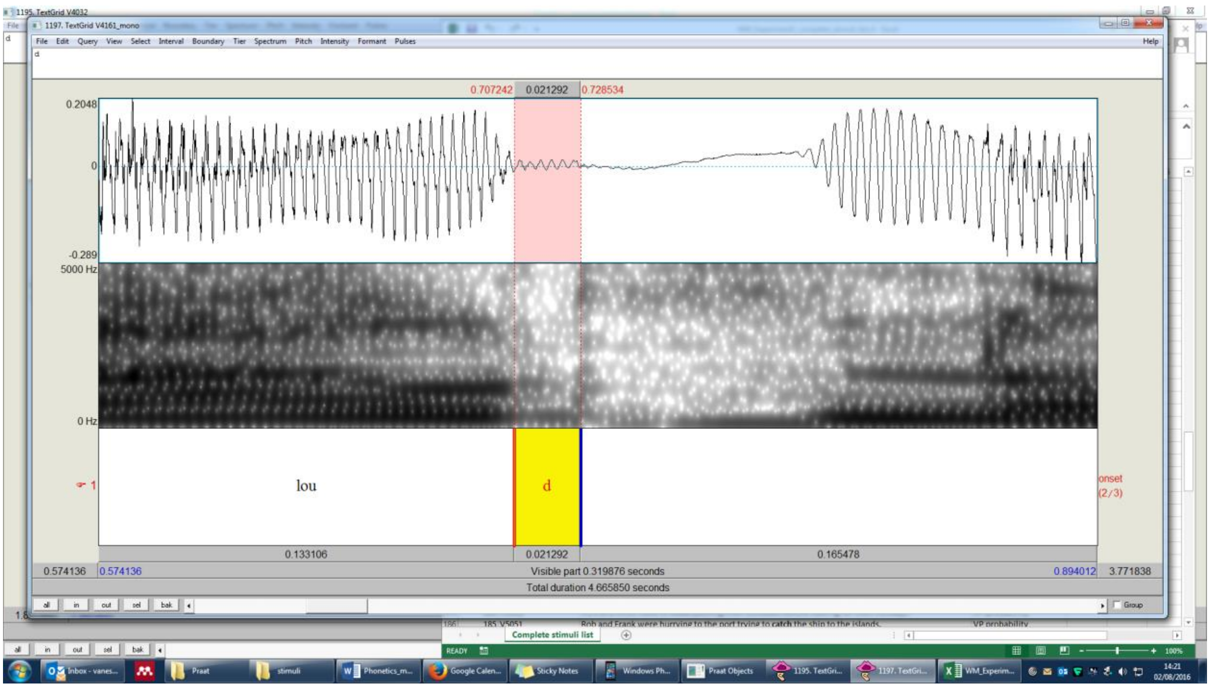
Example: /t/ at the end of 'caught'

/d/

Voiced. No aspiration at the beginning or end of syllable (followed by /r/ can again lead to frication).



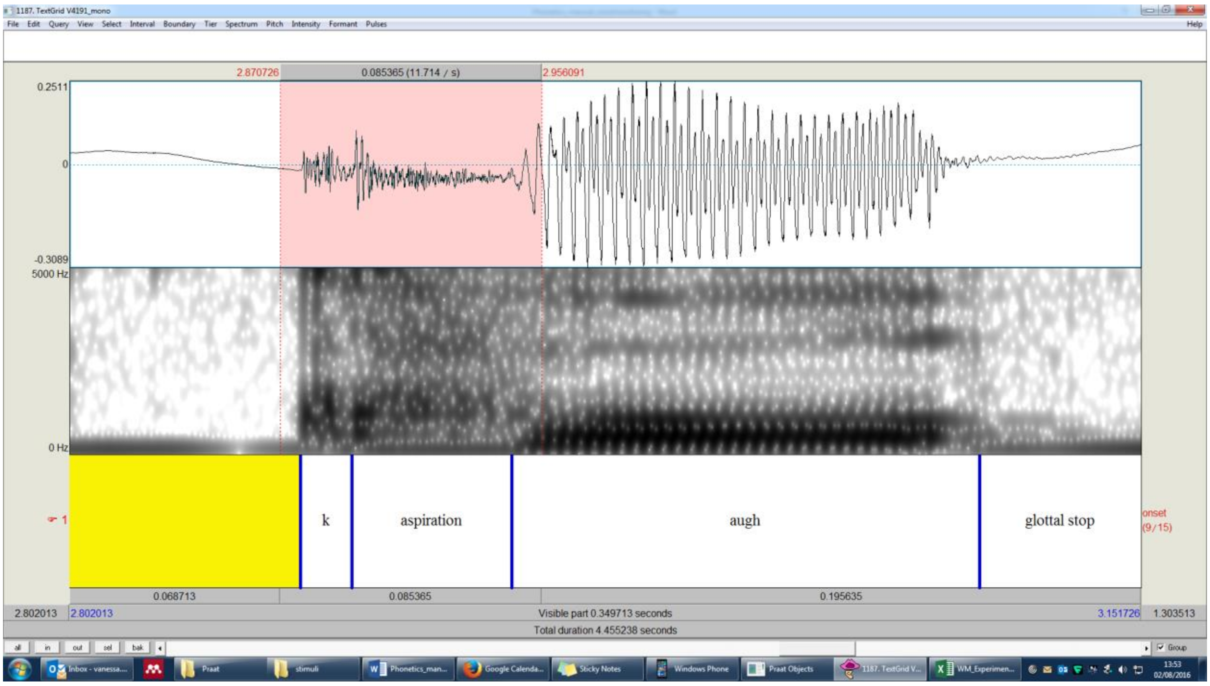
At the end of a syllable, it might be weakened, meaning that there is very little in the signal to identify.



Example: /d/ at the end of 'loud'

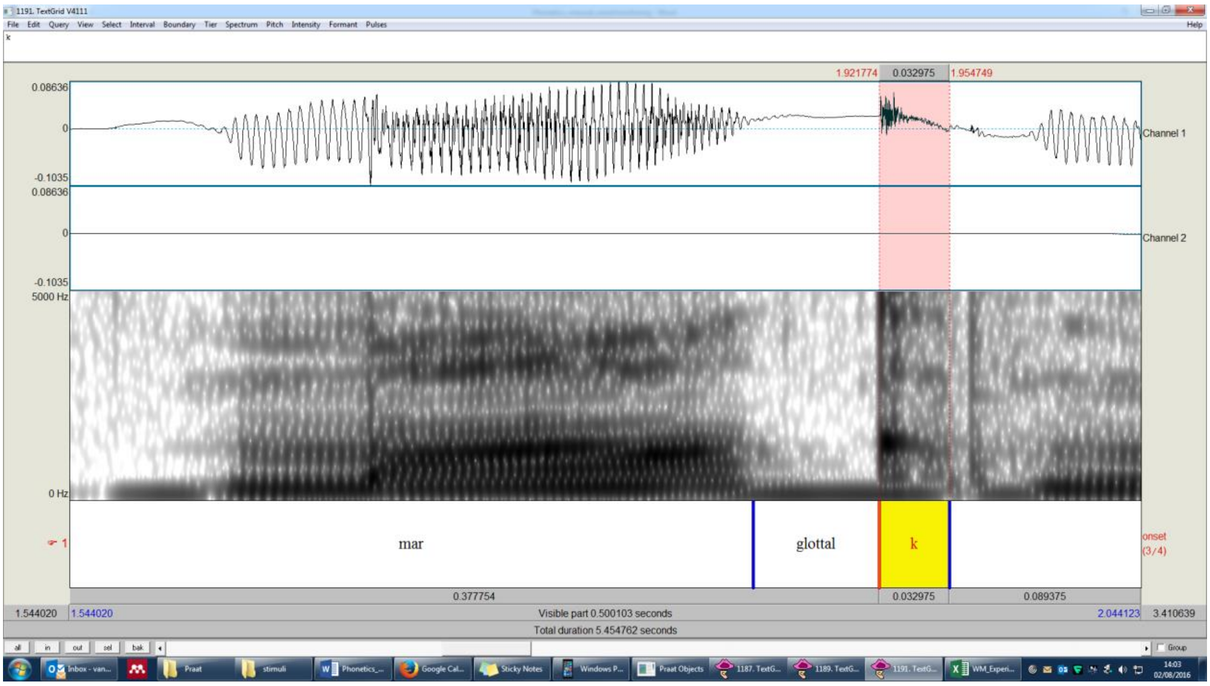
/k/

Voiceless. Aspirated at the beginning of a syllable unless followed by /r/ or /l/ or when in /sk/.

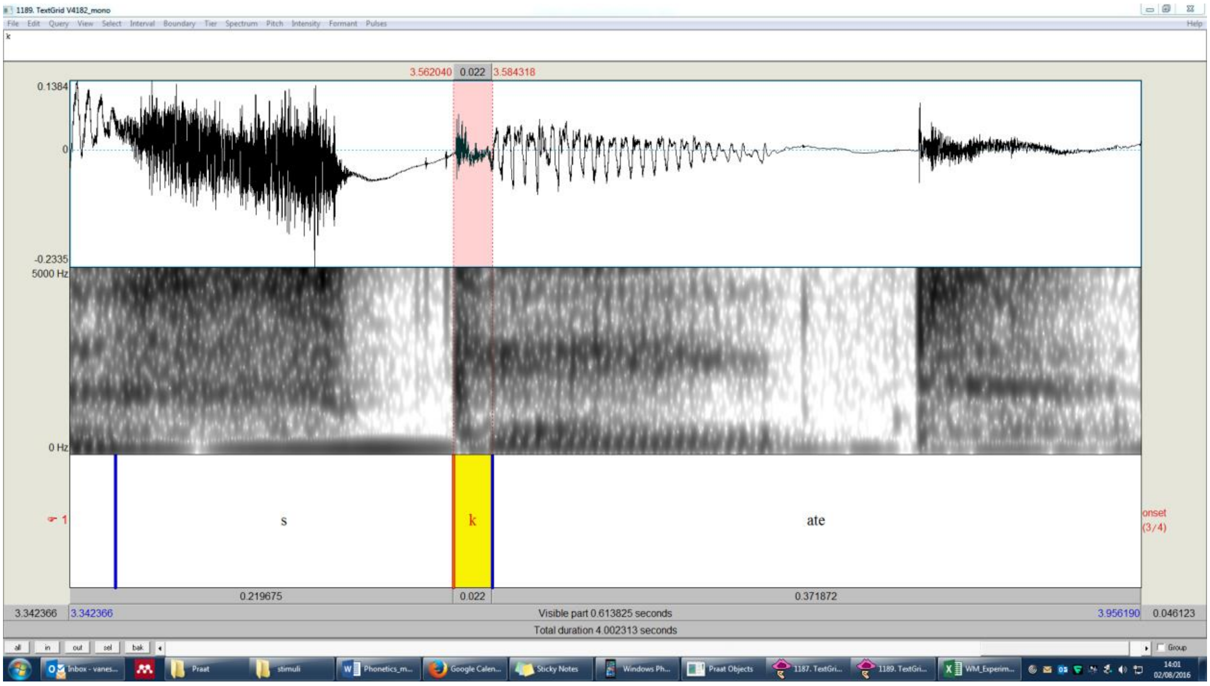


Example: /k/ in 'caught'

At the end of a syllable, not aspirated, but preceded by a glottal stop instead.



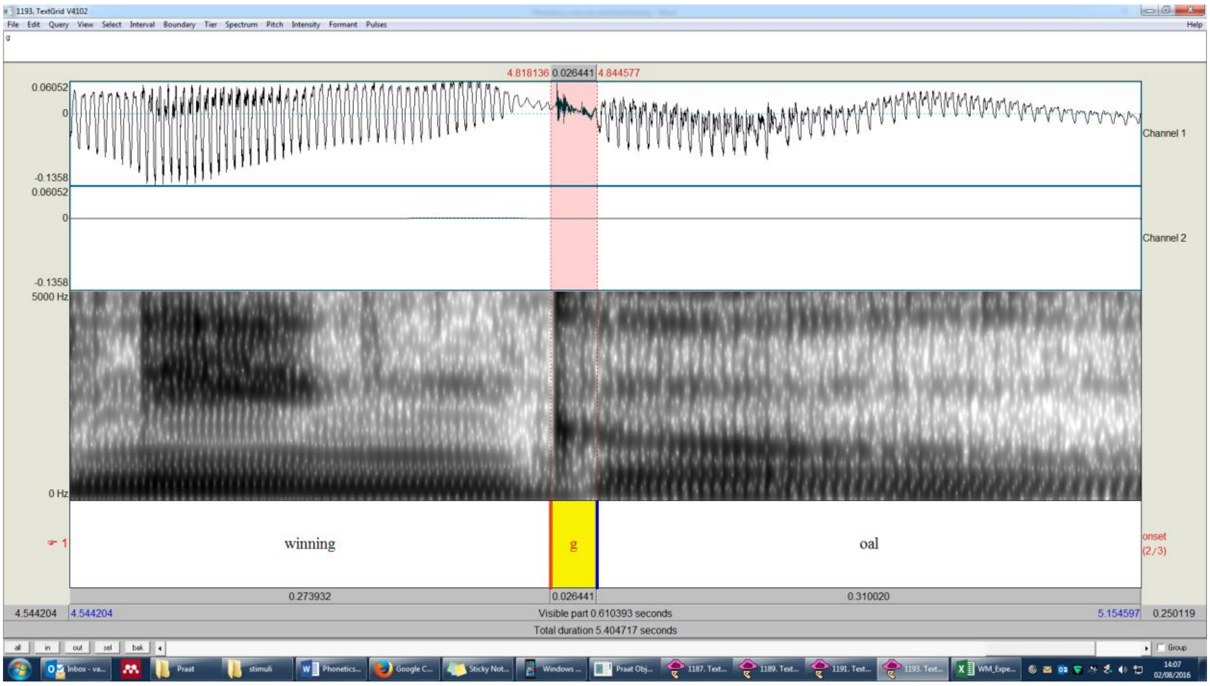
Example: /k/ in 'Mark'



Example: /k/ in ‘skate’, comes without aspiration because of the preceding /s/.

/g/

Voiced. No aspiration at the beginning or end of syllable. There should not be a difference between the /g/ at the beginning of a syllable and the /g/ at the end of a syllable.



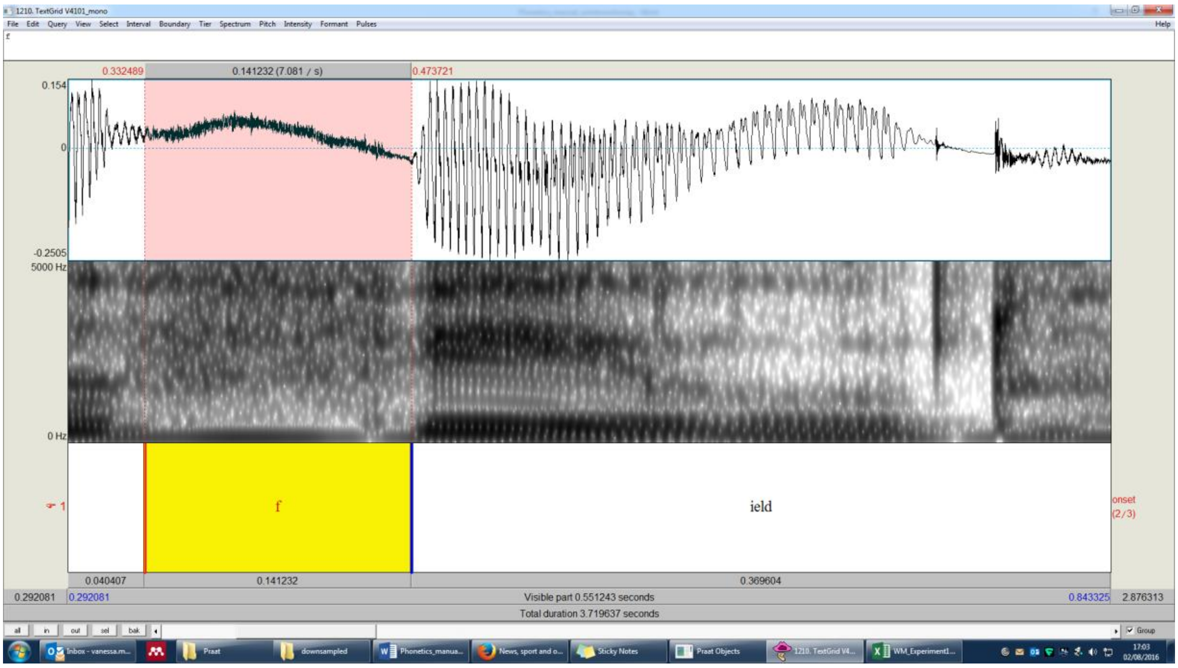
Example: /g/ in ‘goal’

Fricatives

Fricatives are noise-like in their signal. Some are more noisy than others in the size of the amplitude, and there is also a frequency difference in the spectrum of where the noisy part is (whether the spectrum is darkest in higher or lower frequencies).

