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Neurocognitive Correlates of Nouns and Verbs: Zero-Derivation and Lexico-Semantic Processes

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Sladjana Lukic

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Abstract

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Sladjana Lukic

In the past few decades, psycholinguistic and neurolinguistic research has shown that nouns and verbs are processed differently in cognitively healthy individuals, and can be selectively impaired in aphasic individuals. However, this noun-verb dichotomy is poorly understood. This dissertation investigated cognitive and neural distinctions between nouns and verbs by studying categorically ambiguous words in English, providing insight into the domains of category ambiguity and derivational morphology. Using grammaticality judgment tasks and fMRI, three studies tested whether the two forms (noun/verb) of ambiguous words (e.g., *brush*) are listed under separate lexical entries or share a single entry with one form being zero-derived from the other.

Studies 1 and 2 examined processing of noun-derived forms like *brush* and verb-derived forms like *bite,* presented for grammaticality judgment with either *the* or *to,* and response time and selection rates were measured. Results showed that for healthy speakers, derived forms (*to brush, the bite*) induced greater processing cost and, therefore, delayed recognition when compared to base forms (*the brush, to bite*) (Study 1). Additionally, base forms were selected more frequently compared to derived forms across categories in both healthy and aphasic participants without verb impairments, while decreased selection rates of verbal base forms occurred in aphasic participants with verb impairments (Study 2), indicating that impaired access to verb-base forms precluded retrieval of associated verb-derived nouns. These findings support

the existence of a single base-form entry for ambiguous words in normal and impaired lexical processing.

Study 3 used fMRI to examine the neurocognitive correlates of noun-derived verbs (*to brush*), non-derived verbs (*to bear*) and unambiguous verbs (*to bake*), compared to nouns (*the bell*). A distinct left frontal and bilateral temporal neural basis for verbs and nouns, respectively, was observed, suggesting that separable cognitive and neural systems are implicated in the processing of each word-class. A distinct bilateral temporal and left fronto-parietal neural activation pattern for noun-derived verbs vs. non-derived verbs was identified, suggesting a relation between morphological and semantic complexity, respectively, and neural processing. Overall, these data provide behavioral and neural support for a zero-derivation.

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To my Mom, my hero.

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Chapter 1. Introduction

Language is essential for human communication and for establishing social relations and human interactions. Although language comes naturally, the linguistic system is highly complex, composed of a lexicon and grammar (Chomsky, 1970). The lexicon is more than a simple collection of words; it has a structure and consists of lexical components (e.g., Nouns, Verbs, Adjectives, etc.), and lexical knowledge (knowledge about them). Operating on the lexicon are the rules of grammar, a system of transformations that relate lexical form and meaning.

Nouns and Verbs are two major word classes in the lexicon. Different theories exist about whether these two word classes are selectively represented in the lexicon and processed separately or by overlapping systems. Several lines of research have sought to identify the cognitive and neural systems associated with representation and processing of each word class, with compelling evidence that the two are separable coming from several sources. The first evidence comes from neuropsychological studies, showing that word-class impairments are prevalent in language disorders, such as aphasia. Individuals with stroke-induced aphasia often show selective impairments in accessing either nouns or verbs. Consequently, dissociations between nouns and verbs can be mapped to different parts of the brain based on lesion location (Crepaldi, 2011; Mätzig et al., 2009). The second evidence for a noun-verb dichotomy comes from psycholinguistic studies in healthy individuals reporting that verbs are cognitively harder (longer) to process than nouns (e.g., Bogka et al., 2003; Druks et al., 2006; Sereno, 1999; Sereno & Jongman, 1997; Szekely et al., 2005).

Despite the large body of research examining normal and impaired lexical processing, studies of the noun-verb dichotomy have been limited to typical object-denoting nouns (e.g., *bell*) and event-denoting verbs (e.g., *bake*). Importantly however, there is a large class of nouns, which can denote events, and verbs, which carry the meaning of an object. In this way, many words in the English language are ambiguous with regard to word category (e.g., *brush, bite*). These words comprise 80% of common English words (Lipka, 1992), and despite their high productivity, they have received little attention in normal and impaired lexical processing.

The overarching goal of this dissertation was to understand how nouns and verbs are stored, accessed, and processed in the human mind of cognitively healthy individuals and how these processes break down in individuals with stroke-induced aphasia. To this end, the studies undertaken examined healthy and aphasic individuals' ability to process categorically ambiguous and unambiguous nouns and verbs, and investigated the neural basis of these two word classes in healthy individuals. Understanding the cognitive and neural mechanisms that support processing of the two word classes will not only inform existing neurocognitive theories of lexical processing, but will provide behavioral and neurological data relevant to treatment of word-class impairments in aphasia. We begin with a brief review of research spanning multiple disciplines that has advanced our understanding of lexical processing. We then discuss a neural disorder that affects language – stroke-induced aphasia. Finally, we outline the structure, research aims and questions of the dissertation.

1.1. NORMAL LEXICAL PROCESSING: Nouns and Verbs

Nouns and verbs belong to different grammatical categories and hence share few properties and have different degrees of *morphological* complexity. For example, in English, while nouns inflect for number and appear in two forms: singular and plural (e.g., *bell, bells*), verbs inflect for tense, aspect and person, and can appear in five forms: base (uninflected), past tense, third person singular present, passive and progressive form (e.g., *bite, bit, bitten, biting*). Thus, nouns versus verbs are restricted as to the features that are assigned to them (e.g., the tense feature cannot occur on nouns — **belled*). *Semantically*, nouns and verbs require different underlying semantic knowledge. While nouns usually relate to visual-perceptual information and refer to objects and entities, verbs relate to functional information and refer to actions and events. Finally, nouns and verbs differ in *syntactic* properties. Nouns serve as sentential subjects, where as verbs typically do not. In addition, verbs are predicates and nouns are typically arguments, and verbs assign thematic roles to nouns. Thus, nouns and verbs differ with regard to argument structure properties: while verbs always have an argument structure, most nouns (e.g., objects) do not. Therefore, when processing a word—specifically nouns and verbs—speakers access different semantic and syntactic representations. For instance, the word *bake* as in (1) expresses an *action* verb, incorporating in its meaning, two thematic roles (an agent that initiates the action and a theme) that occur in a syntactic environment with two Noun Phrases (NPs: a subject and an object):

(1) Mary baked cookies.

Importantly however, there is a large class of nouns, which denote events, and verbs, which carry the meaning of objects. For example, the pair of sentences in (2) show that the word *bite* can be used as a noun like in (2a) or as a verb as in (2b). Notably, even when *bite* serves as a noun in 2a and a verb in 2b, these two sentences have basically the same meaning, where *Mary engages the action of biting*.

(2) a. Mary took a bite of the cookie.

b. Mary bit the cookie.

In the similar way, a word such as *brush* can also be used as a noun or a verb. In (3a), *brush* is used as a verb, and the past-tense marker is attached to it. On the other hand, in (3b) it is used as a noun. (3a), indeed means that a *brush* or object related to *brush* is used as a tool to fix the hair. In this sense, the verb *brush* incorporates the meaning of the object *brush*, or it denotes an action that crucially involves a tool like *brush*.

(3) a. Mary brushed her hair.

b. Mary fixed her hair with a brush.

1.1.1. Theoretical Models of Lexical Representation

The internal structure for some words is simple as in (4a and b), and for others it is more complex as in (5a and b). For example, the internal structure of the verb *bake* and the noun *bell* is composed of one verbal or noun node. Conversely, when the word *brush* is used as a verb, its internal structure is formed by Zero-derivation from the noun. First, the nominal base is formed, which is combined with a verbal node that adds an external theta role forming the Noun-derived verb. The zero-suffix in the Noun-derived verb *brush* determines that *brush* is a verb, unlike its base, the noun *brush*, and it contributes the meaning ‘to act using Ns’, where the N is here filled in by *the brush.* In contrast, the noun *bite* is a Verb-derived noun and inherits the components of the event of its verbal base. Therefore, words, like *brush* and *bite*, when used in their base form have a simple structure. When considering their derivation, the internal structure of these words is more complex than non-derived forms since they originate from their base (cf. Lipka 1986b) (see more on zero-derivation in section 1.1.3)

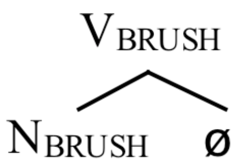
(4)

a. Simple Verb

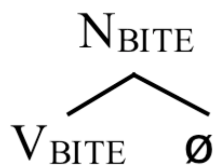
b. Simple Noun

(5)

a. Complex (Noun-derived) Verb



b. Complex (Verb-derived) Noun



The lexical representation of complex words as in (5a and b) has been discussed in two ways: as entailing only a single-entry or as involving separate-entries as discussed below.

1. The **single-entry approach** (Nunberg, 1979, Pustejovsky, 1995; also see Taft and Foster, 1975 "*fully decompositional" account*) proposes that the noun and verb forms of *brush* are listed under a single lexical entry, with one being derived upon the other. While one base form is stored in the mental lexicon, the other form arises from a base, via a morphological operation.
2. The **separate-entry approach** (Jackendoff, 1976 *"full-listing" account*; also see Langacker, 1987) suggests that the noun and verb forms of *brush* are listed as separate lexical entries (as whole forms) in the mental lexicon and that such forms do not undergo derivational processes. Thus, according to this account each form is stored separately in the mental lexicon and is tied to a single orthographic and phonological form.

These approaches provide the architecture for representations of ambiguous words, but they do not address how two forms of an ambiguous word are accessed. However, they serve as a base in predicting the processing of two lexical forms. Accordingly, a *single-entry approach* suggests that when processing ambiguous forms (like *brush*), listeners/speakers initially activate the base form before constructing the derived form. Consequently, this additional morphological complexity may influence processing time. A *separate-entry approach* suggests that individuals simultaneously co-activate noun and verb forms, which, in turn, negates the effect of morphological complexity (see section 1.3 for more detailed discussion on the aforementioned hypothesis and predictions). From here, we turn to psycholinguistic or computational theories on lexical processing, which draw on psycholinguistic and neurocognitive studies.

1.1.2. Theoretical Models of Lexical Processing

In the last decades, a number of models of word processing have been proposed, which can be divided into two contrasting frameworks: serial and distributed processing models. In serial models, word processing entails a set of distinct, hierarchically organized processing stages, such that each stage occurs in a strictly feed-forward and sequential manner; for example, in visual word processing, visual orthographic information (low-level processes) is computed first, followed by higher-level processes, such as semantic and phonological processes (e.g., Forster, 1976; Levelt, Roelofs, & Meyer, 1999; Morton, 1969, 1979b). For example, Levelt, Roelofs, & Meyer (1999) proposed a serial model of spoken word production. According to this model (Levelt, Roelofs, & Meyer 1999), words are processed through several stages. The first is the conceptual preparation stage, in which the message content is determined (word's meaning). The second stage is lexical selection, in which the syntactic properties (lemma) of a given lexical concept are accessed (e.g., grammatical gender of the noun, verb argument structure). Then, at the stage of morphological encoding, the appropriate morphemes are selected (e.g. verb suffixes indicating tense, or noun suffixes indicating singular/plural). The following stage is phonological encoding, in which the word form (or lexeme) is selected. Finally, articulation is initiated. Thus, this model assumes that both lexical and lemma level are part of the lexicon, i.e., when people encounter the word '*brush*', the speakers/readers access both the lexical and grammatical category information.

In contrast to serial models, in interactive activation models, lexical entries are conceptualized as patterns of activation over a set of levels (letters, phonemes, meanings), with processing occurring in parallel at the different levels and feeding in a bidirectional fashion (e.g., Gaskell & Marslen-Wilson, 1997; Seidenberg & McClelland, 1989). Therefore, the two model classes are differentiated based on the directionality of information flow (i.e., top-down and/or bottom-up). The former assumes only bottom-up processing, e.g., only after orthographic word information is completed is other higher-level linguistic information (e.g., phonology, morphology, semantics) processed. The latter suggests a fully interactive processing system whereby, for example, higher-level linguistic information modulates early orthographic processing. In this dissertation, an interactive activation model is adopted, as current research suggest that interactive models have the capacity to account for the processing of categorically ambiguous words, as explained below.

Over the years, several models have been proposed with an interactive activation of distributed representations of orthography, phonology and semantics. For example, Carreiras, Armstrong, Perea, and Frost (2014) provide an explicit mechanistic interactive model of visual word processing by integrating behavioral, neuroimaging, and biologically plausible interactive models (for other models see Gaskell & Marslen-Wilson, 1997; Seidenberg & McClelland, 1989). In agreement with other interactive activation models, this model consists of orthographic, phonological, and semantic representations, including additional units that mediate between the groups of representational units, as shown in Figure 1.1. The model assumes an interactive activation of these distributed representations, which are stored in different brain regions and accessed at different points in time (as shown by the color of the circles in Figure 1.1). The bidirectional connectivity between brain regions that process different aspects of word representation (e.g., orthography, phonology, semantics) is represented by bidirectional arrows.

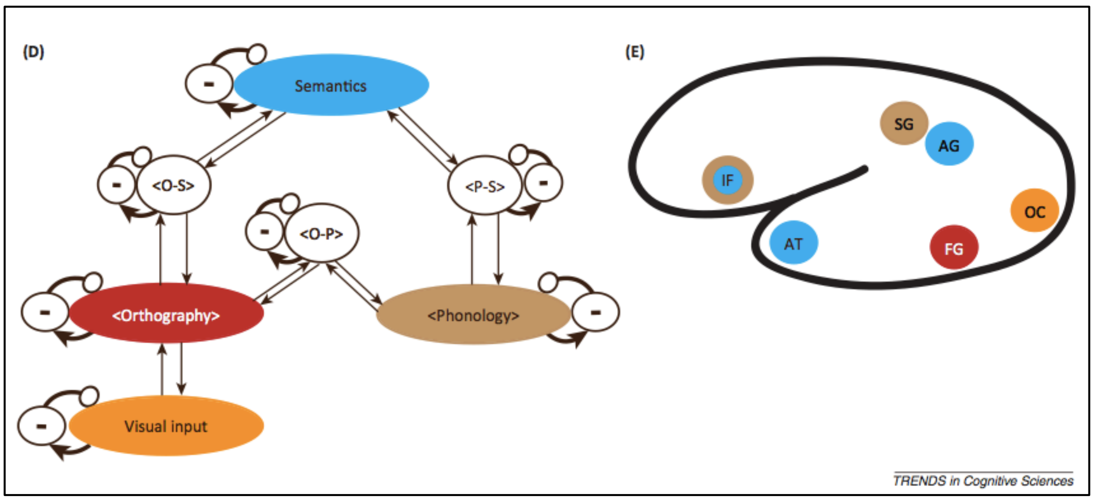


Figure 1.1. Integration of insights from biologically plausible connectionist models and neuroimaging data, adapted from Carreiras et al. (2014): (D) illustrates intermediate pools of neurons that map between orthography, phonology, and semantics (shown by the <o-p>, <o-s>, and <p-s> labels), (E) displays the most critical brain regions associated with different representations, with the color denoting the theoretical representations in the model that these regions might subserve. Abbreviations: IF, inferior frontal cortex; SG, supramarginal gyrus; AG, angular gyrus; AT, anterior temporal cortex; FG, fusiform gyrus (includes visual word form area, VWFA); OC, occipital cortex.

For example, the visual information of a written word like *bake* passes through the entire orthographic–phonological–semantic network as brain activity cascades throughout the entire occipito-temporal-frontal brain network. Initially, the left fusiform gyrus (FG) computes and stores prelexical orthographic information associated with *bake*, and then the activated representation spreads to two other units, containing semantic and phonological representations of the visual input '*bake*'. Anterior temporo-frontal and parietal brain regions support these processes. Yet, this activation can feed back and provide constraints on lower levels of representation in the network such as orthography. In the case of multiple lexical candidates (as in *brush*), the orthographic input of *brush* must be associated with multiple representations (a noun, a verb). The intended word is selected through competition and inhibitory connections of excitatory neurons and small pools of inhibitory neurons (as shown in Figure 1.1, inhibitory neurons are denoted by a dash (–), while all other neurons are excitatory).

Psycholinguistic evidence of word-class processing

Numerous studies have provided differential processing evidence for nouns and verbs. For example, Kauschke and Stenneken (2008) in their lexical-decision experiment in German, tested processing time for nouns that denote concrete objects such as *apple*, compared to verbs that denote actions such as *pour*. They found longer reaction times for verbs than for nouns. Importantly, even when controlling for the morphological differences of nouns and verbs, longer processing time for verbs compared to nouns still persisted. This verb over noun disadvantage effect has been replicated in studies across different languages (i.e. English (Bogka et al., 2003; Druks et al., 2006; Sereno, 1999; Sereno & Jongman, 1997; Szekely et al., 2005), French (Cordier et al., 2013), Chinese (Hsu et al., 1998), Hebrew (Deutsch et al., 1998; Frost, Forster & Deutsch 1997), Serbo-Croation (Kostic & Katz, 1987), and German (Kauschke & von-Frankenberg, 2008)). However, nouns and verbs employed in these studies were not controlled for argument structure properties: whereas verbs always have an argument structure, nouns referring to objects do not (see section 1.1 above).