/f/

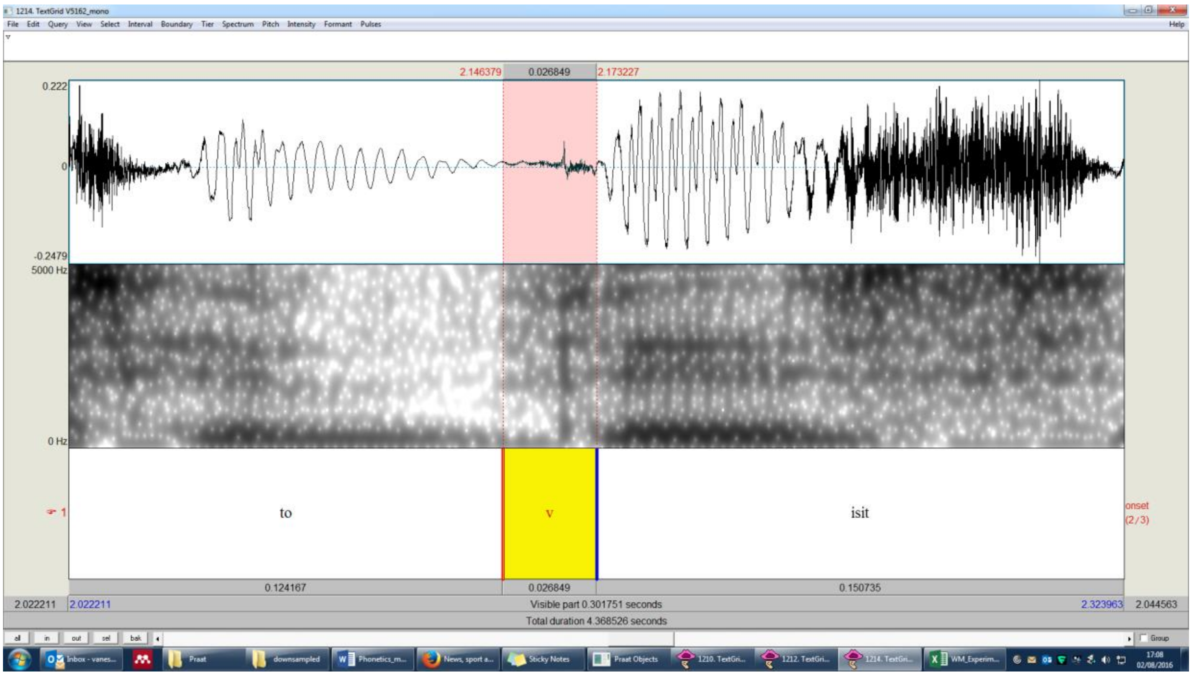
Voiceless. Similar to /th/ in spectrum.



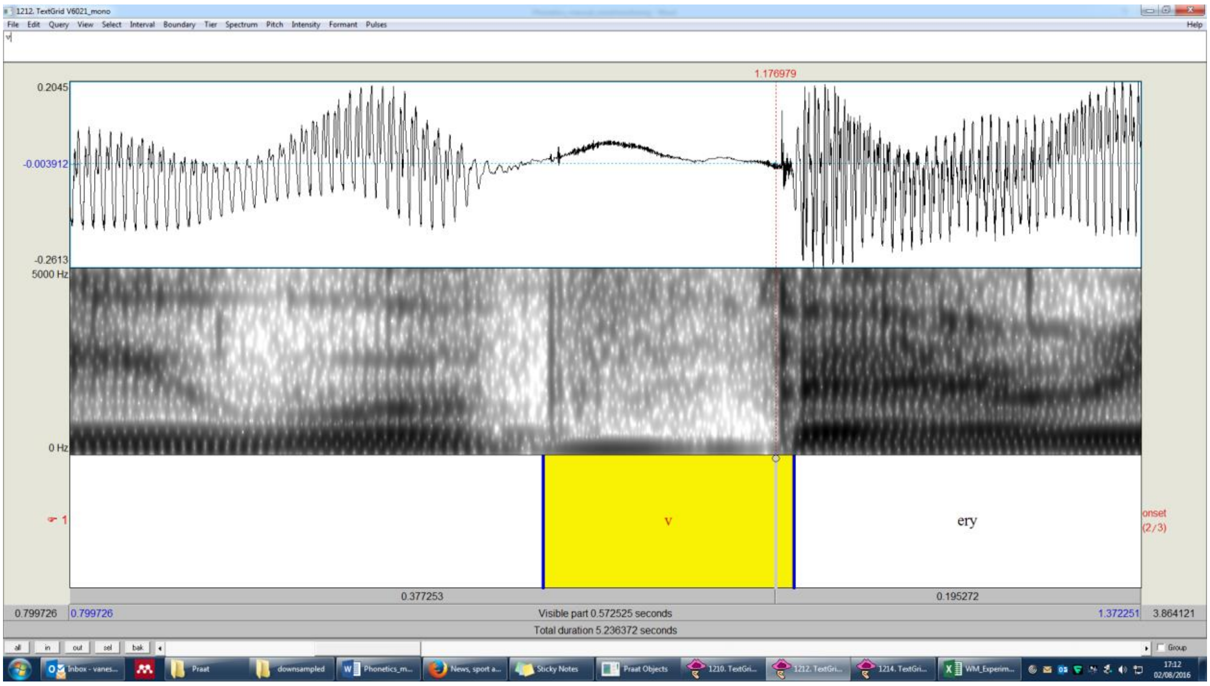
Example: /f/ in 'on the field'

/v/

voiced



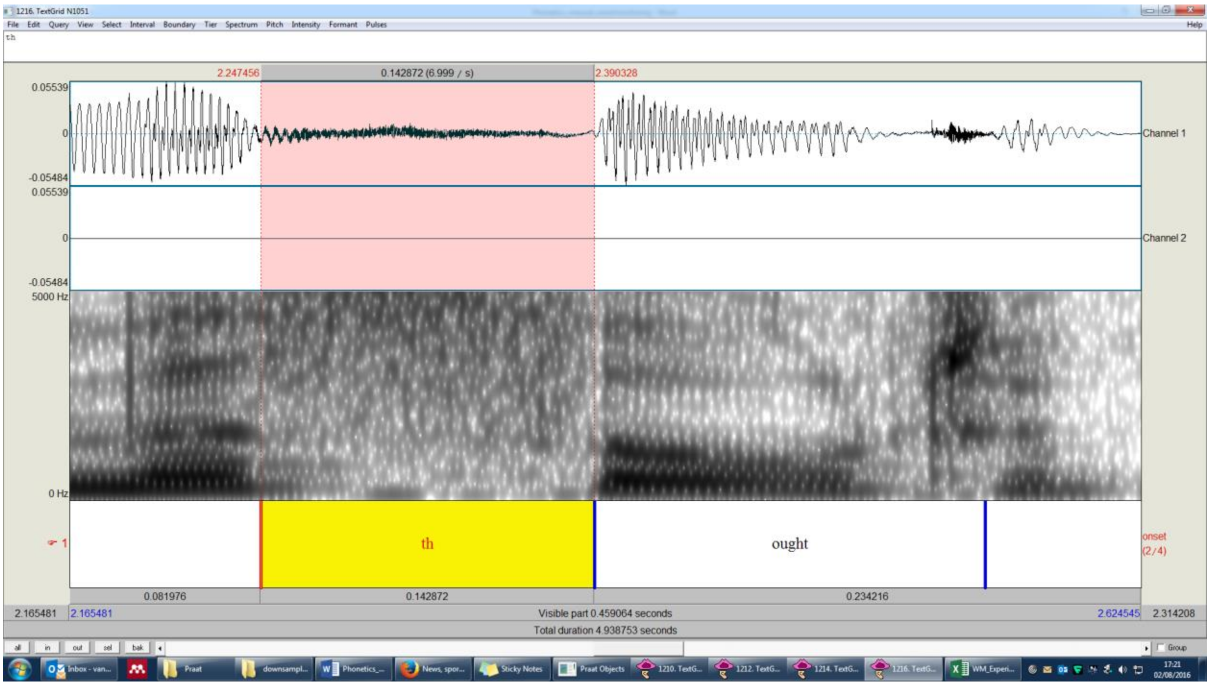
Example: /v/ in 'visit'



Example: /v/ in 'very' (emphasised, hence the burst at the end)

/th/ in 'think'

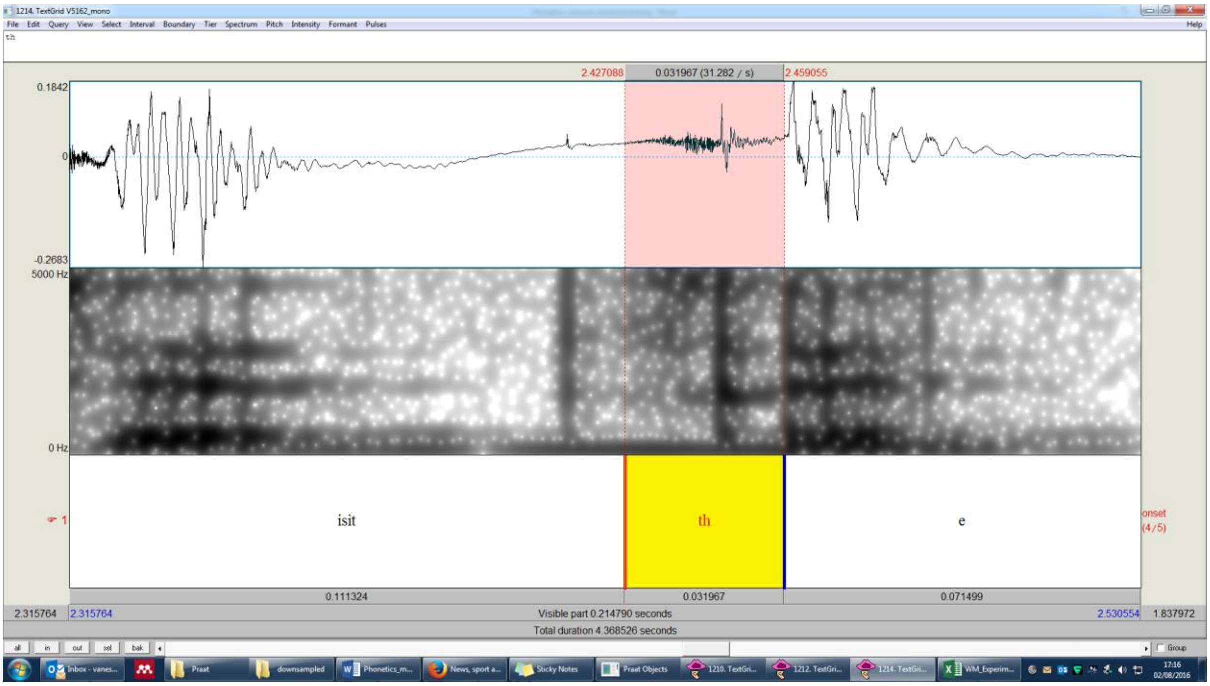
Voiceless. Generally a bit longer than the other 'th' (see below).



Example: /th/ in 'thought'

/th/ in ‘this’

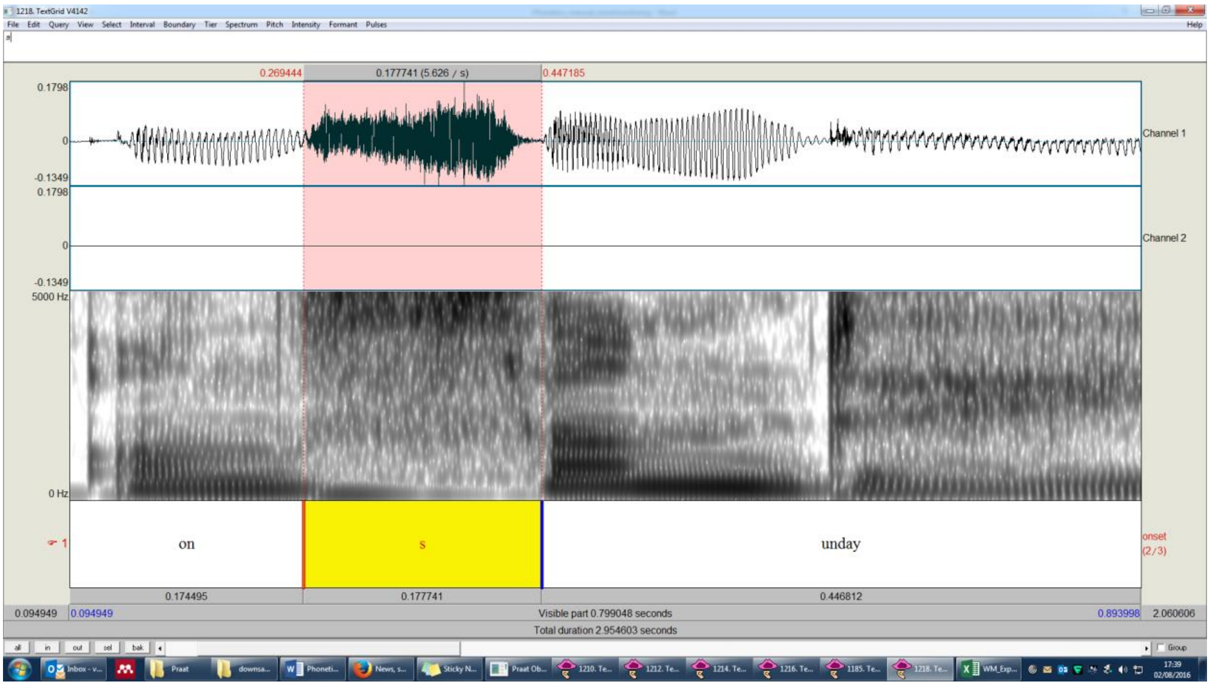
Voiced. Most often occurs in function words (e.g. ‘them’, ‘this’) or in the middle of words (e.g. ‘either’).



Example: /th/ in ‘the’

/s/

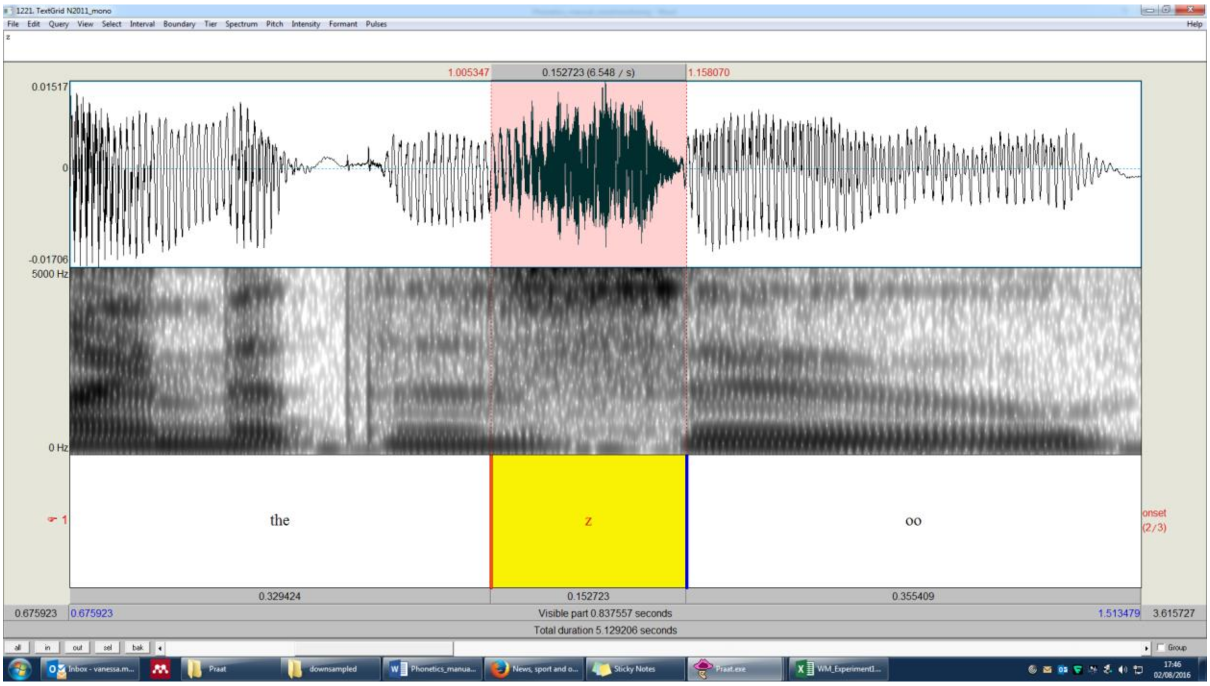
Voiceless.



Example: /s/ in ‘Sunday’

/z/

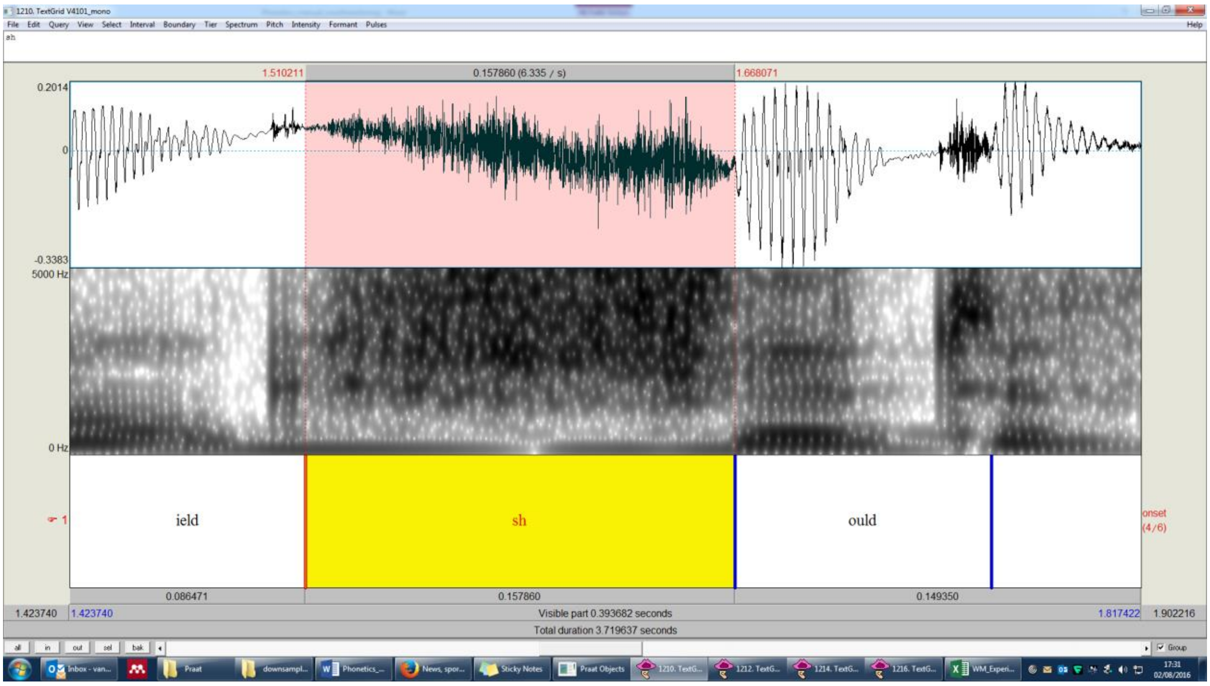
Voiced. Spelling tends to be consistently ‘z’.



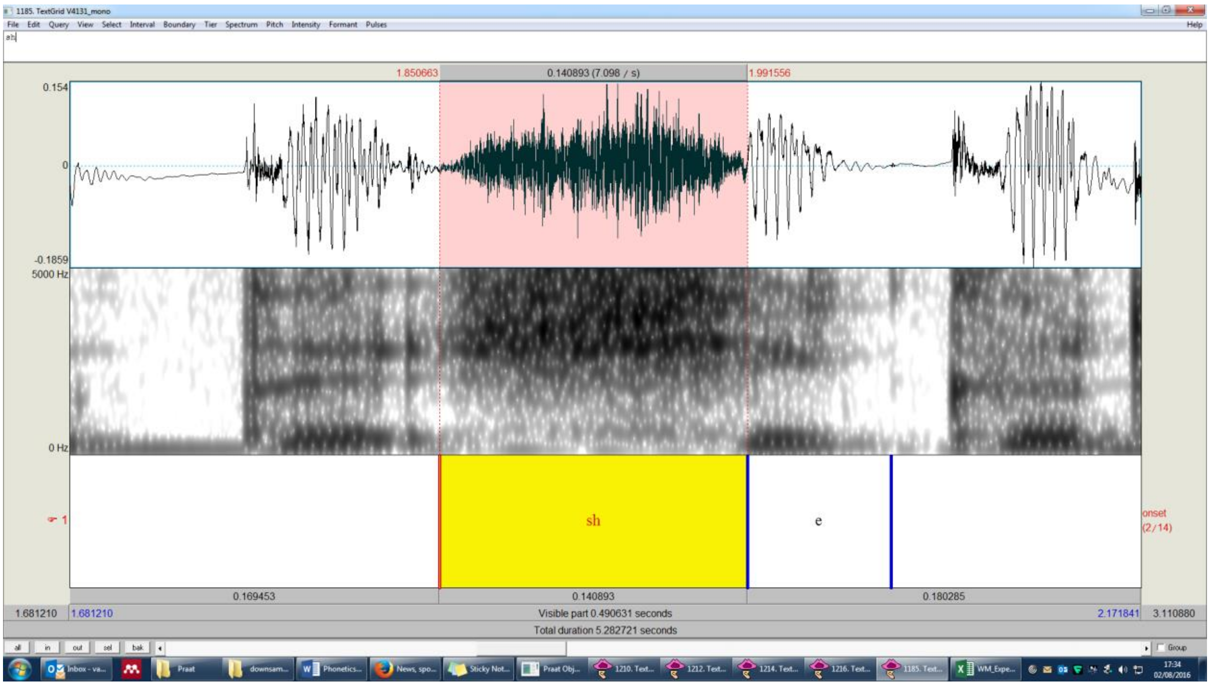
Example: /z/ in ‘zoo’

/sh/

Voiceless



Example: /sh/ in ‘should’



Example: /sh/ in 'she'

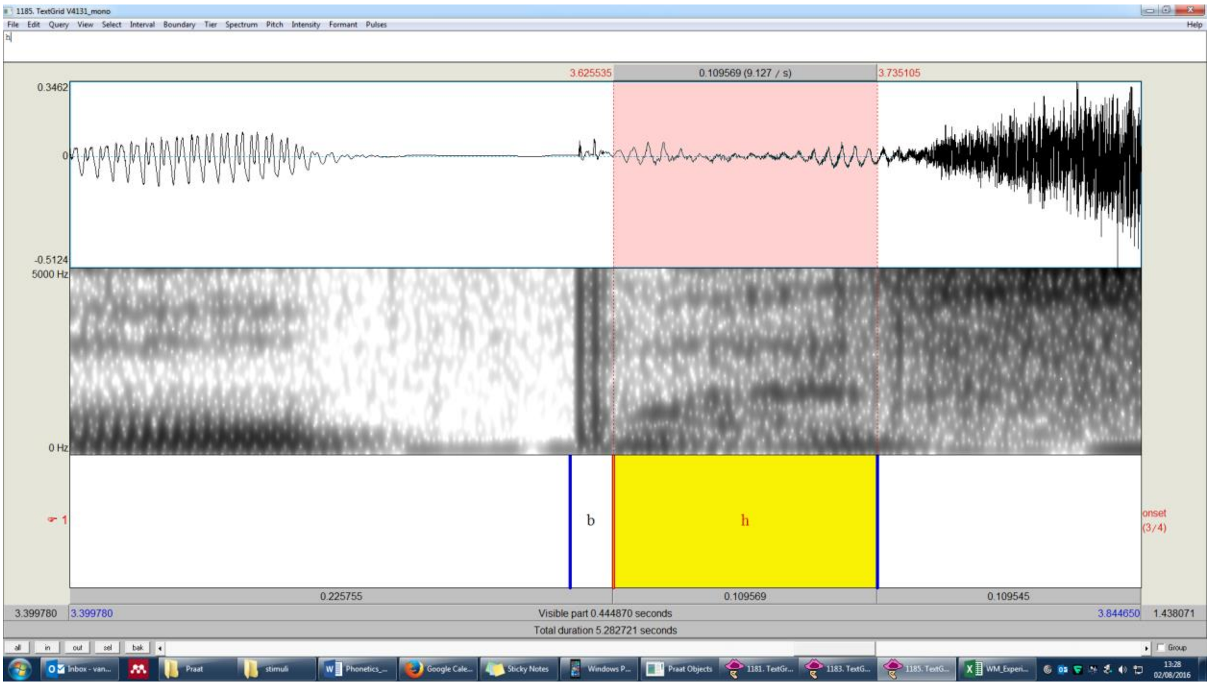
/zj/

Voiced. There are few, if any, words starting with /zj/ in English. E.g. 'zj' in measure.

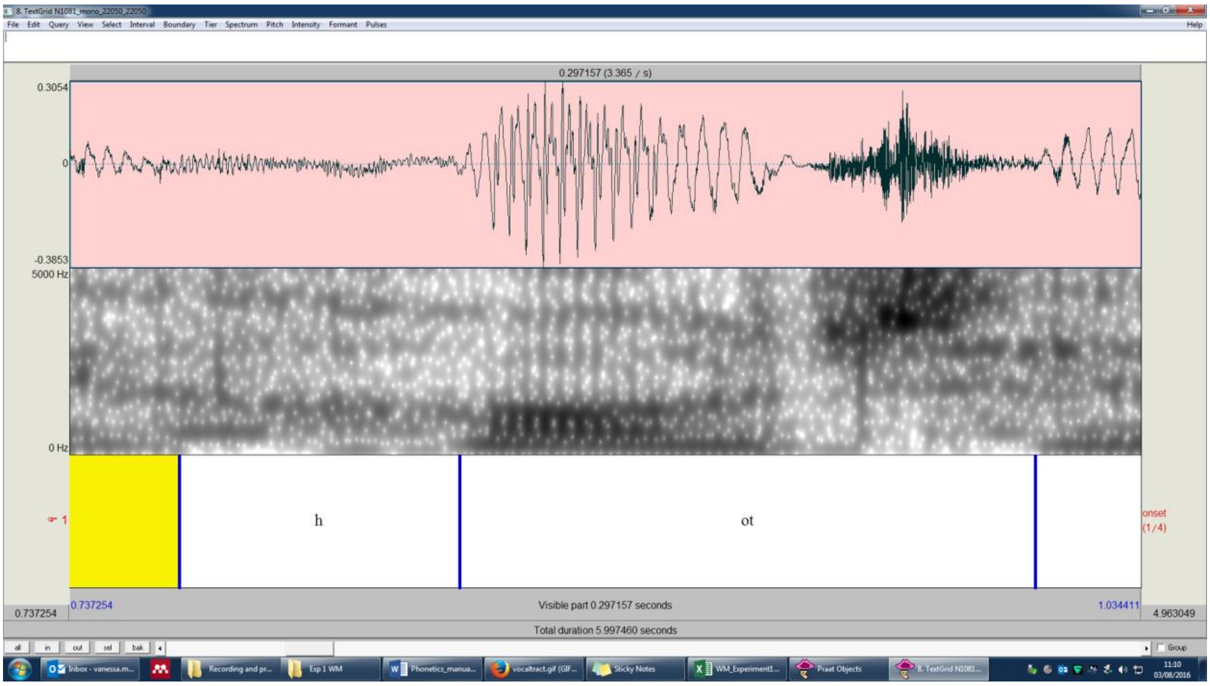
[NO EXAMPLE IN YOUR STIMULI]

/h/

See spectrogram below for the reason to not use /h/ in target onset if possible; it can be weakened in a lot of positions making it hard to determine. Only use when in onset of a stressed word.



Example: weakened /h/ in 'herself



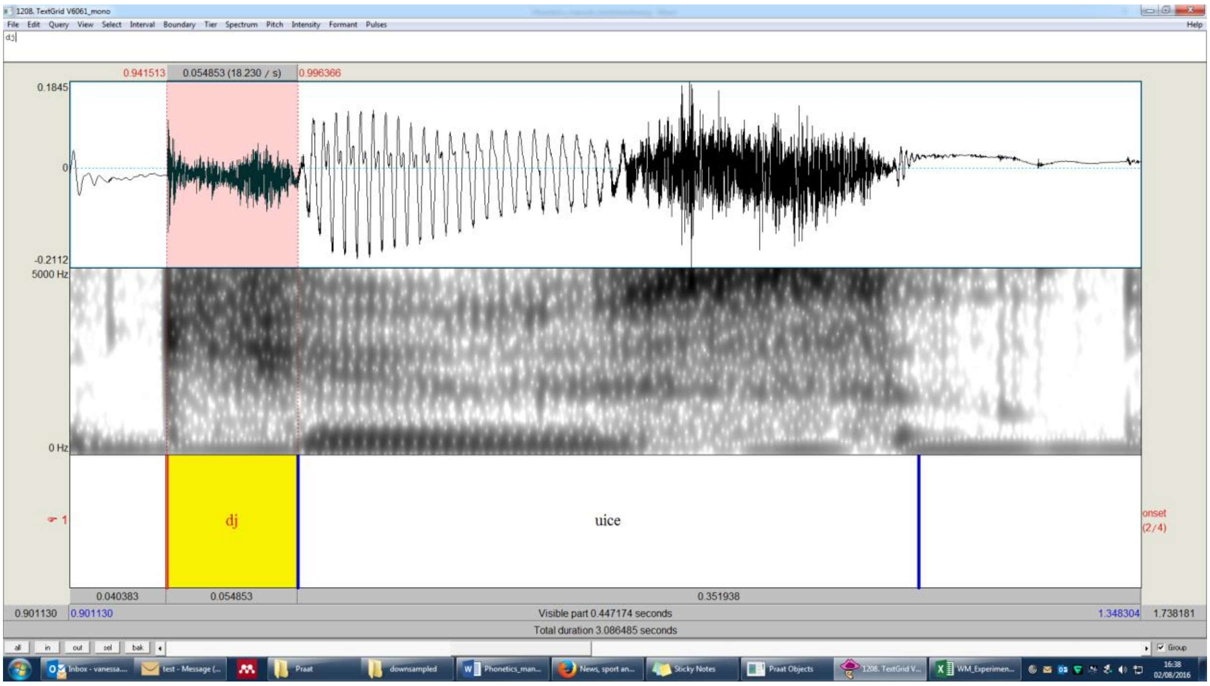
Example: /h/ in stressed 'hot'

<u>Affricates</u>

Start with a plosive, and then continue in a fricative way.

/dj/

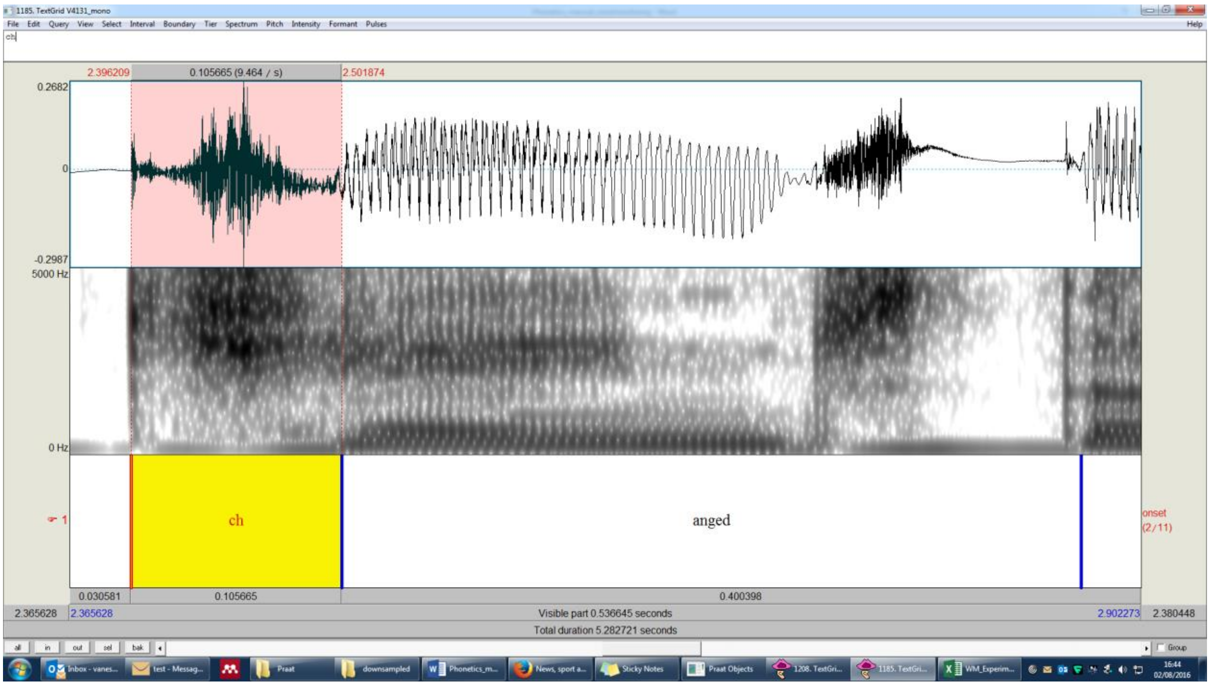
Voiced. Starts with a 'd' sound, then continues with 'zj'.