Several studies have provided processing evidence that verb argument structure is automatically accessed when verbs are encountered. For example, in a series of cross-model lexical-decision experiments, Shapiro and colleagues (1987) demonstrated that dative verbs such as *lend* (which allow both a two-place and optional three-place argument structure) engendered longer reaction time (RT) than transitive verbs such as *solve* (which allow only one argument structure) during real-time sentence processing. Similar findings were confirmed for obligatory transitive verbs (*visit*) as compared to intransitive verbs (*sneeze*) in Gorrell's study (1991) and also for transitive verbs when they require three (*give*) compared to two arguments (*kick*) in Ahrens's study (2003). Moreover, Gennari and Poeppel (2003) tested whether the semantic complexity of event (*build*) and state (*love*) verbs involves different processing costs, across lexical-decision and self-paced reading experiments. They found that event verbs take longer to process than state verbs. They argued that processing the meaning of an event entails activating more complex semantic representation, involving an initial state, a change and a final state.

Taken together, these findings suggest that semantic complexity and complexity of argument structure affects word processing time. Therefore, it is widely believed that verbs have a richer structure than nouns and that the argument structure/semantic property of verbs is categorically more complex than nouns. However, current studies showing verb over noun disadvantage, pointing to the role of argument structure, have not directly tested this. This is further addressed in Study 1 (see Chapter 2).

Neuroimaging evidence of word-class processing

In contrast to the relatively consistent behavioral evidence showing differences in processing of nouns and verbs, neuroimaging studies have been unable to reach consensus as to whether nouns and verbs are anatomically and functionally separated in the brain (see Crepaldi et al., 2011; Crepaldi et al., 2013; Vigliocco et al., 2011 for reviews). Whereas some studies have shown distinct brain areas activated for noun and verb processing, others report either no activation (for one of the word classes or for both), or overlapping brain areas activated for the two categories.

Crepaldi and colleagues (2011) summarized and compared the results of neuroimaging studies directly contrasting noun and verb processing, carried out using a variety of experimental tasks, both within production and comprehension domains. Notably, different experimental techniques (e.g. fMRI, PET) and behavioral tasks (e.g., lexical decision, semantic decision, picture naming) were used across studies, accounting for at least some inconsistencies in findings across studies. However, Crepaldi and colleagues also noted inconsistent findings derived from studies using the same task (e.g. Perani et al., 1999 and Siri et al., 2008; Tyler et al., 2001 and Saccuman et al., 2006; Shapiro et al., 2001 and Cappa et al., 2002). In particular, studies failed to find evidence that specific areas of the brain are engaged for either noun or verb processing (Cappa et al., 2002; Tyler et al., 2001) and, although some studies found left inferior frontal gyrus (IFG) activation for verbs, noun processing did not engender consistent activations, with some studies reporting activation in left temporal regions and others reporting no regions of significant activation (Perani et al., 1999; Shapiro et al., 2005; Tyler et al., 2003). Crepaldi and colleagues concluded that nouns and verbs are spatially segregated at certain levels of processing, but overlap anatomically at some others. Specifically, they suggested that certain brain areas underlie the processing of both nouns and verbs, namely the left IFG, insula, middle and inferior temporal gyri (MTG and ITG), and inferior and superior parietal lobes (IPL and SPL). They also conclude that this fronto-temporal circuit may underlie cognitive processes that are not language-specific, e.g., monitoring and other attentional processes that are necessary to carry out most of the tasks used to assess noun-verb comprehension and production (e.g., Bedny & Thompson-Schill, 2006; Berlingeri et al., 2008; Crescentini, Shallice & Macaluso, 2010). For example, the left IFG recruited for verb processing, has also been implicated in decision and selection processes (e.g., Binder, 2004; Thompson-Schill, et al., 1997).

The different tasks employed in investigations of noun and verb processing may not be the only reason for the discrepancy among data in the neuroimaging literature. In fact, the type of stimuli also has an effect on the results (e.g. action words vs. object words, and unambiguous vs. ambiguous words). Burton et al. (2009), using an auditory grammaticality judgment task, attempted to control all these confounding variables within their stimuli set. They included both ambiguous and unambiguous words, in the context of "the" or "to", ensuring that the selected stimuli included the full range of noun and verb types. The first analysis of the results demonstrated an effect of ambiguity in the left IFG, with greater activation for ambiguous (the/to *smell*) than unambiguous words (the *song*, to *send*), due to greater selection demands. Also, greater activity was observed for the "no" response ("grammatically unacceptable stimuli") in the left superior temporal gyrus (STG) compared to the "yes" response ("grammatically acceptable stimuli"), consistent with greater activation for trials with greater conflict. Additionally, a second analysis of the correct "yes" trials across unambiguous and ambiguous stimuli indicated a small cluster of activation for nouns compared to verbs in the left IFG, as well as a significant interaction effect between ambiguity and word class. For ambiguous trials, noun activation was significantly greater in the left STG than verb activation; however, for unambiguous trials, verb activation was significantly greater than that of nouns.

As Burton et al. noted, native English speakers could have relative difficulty accepting "ambiguous" items as nouns compared to verbs. This is because a noun phrase (e.g. *the smell*) outside of a discursive context may be more difficult to interpret than a verb phrase (e.g. *to smell*). This could have influenced the word class results. Additionally, the main effect of class may have been obscured by very strong effects of the other variable in the analysis—ambiguity in one analysis and response in the other. Importantly, empirical evidence suggests that ambiguity processing could be more or less demanding depending upon the type of ambiguity, demonstrating either an advantage or a disadvantage.

1.1.3. Semantic Ambiguity

Psycholinguistic evidence of semantic ambiguity

Many words in the English language have multiple meanings and can be used both as a noun or a verb. For example, *brush* can be used to refer to an object used for grooming (noun), or an action that implies the object (verb). Another example is *bite*, which can refer to an action or an item being eaten. But importantly, these words can be ambiguous in different ways: while words like *brush* and *bite* have two semantically related meanings (brush-a tool used for grooming, brush-to groom with a brush; bite-an act of biting, bite-to eat), words like *bear* have two semantically unrelated meanings (bear-an animal, bear-to support), both sharing the same spoken/phonological and written/orthographic form.

Previous psycholinguistic studies have shown that the meanings of categorically ambiguous words are initially activated even when the context is unambiguously nominal (the noun) or verbal (to verb) (see Eddington and Tokowicz, 2015 for review of studies published between 2001 and the present). Overall, studies have shown an ambiguity disadvantage, i.e., ambiguous words, like *bear*, *brush*, and *bite* take longer to process compared to unambiguous words, like *bake.* The processing of ambiguous words, however, is affected by semantic (related, unrelated) or syntactic (noun-noun, noun-verb) properties, here referred as semantic versus categorical ambiguity, respectively. In a series of lexical-decision experiments[1], Rodd and colleagues (2002) found an advantage (quicker response) for words with many related meanings (i.e., polysemy/senses; to twist-an ankle, to twist-the truth), and a disadvantage (slower response) for words with multiple unrelated meanings (i.e., homonym; bark-tree, bark-dog sound)[2]. Rodd suggested that related meanings facilitate recognition, whereas unrelated meanings inhibit recognition. Moreover, Mirman et al., (2010) across two experiments examined the effects of semantic and syntactic representational distance between meanings, by comparing recognition of unambiguous words (e.g., acorn), noun-verb homonyms (e.g., bark), and noun-noun homonyms (e.g., deck). They showed that auditory lexical decision (exp1) and matching spoken words to pictures (exp2) response time was fastest for unambiguous words, slower for noun-verb homonyms, and slowest for noun-noun homonyms. In addition, eye fixation time courses revealed a gradual time course difference between conditions. They suggested that it is more difficult to process ambiguous words if they belong to the same grammatical class.

Neuroimaging evidence of semantic ambiguity

Neuroimaging studies also support findings that show a behavioral processing cost associated with words with multiple meanings (see Binder, Desai, Graves, & Conant, 2009 for review). In a descriptive review and meta-analysis of 120 neuroimaging studies investigating the neural basis of semantic processing (including studies on semantic ambiguity), Binder and colleagues (2009) reported a left-lateralized network comprised of 7 regions, including the 1)

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[1] Lexical-decision task has been used, so that participants can rely on the recognition of the orthographic and phonological form of the word and not necessarily on specific semantic activation.

[2] Homonyms, such as the two *unrelated meanings* of *bark*, are considered to be different words that, by chance, share the same orthographic and phonological form. Polysemous word like *twist* or *belt* is considered to be a single word that has more than one *related senses* (Rodd et al., 2002).

posterior inferior parietal lobe (angular/supramarginal gyri (AG/SMG)), 2) lateral temporal cortex (MTG and ITG), 3) ventral temporal cortex (FG and adjacent parahippocampal gyrus), 4) dorsomedial prefrontal cortex (DMPFC), 5) IFG, 6) ventromedial prefrontal cortex (VMPFC), and 7) posterior cingulate gyrus. They further organized these regions into 2 groups: posterior and frontal, corresponding to storage and retrieval aspects of semantic processing, respectively.

The review included studies utilizing different tasks and various forms of ambiguous words, presented individually or within syntactic context. For example, studies that examined ambiguous words in isolation found that processing ambiguous words (e.g., *brush, division*) was associated with increased activation in the left IFG, whereas no increased neural activation was associated with processing unambiguous words (e.g., *belief*, *debut*) in a semantic categorization task (Hargreaves et al., 2011). It is worth noting that neural processing cost for ambiguous words with multiple meanings existed in the absence of a behavioral effect. Similarly, processing ambiguous words (e.g., *dress*) relative to unambiguous words (e.g., *mother*) was also associated with increased activation in the bilateral superior and middle fontal gyri (SFG and MFG) in a semantic generation task in Chinese (Chan et al., 2004). Furthermore, Gennari, MacDonald, Postle, and Seidenberg (2007) examined the neural mechanisms involving semantic ambiguity in syntactic contexts (the/to). They found that ambiguous words (the/to *brush*) elicited more activity in the left IFG and MTG than unambiguous words (the *tray,* to *dig*). Critically, ambiguous words also elicited more activity in *to*-contexts than *the*-contexts in the left posterior IFG and MTG.

Further evidence on semantic ambiguity comes from a magneto-encephalography (MEG) study. Beretta, Fiorentino and Poeppel (2005) in a 2 x 2 factorial design, with the two factors being homonymy (single meaning vs. more than one meaning) and polysemy (many senses vs.

few senses), examined the neural correlates of semantic ambiguity by measuring changes in MEG recordings during a visual lexical-decision task. They referred to the M350 component, indexing the initial stage of lexical access. The MEG results were consistent with the behavioral RT results. That is, longer RT and later onset of an M350 were observed for words with more than one meaning (e.g., *bark*) relative to words with one meaning (e.g., *cage*), and shorter RT and earlier onset of an M350 were elicited for words with many senses (e.g., *belt*) than for words with few senses (e.g., *ant*). Their behavioral and neurophysiological findings supported a separate-entry account for homonymy, and a single-entry account of polysemy.

In summary, Table 1.1 summarizes previous studies using a mix of ambiguous word forms. Generally, findings suggest that processing ambiguous words requires greater computational resources due to greater selection demands associated with co-activation of two meanings, which mainly depend on frontal lobe structure. However, due to stimulus differences across studies, a cohesive picture cannot be drawn. A big question that has not been addressed in the ambiguity literature has to do with how two forms of an ambiguous word are related. In some noun-verb pairs (*brush, smell*), the two forms (noun, verb) are morpho-semantically related but not in others (*bark*, *bear*). A theory that attempts to address this phenomenon is Zero-Derivation Theory (see section 1.1.4 below). Assuming zero-derivation, a word like *brush* corresponds both to a base form (the noun *the brush*) and to a derived form (the verb *to brush*, [$_V$ [$_N$ *brush*] -ø]). Similarly, *smell* corresponds to a verbal base form (*to smell*) and a derived nominal form (*the smell,* [$_N$ [$_V$ *smell*] -ø]). Processing derived forms (versus base forms) could induce additional computation reflected in neural activations. However, former studies on semantic ambiguity did not consider the morphological complexity of the noun and verb forms. Thus, the exact nature of the computational difficulty underlying various ambiguous words is still to be understood. This is further addressed in Study 3 (see Chapter 4).

Table 1.1. Example stimuli from MEG/fMRI studies of semantic ambiguity.

Ambiguity Study	***Condition***	***Example***	***Type***
Beretta, Fiorentino & Poeppel (2005)	ambiguous (w/unrelated meanings), unambiguous	*bark, cage*	NV, NN
	ambiguous (w/multiple senses), unambiguous	*belt, ant*	NN, N
Hargreaves et al. (2011)	ambiguous	*brush, division*	NV, NN
	unambiguous	*belief, debut*	N
Gennari, MacDonald, Postle & Seidenberg (2007)	ambiguous	*the/to brush*	NV
	unambiguous	*the tray, to dig*	N, V
Burton, Krebs-Noble, Gullapalli, & Berndt (2009)	ambiguous	*the/to smell*	NV
	unambiguous	*the song, to send*	N, V
Grindrod et a., (2014)	ambiguous (balanced & unbalanced FRQ)	*rock & duck*	NV
	ambiguous (balanced & unbalanced FRQ)	*match & toast*	NN
	unambiguous	*lake, grow*	N, V

1.1.4. Derivational Morphology

Explicit Derivation

Derivational morphology has been widely studied in the domain of explicit derivation and the knowledge of explicit derivation can help us understand and explain implicit zero-derivation. Therefore, the literature on explicit derivation will be reviewed prior to discussing zero-derivation.

Derivational morphological processes produce new words, where the base form combines with a suffix to form a new lexical item with its own grammatical properties and meaning (William Marslen-Wilson, 2003). This process, in turn, assumes morphologically structured lexical representations that are accessed by decomposing complex forms into their constituent morpheme (see “decomposition accounts” by Taft and Foster, 1975, and William Marslen-Wilson, 2003). Research on explicit derivational morphology has been addressed using either a frequency-based approach: patterning between base/surface frequency (FRQ) slows recognition, or the masked repetition-priming paradigm: patterning between shared base/surface form speeds recognition. For example, in frequency studies, FRQ affects speed and accuracy in a lexical-decision task, so that strong base FRQ effects are consistent with decompositional access, while, conversely, weak base FRQ effects and strong surface FRQ effects suggests that words were stored and accessed as full forms. Additionally, in priming studies the two words, as in the pair *darkness/dark*, prime each other (one speeds the recognition of the other) due to the shared morpheme (*–dark*). This suggests a morphologically structured lexical representation. However, some might argue that the priming effect is reducible to form and meaning overlap, yet, the effect still persists when controlled for phonological, orthographic and semantic properties. In one study by Forster and Azuma (2000), robust morphologically driven priming effects were shown for word pairs with no semantic relation like *permit/submit* (shared morpheme –mit) as well as for semantically related pairs *unhappy/happy*. Importantly, orthographically controlled word pairs such as *rodent/student* showed no priming. Moreover, whereas facilitatory priming was observed for semantically related pairs, semantically unrelated pairs *department/depart* failed to prime each other (Marslen-Wilson et al. 1994). These pairs, although, they may be co-activated when either one of them is seen or heard (cohort competitors) slowing down lexical decision time, they are treated as lexically and semantically distinct and unrelated words.

In summary, these results provide clear evidence for decompositional analysis, where at early stages of access, all morphologically decomposable surface forms are segmented into potential base forms and affixes, independent of form and meaning (William Marslen-Wilson, 2003). Similar to morpho-semantically related word pairs like *darkness/dark*, the noun and verb forms, like *the bite/to bite* or *the brush/to brush,* are also derivationally connected, and thus could be analyzed as the combination of the base form and suffix, as explicitly derived forms are. On the other side, similar to word pairs *department/depart*, the noun and verb forms like *the bear/to bear* could be treated as distinct and unrelated words. Since, the derivation is not formally expressed by a suffix, but by an invisible and unpronounced zero-morpheme, it is usual to refer in such cases to Zero-Derivation (Lipka 1986, 1992).

Zero-Derivation

The theory that can capture the meaning relation between the noun and verb forms of categorically ambiguous words, like *brush* and *bite*, is called Zero-Derivation/Conversion theory (Don 2005; Lipka 1986, 1992). Under the Zero-Derivation theory, it has been argued that these words are either derived from a noun (*the base form*) to a verb (*the derived form*)(e.g., [$_N$ *brush*] -- > [$_V$ *brush*]) or from a verb to a noun (e.g., [$_V$ *bite*] -- > [$_N$ *bite*]). Don (2005) sees conversion as a grammatical process: "The analysis of conversion involves a base, which is lexically stored with its categorical information, and that this base can be used, either or not after some morphological zero-operation, in a different category" (p. 2).

Similarly to explicit derivation, where the derivation process is expressed morphologically by a suffix (e.g., ($_V$ [$_N$ *class*]-*ify*]), zero-derived words are implicitly derived, i.e., one form is the base, while the other one is derived from it by means of an invisible and unpronounced morpheme, a so-called zero-morpheme (ø). Following this convention the derived form is represented as: [$_V$ [$_N$ *brush*] -ø] or [$_N$ [$_V$ *bite*] -ø], where a zero-morpheme (ø) signals the category change. Likewise, the English past tense morpheme of *hit* is realized as a zero-morpheme, symbolized by ø, and the plural form *sheep* (so-called 'zero-plural' nouns) also is analyzed as carrying a zero-morpheme (Carstairs-McCarthy, 2002).

From linguistic and psychological perspectives, a set of rules based on the relationship between the base and derived forms can be used to categorize words as zero-derived or not. Zero-derivation (ZD) implies the following: (1) ZD words share the same stress pattern, (2) ZD words are syntactically analyzed in that such words permit further derivational processes, and (3) ZD words are semantically analyzed in some specific way. The three linguistic tests, as described below and in Table 1.2, demonstrate the way ZD words are syntactically and semantically analyzed.

Words related by ZD share the ***same stress pattern***. Myers (1984) claims that zero-derivation does not affect stress, thus, the derived word shares the stress pattern of the base word. For example, words like *brush* and *bite*, share the same stress pattern and, therefore, could be classified as ZD words. However, words like *record,* which have a regular stress pattern as a noun (with the emphasis on the first syllable), and as a verb (with the emphasis on the second syllable), are not in fact related by ZD.

Words related by ZD follow a ***specific syntactic distribution*** in that ZD cannot enable derivational suffixation (Myers's Generalization, 1984). According to Myers*:* "no derivational suffix may be added to a zero-derived word, crucially suffixes that subcategorize for a particular category[3]" (p. 68). The verb *bake* and the noun *bell* are always a verb and a noun, respectively, and can take verbal (bake-*ery*) and nominal (bell-*less*) suffixes, respectively. However, the verb *brush* and the noun *bite* do not capture the same generalization, in that category-specific suffixes

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[3] For example, nominal suffixes (*-al/ial/ual*$_A$, *-ary*$_A$, *-ous*$_A$, *-izy*$_V$, *-ify*$_V$, *-ess*$_N$) and verbal suffixes (*-ive*$_A$, *-ery*$_N$, *-al*$_N$, *-ant*$_N$, *-ate*$_N$, *-ion*$_N$, *-ance*$_N$, *-ation*$_N$). There are a few exceptions to Myers's Generalization: *–er*, *–able, -ful, -ment* (suffixes that are compatible with more than one category; Myers, S., 1984, page 68).

(verbal and nominal, respectively) cannot be attached to zero-derived verbs or nouns. Therefore, the base form representation must be something other than the verb and noun, respectively. Adopting Myers' generalization, let us take an example of the lexical item *brush*: brush can take a nominal suffix that turns a noun into a noun (e.g., brush-*ness*) or noun into an adjective (e.g., brush-*like,* brush-*y*). On the other hand, *brush* cannot take verbal suffixes that turn a verb to a noun (e.g*.,* *brush-*ery*) or that turn a verb into an adjective (e.g*.,* *brush-*ive*), respectively. This pattern suggests that *brush* is a noun-derived verb because it cannot take verbal suffixes, i.e., it is already derived and as a result, it cannot go through a further derivational morphological process. On the other hand, *bake* is a non-derived verb because it is not derived from any other category and it can take further derivational suffixes.

Words related by ZD follow a ***specific semantic distribution*** expressed by paraphrases (Clark & Clark 1979 and Marchand 1964 Tests). Marchand analyzed verb-derived nouns as nominalized sentences and classified them according to the syntactic-semantic relations underlying them. In Marchand's classification there are four main classes: predication*,* object, subject, and adverbial complement types. For example, the noun *bite* was classified as a predicate type verb-derived noun because it denotes an instance or occurrence of the action denoted by the base form verb (i.e., the bite = convert V into N, as in "*Mary took a bite of the cookie"*). While Marchand has demonstrated directionality of derivation in verb-derived nouns, Clark and Clark (1979) have shown the directionality of derivation in noun-derived verbs. Clark and Clark identified six classes of noun-derived verbs based on the semantic role of the base form noun in the verb paraphrase: locatum verb, location and duration verbs, agent and experiencer verbs, goal and source verbs, instrument verbs, and miscellaneous verbs. According to Clark and Clark, to be considered a noun-derived verb, the base form noun must denote one of these six roles in the state, event, or process expressed by that verb. For example, the verb *brush* is classified as a noun-derived instrument verb because it denotes an action where the base form noun of the verb denotes one role in this event (i.e., to brush = to act with N, as in "*Mary brushed her hair"*).

Table 1.2. Description of three linguistic tests used to categorize zero-derived words.

Ambiguous word	***Syntactic Root Suffixation Test*** *(Myers, 1969)*	***Semantic Paraphrase Test*** *(Clark & Clark 1979 and Marchand 1964)*
Brush	Cannot take a verbal suffix E.g., *brush-*ery* $_N$ (versus bake-*ery* $_N$)	Verb = to act with the Noun E.g., "to groom with a brush"
	Can take a nominal suffix Brush-*ness* $_N$, brush-*y* $_A$	Paraphrase: 1) Mary brushed her hair in the bathroom. 2) Mary caused it to come about that she was in the bathroom by doing the act one would normally expect [using N].
Bite	Cannot take a nominal suffix E.g., *bite-*less* $_A$ (versus bell-*less* $_A$)	Noun = the act of the Verb E.g., "took a bite of cookie"
	Can take a verbal suffix E.g., bite-*ive* $_N$, bite-*y* $_A$	Paraphrase: 1) Mary bit the cookie. 2) Mary took a bite of the cookie [an instance of V].

To our knowledge, there are no studies examining the processing costs of ZD, with the exception of one fMRI study by Pliatsikas et al., (2014). This study examined processing of zero-derived verbs in English using a lexical-decision task comparing one-step and two-step derived verbs. The one-step verbs are directly derived from their verb base-form ([*bouncing*] -- > [$_V$ bounce]), whereas the two-step derived verbs are derived via zero-derivation from their base-form noun ([*brushing*] --> [$_V$ brush] --> [$_N$ brush]).

The authors found increased brain activity within the left IFG for verbs like *brushing* compare to verbs like *bouncing*, and interpreted this finding as a "derivational depth" effect. The authors selected the derived verbs according to a 9-point scale questionnaire (9=only referring to an action), where participants judged one-step verbs more as an action than an object, therefore, implying they were base verbs. Two-step verbs were judged more as an object than an action indicating that these verbs were base nouns. However, this study's methodology does not allow for words that can be rated both as an object or an action. These words do not necessarily have derivational and semantic relationships, and therefore, they cannot be considered zero-derived (e.g., *bear*). Accordingly, it remains unclear if increased activity within the left IFG for verbs like *brushing* reflects the process of zero-derivation or grammatical category selection (the noun 'brush' and the verb 'brush') as suggested by semantic ambiguity literature. This is further addressed in Study 3 (see Chapter 4).

1.2. IMPAIRED LEXICAL PROCESSING: Noun and Verb impairments in Aphasia

Aphasia is an acquired language disorder resulting from damage to the brain, affecting one million people in the United States. One of the most prevalent symptoms of aphasia is the inability to produce words. This often aligns with word class, in that many individuals suffering stroke-induced aphasia have difficulty in producing either nouns or verbs (e.g., they show word-class production deficits). Although numerous studies on lexical retrieval of nouns and verbs in aphasia have been carried out, they are based primarily on naming objects (nouns) and actions (verbs). This section reviews behavioral and neural research on noun and verb processing in people with aphasia and addresses limitations of published research, particularly with regard to categorical ambiguity of the nouns and verbs studied. Also, the nature of word-class production deficits is not clearly understood. That is, there are many factors that may contribute to difficulties in processing the two word-classes.

1.2.1. Behavioral studies on nouns and verbs

Many individuals suffering stroke-induced aphasia have difficulty with lexical retrieval of either nouns (typically denoting objects) or verbs (typically denoting actions). The observed pattern is that individuals who have difficulty accessing nouns generally have no difficulty accessing verbs, and individuals who have difficulty accessing verbs typically do not have difficulty in accessing nouns. According to some studies, verb-specific deficits are associated with non-fluent, agrammatic aphasia, whereas noun-specific deficits are found in patients with fluent, anomic aphasia (Berndt et al., 1997; Kim & Thompson, 2000, 2004; McCarthy & Warrington, 1985; Miceli et al., 1984; Thompson et al., 2012; Zingeser & Berndt, 1990; but see Luzzatti et al., 2002 for some conflicting findings).

This selective deficit in processing of single word categories also includes noun-verb homonyms (e.g., *comb* and *crack*), and can be restricted to either spoken or written production (Caramazza and Hillis 1991, Hillis and Caramazza, 1995). Caramazza and Hillis (1991) found a deficit in verb processing in two patients (phonologically in one and orthographically in the other) for noun–verb homonyms when the context required a verb, but not when the noun was needed (e.g., There's a crack in the mirror; Don't crack the nuts in here). Although one patient (HW) was able to write both nouns and verbs, she was unable to translate this skill orally to verbs. In contrast, another patient (SJD) showed flawless oral and written production of nouns, but evinced difficulty writing verbs. Furthermore, Hillis and Caramazza (1995) reported on another patient EBA, who, when presented with speech tasks, was significantly more impaired in producing nouns compared to verbs, but his/her recognition of the written form of verbs was more impaired than nouns.

However, these studies on noun-verb homonyms did not consider the morphology of the noun and verb forms (e.g., [$_{N}$ *comb*] -- > [$_{V}$ *comb*], [$_{V}$ *crack*] -- > [$_{N}$ *crack*]). Therefore, it is still questionable if aphasic individuals with selective noun and verb deficits show equal retrieval impairments for the two forms of categorically ambiguous words. This is addressed in Study 2 (see Chapter 3).

1.2.2. Theoretical accounts

According to the interactive activation model (see 1.1.2 for more detailed description), word-class deficits found in the production of many individuals suffering stroke-induced aphasia may arise at various levels of lexical processing, as well as emerge from the functional interplay between fully interactive levels (orthography, morphology, semantics and phonology). Two hypotheses regarding the nature of word-class deficits have been proposed: the first interprets deficit as a *lexical representational deficit* and the second sees such deficit as a *syntactic* *grammatical category* deficit.

Under the lexical representation deficit hypothesis, some researchers propose an account in terms of complexity of morphology, given that verbs are generally morphologically more complex than nouns (Shapiro & Caramazza, 2003a, 2003b; Shapiro, Shelton & Caramazza, 2000). Others espouse a semantic interpretation since, generally, verbs refer to actions and nouns refer to objects (Vinson & Vigliocco, 2002; Vigliocco et al., 2004). For instance, Vinson and Vigliocco (2002) showed that dissociations between objects and actions arise as a consequence of damage to a lexico-semantic space or to specific perceptual/sensory features. Crucially, they found that the lexico-semantic representations of action nouns do not differ from the representations of their associated verbs. Another related semantic account is that the noun-verb dissociation results from an effect of imageability in that most nouns are usually highly imageable, most verbs are not (Bird, Howard & Franklin, 2000, 2001, 2002). Particularly, a unitary nonlexical semantic account by Bird, Howard and Franklin (2000) argues that verb (action) deficits actually arise from differences in imageability between verbs and nouns (objects). They demonstrated that for patients with a verb-selective deficit, imageability was shown to be a strong predictor of naming performance, hence, when this variable was controlled, no class effect remained. However, there is evidence that the noun-verb dissociation is not fully accounted for by imageability (Luzzatti et al., 2002).

Different performance patterns for nouns and verbs could also reflect a grammatical category deficit arising at the syntactic level (e.g., Caramazza & Hills, 1991; Hills & Caramazza, 1995; Luzzatti et al., 2002; Miceli et al., 1984, 1988; Saffran, Schwartz, & Marin, 1980; Saffran, 1982; Zingeser and Berndt, 1990). The greater syntactic complexity of verbs in terms of verb argument structure, for example, may affect the ability of agrammatic individuals to produce verbs. In one study by Collina, Marangolo and Tabossi (2001), three Italian agrammatic individuals with a selective verb-production deficit were given a picture-naming task that tested their ability to produce nouns and verbs of different argument structure complexity: non-argumental nouns (e.g., *medaglia-medal*), argumental nouns (e.g., *pianto-crying*), one-argument (e.g., *dormire-to sleep*) and two-argument verbs (e.g., *sparate-to shoot*). The results indicated that all three individuals made fewer errors with non-argumental nouns than with verbs. Importantly, these three agrammatic individuals also demonstrated low ability in producing argumental nouns and, for both nouns and verbs, an effect of argument structure complexity was found. That is, nouns with greater argument structure complexity were more difficult to produce than those with less complex representations. This finding is also in line with several studies on agrammatic patients, which found a hierarchy of difficulty in verb production based on argument structure, i.e., greater difficulty producing transitive as compared to intransitive verbs, and unaccusatives as compared to unergatives verbs (Kim and Thompson, 2000, 2004; Thompson et al., 1997; Thompson, C. K., 2003). These findings suggest that deficits in accessing verbs for production are influenced by verb argument structure (cf.*'Argument Structure Complexity Hypothesis (ASCH)',* Thompson, 2003).

1.2.3. Neuropsychological studies on nouns and verbs

The noun-verb dissociation findings in aphasic individuals' production suggests that distinct neural mechanisms may be involved in producing each word class. Damasio and Tranel (1993) formulated the fronto-temporal dichotomy hypothesis (FTDH), according to which temporal lobe lesions cause selective difficulties retrieving nouns as opposed to verbs in a picture -naming task, whereas frontal lobe lesions lead to deficits in retrieving verbs. However, findings not in line with the FTDH have been reported (Silveri & Di Betta, 1997; Silveri, Perri & Cappa, 2003; Crepaldi et al., 2011; Matzig, Druks, Masterson & Vigliocco, 2009 for reviews). Matzig et al. (2009) reviewed lesion studies published between 1984 and 2005 on selective noun or verb deficits in picture naming with a total of 280 aphasic participants studied. They showed that of the 36 aphasic individuals (with large noun-verb differences and available lesion site information) those with verb deficits showed damage to either the frontal or parietal lobes or basal ganglia, while those with noun deficits showed damage to the temporal lobe.

Now that advanced lesion-mapping methods are widely used, we can localize the lesions associated with noun and verb production deficits on a larger number of aphasic individuals. In one study, Piras and Marangolo (2007) examined lesions associated with verb and noun naming deficits in a group of 16 individuals with stroke-induced aphasia using voxel-lesion symptop mapping (VSLM). They found that verb naming deficits were associated with the IFG as well as the superior and polar temporal lesions, while noun naming deficits were associated with lesions located in the STG and MTG. In addition, Geva et al., (2012) also used VLSM to investigate lesion–symptom relationships in a cohort of 20 patients with chronic post-stroke aphasia and found that poorer performance on the object naming task was significantly associated with IFG and insula lesions, extending posteriorly into the STG and SMG. Recently, we also examined the relationship between lesions within the left hemisphere language network and aspects of language (verb) production ability in 34 individuals with LH stroke-induced aphasia (Lukic et al., submitted). Results showed that lesion volume within the IFG, STG, and insula predicted performance on verb naming; moreover lesions in the aforementioned regions affected production of transitive verbs more than intransitive verbs. These data are in line with the neurocognitive model of verb argument structure (VAS) comprehension and production proposed by Thompson and Meltzer-Asscher (2014). According to the VAS production model, the bilateral AG and SMG support retrieval of associated argument structure information. This information is used to generate initial phrase structure building processes for sentences in the left IFG, with sentence level syntactic and semantic integration engaging the left temporal regions (MTG and STG).

To summarize, lesion data on individuals with aphasia, similar to neuroimaging data on healthy individuals, yield inconsistent results when reporting areas associated with noun or verb deficit (see Crepaldi et al., 2011 for review). In order to better understand the neural correlates of noun and verb processing and how they relate to selective noun-verb deficit in aphasia, further behavioral and neural study on noun and verb processing is needed, particularly addressing the effects of syntactic, semantic and morphological factors. Clearly, each factor may have differentially effect noun and verb processing, with some factors playing a more important role than others. Moreover, the role of the morphological properties of nouns and verbs, such as zero-derivational morphology, has not been considered in previous studies in aphasia. The lack of such knowledge limits our understanding of noun- and verb-specific lexical impairments in aphasic individuals and the neurological mechanisms associated with recovery.

1.3. OUTLINE OF THE DISSERTATION: Study Aims and Research Questions

The research presented in this dissertation examines cognitive and neural distinctions between nouns and verbs by studying processing of categorically ambiguous words (*brush, bite, bear*). Three studies addressed how two forms of ambiguous words – a noun and a verb form – are cognitively and neurally represented and processed in healthy people. This thesis also tested how word-class deficits in aphasia impact closely related noun and verb forms.

Chapter 2 of this dissertation comprises two experiments that exploit linguistic theories of argument structure and morphology. The aim of Study 1, *The Role of Argument Structure and Zero-Derivation in Lexical Processing,* was to test the role of two factors – argument structure and zero-derivational morphology – in word-class processing using a grammaticality judgment task with categorically ambiguous nouns and verbs. The study addressed the question of whether the argument structure and morphological complexity of nouns and verbs incur differential processing costs in young cognitively healthy participants. We hypothesized that processing cost is associated with either argument structure or zero-derivation in both word classes, consistent with previous studies on argument structure and semantic complexity in verbs (e.g., Ahrens, 2003; Gennari and Poeppel 2003; Shapiro et al., 1987).

The research presented in Chapter 3 further examines the role of zero-derivation in healthy people and extends this work to include participants with aphasia. The aim of Study 2, *The role of Zero-Derivation in Normal and Impaired Lexical Processing,* was to examine healthy and aphasic (with and without verb deficit) participants' ability to process categorically unambiguous and ambiguous nouns and verbs, using a forced-choice response paradigm. The study addressed the question of whether healthy and aphasic participants show a noun-verb bias (base-form bias) for ambiguous words.