Example: /dj/ in 'juice'

/ch/

Voiceless. Starts with a ‘t’ sound, then continues with ‘sh’.



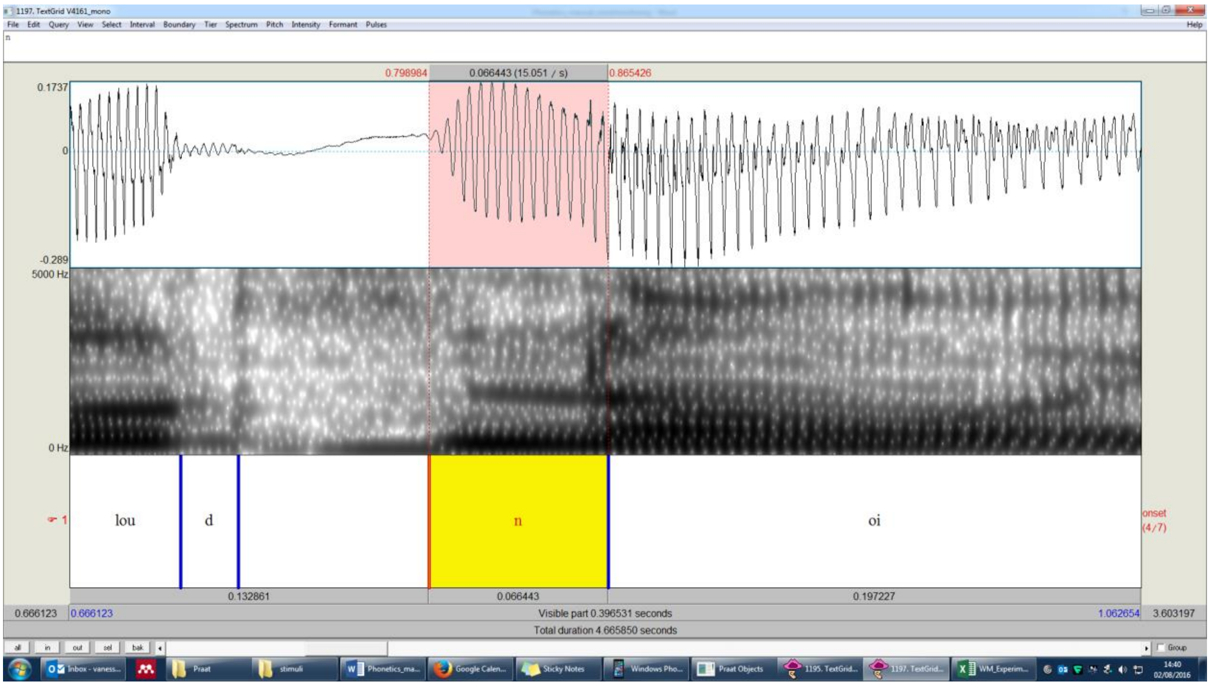
Example: /ch/ in ‘changed’

<u>Nasals</u>

All voiced. Have a regular pattern in the spectrogram, as close to sinewaves as you’ll find in a speech sound. Might take on some features of surrounding vowels, leading to spikiness in the soundwave.

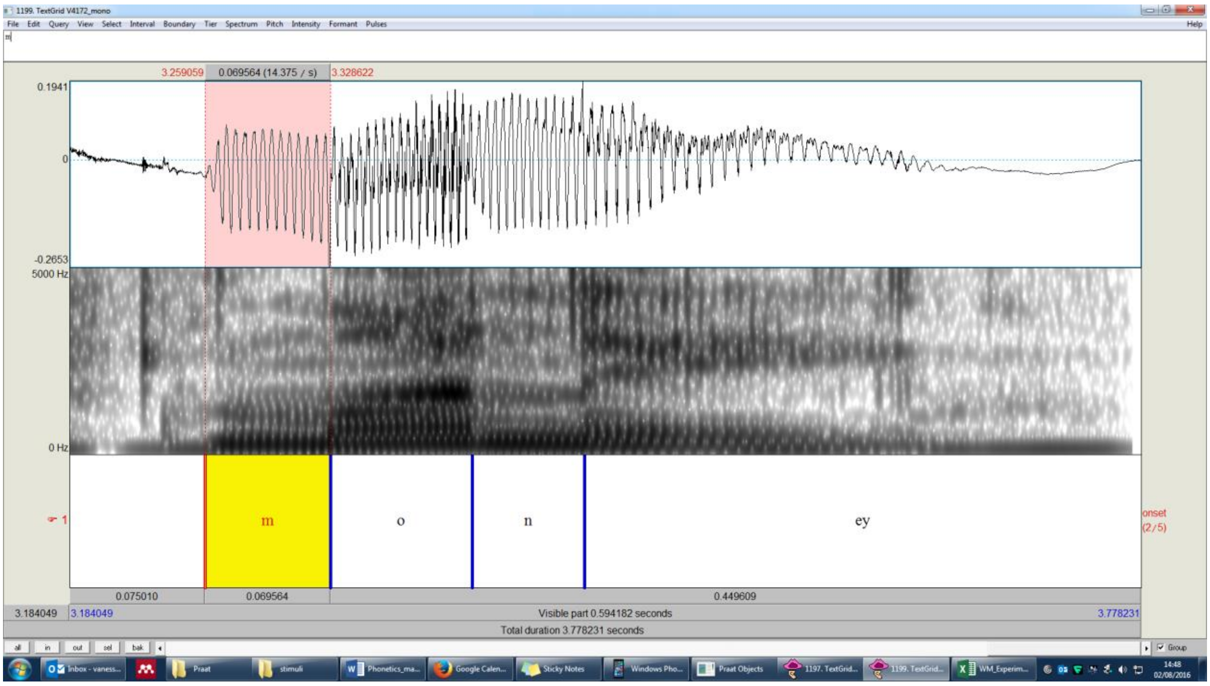
/n/

Voiced, tongue at the back of the teeth.



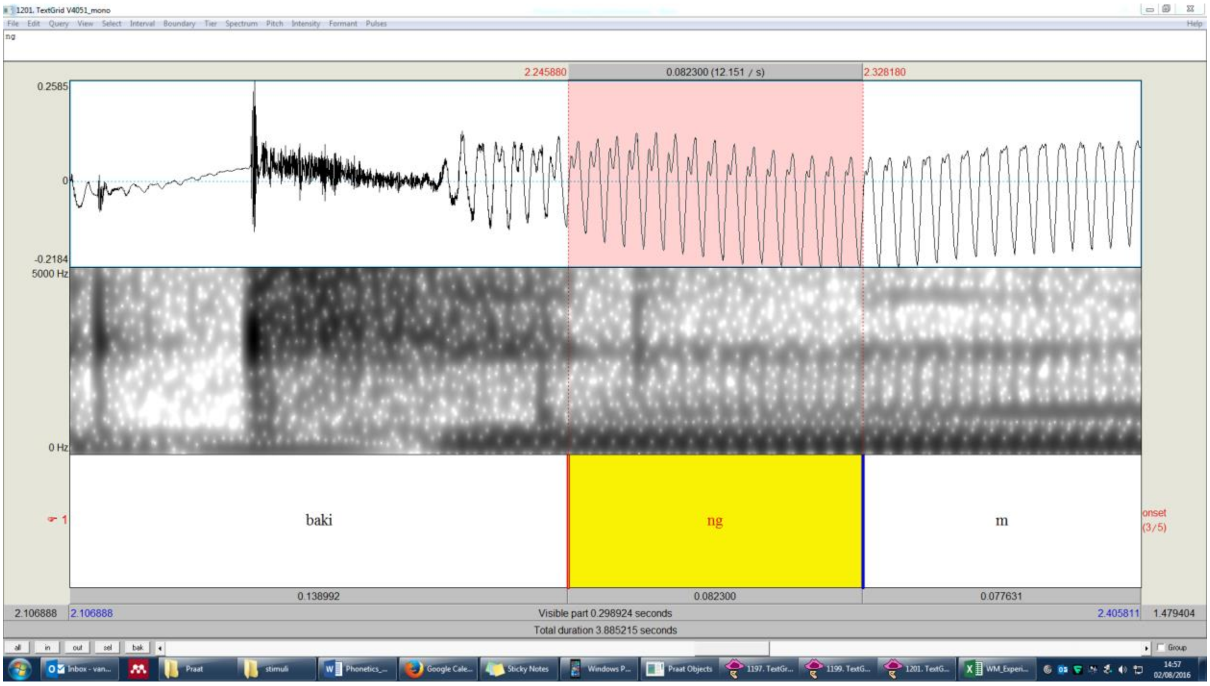
Example: /n/ in ‘noise’.

/m/



Example: /m/ in ‘money’

/ng/



Example: /ng/ in ‘baking’

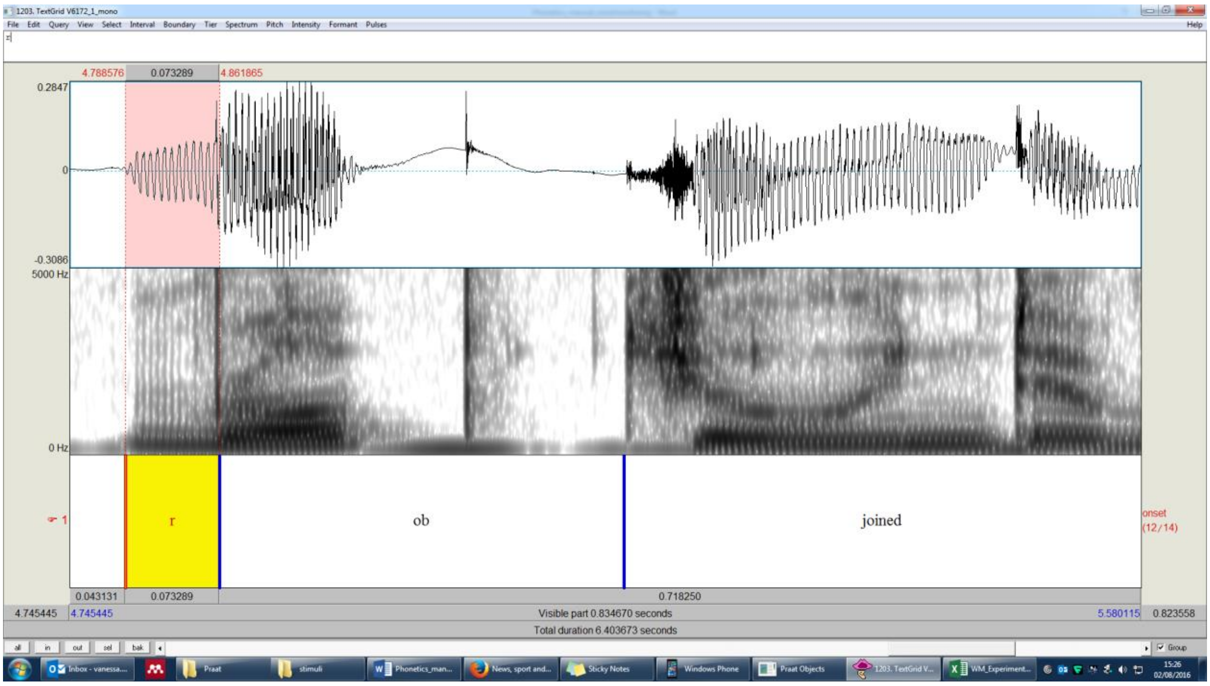
Approximants

Especially hard to identify after a vowel, as they take on the quality from the vowel and look the same. See below.

/w/ is not as bad as /r/ or /l/ when preceded by a fricative or possibly a plosive.

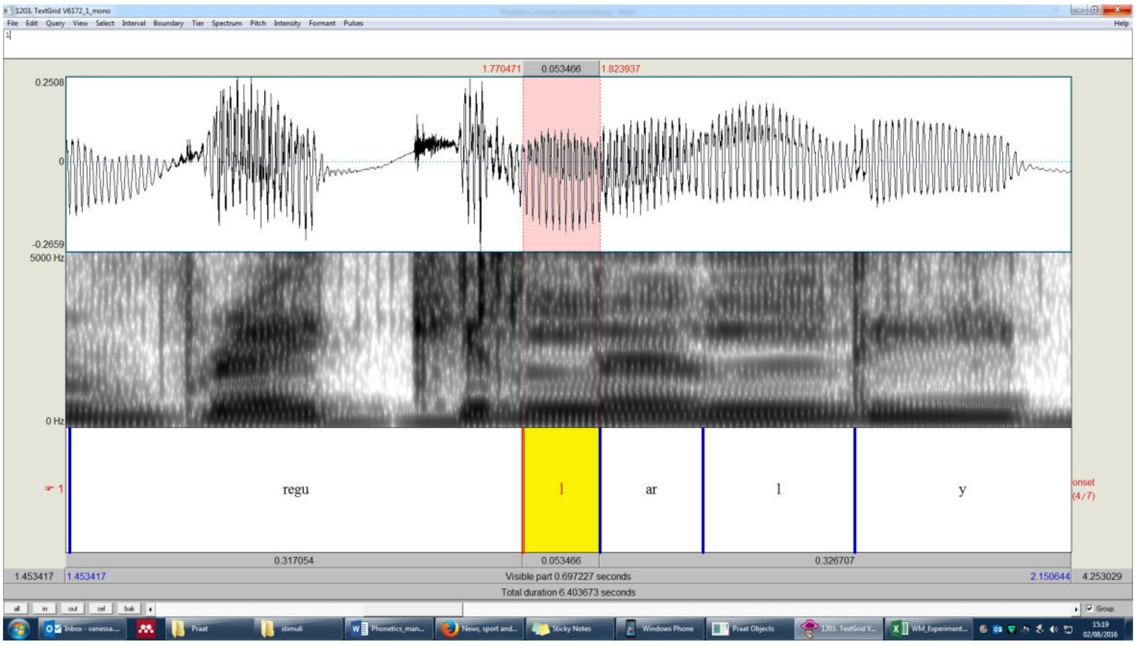
/r/

Vowels before /r/ take on an r-sound so that it is hard to determine the start of the /r/.