Adopting the Zero-Derivation theory (see section 1.1.4), we hypothesized that ambiguous words such as *brush* and *bite* are listed under a single entry, which is lexically stored as a base form (either a noun or a verb), and are subject to morphological processes. The word's derivational status creates ambiguity in *brush* and *bite*. A word like brush corresponds to not only the base form (the noun *the brush*), but also the derived form (the verb *to brush*, [$_{V}$ [$_{N}$ *brush*]-ø]). A word like bite, alternatively, corresponds to the verbal base form (the verb *to bite*) and the nominal derived form (the noun *the bite*, [$_{N}$ [$_{V}$ *bite*]-ø]).

Therefore, if *brush* and *bite* are stored as single entries that are nominal and verbal, respectively, then base-form bias effects would be expected. Specifically, in this case healthy participants would show greater selection rates of *the* for *brush* and *to* for *bite* in a forced-choice paradigm (see Figure 3.1). Moreover, if *brush* and *bite* are processed first in their base forms, the results for Study 2 will correspond with those for Study 1. Namely, increased judgment response time for derived nouns (*the bite*) and verbs (*to brush*) in Study 1 will correspond to higher selection rate of *to* and *the*, respectively in Study 2. In contrast, if ambiguous words entail separate lexical entries and no morphological process is involved, then no difference in selection rates of *to* and *the* for either *brush* or *bite* is expected.

With regard to aphasic participants, we hypothesized that aphasic participants without a verb production deficit would show a pattern similar to that of healthy participants, whereas aphasic participants with a verb deficit would show similar patterns to that of healthy participants for the nominal base forms (i.e., nouns). This is in line with previous findings on word-class deficits in aphasia using a picture-naming paradigm (see 1.2.1. section).

Chapter 4 presents a neuroimaging (fMRI) study focused on examining the neural-cognitive mechanisms of verbs (compared to nouns and letters) using a grammaticality judgment task. The goal of Study 3 was to identify brain regions associated with the computational and representational properties of three verb types: unambiguous verbs (e.g., to *bake*), noun-derived verbs (e.g., to *brush*), and non-derived verbs (e.g. to *bear*). The study specifically addressed the question of whether distinct neural mechanisms are engaged for zero-derivational morphology and lexical-selection during verb processing in cognitively healthy participants. The *overall working hypothesis* was that different brain areas support different cognitive sub-processes, i.e. lexical-selection versus morphological processes. In accordance with previous neuroimaging studies on semantic ambiguity (see section 1.1.3), greater activation within the frontal and temporal areas for noun-derived and non-derived verbs (*to brush, to bear*) compared to unambiguous verbs (*to bake*) was expected. Moreover, distinct frontal and temporal neural activation patterns, suggesting separate and single entry representations, were expected for *to bear* and *to brush,* respectively. In addition, nouns (*the bell*) were included in this fMRI study in order to further elucidate the neural mechanisms involved in noun and verb processing. According to previous neuroimaging studies (see section 1.2.3), frontal and temporal regions are expected to underlie verb and noun processing.

Chapter 5 summarizes the results from these studies and addresses their implications for models of word recognition. We also discuss how/if data derived from aphasic participants informs models of normal representation and processing of categorically ambiguous words. Lastly, we addressed implications for treatment of word-class impairments, as well as limitations and future directions.

Chapter 2

The Role of Argument Structure and Zero-Derivation in Lexical Processing

Abstract

The psycholinguistic literature demonstrates that verbs are categorically more complex and take more time to process than nouns. Yet, it remains unclear if and how argument structure and morphology affect the processing of nouns and verbs. To that end, two experiments were conducted to distinguish the effects of argument structure (experiment 1) and zero-derivational morphology (experiment 2) on noun and verb processing using a grammaticality judgment task with categorically ambiguous words. The relationship between the nouns and verbs studied was varied such that one set of items included *derived* nouns in which the noun was derived from the verb, with both the noun and verb forms having the same argument structure (the/to *bite*), and the second set of items included *derived* verbs with the verb derived from the noun, and only the verb form entailing argument structure (the/to *brush*). Results revealed two findings. First, a grammatical category effect was found, with slower response times to nouns than verbs. Second, there was a zero-derivational morphology effect, with the process of derivation (but not argument structure) influencing lexical processing. The derived forms were processed more slowly than the base forms. These findings suggest that grammatical category effects observed in the literature cannot be attributed solely to a word's status as belonging to one category or another or to the complexity of verbs. Rather, zero-derivational morphology influences processing of categorically ambiguous nouns and verbs, accounting for the overall category effect in the current study.

Introduction

One of the unresolved debates in the lexical processing literature is how different word classes are processed. Lexical representations of word classes (i.e., Nouns, Verbs) entail both semantic and syntactic information. Generally, studies have claimed that verbs are more difficult to process than nouns, but the bulk of this work has focused on a unified group of nouns and verbs describing objects and actions, respectively. Given that instances of nouns related to actions (*the bite*), and verbs related to objects (*to brush*) are common in the English language, the current study examined word-class processing using these variants of nouns and verbs to determine if a verb disadvantage (over noun) still remains. We specifically asked if word-class processing draws upon semantic-syntactic or morphological aspects of nouns and verbs.

Numerous psycholinguistic studies on healthy individuals have investigated how nouns and verbs are processed, providing evidence for the functional distinction that verbs are more difficult to process than nouns (e.g., Bogka et al., 2003; Druks et al., 2006; Monaghan et al. 2003; Sereno & Jongman, 1997; Sereno, 1999; Spenney & Haynes 1989). Several studies have involved lexical decision tasks, in which words that were used only as a noun (e.g., *bell*) or as a verb (e.g., *bake*) were compared. The studies have consistently found a verb disadvantage in that response time for verbs was significantly longer than that for nouns (e.g., Sereno, 1999; Sereno & Jongman, 1997). The authors attributed this effect to differences in inflectional structure between nouns and verbs in English in that nouns occur more frequently as uninflected forms. Similarly, Tyler et al. (2001) found a reliable effect of grammatical category in a lexical decision task (i.e., in their experiment 1) and in a semantic decision task (i.e., in their experiment 2), with verbs taking significantly longer than nouns.

This grammatical category effect has been replicated in studies across different languages, including French, Chinese, Hebrew, German and Serbo-Croation (Cordier et al., 2013; Deutsch et al., 1998; Frost, Forster & Deutsch 1997; Hsu et al., 1998; Kauschke & von-Frankenberg, 2008; Kostic & Katz, 1987). For example, Cordier et al., (2013) used a lexical decision task in French and attempted to differentiate between the effects of lexical (e.g., frequency, age of acquisition) or semantic (e.g., imagery, number of meanings) variables and the genuine effects of grammatical categories. They observed a verb over noun disadvantage, even after the addition of lexical and semantic factors. Based on findings such as these, the widely acknowledged position in the literature is that verbs are more difficult to process than nouns.

Support for this position is fostered by considering the syntactic and semantic differences between verbs and nouns. Action verbs typically select for a subject and an object and specify the thematic roles that the subject and object play in the event denoted by the verb (e.g., agent and theme). For example, verbs, such as *bake,* express an action-function, incorporating in their meaning two thematic roles: an agent that initiates the action and a theme that undergo the action (e.g., *Mary bakes the cake*); while nouns, such as *bell,* refer to concrete objects, and generally lack semantic relation (e.g., **Mary's bell of the door*). Numerous findings, from both psycholinguistic and neuroimaging studies, provide evidence that argument structure information is automatically accessed when verbs are encountered. Greater processing cost (increased response time) was reported for verbs requiring a direct object (*bake*) compared to verbs, which do not select for a direct object (*run*) (Ahrens, 2003; Gorrell, 1991; Shapiro et al., 1987). Moreover, data from neuroimaging studies that have manipulated argument structure complexity of verbs have consistently shown increased activity of neural tissue (mostly in posterior perisylvian regions) when processing verbs with more complex argument structure representation (den Ouden et al., 2009; Thompson et al., 2007; Thompson et al., 2010a; Thompson and Meltzer-Asscher, 2014). Importantly, these findings indicate that complex verb representation is associated with greater processing demands.

Most studies examining the processing of nouns and verb have included only nouns denoting concrete objects (*the bell*), with less attention given to event nouns, such as *the bite*, which, on some linguistic accounts, inherit the argument structure of their verb counterparts, such as *to bite*. For example, when *bite* is used as a noun, it denotes a similar meaning as when used as a verb, based on its argument structure properties. Most crucially, both the verb *bite* and the noun *bite* can potentially be used in a context that includes both a subject, namely *Mary,* and an object namely *the cookie,* as in (1). In both of the examples, *Mary* is unambiguously interpreted as *the agent* and *the cookie* is unambiguously interpreted as *the theme*. In other words, both in the verbal-use and the nominal-use, *bite* assigns the same thematic roles to the subject and the object.

(1) Mary bit the cookie (*bite* used as the verb form)

Mary's bite of the cookie (*bite* used as the noun form)

Subsequently, the word *bite*, when used as a noun, differs from other nouns (e.g. *brush*), with regard to its morphological representation. Such event nouns are assumed to be derived from their verb counterparts through the process of Conversion/Zero-Derivation (Don 2005; Lipka 1986). As a result, derived nouns are analyzed as the combination of the base form and an invisible and unpronounced zero-morpheme (e.g., $[_N [_V$ *bite*$]$ -ø]). In turn, the derived noun denotes an instance or occurrence of the action denoted by the base form verb (i.e., the act of Verb, as in *"Mary bit the cookie = Mary took a bite of the cookie*"). Conversely, in its verb form, the word *brush* is much like *bite*, but in its noun form is much like *bell* (*Mary's *bell* of the door) as in (2).

(2) Mary brushed her hair (*brush* used as the verb form)

*Mary's brush of her hair (*brush* used as the noun form)

However, the word *brush*, when used as a verb, differs from other verbs (e.g. *bite*), in that the verb *brush* is derived from the noun form, and as a result, denotes an event where the base form noun denotes one role in this event (i.e., to act with Noun, as in "*Mary brushed her hair = Mary acted on her hair with a brush"*).

Despite the extensive literature on noun and verb processing, to our knowledge there is no study directly comparing nouns and verbs, controlled for the argument structure. Moreover, the role of the morphological complexity of nouns and verbs, such as zero-derivation, has not been considered in previous studies. The purpose of this study was to examine the processing of nouns and verbs using categorically ambiguous noun/verb minimal pairs (the/to *brush, bite*), controlled for relevant semantic-syntactic and morphological properties. Crucially, this study intended to determine the source of differential processing patterns — i.e., whether semantic-syntactic (argument structure) and/or morphological (zero-derivation) complexity contribute to differential processing of nouns versus verbs. Based on previous findings, we hypothesized that complexity in terms of argument structure and/or morphology could affect the processing of the two word classes. Namely, either more complex argument structure or more complex morphology would be associated with increased processing cost.

To address this question, participants performed a Grammaticality Judgment Task (GJT) on noun/verb minimal pairs. These pairs were controlled for both their argument structure (experiment 1), and morphological properties (experiment 2), in addition to form aspects including word length and frequency. Therefore, half of the experimental items consisted of lexical forms such as *bite*, in which the noun form is generally derived from the verb and, hence the noun and verb form entail the same semantic-thematic relations (see 1 above). The other half consisted of lexical forms such as *brush*, in which the verb form is generally derived from the noun and only the verb form engenders semantic-thematic detail (see 2 above). Unlike other tasks, which have focused on lexical or semantic judgments, GJT specifically directed attention to the grammatical properties of target items, namely their status as a noun or a verb, by presenting them with (a) the determiner *the* (to denote the noun form), or (b) the infinitive marker *to* (to denote the verb form).

2.1. Experiment 1

Method

Participants

Participants included 35 native English-speaking individuals (25 females; age range = 18–29 years, *M*=21). The following inclusionary criteria were applied: normal or near normal corrected vision, adequate hearing sensitivity and literacy level, and no history of psychiatric, neurological, speech, or language disorders. Participants were recruited from the Northwestern University student body and staff, as well as from residents within the greater Chicago area. All participants provided written informed consent approved by the Northwestern University Institutional Review Board.

Design

In experiment 1, we examined whether the Argument Structure (AS) properties of lexical entries contribute to differential processing of nouns versus verbs. If argument structure complexity is associated with processing cost and, therefore, influences differences in processing between nouns and verbs (i.e., semantic-thematic representations guide word processing), increased response times were expected for words like *brush,* when used in their verb form compared to when used in their noun form. This is because thematic information is represented only in the verb form (i.e., transitive, agent-theme verb) whereas, in the noun form, there is no associated thematic detail. A word like *brush*, when processed as a noun, is a concrete object that generally lacks thematic relation (see 2 above). Conversely, no difference in response times were expected for words such as *bite* when processed as a verb compared to when processed as a noun because thematic information is entailed in both forms.

To examine the effects of AS, participants performed a GJT on sets of visually presented noun/verb pairs in which (a) both the noun and verb form in the pair entailed argument structure information (e.g., *bite*, transitive, agent-theme for both the noun and verb form) (AS Match condition as in (1)), and (b) the verb, but not the noun, entailed argument structure information (e.g., *brush,* transitive, agent-theme verb form) (AS Mismatch condition as in (2)).

(1) AS Match: a. the bite b. to bite

(2) AS Mismatch: a. the brush b. to brush

Stimuli

Thirty-four noun/verb pairs were selected, each paired with *the* and *to*, creating a total of 68 experimental stimuli. This final set of stimuli was selected following administration of three pre-test ranking tasks in which a group of healthy native English speakers (*N*=45) evaluated the semantic and argument structure properties of words as well as acceptability of each noun/verb pair using a 7-point Likert scale.

To evaluate the semantic properties of nouns and verbs, fifteen participants (8 females, M=25 years of age) were presented with noun and verb pairs (e.g., *a fight/to fight*) and were instructed to rate the degree of semantic similarity between the meaning of the noun and the verb form using a 7-point scale (1 = low similarity, 7 = high similarity). Two practice items were given in order to instruct participants to distinguish meanings between similar and dissimilar pairs. For each of these two practice items participants were given a short scenario to read and then they were presented with two sentences. The target item was used as a noun in one sentence and as a verb in the other. For example, the first practice item *fight* (for which the verb and noun forms have similar meanings) was tested by presenting the following scenario: "*John watched the hockey game.*" Then two sentences were presented: one with the target word used as a noun *("One of the players started a fight during the game")* and one with the target word used as a verb *("One of the players started to fight with his opponent")*. Similarly, to test the second practice item *phone* (for which the verb and noun forms have dissimilar meanings), the scenario *"John needs to discuss an urgent matter"* preceded the presentation of sentences with the target word used as either as a noun *("John gave a phone to Mary')* or as a verb *("John needs to phone Mary"*). Used as a noun phrase, the word *phone* is interpreted as a physical object, whereas when entered into a verb phrase it is interpreted as an action, i.e., making a phone call.

In addition, in order to obtain the acceptability of noun/verb word pairs, the target words were presented in minimal phrasal contexts (i.e., *a fight* and *to fight*) without a sentence, and mean rankings were calculated for each noun and verb pair. We asked fifteen healthy participants (10 females, M=26 years of age) to rate nouns and verbs preceded by syntactic context (*a/to fight*) on a 1-7 scale (1 = low acceptability, 7 = high acceptability).

Based on the results of the two tests, high-acceptability noun and verb pairs were divided into two groups – those with similar (mean ratings > 4.0) and those with dissimilar meaning (mean ratings < 4.0). Accordingly, noun/verb pairs with highest rated semantic similarity, and lowest rated noun/verb pairs were selected for eligibility in the experiment.

With regard to the argument structure properties of nouns and verbs, verb argument structure was tested based on criteria for classification of verbs in Thompson et al. (2007). The noun argument structure was tested using an online argument structure acceptability judgment pre-test as follows: a paraphrase test was designed by developing an expanded noun phrase for each item. For instance, the noun *bite* uses the arguments specified by the verb form (*Mary bit the* cookie) and expends into a noun phrase (*Mary's bite of the cookie*). Fifteen participants (5 males and 10 females, M= 28 years of age) were asked to rate on a 7-point Likert scale (1 = low, 7 = high) the acceptability of each expanded noun phrase (e.g., *Mary's bite of the cookie*, **Mary's brush of her hair*), listed one after another. The mean ranking was calculated for each noun phrase. Based on the results, the nouns were divided into two groups – those with (mean ratings > 4.0) and without argument structure (mean ratings < 4.0). Accordingly, nouns with highest rated and the lowest rated AS properties were selected for eligibility in the experiment.

Among the final set of thirty-four noun/verb pairs, half were composed of forms in which the noun and verb (*N*=17) had similar meaning (M=5.45, SD=0.7) and the same argument structure information (M=6.19, SD=0.65) forming the *Match Condition* (the *bite* and to *bite*). In contrast, the other half of the pairs were composed of forms in which the noun and verb (*N*=17) differed in both meaning (M=3.01, SD=0.7) and argument structure information (M=2.54, SD=0.83) forming the *Mismatch Condition* (the *brush* and to b*rush*). Furthermore, to ensure that a difference between these two groups of stimuli (Match and Mismatch) existed, a non-parametric Mann-Whitney Test was conducted on mean ratings acquired from both the semantic and argument structure pre-tests. The observed Mann-Whitney Test for the Semantic pre-test was Z = -4.982, $p < .000$ and for the Argument Structure pre-test was Z = -4.981, $p < .000$.

Items in the two argument structure conditions (Match, Mismatch) were controlled for the Corpus of Contemporary American English (COCA, Davies, 2008) based frequency and noun/verb acceptability (p's > .05, Welch Two Sample t-tests). However, length was significantly lower (p = .004), while the imageability was significantly higher (p < .000) for the match condition as compared to the mismatch condition. Also, imageability was significantly higher for mismatch nouns versus match nouns (p = .001). Across and within each of the two argument structure conditions, there was no difference between nouns and verbs in COCA-based frequency, orthographic length or imageability (all p's > .05). However, the two categories differed in noun/verb acceptability, with nouns showing significantly lower acceptability than verbs (p = .001), and this difference was only significant within the match condition (p < .000) (see Table 2.1).

Table 2.1. Descriptive data and statistical results for lexical variables across conditions (standard deviations in parentheses) for Experiment 1.

	Length	***Frequency***	***Imageability***	***N/V Acceptability***
Match AS				
nouns	5.88 (0.86)	4.11 (0.49)	3.86 (1.37)	6.44 (0.46)
verbs	5.88 (0.86)	3.92 (0.51)	4.37 (1.23)	6.95 (0.11)
statistics	t = 0, p = 1	t = 1.17, p = .248	t = -1.14, p = .261	***t* = -4.40, *p* = .000**
Mismatch AS				
nouns	5.23 (0.97)	3.91 (0.47)	5.53 (1.29)	6.64 (0.61)
verbs	5.23 (0.97)	3.72 (0.48)	5.11 (1.08)	6.83 (0.34)
statistics	t = 0, p = 1	t = 1.21, p = .236	t = 1.02, p = .315	t = -1.07, p = .292
all nouns vs. verbs	t = 0, p = 1	t = 1.67, p = .099	t = - 0.14, p = .889	***t* = - 3.35, *p* = .002**
match vs. mismatch	***t* = 2.96, *p* = .004**	t = 1.69, p = .247	***t* = - 3.97, *p* = .000**	t = -0.31, p = .755

In addition to the 68 experimental stimuli, another 68 words (unambiguous nouns and verbs (34 each), paired with *to* and *the*, respectively) were selected as fillers. The 68 fillers were selected as follows: 34 unambiguous nouns, from categories of animals (N=7), clothing (N=6), fruits & vegetables (N=5), objects (N=6) and abstract nouns (N=10), and 34 unambiguous verbs. Fillers were selected only if the noun-verb ratio was less than or equal to 0.35 when used as a verb and 7.0 or more when used as a noun. Appendix 2.1 displays a complete list of stimuli.

Procedure

Participants performed a GJT in which they were presented with each word pair and then asked to judge its acceptability: (1) the noun and verb presented as *the brush* and *to brush* (acceptable experimental conditions), and (2) the noun and verb presented as **to bell* and **the bake* (unacceptable filler condition). In each trial, a fixation cross was presented at the center of the computer screen for 1.7 seconds. Then the target or the filler word pair was displayed visually. The trial ended with the participant's button press response ("Y" and "N" keys), indicating whether or not they found the word pair to be grammatically acceptable (see Figure 2.1). Participants were told to respond as quickly and accurately as possible. Detailed instructions and sixteen practice trials with feedback were administered prior to the actual experiment in order for participants to become familiar with the task. The stimuli were counterbalanced across participants. The experiments were presented using E-Prime software (Bates, Maechler, & Bolker, 2012) on a Lenovo desktop computer running Windows XP Professional with an Intel Core 2Quad CPU processor.

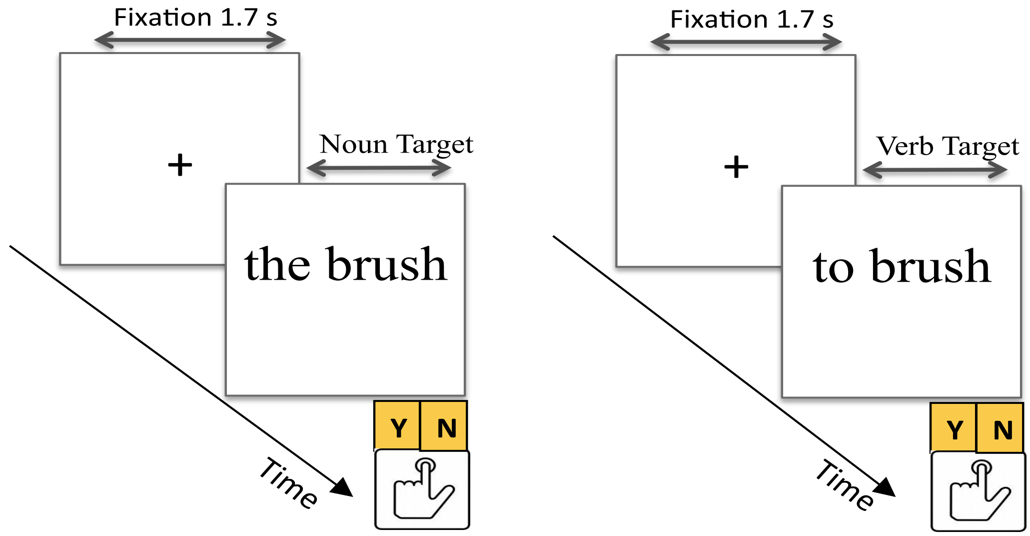

Figure 2.1. Schematic of noun (left) and verb (right) targets in the grammaticality judgment task**.**

Data Analysis

Accuracy (% correct responses) and Response time (RT) were recorded on each trial of the GJT, with RT measured from the onset of the trial to the participant's response. Mean accuracy and RT were calculated for each item and each condition. RTs for incorrect trials were excluded from the analysis. To eliminate outliers from the RT data, the mean and standard deviation of RTs were calculated for each condition of the task, and any RTs above or below three standard deviations of the mean in each condition were excluded from further analysis. The RTs were further log transformed, so as to reduce skewness in the distribution. RTs were analyzed using a Linear Mixed Effect Regression analysis (Baayen et al., 2008), in order to evaluate the effect of the variables of interest, i.e. *Grammatical Category* (Nouns vs. Verbs) and *Argument Structure* (Match vs. Mismatch). Subjects and items were encoded as random factors.

Results

Accuracy and Response Time data

Accuracy and RT means and standard deviations for each condition are summarized in Table 2.2. Figure 2.2 illustrates accuracy and RT across conditions for young healthy participants. Data from 4 participants were excluded based on either overall low accuracy (2 participants; accuracy < 90%), or abnormal RT distribution (2 participants; 3 x mean group SD). Three items were deleted prior to the analysis because of average low accuracy (<84%) across participants for one of the constructions (e.g. *to tackle* or *the tackle, to store* or *the store, to trace* or *the trace*). This resulted in the exclusion of 7% of the data points, 1.9% of which were incorrect responses and 2.1% of which were outliers.

Participants performed overall very well on both nouns (0.97% correct) and verbs (0.99% correct). Accuracy was equally good when the nouns matched the verbs on the AS and when the nouns and verbs did not match on the AS (0.98% and 0.97%, respectively). RTs obtained on correct trials were longer for nouns (927 ± 292 ms) as compared to verbs (875 ± 270 ms) and for the mismatch condition (918 ± 293 ms) as compared to the match condition (884 ± 270 ms). Also, RTs were longer for verbs in the mismatch condition (907 ± 284 ms) compared to the match condition (845 ± 254 ms), however, this was not the case for nouns between the two conditions (match: 924 ± 281 ms, mismatch: 930 ± 302 ms) (see Table 2.2).

Table 2.2. Mean response time (ms) and accuracy (% correct responses) across conditions for Experiment 1.

	Grammatical Category (GC)			
	Nouns M (SD)		***Verbs M (SD)***	
Argument Structure (AS)	*RT (ms)*	*% Correct*	*RT (ms)*	*% Correct*
Match	924 (281.3)	0.98 (0.04)	845 (254.1)	1.00 (0.02)
Mismatch	930 (302.8)	0.97 (0.04)	907 (284.6)	0.98 (0.03)

Linear mixed effect regression analysis results

Linear mixed effect regression analysis indicated a significant main effect of *Grammatical Category* (t = -5.79, p < .001), with responses to nouns taking significantly longer than responses to verbs. In addition, a significant interaction effect between *Grammatical Category* (Nouns vs. Verbs) and *Argument Structure* (Match vs. Mismatch) was found (t = 3.02, p = .002), whereas the main effect of *Argument Structure* was not significant (t = -0.08, p = .933). Post-hoc analyses showed that the interaction effect between *Grammatical Category* and *Argument Structure* was due to significantly longer response times to nouns compared to verbs in the match condition (t = -5.87, p < .001), but response times to nouns and verbs in the mismatch condition did not differ significantly (t = -1.33, p = .185). Also, there were significantly longer response times to verbs in the mismatch condition compared to verbs in the match condition (t = 2.64, p = .008). However there was no difference in response times between nouns in the two conditions (t = -0.05, p = .959).

To assess whether both the effect of grammatical category and the interaction effect between grammatical category and argument structure could be accounted for by lexical factors, in the follow-up analyses we added length, frequency, imageability and noun/verb acceptability into the model for grammatical category, argument structure, and their interaction as predictors. The results revealed that frequency was the only significant lexical factor and it accounted for a significant part of the variance (frequency: t = -2.05, p = .045; length: t = 0.815, p = .422; imageabity: t = -0.513, p = .609, and acceptability: t = -0.060, p = .952). In addition, effect sizes of RT mean differences for *Grammatical Category* (Nouns vs. Verbs) and *Argument Structure* (Match vs. Mismatch) were computed with Cohen's d. The effect size (Cohen's d) for the grammatical category difference was 0.18 and for the argument structure difference was -0.12, which are considered small effects by Cohen's (1988) standard. Table 2.3 provides the linear regression model summary based on response time results for the healthy participants.

Table 2.3. Results of linear mixed model analysis of response time for the healthy participants for Experiment 1. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***df***	***t-value***	***Pr(>|t|)***
Intercept	6.952	0.08	57.6	85.55	< .001
Grammatical Category	-0.1	0.02	1728.4	-6.12	**< .001****
Argument Structure	-0.012	0.02	54.7	-0.52	0.604
Frequency	-0.037	0.01	50.5	-2.05	**0.045***
Grammatical Category x Argument Structure	0.071	0.02	1793	3.11	**0.002****

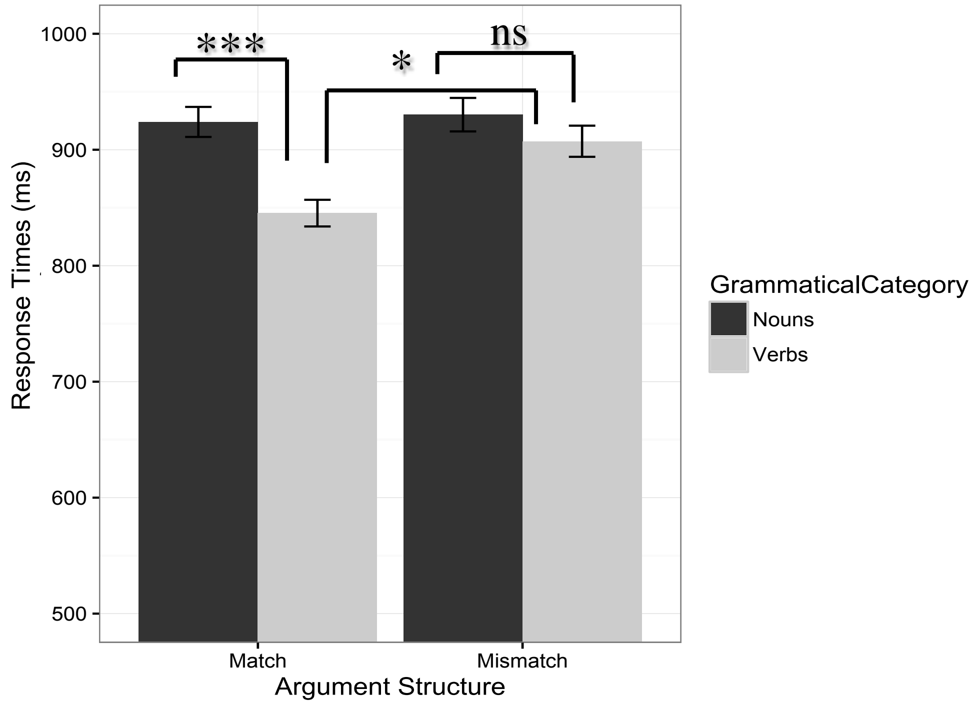

Figure 2.2. Mean response times across the four conditions for the healthy participants in Experiment 1 (*** $p < .001$, * $p < .05$). Bars indicate the standard error of the mean.

Discussion

The results of Experiment 1 revealed longer reaction times to nouns compared to verbs, indicating that, when words are controlled for their argument structure properties, nouns are more difficult to process than verbs. In the Match condition, where nouns and verbs shared argument structure properties, nouns (*the bite*) were processed more slowly than verbs (*to bite*). This finding stands in contrast to those of previous studies, suggesting that verbs are more difficult to process than nouns. However, verbs in the Mismatch condition (*to brush*) were processed more slowly than those in the Match condition (*to bite*), whereas the reaction time for nouns between the two conditions showed no difference.

We suggest that a possible explanation for these results is that words like *brush* and *bite* differ in their morphological representation (which was not controlled in Experiment 1). For example, the noun form of *bite* is zero-derived from its verb form, which might result in greater processing demands for nouns like *bite* compared to verbs like *bite*. In contrast, the verb form of *brush* is zero-derived from its noun form. Thus, the morphological properties of categorically ambiguous nouns and verbs may have contributed to the response time patterns observed in the current study, accounting for the overall category effect. Experiment 2 was designed to examine whether morphological properties affect processing time of nouns and verbs. Using a GJT, we compared response times to nouns and verbs in their base and derived forms, to test whether the derivational status of a word is reflected in processing speed.

2.2. Experiment 2

Method

Participants

Participants included 32 native English-speaking individuals (17 females; age range = 18–30 years, *M*=22), with the same inclusionary criteria as in Experiment 1. All participants provided written informed consent and the experiment was approved by the Northwestern University Institutional Review Board.

Design

In Experiment 2, we examined whether Zero-Derivation (ZD) properties of lexical entries contribute to differential processing of nouns versus verbs. If morphological complexity is associated with processing cost and, therefore, influences differences in processing between nouns and verbs (i.e., processes of derivation guide word processing), increased response times were expected for derived forms like *the bite* and *to brush* compared to base forms like *the brush* and *to bite.* To examine the effects of ZD, participants performed a GJT on sets of auditorily presented noun/verb pairs including (a) base words such as nouns (e.g., *the brush*) and verbs (e.g., *to bite*) (Base condition as in (1)), and (b) derived words such as verbs (e.g., *to brush*) and nouns (e.g., *the bite*) (Derived condition as in (2)).

(1) Base: a. the brush b. to bite

(2) Derived: a. the bite b. to brush

Stimuli and procedure

Forty noun/verb pairs were selected, each paired with *the* and *to*, creating a total of 80 experimental stimuli. Half of the pairs were composed of forms derived from either a noun or from a verb (derived noun and verb: *the bite* and *to brush*; N=20), forming the *Derived Condition.* In contrast, the other half were composed of pairs that do not undergo a derivational process (base noun and verb: *the brush* and *to bite*; N=20), forming the *Base Condition*. Stimuli were classified as derived or base using three linguistic tests (Myers's Root Suffixation test 1984, Clark and Clark's classification 1979, and Marchand's analysis 1969), which elucidate specific syntactic-semantic relations between the noun and verb forms. According to Myers's Root Suffixation test (1984), additional suffixes cannot be added to a zero-derived word. For instance, brush can take a nominal suffix that turns a noun to an adjective (e.g., brush-*less*), but cannot take a verbal suffix that turns a verb to a noun (e.g., *brush-*ery*) or verb to an adjective (e.g., *brush-*ive*). According to Myers (1984), this pattern suggests that *brush* is a noun-derived verb. Additionally, Clark and Clark's 1979 test classified *brush* as a noun-derived instrument verb because it denotes an action where the base form noun of the verb denotes one role in this event (i.e., to brush = to act with N, as in “*Mary brushed her hair = Mary acted on her hair with a brush”*).

Items in the two zero-derivational morphology conditions (Base, Derived) were matched for orthographic length, COCA-based frequency, and noun/verb acceptability (*p*’s > .05, Welch Two Sample t-tests). However, imageability was significantly higher for the base condition as compared to the derived condition (*p* = .012). Also, imageability was significantly higher for base nouns versus derived nouns (*p* < .000), and for derived verbs versus base verbs (*p* = .003). Across the two zero-derivational morphology conditions, there was no difference between nouns and verbs in orthographic length, COCA-based frequency, imagebaility or noun/verb acceptability (all *p*’s > .05). However, verbs were significantly less imageable than nouns in the base condition (*p* = .005), and verbs were significantly more imageable (*p* = .003) but less frequent (*p* = .005) than nouns in the derived condition. See Table 2.4.