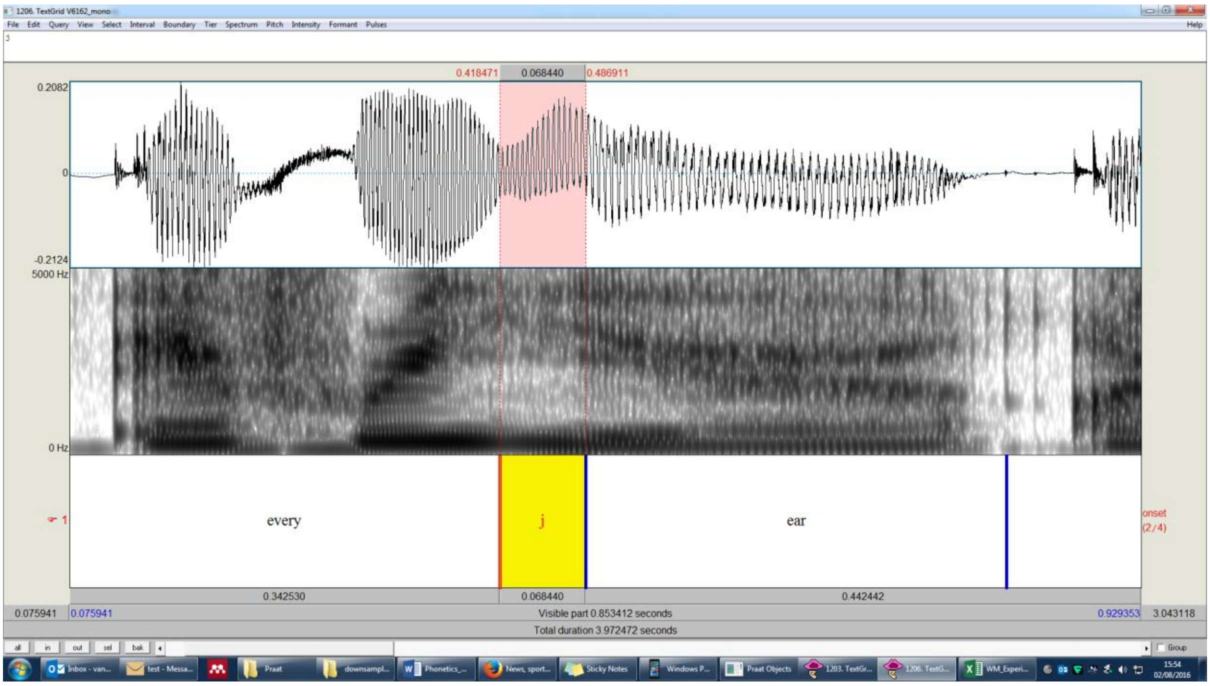
Example: /r/ in 'Rob' after a pause (and therefore relatively clear)

/l/



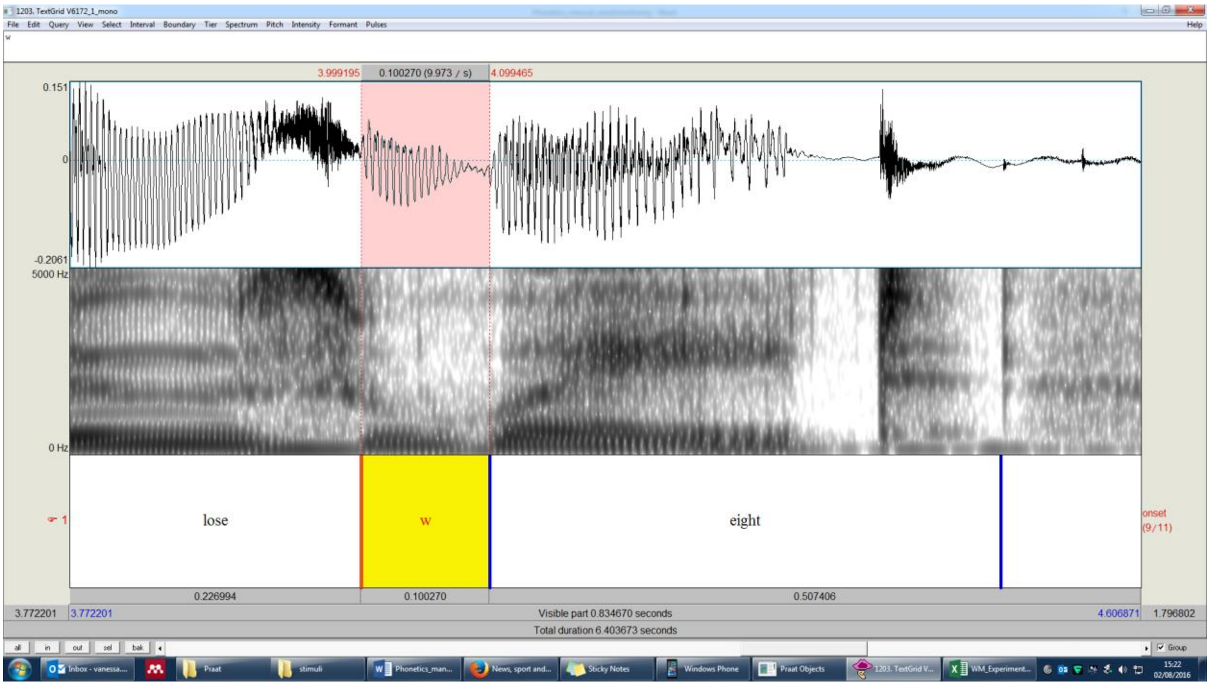
Example: /l/ in 'regularly'

/j/



Example: /j/ in 'year'

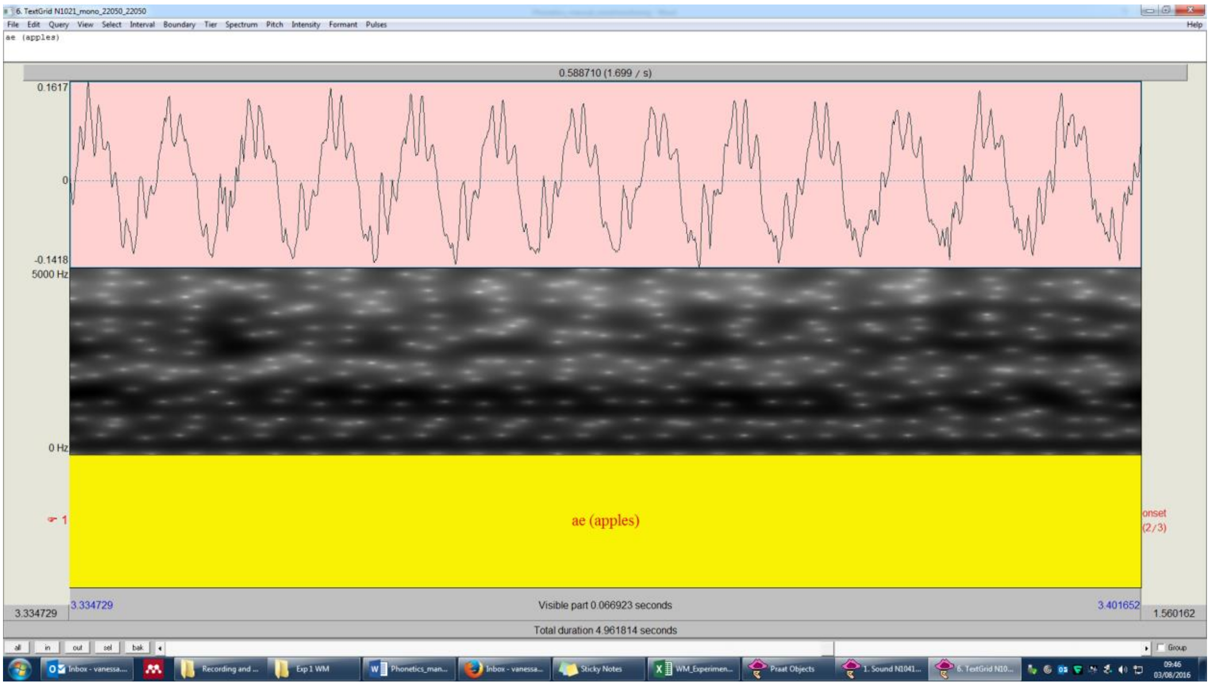
/w/



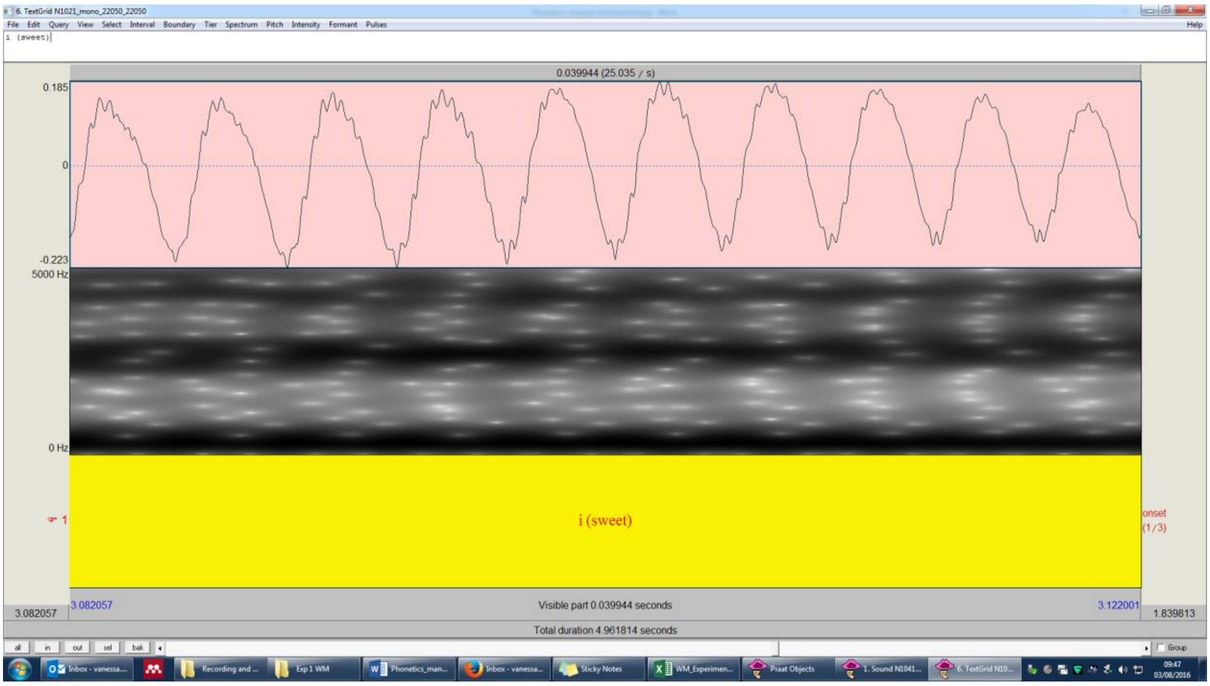
Example: /w/ in 'weight'

Vowels

Vowels have a repeating pattern in the waveform; the shape of this pattern depends on the specific vowel, but it generally has one or more peaks in the pattern.



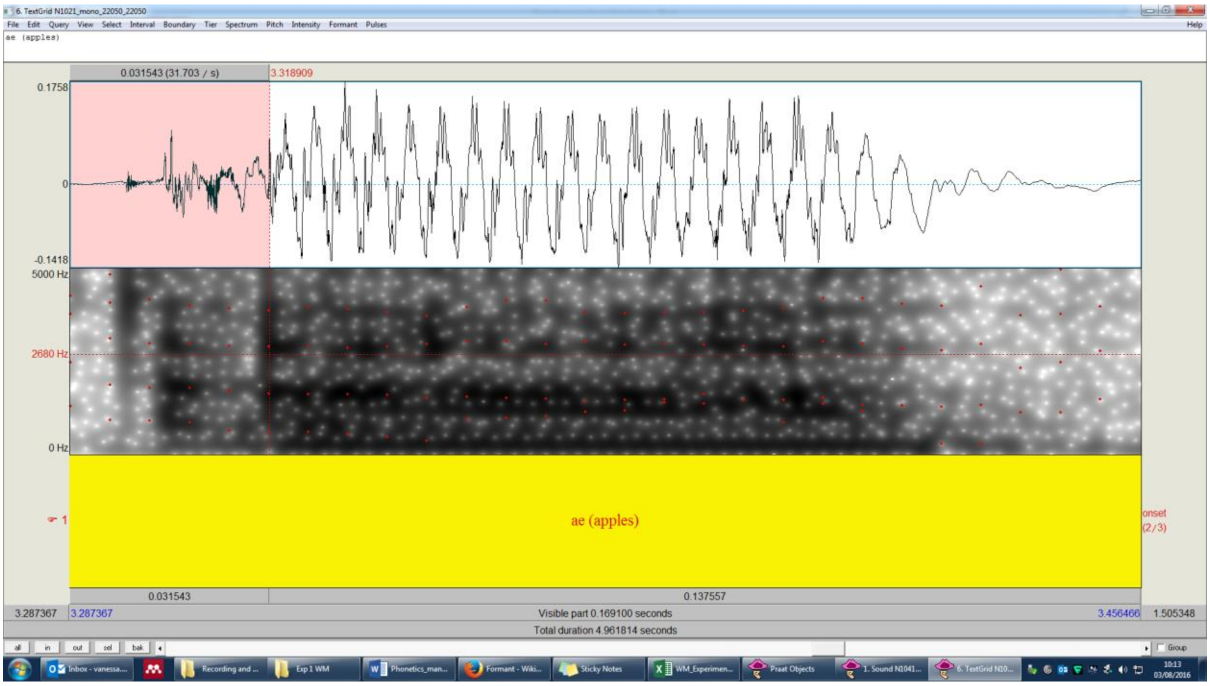
Example: /a/ in apples

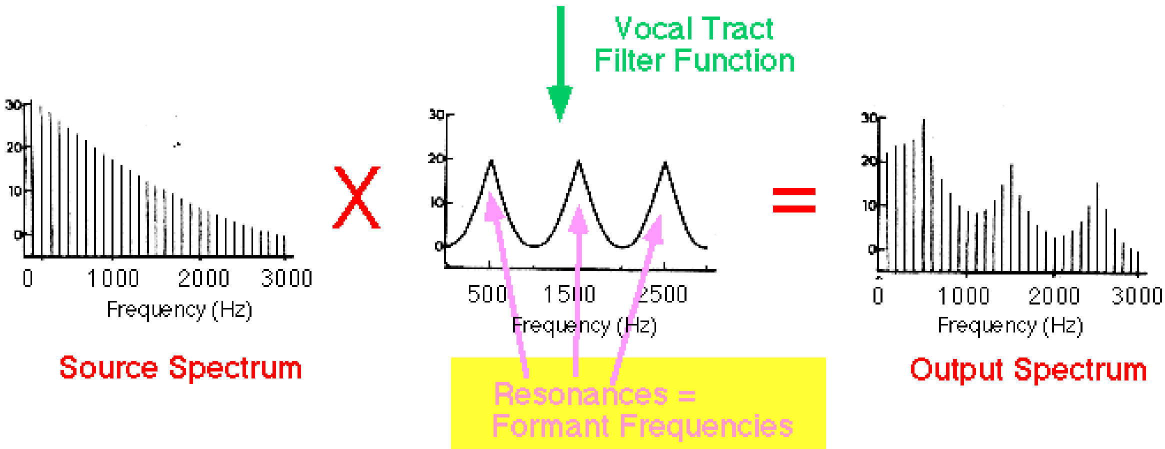


Example: /i/ in 'sweet'

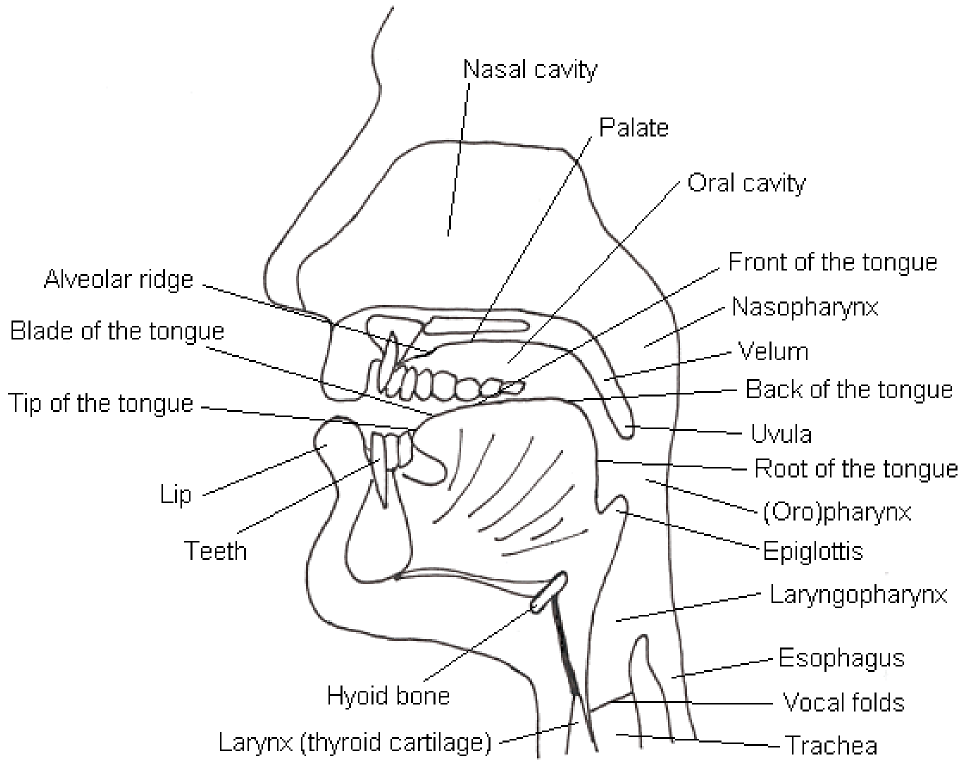
If a word with a vowel at the beginning is stressed, emphasised, or comes after a pause, it might have a glottal stop in front of it, and there might be a peakiness at the start of the sound. This is technically already part of the vowel, but it will not have the recurring pattern in it yet. It does make it easier to determine the word onset.

Example: selected part for /a/ in ‘apples’

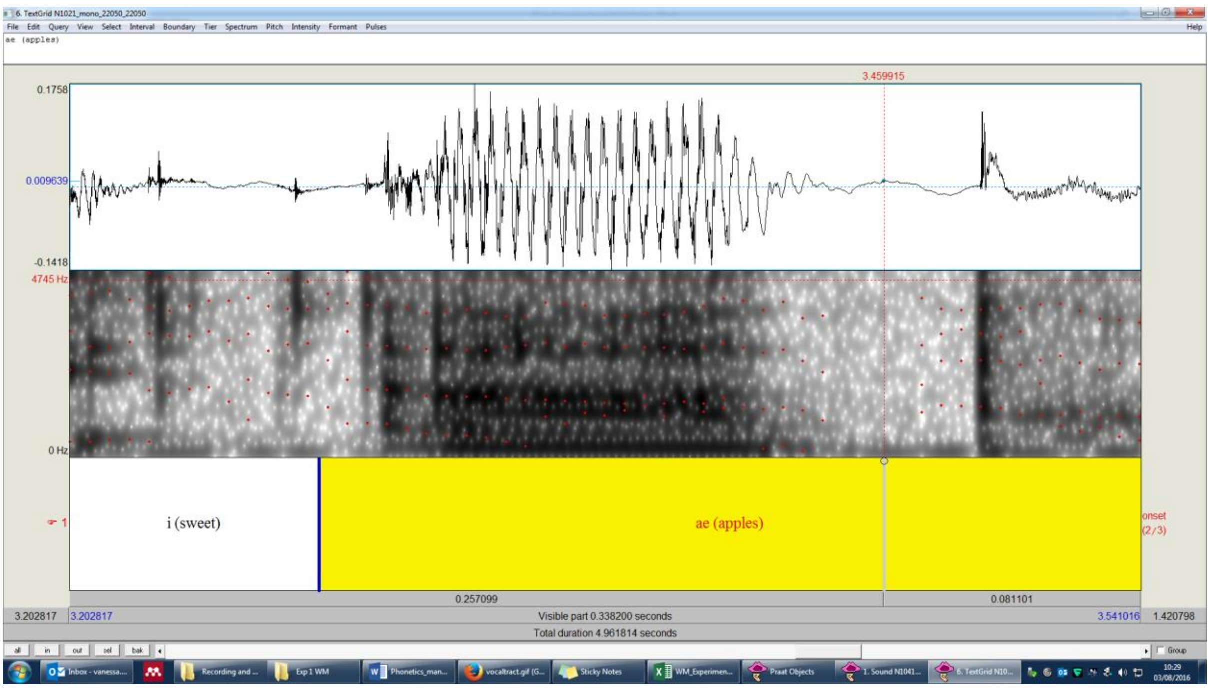




Speech is produced by vibrating the vocal cords. Depending on the size of the vocal cords, this will change the base frequency at which these vibrate (e.g. if they are smaller/shorter, they will vibrate at a higher frequency than if they are larger/longer and will thus make the overall pitch of someone’s voice higher).



This sound that is produced at the vocal cords will then pass through the vocal tract (everything from the vocal cords up to the mouth and nose). The vocal tract then filters the original sound. This means that some frequencies in the sound will be amplified and will become stronger, while others will cancel out and become weaker in the final sound. The frequencies that become stronger are the formants, and you can see these in the spectrum.



Example: formants in /a/, the formants are indicated by the red dots.

For speech, you usually don't need more than the first 3 formants. The first two are always necessary to distinguish the sounds, the 3rd one is needed for lip rounding and nasalisation.

By looking at these formants you can determine which vowel you are looking at.

Formants are mostly specific to vowels, but approximants can have them too because they just filter the sound more. The approximants also take on the sound quality and formants of surrounding vowels. All other consonants have a blockage somewhere that stops the sound so there is no resonance which means there are no formants.

Appendix B – Experiment 4 material

Appendix B.1 Experiment 4 – Subject-verb agreement violation condition stimuli

Quartet nr.	Noun phrase	Verb	Continuation	Number	Grammaticality
1	The toddler	bounces	on the bed.	singular	grammatical
1	The toddler	bounce	on the bed.	singular	ungrammatical
1	The toddlers	bounce	on the bed.	plural	grammatical
1	The toddlers	bounces	on the bed.	plural	ungrammatical
2	The child	plays	with lego for hours and hours.	singular	grammatical
2	The child	play	with lego for hours and hours.	singular	ungrammatical
2	The children	play	with lego for hours and hours.	plural	grammatical
2	The children	plays	with lego for hours and hours.	plural	ungrammatical
3	At the hospital, the doctor	treats	the patients.	singular	grammatical
3	At the hospital, the doctor	treat	the patients.	singular	ungrammatical
3	At the hospital, the doctors	treat	the patients.	plural	grammatical
3	At the hospital, the doctors	treats	the patients.	plural	ungrammatical
4	In the park, the dog	chases	after squirrels.	singular	grammatical
4	In the park, the dog	chase	after squirrels.	singular	ungrammatical
4	In the park, the dogs	chase	after squirrels.	plural	grammatical
4	In the park, the dogs	chases	after squirrels.	plural	ungrammatical

5	The flower	grows	very quickly this time of the year.	singular	grammatical
5	The flower	grow	very quickly this time of the year.	singular	ungrammatical
5	The flowers	grow	very quickly this time of the year.	plural	grammatical
5	The flowers	grows	very quickly this time of the year.	plural	ungrammatical
6	The reporter	publishes	articles about regional news.	singular	grammatical
6	The reporter	publish	articles about regional news.	singular	ungrammatical
6	The reporters	publish	articles about regional news.	plural	grammatical
6	The reporters	publishes	articles about regional news.	plural	ungrammatical
7	The florist	prepares	lovely bouquets for mother's day.	singular	grammatical
7	The florist	prepare	lovely bouquets for mother's day.	singular	ungrammatical
7	The florists	prepare	lovely bouquets for mother's day.	plural	grammatical
7	The florists	prepares	lovely bouquets for mother's day.	plural	ungrammatical
8	The mover	carries	the boxes into the new flat.	singular	grammatical
8	The mover	carry	the boxes into the new flat.	singular	ungrammatical
8	The movers	carry	the boxes into the new flat.	plural	grammatical

8	The movers	carries	the boxes into the new flat.	plural	ungrammatical
9	The visitor	arrives	on Friday at 6pm.	singular	grammatical
9	The visitor	arrive	on Friday at 6pm.	singular	ungrammatical
9	The visitors	arrive	on Friday at 6pm.	plural	grammatical
9	The visitors	arrives	on Friday at 6pm.	plural	ungrammatical
10	The plumber	fixes	the broken pipe in the kitchen.	singular	grammatical
10	The plumber	fix	the broken pipe in the kitchen.	singular	ungrammatical
10	The plumbers	fix	the broken pipe in the kitchen.	plural	grammatical
10	The plumbers	fixes	the broken pipe in the kitchen.	plural	ungrammatical
11	The pancake	tastes	delicious with maple syrup and blueberries.	singular	grammatical
11	The pancake	taste	delicious with maple syrup and blueberries.	singular	ungrammatical
11	The pancakes	taste	delicious with maple syrup and blueberries.	plural	grammatical
11	The pancakes	tastes	delicious with maple syrup and blueberries.	plural	ungrammatical
12	The outdoor swimming pool	closes	during the winter.	singular	grammatical
12	The outdoor swimming pool	close	during the winter.	singular	ungrammatical
12	The outdoor swimming pools	close	during the winter.	plural	grammatical

12	The outdoor swimming pools	closes	during the winter.	plural	ungrammatical
13	The story	captures	my imagination.	singular	grammatical
13	The story	capture	my imagination.	singular	ungrammatical
13	The stories	capture	my imagination.	plural	grammatical
13	The stories	captures	my imagination.	plural	ungrammatical
14	The hotel	charges	extra for breakfast.	singular	grammatical
14	The hotel	charge	extra for breakfast.	singular	ungrammatical
14	The hotels	charge	extra for breakfast.	plural	grammatical
14	The hotels	charges	extra for breakfast.	plural	ungrammatical
15	The mouse	escapes	the traps I set.	singular	grammatical
15	The mouse	escape	the traps I set.	singular	ungrammatical
15	The mice	escape	the traps I set.	plural	grammatical
15	The mice	escapes	the traps I set.	plural	ungrammatical
16	My daughter	believes	in Santa Claus.	singular	grammatical
16	My daughter	believe	in Santa Claus.	singular	ungrammatical
16	My daughters	believe	in Santa Claus.	plural	grammatical
16	My daughters	believes	in Santa Claus.	plural	ungrammatical
17	The nurse	works	long hours at the hospital.	singular	grammatical
17	The nurse	work	long hours at the hospital.	singular	ungrammatical
17	The nurses	work	long hours at the hospital.	plural	grammatical
17	The nurses	works	long hours at the hospital.	plural	ungrammatical

18	At the office, the clerk	files	the documents for the lawyers.	singular	grammatical
18	At the office, the clerk	file	the documents for the lawyers.	singular	ungrammatical
18	At the office, the clerks	file	the documents for the lawyers.	plural	grammatical
18	At the office, the clerks	files	the documents for the lawyers.	plural	ungrammatical
19	My friend	visits	me every few years.	singular	grammatical
19	My friend	visit	me every few years.	singular	ungrammatical
19	My friends	visit	me every few years.	plural	grammatical
19	My friends	visits	me every few years.	plural	ungrammatical
20	The new bridge	connects	the two parts of the city.	singular	grammatical
20	The new bridge	connect	the two parts of the city.	singular	ungrammatical
20	The new bridges	connect	the two parts of the city.	plural	grammatical
20	The new bridges	connects	the two parts of the city.	plural	ungrammatical
21	The old clock	ticks	quite loudly.	singular	grammatical
21	The old clock	tick	quite loudly.	singular	ungrammatical
21	The old clocks	tick	quite loudly.	plural	grammatical
21	The old clocks	ticks	quite loudly.	plural	ungrammatical
22	The host	pours	wine for the guests.	singular	grammatical
22	The host	pour	wine for the guests.	singular	ungrammatical
22	The hosts	pour	wine for the guests.	plural	grammatical
22	The hosts	pours	wine for the guests.	plural	ungrammatical
23	The current artist	paints	abstract art.	singular	grammatical
23	The current artist	paint	abstract art.	singular	ungrammatical

23	The current artists	paint	abstract art.	plural	grammatical
23	The current artists	paints	abstract art.	plural	ungrammatical
24	The duckling	follows	the mother duck to the pond.	singular	grammatical
24	The duckling	follow	the mother duck to the pond.	singular	ungrammatical
24	The ducklings	follow	the mother duck to the pond.	plural	grammatical
24	The ducklings	follows	the mother duck to the pond.	plural	ungrammatical
25	My favourite author	publishes	crime and mystery books.	singular	grammatical
25	My favourite author	publish	crime and mystery books.	singular	ungrammatical
25	My favourite authors	publish	crime and mystery books.	plural	grammatical
25	My favourite authors	publishes	crime and mystery books.	plural	ungrammatical
26	The spider	crawls	underneath the coffee table.	singular	grammatical
26	The spider	crawl	underneath the coffee table.	singular	ungrammatical
26	The spiders	crawl	underneath the coffee table.	plural	grammatical
26	The spiders	crawls	underneath the coffee table.	plural	ungrammatical
27	In court, the lawyer	delivers	the opening statement in front of the judge.	singular	grammatical

27	In court, the lawyer	deliver	the opening statement in front of the judge.	singular	ungrammatical
27	In court, the lawyers	deliver	the opening statement in front of the judge.	plural	grammatical
27	In court, the lawyers	delivers	the opening statement in front of the judge.	plural	ungrammatical
28	In the library, the book	gathers	layers of dust.	singular	grammatical
28	In the library, the book	gather	layers of dust.	singular	ungrammatical
28	In the library, the books	gather	layers of dust.	plural	grammatical
28	In the library, the books	gathers	layers of dust.	plural	ungrammatical
29	The athlete	trains	for the upcoming competition.	singular	grammatical
29	The athlete	train	for the upcoming competition.	singular	ungrammatical
29	The athletes	train	for the upcoming competition.	plural	grammatical
29	The athletes	trains	for the upcoming competition.	plural	ungrammatical
30	The architect	designs	the new Olympic stadium.	singular	grammatical
30	The architect	design	the new Olympic stadium.	singular	ungrammatical
30	The architects	design	the new Olympic stadium.	plural	grammatical
30	The architects	designs	the new Olympic stadium.	plural	ungrammatical

31	In the park, the teenager	kicks	the ball around.	singular	grammatical
31	In the park, the teenager	kick	the ball around.	singular	ungrammatical
31	In the park, the teenagers	kick	the ball around.	plural	grammatical
31	In the park, the teenagers	kicks	the ball around.	plural	ungrammatical
32	The mechanic	tells	me my car needs new tires.	singular	grammatical
32	The mechanic	tell	me my car needs new tires.	singular	ungrammatical
32	The mechanics	tell	me my car needs new tires.	plural	grammatical
32	The mechanics	tells	me my car needs new tires.	plural	ungrammatical
33	My brother	buys	Christmas gifts at the last moment.	singular	grammatical
33	My brother	buy	Christmas gifts at the last moment.	singular	ungrammatical
33	My brothers	buy	Christmas gifts at the last moment.	plural	grammatical
33	My brothers	buys	Christmas gifts at the last moment.	plural	ungrammatical
34	Our dog	barks	whenever a stranger walks by.	singular	grammatical
34	Our dog	bark	whenever a stranger walks by.	singular	ungrammatical
34	Our dogs	bark	whenever a stranger walks by.	plural	grammatical

34	Our dogs	barks	whenever a stranger walks by.	plural	ungrammatical
35	The actor	performs	the part every night for two months.	singular	grammatical
35	The actor	perform	the part every night for two months.	singular	ungrammatical
35	The actors	perform	the part every night for two months.	plural	grammatical
35	The actors	performs	the part every night for two months.	plural	ungrammatical
36	At the cinema, the film	begins	at 8pm.	singular	grammatical
36	At the cinema, the film	begin	at 8pm.	singular	ungrammatical
36	At the cinema, the films	begin	at 8pm.	plural	grammatical
36	At the cinema, the films	begins	at 8pm.	plural	ungrammatical
37	The library	opens	at 9am.	singular	grammatical
37	The library	open	at 9am.	singular	ungrammatical
37	The libraries	open	at 9am.	plural	grammatical
37	The libraries	opens	at 9am.	plural	ungrammatical
38	The plane	flies	through a storm.	singular	grammatical
38	The plane	fly	through a storm.	singular	ungrammatical
38	The planes	fly	through a storm.	plural	grammatical
38	The planes	flies	through a storm.	plural	ungrammatical
39	The expensive hotel room	faces	the sea.	singular	grammatical

39	The expensive hotel room	face	the sea.	singular	ungrammatical
39	The expensive hotel rooms	face	the sea.	plural	grammatical
39	The expensive hotel rooms	faces	the sea.	plural	ungrammatical
40	The TV channel	shows	mostly black and white movies.	singular	grammatical
40	The TV channel	show	mostly black and white movies.	singular	ungrammatical
40	The TV channels	show	mostly black and white movies.	plural	grammatical
40	The TV channels	shows	mostly black and white movies.	plural	ungrammatical
41	The horse	gallops	across the field.	singular	grammatical
41	The horse	gallop	across the field.	singular	ungrammatical
41	The horses	gallop	across the field.	plural	grammatical
41	The horses	gallops	across the field.	plural	ungrammatical
42	The radio station	plays	classic rock.	singular	grammatical
42	The radio station	play	classic rock.	singular	ungrammatical
42	The radio stations	play	classic rock.	plural	grammatical
42	The radio stations	plays	classic rock.	plural	ungrammatical
43	The volunteer	collects	donations from passersby.	singular	grammatical
43	The volunteer	collect	donations from passersby.	singular	ungrammatical
43	The volunteers	collect	donations from passersby.	plural	grammatical

43	The volunteers	collects	donations from passersby.	plural	ungrammatical
44	The street	floods	when it rains a lot.	singular	grammatical
44	The street	flood	when it rains a lot.	singular	ungrammatical
44	The streets	flood	when it rains a lot.	plural	grammatical
44	The streets	floods	when it rains a lot.	plural	ungrammatical
45	The bell	chimes	every half hour.	singular	grammatical
45	The bell	chime	every half hour.	singular	ungrammatical
45	The bells	chime	every half hour.	plural	grammatical
45	The bells	chimes	every half hour.	plural	ungrammatical
46	My favourite dress	fits	perfectly for the occasion.	singular	grammatical
46	My favourite dress	fit	perfectly for the occasion.	singular	ungrammatical
46	My favourite dresses	fit	perfectly for the occasion.	plural	grammatical
46	My favourite dresses	fits	perfectly for the occasion.	plural	ungrammatical
47	The ship	transports	goods to Asia.	singular	grammatical
47	The ship	transport	goods to Asia.	singular	ungrammatical
47	The ships	transport	goods to Asia.	plural	grammatical
47	The ships	transports	goods to Asia.	plural	ungrammatical
48	The chapter	describes	the history of Stonehenge.	singular	grammatical
48	The chapter	describe	the history of Stonehenge.	singular	ungrammatical