Table 2.4. Descriptive data and statistical results for lexical variables across conditions (standard deviations in parentheses) for Experiment 2.

	Length	***Frequency***	***Imageability***	***N/V Acceptability***
Base				
nouns	4.90 (0.85)	3.82 (0.50)	6.00 (0.91)	6.83 (0.23)
verbs	5.45 (1.14)	3.87 (0.43)	4.34 (1.44)	6.83 (0.18)
statistics	*t* = -1.72, *p* = .094	*t* = -0.28, *p* = .782	***t* = 4.34, *p* = .000**	*t* = 0.00, *p* = 1
Derived				
nouns	5.45 (1.14)	4.04 (0.35)	3.63 (1.47)	6.83 (0.22)
verbs	4.90 (0.85)	3.61 (0.54)	5.01 (1.21)	6.87 (0.14)
statistics	*t* = 0.09, *p* = .094	***t* = 3.03, *p* = .005**	***t* = -3.22, *p* = .003**	*t* = -0.76, *p* = .454
all nouns vs. verbs	*t* = 0.00, *p* = 1	*t* = 1.87, *p* = .065	*t* = 0.41, *p* = .686	*t* = -0.51, *p* = .609
base vs. derived	*t* = 0.00, *p* = 1	*t* = 0.23, *p* = *.821*	***t* = 2.57, *p* = .012**	*t* = -0.39, *p* = .691

In addition to the 80 experimental stimuli, another 80 words (unambiguous nouns and verbs (40 each), paired with *to* and *the*, respectively) were selected as fillers. Appendix 2.2 displays a complete list of stimuli. The procedure in Experiment 2 was identical to that in Experiment 1 with the exception that the target or the filler word pair was presented aurally instead of visually (see Figure 2.1).

Results

Accuracy and Response Time data

Accuracy and RT means and standard deviations for each condition are summarized in Table 2.5. Figure 2.3 illustrates accuracy and RT across conditions for young healthy participants. One item (*the recruit*) was deleted prior to the analysis because of average low accuracy (<85%) across participants. Additional data points were excluded based on abnormal RT distribution (3 x mean group SD). This resulted in the exclusion of 5% of the data points, 3.2% of which were incorrect responses and 2.9% of which were outliers.

Participants performed overall very well on both nouns (0.97% correct) and verbs (0.99% correct). Accuracy was equally good for both the base and derived conditions (0.97% and 0.98%, respectively). RTs obtained on correct trials were longer for nouns (1308 ± 329 ms) as compared to verbs (1281 ± 305 ms) and for the derived condition (1315 ± 335 ms) as compared to the base condition (1273 ± 297 ms). Also, RTs were longer for verbs in the derived condition (1303 ± 324 ms) compared to the base condition (1260 ± 285 ms), and for nouns in the derived condition (1327 ± 346 ms) compared to the base condition (1287 ± 309 ms) (see Table 2.5).

Table 2.5. Mean response time (ms) and accuracy (% correct responses) across conditions for Experiment 2.

	Grammatical Category (GC)			
	Nouns M (SD)		***Verbs M (SD)***	
Zero-Derivation (ZD)	*RT (ms)*	*% Correct*	*RT (ms)*	*% Correct*
Base	1287 (309.48)	0.97 (0.16)	1260 (285.60)	0.99 (0.07)
Derived	1327 (346.32)	0.96 (0.17)	1303 (323.91)	0.98 (0.12)

Linear mixed effect regression analysis results

Linear mixed effect regression analysis indicated a significant main effect of *Zero-Derivation* (Base vs. Derived), with responses to derived forms taking significantly longer than responses to base forms (t = 2.68, p = .007). Follow-up analysis revealed that responses to nouns took significantly longer in the derived condition compared to the base condition (t = -2.104, p = .035), and for the verbs in the two conditions (t = -2.478, p = .013). There was no main effect of *Grammatical Category* (t = -1.79, p = .075), or *Grammatical Category* x *Zero-Derivation* interaction (t = 1.43, p = .153). The results further revealed that length and acceptability were the only significant lexical factors that affected performance and they accounted for a significant part of the variance (length: t = -3.03, p = .003; acceptability: t = -2.15, p = .032). In addition, using Cohen's d statistic, the effect size (Cohen's d) for the *Grammatical Category* (Nouns vs. Verbs) difference was 0.08 and for the *Zero-Derivation* (Base vs. Derived) was -0.13, which are considered small effects. Table 2.6 provides the linear regression model summary based on response time results for the healthy participants.

Table 2.6. Results of linear mixed model analysis of response time for the healthy participants for Experiment 2. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***df***	***t-value***	***Pr(>|t|)***
Intercept	7.06	0.033	149.82	215.83	0.000***
Grammatical Category	-0.016	0.009	273.23	-1.79	0.075
Zero-Derivation	0.024	0.009	305.35	2.68	**0.007 ** **
Length	0.016	0.005	141.22	3.03	**0.003** **
Acceptability	-0.055	0.026	274.33	-2.15	**0.032 * **
Grammatical Category x Zero-Derivation	0.028	0.020	233.55	1.43	0.153

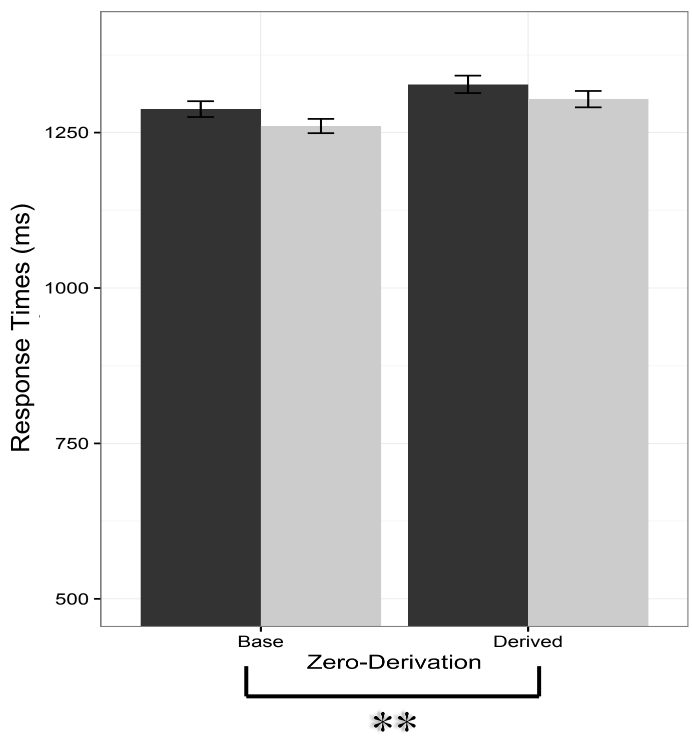

Figure 2.3. Mean response times across the four conditions for the healthy participants in Experiment 2 (** $p < .01$). Bars indicate the standard error of the mean.

Discussion

The results of Experiment 2 revealed that zero-derivational morphology influenced the processing speed of nouns and verbs in healthy young participants. Participants processed nouns and verbs in their derived forms (*the bite* and *to brush*) more slowly than in their base forms (*the brush* and *to bite*). These findings suggest that the morphological properties of words affect lexical processing both within and across grammatical categories, possibly due to the cost of zero-derivation.

General Discussion

This study examined the degree to which argument structure and zero-derivational morphology contribute to differential processing of nouns and verbs. The results of this study suggest that lexical processing is not only sensitive to a word's category (noun/verb) and argument structure, as has been suggested previously. Rather, we found that the morphological properties of words contribute significantly to lexical processing.

Previous psycholinguistic studies on healthy individuals, investigating noun and verb processing have demonstrated a grammatical category effect. For example, Tyler et al. (2001) found a reliable category effect in both lexical decision and semantic decision tasks, with response times for nouns being faster than response times for verbs. Similarly, Coldier et al., (2013) and Kauschke and Stenneken (2008) observed a category effect in favor of nouns in a lexical-decision task in French and German, respectively. These studies suggest that verbs with complex argument structure entries are more difficult to process (thereby taking longer) than nouns. However, most studies examining noun versus verb processing have compared action verbs with concrete nouns, excluding other types of nouns and verbs, and they have not controlled for argument structure. Hence, the present study used word-class ambiguous minimal pairs, varying in argument structure complexity, to examine grammatical-class differential processing.

In Experiment 1, we examined noun and verb processing by controlling for the argument structure properties of selected items, and found a *Grammatical Category effect*, with participants taking longer to respond to nouns than verbs. Indeed, this was an unexpected finding given that previous studies repeatedly demonstrated a disadvantage of verb over noun processing in terms of response times. Furthermore, results of experiment 1 revealed a significant interaction effect between *Grammatical Category* (Nouns vs. Verbs) *and Argument Structure conditions* (Match vs. Mismatch). For the Match condition, responses to nouns were longer than to verbs, but response times to nouns and verbs in the Mismatch condition did not differ significantly. Also, participants took longer to respond to verbs in the Mismatch condition than to verbs in the Match condition. Lexical factors in the regression analysis did not interact with the independent factors of *Grammatical Category* or *Argument Structure,* suggesting that these factors do not affect the word processing.

In contrast to previous studies, these data reveal that verbs are not necessarily more difficult (longer) to process than nouns. Differences between the results of the present study and previous ones are perhaps due to the fact that nouns are not a uniform category. That is, nouns can denote events as well as objects. Indeed, previous studies have primarily studied the latter, however, both types of nouns have often been intermixed in noun stimulus sets tested (e.g., Bogka et al., 2003; Tyler et al., 2001). The present study specifically controlled for the types of nouns studied. First, we included nouns that denote actions (*the bite*), which semantically overlap with their verb counterpart (*to bite*) and, hence, have the same argument structure. Furthermore, we included nouns that denote objects (*the brush*), which, conversely, are semantically distinct from verbs (*to brush*) and therefore have a different argument structure.

If, as the previous studies suggest, greater argument structure complexity of verbs is the crucial factor affecting verb processing, then we expected that nouns and verbs that have the same argument structure should be processed similarly. The results, however, did not support this hypothesis: in the Match condition where nouns and verbs shared argument structure properties, we found faster response times for verbs than for nouns. Contrary to the evidence from numerous studies on verb processing, where complex verb representation is associated with greater processing demands (see section 1.1.2), in this experiment higher argument structure complexity of verbs (compared to nouns) was not associated with greater processing difficulties. The results of Experiment 2 suggest that factors beyond argument structure may affect the processing of nouns and verb, namely, the morphological properties of words within these broad grammatical classes.

Experiment 2 focused on processing of categorically ambiguous nouns and verbs, which were selected based on their derivational morphological properties. In the 2 x 2 design employed, we manipulated *Grammatical Category* (Nouns vs. Verbs) and *Zero-Derivational morphology* (Base vs. Derived). Results revealed a significant *effect of derivational morphology*, with participants responding longer to derived forms compared to base forms, regardless of their status as a noun or a verb. Moreover, the effect persisted even after including word frequency, length and imageability as covariates.

This finding suggests that when derived lexical items are processed, the morphological complexity of nouns like *bite* and verbs like *brush* induces extra processing cost. In our experiments, morphological complexity emerged as the only significant explanatory factor associated with differential processing of nouns and verbs. Similarly, once the semantic and syntactic properties of nouns and verbs were taken into account, such as in the noun and verb form of *bite,* the morphological factor remained the only possible explanation for differential processing.

In conclusion, the results of the present experiments show that verbs are not necessarily more difficult to process. Rather the morphological properties of words within the two grammatical classes affect processing of nouns and verbs, suggesting that zero-derivational morphology can be costly. While previous studies have not directly manipulated morphological and argument structure factors, we attempted to differentiate the contribution of grammatical category, argument structure and morphological complexity to noun and verb processing. Given that we used word-class ambiguous minimal pairs, our findings suggest that the grammatical category effect cannot be entirely attributed either to word form or semantic-syntactic properties of lexical items. Derivational morphology clearly influenced processing of categorically ambiguous words. Theoretically, our results are compatible with approaches suggesting that the complexity of words is reflected in their processing time. With increasingly complex word representation, concerning either the complexity of argument structure (e.g., Shapiro et al., 1987), semantics (e.g., Gennari and Poeppel, 2003) or morphology, more widespread activation is needed, and therefore more processing time is required. This study offers insight into the nature of basic grammatical categories (noun and verb), and also addresses the contribution of argument structure and morphological variables, such as the complexity of particular words within each grammatical category. Moreover, examining multiple variants of nouns and verbs compliments the results established in previous studies of category processing.

Chapter 3

The Role of Zero-Derivation in Normal and Impaired Lexical Processing

Abstract

Word-class deficits are common in individuals with stroke-induced aphasia, who often show difficulty in accessing either nouns or verbs. Many words are categorically ambiguous, having both verb and noun forms (*brush, bite*), and this has received little attention in studies of normal or impaired lexical processing. If these words are lexically stored in their base form (either a noun or a verb), then a base-form bias is expected. The present study tested the base-form bias effects in ambiguous (*brush, bite*) and unambiguous (*bell, bake*) nouns and verbs in healthy young and old individuals (*N*=60) and aphasic individuals with and without verb deficits (*N*=12). Using a binary forced-choice response paradigm, participants were required to indicate whether the determiner *the* or the infinitive marker *to* was compatible with target nouns and verbs. Healthy and aphasic individuals without verb deficits showed base-form effects, a noun bias (selection of *the*) for nouns, and a verb bias (selection of *to*) for verbs, though the effects were greater for unambiguous compared to ambiguous words. Also, a processing cost (longer response time) was found for verbs (over nouns) and for ambiguous (over unambiguous) words. Verb-impaired aphasic individuals showed the same patterns as the healthy and aphasic participant without verb deficits. However, the verb-impaired aphasic individuals showed a base-form effect only for nouns, with chance performance for verbs. These findings suggest that ambiguous words share a single base-form entry, and that impaired access to the base-form (i.e., verbs) precludes associated morphological processes and therefore the retrieval of derived forms (i.e., nouns).

Introduction

Distributed models of word recognition (e.g., Gaskell & Marslen-Wilson, 1997; Seidenberg & McClelland, 1989) suggest that recognizing a word involves a spreading activation of distributed representations of lexical knowledge (e.g., phonology, morphology, semantics, syntax). Within this type of framework, psycholinguistic studies on normal lexical processing have shown that more time is required to process verbs than nouns (Cordier et al., 2013; Deutsch et al., 1998; Frost, Forster & Deutsch 1997; Hsu et al., 1998; Kauschke & von-Frankenberg, 2008; Kostic & Katz, 1987; Sereno, 1999; Tyler et al., 2001). Aphasia, an acquired language disorder, is characterized by stroke-induced lexical impairments. Individuals with stroke-induced lexical impairment often show difficulty in accessing either nouns or verbs (e.g., Cappa & Perani, 2003; Thompson et al., 2012; Zingeser & Berndt, 1990).

Nouns are generally understood as object-denoting elements whereas verbs are understood as event-denoting elements. Hence, most studies of word class deficits in aphasia have examined processing of object nouns and event verbs. Importantly, though, there is a large class of categorically ambiguous words that includes verbs that carry an object meaning[4], as well as nouns that can denote events[5]. Subsequently, these words are either derived from a noun (*the base form*) to become a verb (*the derived form*) (e.g., [$_{N}$ *brush*] -- > [$_{V}$ *brush*]) or from a verb to become a noun (e.g., [$_{V}$ *bite*] -- > [$_{N}$ *bite*]) as suggested in the Zero-Derivation theory (Don 2005; Lipka 1986). Under this theory, it is assumed that when a word is used in the derived form it involves the access of both the derived form and base form. On the other hand, when the word is used in the base form only the base form is accessed with the word.

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[4] a. Mary brushed her hair.
b. Mary fixed her hair using a brush.
[5] a. Mary took a bite of the cookie.
b. Mary bit the cookie.

The present study used a binary forced-choice response paradigm to examine healthy and aphasic individuals' (with and without verb deficit) ability to process these categorically ambiguous words. The study focused on whether healthy individuals show a base-form bias for ambiguous nouns and verbs and if individuals with aphasia demonstrate similar biases, regardless of their specific word-class deficits.

In recent decades, many psycholinguistic studies on healthy individuals have shown verb over noun disadvantage effects, with response times for verbs significantly longer than those for nouns, evident across tasks and languages (Cordier et al., 2013; Deutsch et al., 1998; Frost, Forster & Deutsch, 1997; Hsu et al., 1998; Kauschke & von-Frankenberg, 2008; Kostic & Katz, 1987; Monaghan et al., 2003; Sereno & Jongman, 1997; Sereno, 1999; Spenney & Haynes, 1989). It also has been reported that the verb disadvantage persisted even after controlling for lexical (e.g., number of letters, syllables, homographs) and semantic (e.g., imagery, number of meanings) factors (Cordier et al., 2013). This effect has been attributed to differences in lexical structure between nouns and verbs, such as semantic and syntactic representations.