48	The chapters	describe	the history of Stonehenge.	plural	grammatical
48	The chapters	describes	the history of Stonehenge.	plural	ungrammatical
49	During the show, the magician	vanishes	suddenly from the stage.	singular	grammatical
49	During the show, the magician	vanish	suddenly from the stage.	singular	ungrammatical
49	During the show, the magicians	vanish	suddenly from the stage.	plural	grammatical
49	During the show, the magicians	vanishes	suddenly from the stage.	plural	ungrammatical
50	The lion	devours	the goat.	singular	grammatical
50	The lion	devour	the goat.	singular	ungrammatical
50	The lions	devour	the goat.	plural	grammatical
50	The lions	devours	the goat.	plural	ungrammatical
51	My sister	borrows	my clothes all the time.	singular	grammatical
51	My sister	borrow	my clothes all the time.	singular	ungrammatical
51	My sisters	borrow	my clothes all the time.	plural	grammatical
51	My sisters	borrows	my clothes all the time.	plural	ungrammatical
52	The apple	falls	from the tree.	singular	grammatical
52	The apple	fall	from the tree.	singular	ungrammatical
52	The apples	fall	from the tree.	plural	grammatical
52	The apples	falls	from the tree.	plural	ungrammatical
53	The thief	robs	the store.	singular	grammatical
53	The thief	rob	the store.	singular	ungrammatical
53	The thieves	rob	the store.	plural	grammatical

53	The thieves	robs	the store.	plural	ungrammatical
54	The journalist	talks	about the importance of free speech.	singular	grammatical
54	The journalist	talk	about the importance of free speech.	singular	ungrammatical
54	The journalists	talk	about the importance of free speech.	plural	grammatical
54	The journalists	talks	about the importance of free speech.	plural	ungrammatical
55	The ballet dancer	practices	8 hours every day.	singular	grammatical
55	The ballet dancer	practice	8 hours every day.	singular	ungrammatical
55	The ballet dancers	practice	8 hours every day.	plural	grammatical
55	The ballet dancers	practices	8 hours every day.	plural	ungrammatical
56	The bird	builds	a nest in the tree.	singular	grammatical
56	The bird	build	a nest in the tree.	singular	ungrammatical
56	The birds	build	a nest in the tree.	plural	grammatical
56	The birds	builds	a nest in the tree.	plural	ungrammatical
57	The factory	pollutes	the air by burning fossil fuel.	singular	grammatical
57	The factory	pollute	the air by burning fossil fuel.	singular	ungrammatical
57	The factories	pollute	the air by burning fossil fuel.	plural	grammatical
57	The factories	pollutes	the air by burning fossil fuel.	plural	ungrammatical
58	In this region, the lake	freezes	almost every winter.	singular	grammatical

58	In this region, the lake	freeze	almost every winter.	singular	ungrammatical
58	In this region, the lakes	freeze	almost every winter.	plural	grammatical
58	In this region, the lakes	freezes	almost every winter.	plural	ungrammatical
59	The frog	jumps	into the pond.	singular	grammatical
59	The frog	jump	into the pond.	singular	ungrammatical
59	The frogs	jump	into the pond.	plural	grammatical
59	The frogs	jumps	into the pond.	plural	ungrammatical
60	At the pet store, the hamster	tries	to escape the cage.	singular	grammatical
60	At the pet store, the hamster	try	to escape the cage.	singular	ungrammatical
60	At the pet store, the hamsters	try	to escape the cage.	plural	grammatical
60	At the pet store, the hamsters	tries	to escape the cage.	plural	ungrammatical
61	In the laboratory, the scientist	conducts	an experiment.	singular	grammatical
61	In the laboratory, the scientist	conduct	an experiment.	singular	ungrammatical
61	In the laboratory, the scientists	conduct	an experiment.	plural	grammatical
61	In the laboratory, the scientists	conducts	an experiment.	plural	ungrammatical
62	The teacher	corrects	the students' essays over the weekend.	singular	grammatical

62	The teacher	correct	the students' essays over the weekend.	singular	ungrammatical
62	The teachers	correct	the students' essays over the weekend.	plural	grammatical
62	The teachers	corrects	the students' essays over the weekend.	plural	ungrammatical
63	The swimmer	dives	into the pool.	singular	grammatical
63	The swimmer	dive	into the pool.	singular	ungrammatical
63	The swimmers	dive	into the pool.	plural	grammatical
63	The swimmers	dives	into the pool.	plural	ungrammatical
64	The backpacker	decides	to hitchhike to the next town.	singular	grammatical
64	The backpacker	decide	to hitchhike to the next town.	singular	ungrammatical
64	The backpackers	decide	to hitchhike to the next town.	plural	grammatical
64	The backpackers	decides	to hitchhike to the next town.	plural	ungrammatical
65	The shop assistant	fills	the shelves with fresh produce.	singular	grammatical
65	The shop assistant	fill	the shelves with fresh produce.	singular	ungrammatical
65	The shop assistants	fill	the shelves with fresh produce.	plural	grammatical
65	The shop assistants	fills	the shelves with fresh produce.	plural	ungrammatical
66	In class, the student	presents	a new project.	singular	grammatical
66	In class, the student	present	a new project.	singular	ungrammatical

66	In class, the students	present	a new project.	plural	grammatical
66	In class, the students	presents	a new project.	plural	ungrammatical
67	In the woods, the path	leads	to a lake.	singular	grammatical
67	In the woods, the path	lead	to a lake.	singular	ungrammatical
67	In the woods, the paths	lead	to a lake.	plural	grammatical
67	In the woods, the paths	leads	to a lake.	plural	ungrammatical
68	Once a month the museum	remains	open until 10pm.	singular	grammatical
68	Once a month the museum	remain	open until 10pm.	singular	ungrammatical
68	Once a month the museums	remain	open until 10pm.	plural	grammatical
68	Once a month the museums	remains	open until 10pm.	plural	ungrammatical
69	The surfer	drives	to the beach in the summer.	singular	grammatical
69	The surfer	drive	to the beach in the summer.	singular	ungrammatical
69	The surfers	drive	to the beach in the summer.	plural	grammatical
69	The surfers	drives	to the beach in the summer.	plural	ungrammatical
70	The gardener	trims	the hedges in the park.	singular	grammatical
70	The gardener	trim	the hedges in the park.	singular	ungrammatical
70	The gardeners	trim	the hedges in the park.	plural	grammatical

70	The gardeners	trims	the hedges in the park.	plural	ungrammatical
71	The farmer	milks	the cows twice a day.	singular	grammatical
71	The farmer	milk	the cows twice a day.	singular	ungrammatical
71	The farmers	milk	the cows twice a day.	plural	grammatical
71	The farmers	milks	the cows twice a day.	plural	ungrammatical
72	My favourite chef	makes	the most delicious lasagne.	singular	grammatical
72	My favourite chef	make	the most delicious lasagne.	singular	ungrammatical
72	My favourite chefs	make	the most delicious lasagne.	plural	grammatical
72	My favourite chefs	makes	the most delicious lasagne.	plural	ungrammatical
73	The hunter	tracks	a deer in the forest.	singular	grammatical
73	The hunter	track	a deer in the forest.	singular	ungrammatical
73	The hunters	track	a deer in the forest.	plural	grammatical
73	The hunters	tracks	a deer in the forest.	plural	ungrammatical
74	The player	draws	another card.	singular	grammatical
74	The player	draw	another card.	singular	ungrammatical
74	The players	draw	another card.	plural	grammatical
74	The players	draws	another card.	plural	ungrammatical
75	The interrogator	questions	the suspect about his whereabouts.	singular	grammatical
75	The interrogator	question	the suspect about his whereabouts.	singular	ungrammatical
75	The interrogators	question	the suspect about his whereabouts.	plural	grammatical

75	The interrogators	questions	the suspect about his whereabouts.	plural	ungrammatical
76	The tourist	goes	to the national park.	singular	grammatical
76	The tourist	go	to the national park.	singular	ungrammatical
76	The tourists	go	to the national park.	plural	grammatical
76	The tourists	goes	to the national park.	plural	ungrammatical
77	The reviewer	praises	the new play.	singular	grammatical
77	The reviewer	praise	the new play.	singular	ungrammatical
77	The reviewers	praise	the new play.	plural	grammatical
77	The reviewers	praises	the new play.	plural	ungrammatical
78	The boxer	punches	the training bag repeatedly to build strength and endurance.	singular	grammatical
78	The boxer	punch	the training bag repeatedly to build strength and endurance.	singular	ungrammatical
78	The boxers	punch	the training bag repeatedly to build strength and endurance.	plural	grammatical
78	The boxers	punches	the training bag repeatedly to build strength and endurance.	plural	ungrammatical
79	The island	lies	off the coast of Italy.	singular	grammatical
79	The island	lie	off the coast of Italy.	singular	ungrammatical
79	The islands	lie	off the coast of Italy.	plural	grammatical
79	The islands	lies	off the coast of Italy.	plural	ungrammatical
80	The cat	leaps	onto the furniture.	singular	grammatical
80	The cat	leap	onto the furniture.	singular	ungrammatical

80	The cats	leap	onto the furniture.	plural	grammatical
80	The cats	leaps	onto the furniture.	plural	ungrammatical

Appendix B.2 Experiment 4 – Verb premodification condition stimuli. Target verbs are shown capitalized, while premodifiers are underlined and baseline words across sentence pairs are italicized.

Pair number	Premodified	Bare	Premodified sentence	Bare sentence
1	will have merrily danced	merrily danced	The wedding guests will have *merrily* DANCED until the morning.	At the wedding the guests *merrily* DANCED until the morning.
2	will have patently taught	patiently taught	Rose will have *patiently* TAUGHT the children how to ice skate.	Last summer Rose *patiently* TAUGHT the children how to roller skate.
3	will have neatly packed	neatly packed	Tom will have *neatly* PACKED his suitcase last night. He was taking an early train to the airport.	As usual Tom *neatly* PACKED his suitcase last night. He is very organized.
4	will have briefly discussed	briefly discussed	The teacher will have *briefly* DISCUSSED the assignment with the students before they left for half term.	On Friday, the teacher *briefly* DISCUSSED the assignment with the students because they still had questions.
5	will have successfully completed	successfully completed	Emma will have *successfully* COMPLETED her last year at secondary school soon.	This summer, Emma *successfully* COMPLETED her last year at university.
6	will have finally chopped	finally chopped	Tom will have *finely* CHOPPED the vegetables and then marinated the meat.	Before dinner Tom *finely* CHOPPED the vegetables and then prepared the salad.

7	will have thoroughly tested	thoroughly tested	Mark bought a new electric car. He will have *thoroughly* TESTED the battery before driving to Wales.	Last month, Mark bought a new electric car. He *thoroughly* TESTED the battery before driving to Wales.
8	will have publicly performed	publicly performed	The artists will have *publicly* PERFORMED the dance in elaborate costumes.	The group of artists *publicly* PERFORMED the dance in elaborate costumes.
9	will have confidently bought	confidently bought	Mark likes to gamble. He will have *confidently* BROUGHT a lot of money to the casino.	I think Mark likes to gamble. He *confidently* BROUGHT a lot of money to the poker game.
10	will have hastily prepared	hastily prepared	A storm is coming. The residents will have *hastily* PREPARED themselves for floods.	A very strong storm is coming. The residents *hastily* PREPARED themselves for floods.
11	must have finally travelled	finally travelled	Rose must have *finally* TRAVELLED to Scotland to visit her relatives. She has not seen them in months.	On Saturday Rose *finally* TRAVELLED to Scotland to visit her friends. She has not seen them in months.
12	must have already bought	already bought	Sarah must have *already* BOUGHT the tickets weeks ago. She had a great seat.	This time, Sarah *already* BOUGHT the tickets weeks in advance. She had a great seat.
13	must have happily played	happily played	The kids must have *happily* PLAYED together until they fell asleep.	On Sunday, the kids *happily* PLAYED together until they had to go home.
14	must have accidentally knocked over	accidentally knocked over	John must have *accidentally* KNOCKED OVER the glass vase	This morning, John *accidentally* KNOCKED OVER the glass vase

			when he reached for his scarf.	while looking for his keys.
15	must have finally put	finally put	Mark <u>must have</u> *finally* PUT a lot of old toys in the attic.	Last weekend, Mark *finally* PUT a lot of old toys in storage.
16	must have thoroughly cleaned	thoroughly cleaned	Paul <u>must have</u> *thoroughly* CLEANED the car before he went for a stroll.	On Saturday Paul *thoroughly* CLEANED the car before taking a well-deserved break.
17	must have really cost	really cost	Mark's new TV <u>must have</u> *really* COST him a lot of money.	I think Mark's new TV *really* COST him a lot more than he had expected.
18	must have idly chatted	idly chatted	I went to the hair dresser. She <u>must have</u> *idly* CHATTED the entire time.	I went to the hair dresser on Friday. She *idly* CHATTED the entire time.
19	must have just caught	just caught	Paul <u>must have</u> *just* CAUGHT the first train to work in the morning.	This morning, Paul *just* CAUGHT the first train to the airport.
20	must have carefully compared	carefully compared	Before buying his car, John <u>must have</u> *carefully* COMPARED prices between different dealerships. He found a great bargain.	Before buying his brand new car, John *carefully* COMPARED prices between different dealerships. He found a great bargain.
21	should have slowly cooked	slowly cooked	We <u>should have</u> *slowly* COOKED the turkey a while ago.	Thinking ahead, we *slowly* COOKED the turkey a while ago.
22	should have quickly cut	quickly cut	Mark <u>should have</u> *quickly* CUT the cake before all his guests left.	After dinner, Mark *quickly* CUT the cake before all his friends left.

23	should have swiftly kicked	swiftly kicked	On the pitch, Tom should have *swiftly* KICKED the ball to his team mate.	On the all-weather pitch, Tom *switfly* KICKED the ball to his team mate.
24	should have regularly trained	regularly trained	Kate should have *regularly* TRAINED before running her first marathon.	For months Kate *regularly* TRAINED before running her first marathon.
25	should have finally posted	finally posted	Tom should have *finally* POSTED the parcel with presents for his nephew last week.	On Monday Tom *finally* POSTED the parcel with presents for his niece.
26	should have immediately dropped	immediately dropped	When he heard the school bell, Paul should have *immediately* DROPPED the ball and walked back to the classroom.	When he heard the school bell ring twice, Paul *immediately* DROPPED the ball and walked back to the classroom.
27	should have fairly paid	fairly paid	The company should have *fairly* PAID the female and male workers.	I think the company *fairly* PAID the female and male workers.
28	should have honestly told	honestly told	Paul should have *honestly* TOLD Sarah that he is coming home late tonight.	Last night Paul *honestly* TOLD Sarah that he loved her.
29	should have diligently practiced	diligently practiced	Kate should have *diligently* PRACTICED her lines for the play.	All day, Kate *diligently* PRACTICED her lines for the play.
30	should have quickly brushed	quickly brushed	Mark should have *quickly* BRUSHED his teeth before going to bed.	This morning Mark *quickly* BRUSHED his teeth before going to work.
31	could have quickly changed	quickly changed	Rose could have *quickly* CHANGED her clothes before going out to	After work, Rose *quickly* CHANGED her clothes before going out to

			dinner. Everyone else was smartly dressed.	dinner. Her friends were already waiting.
32	could have probably collected	probably collected	John could have *probably* COLLECTED his shirts from the dry cleaners by now.	On Monday John *probably* COLLECTED his shirts from the dry cleaners before going to work.
33	could have officially counted	officially counted	The zoo could have *officially* COUNTED the number of visitors who came to see the baby bears.	This year the zoo *officially* COUNTED the number of visitors who came to see the baby elephants.
34	could have nearly caught	nearly caught	Rose realized she could have *nearly* CAUGHT the train which stopped only at a few stations.	Once aboard, Rose realized she *nearly* CAUGHT the train which stopped at every station.
35	could have actually planted	actually planted	Mark and Rose have so much space they could have *actually* PLANTED a rose garden in their backyard.	At home, Mark and Rose have so much space they *actually* PLANTED a rose garden in their backyard.
36	could have officially proposed	officially proposed	I am disappointed. The committee could have *officially* PROPOSED a plan that tackles air pollution in the city.	I am excited, the newly appointed committee *officially* PROPOSED a plan that tackles air pollution in the city.
37	could have almost cried	almost cried	Emma was worried her toe was broken. She could have *almost* CRIED when she hit it against the door.	Emma was very worried her big toe was broken. She *almost* CRIED when she hit it against the table.