Studies also have shown that greater argument structure complexity of verbs is associated with processing cost (increased response time and/or greater neuronal activity) for verbs requiring a direct object (*bake*) compared to verbs which do not select for a direct object (*run*) (Ahrens, 2003; Gorrell, 1991; Shapiro et al., 1987; Thompson et al., 2007; Thompson et al., 2010a; Thompson and Meltzer-Asscher, 2014). These findings indicated that argument structure information is included with the lexical representation of verbs and it is associated with greater processing resources. We also examined the role of two factors—argument structure and zero-derivational morphology—in lexical processing using ambiguous noun and verb minimal pairs (e.g., *the brush/to brush*) (see Chapter 2). The results showed that morphological complexity (but not argument structure) influenced the speed of lexical retrieval of categorically ambiguous words in healthy young participants. Nouns and verbs in their derived forms (*to brush* and *the bite*) were retrieved more slowly than those in the base forms (*the brush* and *to bite*). These findings suggest that the morphological properties of words affect lexical processing both within and across word classes, possibly due to the cost of zero-derivation.

Within the aphasia literature, several studies show that individuals with non-fluent agrammatic aphasia evince verb production-specific deficit, whereas those with fluent anomic aphasia show noun production-specific deficit (Berndt et al., 1997; Kim & Thompson, 2000, 2004; McCarthy & Warrington, 1985; Miceli et al., 1984; Thompson et al., 2012; Zingeser & Berndt, 1990). Several interpretations of the nature of such deficits have been put forward, mainly focusing on grammatical, morphological, and semantic aspects of nouns and verbs. According to the *syntactic grammatical category specific account*, different performance patterns for nouns and verbs reflect a grammatical class effect arising at the syntax level (e.g. Caramazza & Hills, 1991; Hills & Caramazza, 1995; Luzzatti et al., 2002; Miceli & Caramazza, 1988; Miceli et al., 1988). For example, verb production deficits in agrammatic aphasia often are considered as part of a larger symptom-complex, affecting grammatical aspects of language, i.e., verbs are central to grammatical sentence processing, hence, verb deficits are part of a larger constellation of grammatical impairments.

Studies reporting differential performance based on the argument structure of verbs support the grammatical category account, with a hierarchy of difficulty based on argument complexity. Transitive verbs (two- and three-argument verbs like *bake* and *send*) are more difficult to process than simple unergatives intransitive verbs (one-argument verbs like *run*) in aphasic individuals (Bastiaanse and Jonkers, 1998; Kim and Thompson, 2000; Luzzatti et al., 2002; Shapiro & Levine, 1990; Shapiro et al., 1993; Thompson et al., 1997; Thompson, 2003). Argument structure properties also appear to affect the production of nouns; for example nouns that take arguments, like *destruction*, are more difficult to produce than non-argumental nouns, like *medal* (Collina, Marangolo and Tabossi, 2001). Importantly, however, not all patients show this pattern (see Luzzatti et al., 2002), perhaps because grammatical class, per se, is not the source of the impairment; rather, some other variable(s) may contribute. Accordingly, some researchers propose accounts in terms of the complexity of grammatical morphology, given that verbs are generally morphologically more complex than nouns (Shapiro & Caramazza, 2003a, 2003b; Shapiro, Shelton & Caramazza, 2000), and others espouse a semantic interpretation since, generally, verbs refer to actions and nouns refer to objects (Vinson & Vigliocco, 2002; Vigliocco et al., 2004).

Despite the extensive literature on noun and verb processing in both normal and impaired lexical processing, a paucity of studies have taken into account the fact that many nouns and verbs in the English language are categorically ambiguous in that they can have both a noun forms and a verb forms. Two competing accounts about how these forms are stored and accessed within the lexicon have been proposed, the first being a *single-entry account* wherein the noun and verb forms of ambiguous words (e.g., *brush* and *bite*) are listed as single lexical entry. On this account ambiguous words are stored in their base form, on which morphological operation may be performed to develop a derived form (Zero-derivational/Conversion theory, Don 2005). The second storage account, a *separate-entry account,* argues that the noun and verb forms of ambiguous words (e.g., *brush* and *bite*) are listed as separate lexical entries (as a whole form) in the mental lexicon and such forms do not undergo additional derivational processes.

The present study tested for base-form bias effects in ambiguous (*brush, bite*) and unambiguous nouns and verbs (*bell, bake*) in individuals with and without aphasia using a forced-choice response paradigm**.** Within this paradigm, participants were required to indicate (via forced choice) whether the determiner *the* or the infinitive marker *to* is compatible with target nouns and verbs. This paradigm was selected in order to test aphasic individuals' ability to covertly produce nouns and verbs, which differentiates this from other studies that mainly used a picture-naming task (PNT) and require overt production of nouns and verbs. Moreover, the dichotomous nature of the binary forced-choice task enables the observation of clear base-form biases if they exist.

Adopting the aforementioned Zero-derivation theory, we hypothesized that the noun and verb forms such as *brush* and *bite* are listed under a single lexical entry, with one being derived upon the other. Because '*brush'* and '*bite*' are stored in their base form as a noun and as a verb, respectively, greater selection rates are expected of *the* in *brush* and *to* in *bite*, as an index of the base-form bias effect. In contrast, if these words entail separate lexical entries and no morphological process is involved, then no difference in selection rates of *the* and *to* in *brush* and *bite* is expected. Additionally, longer response times for ambiguous words (*brush, bite*) compared to unambiguous words (*bell, bake*) are expected. Results of our recent study (see Chapter 2) showing increased response times for derived forms, such as *to brush* and *the bite* (over base forms, such as *the brush* and *to bite*), support this idea (also see Chapter 1, section 1.3 on the ambiguity disadvantage).

Furthermore, the study considered whether individuals with aphasia would show similar performance patterns to that of healthy individuals regardless of their specific word-class deficits. We postulated that aphasic individuals without verb production deficits would show a pattern similar to that of healthy individuals, whereas aphasic individuals with verb deficits would only show similar patterns to that of healthy individuals for the nominal base forms (i.e., unambiguous and ambiguous nouns).

Methods

Participants

Participants included 12 aphasic individuals, 6 with and 6 without verb deficit (5 females; age range = 43-72 years, *M*=57.67) and 60 healthy individuals (30 young: 21 females, age range = 18-32 years, *M*=22.86, and 30 older: 17 females; age range = 37-75 years, *M*=58.53). All participants were monolingual English speakers with normal or corrected-to normal vision and hearing, and provided written informed consent, approved by the Institutional Review Board of Northwestern University. Healthy participants had no history of speech-language, learning or neurological disorders, or psychiatric disturbances (self-reported).

Aphasic participants were at least six months post-onset of stroke (6-294 months post, *M*=74.42, *SD*=81.77). Six (out of 12) aphasic participants showed a verb production deficit as indicated by low scores (less than 85% accuracy) on verb-naming tests of the *Northwestern Assessment of Verbs and Sentences* (NAVS; Thompson, 2011), *Northwestern Naming Battery* (NNB; Thompson & Weintraub, 2014), and *An Object and Action Naming Battery* (OANB; Druks & Masterson, 2000). Additionally, a verb deficit was confirmed by noun-verb ratios obtained from administration of the NNB (> 1.10). In addition, aphasic participants exhibited symptoms consistent with agrammatism, as indicated by low fluency scores on the *Western Aphasia Battery-Revised* (WAB-R; Kertesz, 2007), greater impairment of non-canonical as compared to canonical sentence structures on the NAVS and greater impairment of verbs as compared to nouns on the noun and verb naming tests of the NNB and OANB. In contrast, the other six aphasic participants showed no verb production impairment as illustrated by high performance (greater than 85% accuracy) on verb-naming tests. Language testing results for aphasic participants are reported in Table 3.1.

Table 3.1. Aphasic participants' language testing data. N/A= not available.

Language Measures	Aph1	Aph2	Aph3	Aph4	Aph5	Aph6	All (w/ verb deficit)	Aph1	Aph2	Aph3	Aph4	Aph5	Aph6	All (w/o verb deficit)
Western Aphasia Battery-Revised														
Aphasia Quotient	53.5	48.0	85.0	72.6	63.8	54.0	**62.8**	80.4	75.0	89.8	93.7	79.6	89.0	**84.6**
Fluency	4	4	6	4	2	2	**4**	9	5	8	9	5	9	**8**
Information Content	6	7	10	7	8	6	**7**	6	9	9	9	9	9	**9**
Auditory Comprehension	7.8	6.7	7.8	7.6	7.8	7.1	**7.5**	8.6	9.0	10	9.9	10	9.9	**9.6**
Repetation	3.4	2	7.2	9	6.2	5.4	**5.5**	9	5.6	8.8	9.8	6.8	7.4	**7.9**
Naming	5.5	4.3	8.5	8.7	7.9	6.3	**6.9**	7.6	8.9	9.1	9.2	9.0	9.2	**8.8**
Action and Object Naming Test														
Objects	48%	46%	90%	86%	66%	28%	**61%**	N/A	94%	100%	100%	100%	N/A	**99%**
Actions	**30%**	**38%**	**78%**	**72%**	**60%**	**34%**	**52%**	N/A	90%	94%	100%	98%	N/A	**96%**
Northwestern Naming Battery														
Nouns	50%	56%	100%	100%	75%	69%	**75%**	88%	100%	100%	100%	94%	100%	**97%**
Verbs	**31%**	**38%**	**75%**	**75%**	**62%**	**31%**	**52%**	94%	100%	94%	100%	100%	100%	**98%**
Noun: Verb ratio	1.6	1.5	1.3	1.3	1.2	2.2	**1.44**	0.9	1.0	1.1	1.0	0.9	1.0	**0.99**
Northwestern Assessment of Verbs and Sentences														
Verb Naming	**23%**	**41%**	**72%**	**82%**	**45%**	N/A	**53%**	86%	95%	86%	100%	95%	100%	**94%**
Intransitive (1-arg verbs)	40%	40%	80%	80%	60%	N/A	**60%**	100%	100%	80%	100%	100%	100%	**97%**
Transitive (2 and 3-arg verbs)	17%	41%	29%	87%	41%	N/A	**43%**	82%	94%	88%	100%	94%	100%	**93%**
Verb Comprehension	100%	95%	100%	95%	100%	N/A	**98%**	95%	100%	100%	100%	100%	100%	**99%**
Argument Structure Production (all arguments)	N/A	65%	78%	50%	75%	N/A	**67%**	100%	91%	100%	100%	100%	97%	**98%**
Intransitive (1-arg verbs)	N/A	80%	100%	80%	100%	N/A	**90%**	100%	100%	100%	100%	100%	100%	**100%**
Transitive (2 and 3-arg verbs)	N/A	63%	74%	44%	70%	N/A	**63%**	100%	88%	100%	100%	100%	96%	**97%**
Sentence Production Priming Test	17%	33%	40%	23%	60%	N/A	**35%**	23%	50%	97%	100%	60%	57%	**65%**
Canonical	33%	66%	67%	26%	60%	N/A	**50%**	33%	86%	100%	100%	87%	80%	**81%**
Noncanonical	0%	0%	13%	20%	60%	N/A	**19%**	20%	13%	93%	100%	33%	33%	**49%**
Sentence Comprehension Test	70%	13%	60%	67%	57%	N/A	**53%**	60%	87%	73%	100%	87%	76%	**81%**
Canonical	80%	13%	80%	60%	60%	N/A	**59%**	66%	93%	87%	100%	100%	87%	**89%**
Noncanonical	60%	13%	40%	73%	53%	N/A	**48%**	53%	80%	60%	100%	73%	67%	**72%**

Design

In this study, Grammatical Category (Noun versus Verb) and Ambiguity (Unambiguous versus Ambiguous) were manipulated as independent factors. The study consisted of four experimental conditions: (a) unambiguous nouns (e.g., *bell*) and verbs (e.g., *bake*) (as in (1)), and (b) ambiguous nouns (e.g., *brush*) and verbs (e.g., *bite*) (as in (2)).

(1) Unambiguous nouns and verbs: a. __ bell (the/to) b. __ bake (the/to)

(2) Ambiguous nouns and verbs: a. __ brush (the/to) b. __ bite (the/to)

Stimuli

The stimuli consisted of 40 unambiguous and 40 ambiguous nouns and verbs, creating a total of 80 experimental stimuli. Unambiguous stimuli were selected only if the word was used solely as a noun (e.g., *bell*) or as a verb (e.g., *bake*). Ambiguous stimuli (e.g., *brush, bite*) were selected only if the noun and verb forms had: (a) identical orthographic and phonologic form (i.e., all are homographs, homophones, respectively), (b) near-equal frequency of usage (range: 0.85-1.25) as a noun and as a verb (the Corpus of Contemporary American English (COCA), Davies, 2008) and (c) specific semantic and syntactic properties characterizing zero-derived forms (Myers's Root Suffixation test 1984, Clark and Clark's classification 1979, and Marchand's analysis 1969).

Whether the ambiguous word was a base or a derived form, it was tested using the Root Suffixation test (Myers, 1984). Myers claims that no derivational suffixes (crucially suffixes that are subcategorized for a particular category) may be added to a zero-derived word. For example, *brush* cannot take a verbal suffix that turns a verb to a noun (e.g., *brush-*ery*) or a verb to an adjective (e.g., *brush-*ive*), but it can take a nominal suffix that turns a noun to an adjective (e.g., brush-*less*). Thus, *brush* was classified as a derived verb: because it is already derived, it cannot take verbal suffixes. Moreover, from a semantic perspective, *brush* was classified as a derived instrument verb because it denotes an action that crucially involves a tool like *brush* (i.e., verb = to act with N, as in "*Mary acted on her hair with a brush"*; Clark and Clark's classification, 1979). Conversely, *bite* was classified as a derived predicate noun because it denotes an instance or occurrence of the action verb (i.e., noun = the act of V, as in "*Mary took a bite of the cookie*"; Marchand's analysis 1969). See section 1.1.4. In addition to the 80 experimental stimuli, another 80 words, 40 adjectives and 40 adverbs paired with either *too/so* or *very/from*, were selected as fillers. Appendix 3.1 and 3.2 display a complete list of stimuli.

Items in the two ambiguity conditions (unambiguous, ambiguous) were matched in orthographic length or COCA-based frequency ($p > .05$, Welch Two Sample t-tests). Also within each of the two ambiguity conditions, there was no difference between nouns or verbs in COCA-based frequency, orthographic length or imageability (all *p*'s > .05). There was also no difference between nouns and verbs in COCA-based frequency, however, the two categories were significantly different in length ($p = .002$). Length was significantly lower in nouns as compared to verbs. Also, while nouns and verbs were matched for orthographic length and COCA-based frequency within the ambiguous condition, nouns were significantly lower in length compared to verbs within the unambiguous condition (see Table 3.2).

Table 3.2. Descriptive data and statistical results for lexical variables across conditions (standard deviations in parentheses).

	Length	***Frequency***
Unambiguous		
nouns	5.10 (1.07)	3.66 (0.57)
verbs	6.10 (1.07)	3.91 (0.47)
statistics	***t* = -2.95, *p* = .005**	*t* = -1.48, *p* = .147
Ambiguous		
nouns	4.90 (0.85)	3.83 (0.50)
verbs	5.45 (1.14)	3.87 (0.43)
statistics	*t* = -1.72, *p* = .094	*t* = -0.28, *p* = .782
all nouns vs. verbs	***t* = -3.28, *p* = .002**	*t* = -1.30, *p* = .197
unambiguous vs. ambiguous	*t* = -1.72, *p* = .089	*t* = 0.55, *p* = .583

Procedure

Participants performed a binary forced-choice response task in which they were presented with unambiguous or ambiguous target words and then asked to fill in the blank preceding each target word, with one of two word forms: a determiner *the* or infinitive marker *to*. In each trial, a fixation cross was displayed at the center of the computer screen for 1.7 seconds. Then the target or the filler word was presented, along with two words on the lower left and right bottom of the screen (e.g., *the* and *to*, *too* and *so*, or *very* and *from*). The trial ended with the participant's button press response ("L" and "R" keys), indicating which of the two words they selected (see Figure 3.1). The location of two words (e.g., *the* and *to)* was counterbalanced. Detailed instructions and twelve practice trials with feedback were administered prior to the actual experiment for participants to become familiar with the task. The stimulus list was generated randomly for each participant by the program, so that the same words were administered in a different random order at each test time. The experiment was presented using E-Prime software (Bates, Maechler, & Bolker, 2012) on a Lenovo desktop computer running Windows XP Professional with an Intel Core 2Quad CPU processor.

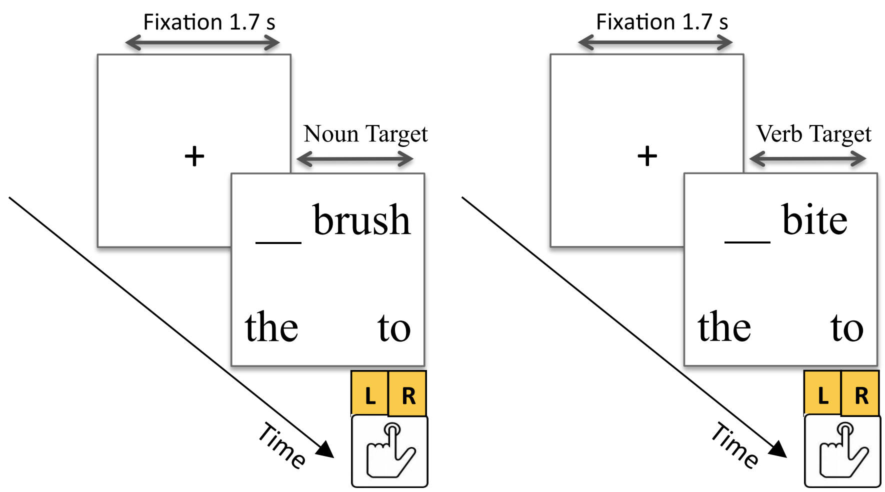

Figure 3.1. Schematic of noun (left) and verb (right) targets in the forced-choice response task.