38	could have quickly called	quickly called	John could have *quickly* CALLED his aunt to wish her happy birthday.	Last night John *quickly* CALLED his aunt to wish her a happy new year.
39	could have just pitched	just pitched	We went camping and could have *just* PITCHED our tent by the lake. But there were too many mosquitos.	Last weekend we went camping and *just* PITCHED our tent by the lake. We had a beautiful view.
40	could have bravely continued	bravely continued	Sarah could have *bravely* CONTINUED walking but Rose was getting tired.	Emma and Sarah *bravely* CONTINUED walking but Rose was getting tired.
41	may have safely crossed	safely crossed	The animals may have *safely* CROSSED the road at night. We saw them grazing in the next field.	Most of the animals *safely* CROSSED the road at night. We saw them grazing in the next field.
42	may have unexpectedly discovered	unexpectedly discovered	Scientists may have *unexpectedly* DISCOVERED a new species of fish.	In Australia scientists *unexpectedly* DISCOVERED a new species of spiders.
43	may have freshly ploughed	freshly ploughed	The farmer may have *freshly* PLOUGHED the field before planting new seeds.	This morning the farmer *freshly* PLOUGHED the field before planting new seeds.
44	may have recently moved	recently moved	Kate may have *recently* MOVED to a new neighbourhood.	I think Kate *recently* MOVED to a new neighbourhood.
45	may have secretly planned	secretly planned	He *may have secretly* PLANNED a surprise birthday party for his sister.	On Monday he *secretly* PLANNED a surprise birthday party for his wife.

46	may have routinely cheated	routinely cheated	When we were younger, my sister <u>may have</u> *routinely* CHEATED at card games but I never found out how.	When we were a lot younger, my sister *routinely* CHEATED at card games but I never found out how.
47	may have badly damaged	badly damaged	Paul <u>may have</u> *badly* DAMAGED his bicycle on the way to work. Luckily he was not injured.	On Tuesday Paul *badly* DAMAGED his bicycle on the way to work. Luckily he was not injured.
48	may have spontaneously decided	spontaneously decided	John and Emma <u>may have</u> *spontaneously* DECIDED to travel to Portugal for a short break.	Last week John and Emma *spontaneously* DECIDED to travel to Portugal to visit his parents.
49	may have already delivered	already delivered	Paul ordered a book. They <u>may have</u> *already* DELIVERED it while he was at work.	Last week Paul ordered a book. They *already* DELIVERED it while he was at work.
50	may have seriously considered	seriously considered	We <u>may have</u> *seriously* CONSIDERED going skiing in the Alps this winter. But I can't quite remember.	This winter, we *seriously* CONSIDERED going skiing in the Alps. But there wasn't enough snow.
51	might have accidentally left	accidentally left	John <u>might have</u> *accidentally* LEFT his wallet at home. Luckily he had £20 in his pockets.	This morning John *accidentally* LEFT his wallet at home. Luckily he had £10 in his pockets.
52	might have directly competed	directly competed	Paul and John <u>might have</u> *directly* COMPETED against each other at the tennis tournament if Paul hadn't lost his first match.	On Sunday Paul and John *directly* COMPETED against each other at the tennis tournament. Mark won.

53	might have truly enjoyed	truly enjoyed	Kate and Emma might have *truly* ENJOYED the rock concert if they had had a better view.	I heard Kate and Emma *truly* ENJOYED the rock concert as they had a great view.
54	might have cheekily asked	cheekily asked	Mark might have *cheekily* ASKED his parents to pick him up from the train station.	I think Mark *cheekily* ASKED his parents to pick him up from the airport.
55	might have blissfully believed	blissfully believed	When I was younger, I might have *blissfully* BELIEVED in the tooth fairy.	When I was a lot younger, I *blissfully* BELIEVED in the tooth fairy.
56	might have blindly trusted	blindly trusted	I was in a hurry and might have *blindly* TRUSTED the driver to know the way if he hadn't taken the wrong exit.	I was in such a terrible hurry and *blindly* TRUSTED the driver to know the way to the airport.
57	might have seirously pursued	seriously pursued	Emma might have *seriously* PURSUED a career in journalism, but she decided to become a novelist instead.	After university, Emma *seriously* PURSUED a career in journalism and recently got promoted.
58	might have officially joined	officially joined	Kate told me she might have *officially* JOINED a walking group if she had not already signed up for the gym.	Over coffee, Kate told me she *officially* JOINED a walking group. It was a great way to stay active and meet new people.
59	might have locally produced	locally produced	This region in Greece might have *locally* PRODUCED olive oil since antiquity. I saw it on a TV programme.	This south east region in Greece *locally* PRODUCED olive oil since antiquity. Unfortunately a fire destroyed the area.

60	might have completely destroyed	completely destroyed	The injury might have *completely* DESTROYED Sarah's chances of winning the marathon.	The recent ankle injury *completely* DESTROYED Sarah's chances of winning the race.
61	would have properly introduced	properly introduced	Paul would have *properly* INTRODUCED his new partner to his parents.	Last weekend, Tom *properly* INTRODUCED his new partner to his parents.
62	would have easily climbed	easily climbed	When I was younger, I would have *easily* CLIMBED that tree to the top.	When I was fitter and younger, I *easily* CLIMBED that tree to the top.
63	would have actually preferred	actually preferred	Sarah would have *actually* PREFERRED to stay at home. It was too cold to watch the fireworks outside.	Last night, Sarah *actually* PREFERRED to stay at home. It was too cold to watch the fireworks outside.
64	would have partially covered	partially covered	Emma's parents would have *partially* COVERED the cost of her new car.	I heard Emma's parents *partially* COVERED the cost of her new bicycle.
65	would have regularly baked	regularly baked	In the past, Sarah would have *regularly* BAKED cookies for her family.	On several weekends before Christmas, Sarah *regularly* BAKED cookies for her family.
66	would have completely closed	completely closed	Before going to bed, John would have *completely* CLOSED the shutters but they were broken.	Last night before going to bed, John *completely* CLOSED the shutters but left the window open.
67	would have angrily complained	angrily complained	At the restaurant, we waited a long time to order. I would have	At the new restaurant, we waited a terribly long time to order. I *angrily*

			angrily COMPLAINED to the manager but it was the waiter's first day on the job.	COMPLAINED to the manager and we received a free dessert as compensation.
68	would have eagerly participated	eagerly participated	Many people <u>would have</u> *eagerly* PARTICIPATED in the marathon if the weather had been better.	This year, many people *eagerly* PARTICIPATED in the marathon as the weather was ideal.
69	would have personally contacted	personally contacted	After the results, we <u>would have</u> *personally* CONTACTED our local councillor if she had won.	After we heard the results, we *personally* CONTACTED our local councillor to congratulate her.
70	would have quickly grabbed	quickly grabbed	I <u>would have</u> *quickly* GRABBED an umbrella and raincoat if it had rained more heavily.	This morning I *quickly* GRABBED an umbrella and raincoat as it rained quite heavily.

Appendix B.3 Experiment 4 – Filler condition stimuli including cloze values.

Pair number	Frame	Target word	Continuation	Cloze
1	They drank champagne to celebrate their twelfth wedding	ANNIVERSARY	with friends and family.	>.75
1	They drank champagne to celebrate their twelfth wedding	CAKE	with friends and family.	0
2	The mother fed the newborn	BABY	right after her lunch.	>.75
2	The mother fed the newborn	HEN	right after her lunch.	0
3	The halftime entertainment was the school marching	BAND	playing their fight song.	>.75
3	The halftime entertainment was the school marching	CHOIR	playing their fight song.	0
4	On hot days many people sun themselves on the	BEACH	and read a book.	>.75
4	On hot days many people sun themselves on the	ROOF	and read a book.	0
5	Emily poured cereal in a	BOWL	to eat for breakfast.	1
5	Emily poured cereal in a	CLOSET	to eat for breakfast.	0
6	The kids fed the ducks some stale	BREAD	from their pantry.	>.75
6	The kids fed the ducks some stale	CREAM	from their pantry.	0
7	On my birthday my grandma always bakes me a	CAKE	with pink and white frosting.	1
7	On my birthday my grandma always bakes me a	LOAF	with pink and white frosting.	0
8	The boys helped Jane wax her	CAR	because she didn't know how.	0.82

8	The boys helped Jane wax her	PAPER	because she didn't know how.	0
9	The teller cashed the large traveller's	CHECK	that John gave him.	>.75
9	The teller cashed the large traveller's	POUNDS	that John gave him.	0
10	On top of the hamburger there was melted	CHEESE	and it tasted great.	>.75
10	On top of the hamburger there was melted	SANDWICH	and it tasted great.	0
11	The organist accompanied the church	CHOIR	every Sunday morning at 10am.	>.75
11	The organist accompanied the church	DENTIST	every Sunday morning at 10am.	0
12	Every Sunday morning people pray in their local	CHURCH	with their families and neighbors.	>.75
12	Every Sunday morning people pray in their local	SCHOOL	with their families and neighbors.	0
13	New York is a very busy	CITY	that never sleeps.	0.81
13	New York is a very busy	BABY	that never sleeps.	0
14	The butler hung their clothes in the	CLOSET	in the back hallway.	>.75
14	The butler hung their clothes in the	CHURCH	in the back hallway.	0
15	The tenants decided to take their landlord to	COURT	for treating them so unfairly.	>.7
15	The tenants decided to take their landlord to	TEA	for treating them so unfairly.	0
16	I like hot fudge with ice	CREAM	and a cherry on top.	>.75
16	I like hot fudge with ice	LEMON	and a cherry on top.	0

17	John poured himself a glass of sparkling red	WINE	to enjoy with dessert.	>.75
17	John poured himself a glass of sparkling red	SOIL	to enjoy with dessert.	0
18	Because he had a toothache he called his	DENTIST	to see what he would recommend.	>.75
18	Because he had a toothache he called his	BAND	to see what he would recommend.	0
19	Tim put his feet up on his father's oak	DESK	even though he knew it was wrong.	>.75
19	Tim put his feet up on his father's oak	MAP	even though he knew it was wrong.	0
20	The society's annual dues were fifty	POUNDS	from each returning member.	>.75
20	The society's annual dues were fifty	LESSONS	from each returning member.	0
21	The racing cars received the checkered	FLAG	to begin the race.	>.75
21	The racing cars received the checkered	STAR	to begin the race.	0
22	The ship disappeared into the thick	FOG	and was never seen again.	0.88
22	The ship disappeared into the thick	GROUND	and was never seen again.	0
23	Jack ordered a hamburger and french	FRIES	from the cashier.	>.75
23	Jack ordered a hamburger and french	MEAL	from the cashier.	0
24	My cat is covered with white	FUR	and a few brown spots.	>.75

24	My cat is covered with white	FOG	and a few brown spots.	0
25	We sometimes forget that golf is just a	GAME	that doesn't mean life or death.	0.82
25	We sometimes forget that golf is just a	RACE	that doesn't mean life or death.	0
26	The attendant filled the car with	PETROL	and washed the windows.	>.75
26	The attendant filled the car with	SHADE	and washed the windows.	0
27	The mole lived in a hole in the	GROUND	at the bottom of the hill.	0.74
27	The mole lived in a hole in the	PILL	at the bottom of the hill.	0
28	The carpenter pounded in the last nail with his	HAMMER	and was glad to be done.	1
28	The carpenter pounded in the last nail with his	CAR	and was glad to be done.	0
29	A female chicken is called a	HEN	and her babies are called chicks.	>.75
29	A female chicken is called a	HAMMER	and her babies are called chicks.	0
30	The policeman's gun was sitting in his shoulder	HOLSTER	when the phone rang.	>.75
30	The policeman's gun was sitting in his shoulder	LEAD	when the phone rang.	0
31	They sat together without speaking a single	WORD	and looked out the window.	0.98
31	They sat together without speaking a single	TIME	and looked out the window.	0
32	George must keep his pet on a	LEAD	so it does not run away.	0.89
32	George must keep his pet on a	SHORE	so it does not run away.	0

33	The cold drink was served with a slice of	LEMON	and a bright green straw.	>.7
33	The cold drink was served with a slice of	CHEESE	and a bright green straw.	0
34	They could not afford to give their daughter piano	LESSONS	so she taught herself.	>.75
34	They could not afford to give their daughter piano	MUSCLES	so she taught herself.	0
35	I added my name to the	LIST	right after Mary.	0.85
35	I added my name to the	CHECK	right after Mary.	0
36	Cut me a slice of bread from that	LOAF	sitting on the counter.	>.75
36	Cut me a slice of bread from that	HOLSTER	sitting on the counter.	0
37	The gambler had a streak of bad	LUCK	right after his birthday.	0.94
37	The gambler had a streak of bad	PETROL	right after his birthday.	0
38	The maid loaded the laundry into the washing	MACHINE	and poured in the detergent.	>.75
38	The maid loaded the laundry into the washing	RIVER	and poured in the detergent.	0
39	To help everyone find her house, Lisa drew a	MAP	with lots of colours.	>.7
39	To help everyone find her house, Lisa drew a	FLAG	with lots of colours.	0
40	Abby brushed her teeth after every	MEAL	and every snack.	0.88
40	Abby brushed her teeth after every	GAME	and every snack.	0
41	Before exercising Jack always stretches his	MUSCLES	for at least 10 minutes.	>.75
41	Before exercising Jack always stretches his	LUCK	for at least 10 minutes.	0

42	My car needs a new coat of	PAINT	as soon as possible.	>.75
42	My car needs a new coat of	FUR	as soon as possible.	0
43	They placed an ad in the daily	PAPER	asking for a babysitter.	>.75
43	They placed an ad in the daily	LIST	asking for a babysitter.	0
44	They ate ice cream and cake at his birthday	PARTY	last Sunday afternoon.	>.75
44	They ate ice cream and cake at his birthday	ANNIVERSARY	last Sunday afternoon.	0
45	In the morning he forgot to take his vitamin	PILL	so he had to take it later.	>.75
45	In the morning he forgot to take his vitamin	BREAD	so he had to take it later.	0
46	The horse collapsed right after winning the	RACE	at the famous racetrack.	>.75
46	The horse collapsed right after winning the	DESK	at the famous racetrack.	0
47	Yesterday they canoed down the	RIVER	with a big group of friends.	0.89
47	Yesterday they canoed down the	ROOM	with a big group of friends.	0
48	He finally decided to mend the damaged	ROOF	that the storm had ruined last year.	>.75
48	He finally decided to mend the damaged	CITY	that the storm had ruined last year.	0
49	The bad boy was sent to his	ROOM	without any dessert.	0.78
49	The bad boy was sent to his	BEACH	without any dessert.	0
50	I ordered a ham and cheese	SANDWICH	for lunch yesterday.	>.75
50	I ordered a ham and cheese	BOWL	for lunch yesterday.	0

51	Pam weighed herself on the bathroom	SCALE	to monitor her progress.	>.75
51	Pam weighed herself on the bathroom	MACHINE	to monitor her progress.	0
52	The wealthy child attended a private	SCHOOL	on the far side of town.	0.83
52	The wealthy child attended a private	PARTY	on the far side of town.	0
53	Karen cut the long string with a pair of	SCISSORS	that she found in the cabinet.	1
53	Karen cut the long string with a pair of	WEEDS	that she found in the cabinet.	0
54	The cows moved from the sun into the	SHADE	because of the heat.	0.82
54	The cows moved from the sun into the	COURT	because of the heat.	0
55	Most shark attacks occur very close to	SHORE	and in the summer months.	0.74
55	Most shark attacks occur very close to	SCISSORS	and in the summer months.	0
56	The fertilizer enriched the	SOIL	so the plants could grow.	0.71
56	The fertilizer enriched the	PAINT	so the plants could grow.	0
57	Tonight make sure you wish on a	STAR	like Sara told you to.	1
57	Tonight make sure you wish on a	SCALE	like Sara told you to.	0
58	He liked milk and sugar in his	TEA	but not in his coffee.	0.94
58	He liked milk and sugar in his	WINE	but not in his coffee.	0
59	All the guests had a very good	TIME	at the party he gave.	0.72

59	All the guests had a very good	WORD	at the party he gave.	0
60	They're out in the garden pulling	WEEDS	so the flowers can grow.	>.75
60	They're out in the garden pulling	FRIES	so the flowers can grow.	0