Data Analysis

Selection Rate (SR) and Response Time (RT) were recorded on each trial of the task, with RT measured from the onset of the trial to the subject's response. Mean SR and RT were calculated for each item and each condition. To eliminate outliers from the RT data, the mean and standard deviation of RTs were calculated for each condition of the task, and any RTs above or below three standard deviations of the mean were excluded from further analysis. The RTs were log transformed, so as to reduce skewness in the distribution.

Since the SR was binary (1=base-compatible response or 0=base-incompatible response), a standard ANOVA was avoided; instead a Logistic Mixed Effect Regression analysis was selected using the glmer function from the language R statistical package in R (Baayen, 2011). The analyses were conducted using mixed effect logistic regressions (for SRs) as well as linear regressions (for RTs) with fixed effects for *Grammatical Category* (Nouns vs. Verbs) and *Ambiguity* (Unambiguous vs. Ambiguous), and the maximal appropriate random effect structure (i.e., random by-participant intercepts and random by-item intercepts). The dependent variable was either SR (i.e. proportion of compatible responses: selection of *the* for *bell* and *brush*, and selection of *to* for *bake* and *bite*) for logistic regression or RT (milliseconds) for linear regression. Additionally, the one-sample proportions test was used to further analyze selection rate by determining if the selection of *the* or *to* was significantly different from the selection determined by chance (± 50 %).

Results

Results from young and old healthy participants

Selection Rate and Reaction Time Data

SR and RT means and standard deviations for each condition are summarized in Table 3.3. Figure 3.2 illustrates SR and RT across conditions for healthy participants. Data from 6 young and 3 older participants were excluded based either on low average SR in the unambiguous condition (< 85%), or on an abnormal RT distribution (3 x mean group SD). One item (*play*) was deleted prior to the analysis because of average low SR (<15%) across participants. This resulted in the exclusion of 2.26 % of the data points for healthy participants. Both young and older participants results were combined, as the results were the same when analyzed individually.

Table 3.3. Mean and standard deviation of selection rate (SR) and response time (RT) across conditions for the healthy participants.

		Grammatical Category (GC)			
		Nouns M (SD)		***Verbs M (SD)***	
Group	***Ambiguity***	***SR***	***RT***	***SR***	***RT***
Young Adults	*Unambiguous*	0.97 (0.16)	1042 (394.92)	0.97 (0.16)	1104 (483.42)
	Ambiguous	0.56 (0.49)	1154 (463.68)	0.67 (0.47)	1140 (482.83)
Old Adults	*Unambiguous*	0.99(0.08)	1835 (879.96)	0.98 (0.13)	2034 (990.03)
	Ambiguous	0.62 (0.48)	2453 (1522.50)	0.63 (0.48)	2354 (1304.51)
Total Adults	*Unambiguous*	0.98 (0.12)	1438 (788.55)	0.97 (0.14)	1569 (907.31)
	Ambiguous	0.59 (0.49)	1810 (1303.36)	0.65 (0.47)	1743 (1153.50)

Logistic mixed effect regression analysis indicated a significant main effect of *Ambiguity* (Unambiguous vs. Ambiguous), with SR being significantly higher in the unambiguous condition compared to the ambiguous condition (t = 15.15, p < .000). There was no main effect of *Grammatical Category* (t = 0.079, p = .937) or *Grammatical Category* x *Ambiguity* interaction (t = -1.322, p = .186). Further, the one-sample proportions T-test used to test SR against chance performance revealed that SR was significantly above chance for both noun (unambiguous: χ^2 (1) = 1092.3, p < .000; ambiguous: χ^2 (1) = 35.439, p < .000) and verb conditions (unambiguous: χ^2 (1) = 1071.9, p < .000; ambiguous: χ^2 (1) = 101.38, p < .000). In addition, effect sizes of SR mean differences for *Grammatical Category* (Nouns vs. Verbs) and *Ambiguity* (Unambiguous vs. Ambiguous) were computed with Cohen's d. The effect size (Cohen's d) for the grammatical category difference was -0.08, which is considered a small effect. On the other hand, the effect size for the ambiguity was 1.16, and this value represents a large effect by Cohen's (1988) standard. Table 3.4 provides the logistic regression model summary based on SR results for the healthy participants.

Table 3.4. Results of logistic mixed model analysis of selection rate for the healthy participants. Significance is indicated by asterisks: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’

Predictor	***Estimate***	***SE***	***z-value***	***Pr(>|z|)***
Intercept	2.361	0.122	19.391	0.000 ***
Grammatical Category	0.019	0.235	0.079	0.937
Ambiguity	3.621	0.239	15.147	**0.000** ***
Frequency	-0.620	0.469	-1.322	0.186
Grammatical Category x Ambiguity	-0.568	0.464	-1.224	0.221

Linear mixed effect regression analysis revealed a significant main effect of *Grammatical Category* (Nouns vs. Verbs), with responses to verbs being significantly longer than responses to nouns (t = 2.057, p = .043). There was also a significant effect of *Ambiguity* (Unambiguous vs. Ambiguous), with significantly longer responses to ambiguous words compared to unambiguous words (t = -9.477, p < .000). Finally, the interaction effect between *Grammatical Category* and *Ambiguity* was found (t = -3.619, p < .000). Responses to nouns were significantly longer in the ambiguous condition compared to the unambiguous condition (t = 7.707, p < .000), and for verbs in the two conditions (t = 3.259, p = .001). However, the difference was greater for the noun condition. Interestingly, there was significantly longer response time to verbs compared to nouns but only in the unambiguous condition (unambiguous: t = -3.669, p < .000; ambiguous: t = 0.972, p = .331).

To assess whether the effects could be accounted for by variations of lexical factors, in the follow-up analyses length and frequency was added to the regression models for *Grammatical Category, Ambiguity,* and their interaction as predictors. Results revealed that all effects persisted and length and frequency were not significant and did not account for a significant part of the variance (length: z = -1.217, p = .223 for SR and t = 0.569, p = .571 for RT; frequency: z = 0.227, p = .820 for SR and t = -1.418, p = .159 for RT). Using Cohen's d statistic, the effect size (Cohen's d) for the grammatical category difference was -0.03 and for the ambiguity was -0.26, which are considered small effects. Table 3.5 provides the linear regression model summary based on RT results for the healthy participants.

Table 3.5. Results of linear mixed model analysis of response time for the healthy participants. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***df***	***t-value***	***Pr(>|t|)***
Intercept	7.256	0.054	60.89	133.72	0.000***
Grammatical Category	0.027	0.013	79.36	2.06	**0.043***
Ambiguity	-0.123	0.013	79.40	-9.48	**0.000*****
Frequency	0.094	0.026	79.36	3.62	**0.000*****
Grammatical Category x Ambiguity	0.097	0.027	78.15	3.63	**0.000*****

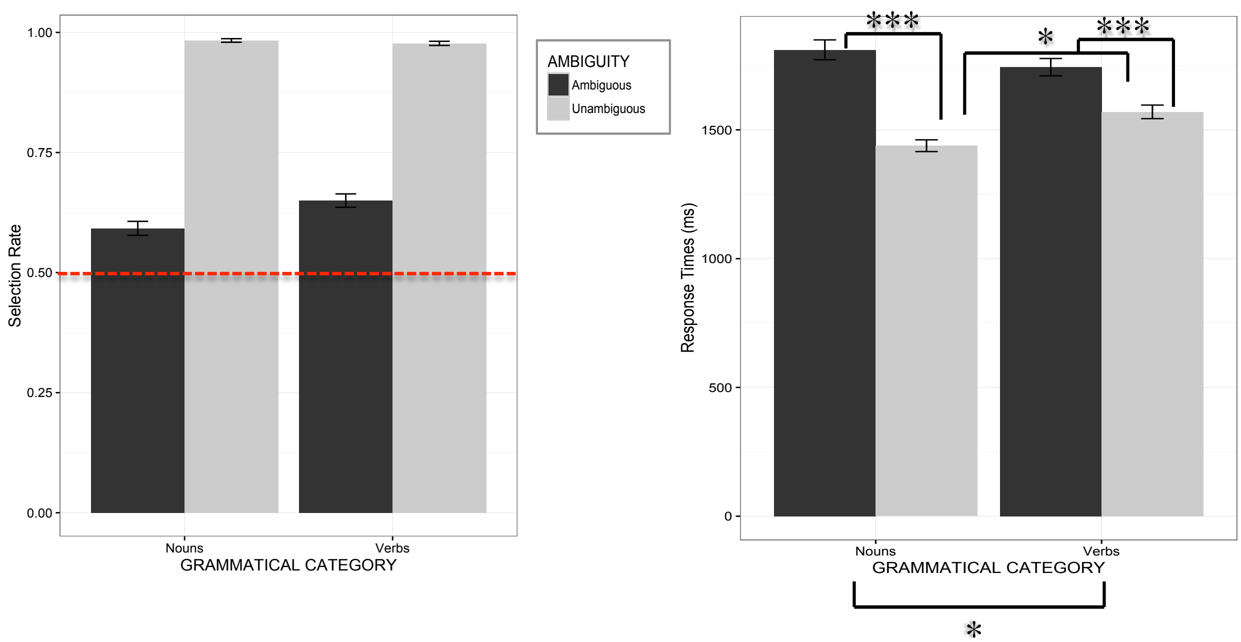

Figure 3.2. Mean selection rates (left) and response times (right) across the four conditions for the healthy participants (*** $p < .001$, *$p < .05$). Bars indicate the standard error of the mean.

Results from aphasic participants with and without verb production deficits

Selection Rate and Response Time Data

SR and RT means and standard deviations for each condition are summarized in Table 3.6. Figures 3.3 and 3.4 illustrate SR and RT across conditions for aphasic participants without and with verb deficits, respectively. Data from one item (*play*) were deleted prior to the analysis because of low average SR (<15%) across participants. Additional data points were excluded based on an abnormal RT distribution (3 x mean group SD). This resulted in the exclusion of 12.08 % of the data points for the aphasic participants without a verb deficit and 4.58 % for the aphasic participants with a verb deficit.

Table 3.6. Mean and standard deviation of selection rate (SR) and response time (RT) across conditions for the aphasic participants.

		Grammatical Category (GC)			
		Nouns M (SD)		***Verbs M (SD)***	
Group	***Base***	***SR***	***RT***	***SR***	***RT***
Aphasics w/o verb deficit	*Unambiguous*	0.99 (0.09)	3796 (1590.09)	0.99 (0.09)	4430 (1776.95)
	Ambiguous	0.65 (0.47)	4515 (1909.09)	0.62 (0.48)	4547 (1736.25)
Aphasics w/ verb deficit	*Unambiguous*	0.87 (0.32)	5965 (3197.87)	0.52 (0.50)	7234 (3258.26)
	Ambiguous	0.76 (0.42)	6879 (3399.31)	0.46 (0.50)	7379 (3700.91)

Aphasic participants without a verb deficit, similar to healthy participants, showed an effect of *Ambiguity* (z = 5.699, p < .000), with SR being significantly higher in the unambiguous condition compared to the ambiguous condition. There was no main effect of *Grammatical Category* (z = -0.135, p = .892) or *Grammatical Category* x *Ambiguity* interaction (z = 0.036, p = .971). Further, the one-sample proportions T-test used to test SR against chance performance revealed that SR was significantly above chance for both noun (unambiguous: χ^2 (1) = 111.08, p < .000; ambiguous: χ^2 (1) = 8.25, p = .004), and verb conditions (unambiguous: χ^2 (1) = 103.08, p < .000; ambiguous: χ^2 (1) = 5.703, p = .016). Using Cohen's d statistic, the effect size (Cohen's d) for the grammatical category difference was -0.05, which is considered a small effects. On the other hand, the effect size for the ambiguity was 1.26, which represents a large effect. Table 3.7 provides the logistic regression model summary based on SR results for the aphasic participants without a verb deficit.

Table 3.7. The logistic mixed model summary of selection rate for the aphasic participants without a verb deficit. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***z-value***	***Pr(>|z|)***
Intercept	2.665	0.375	7.116	0.000 ***
Grammatical Category	-0.098	0.728	-0.135	0.892
Ambiguity	4.179	0.733	5.699	**0.000*****
Grammatical Category x Ambiguity	0.053	1.456	0.036	0.971

With regard to RT, significant effects of *Grammatical Category* (t = 3.102, p = .002), *Ambiguity* (t = - 4.661, p < .000), and interaction between *Grammatical Category* and *Ambiguity* (t = 2.706, p < .000) were found. Responses to verbs were significantly longer than responses to nouns, and responses to ambiguous words were significantly longer compared to unambiguous words. Finally, the interaction effect between *Grammatical Category* (Nouns vs. Verbs) and *Ambiguity* (Unambiguous vs. Ambiguous) was due to significantly longer responses to nouns in the ambiguous condition compared to the unambiguous condition (*t* = 2.781, *p* = .005), but no difference between responses to verbs in the two conditions (*t* = 0.572, *p* = .568).

To assess whether the effects could be accounted for by variations of lexical factors or language severity (measured by WAB AQ), in the follow-up analyses length, frequency, and WAB-AQ was added to the regression models for *Grammatical Category, Ambiguity,* and their interaction as predictors. Results revealed that all effects persisted. Frequency and WAB-AQ accounted for a significant part of the variance, but only in the analysis of RT (frequency: *z* = -0.56, *p* = .569 for SR, and *t* = -2.41, *p* = .016 for RT; WAB-AQ: *z* = -0.99, *p* = .320 for SR, and *t* = 2.52, *p* = .012 for RT). Using Cohen's d statistic, the effect size (Cohen's d) for the grammatical category difference was -0.19, which is considered a small effect. On the other hand, the effect size for the ambiguity was -0.24, and this is considered a medium effect. Table 3.8 provides the linear regression model summary based on RT results for the aphasic participants with a verb deficit.

Table 3.8. The linear mixed model summary of response time for the aphasic participants without a verb deficit. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***df***	***t-value***	***Pr(>|t|)***
Intercept	7.850	0.216	41.7	36.283	0.000***
Grammatical Category	0.099	0.032	416.8	3.102	**0.002 ****
Ambiguity	-0.154	0.033	420.9	-4.661	**0.000*****
Frequency	-0.078	0.033	416.1	-2.407	**0.016 ***
Severity (WAB-AQ)	0.005	0.002	293.1	2.521	**0.012 ***
Grammatical Category x Ambiguity	0.171	0.063	416	2.706	**0.000*****

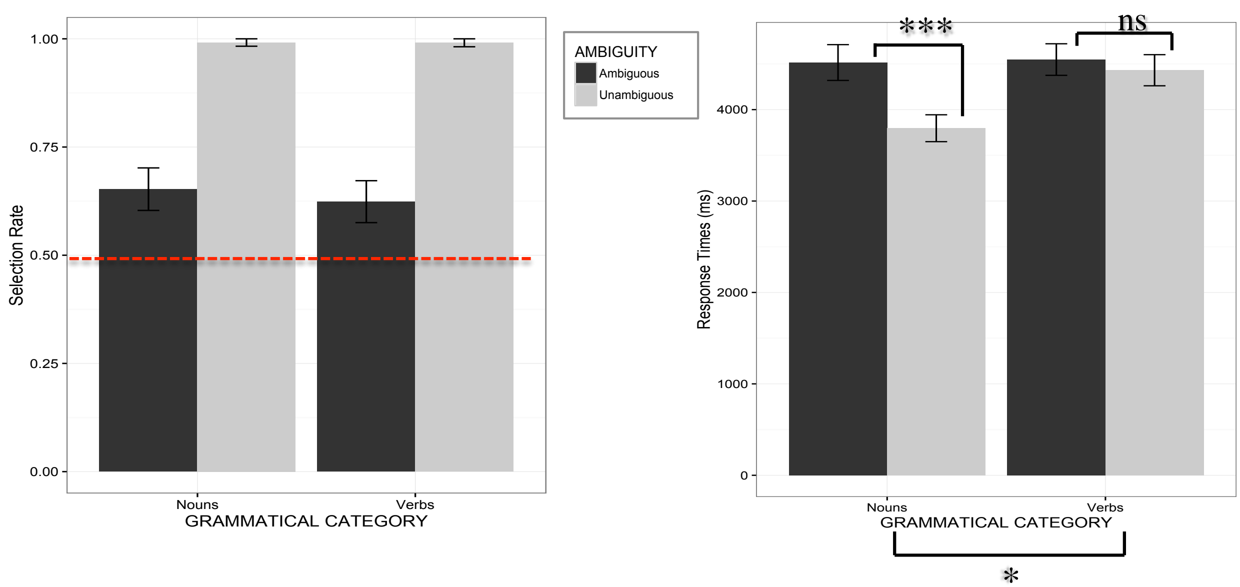

Figure 3.3. Mean selection rates (left) and response times (right) across the four conditions for the aphasic participants without a verb deficit (*** $p < .001$, *$p < .05$). Bars indicate the standard error of the mean.

<u>Aphasic participants with a verb production deficit</u> showed a significant effect of *Grammatical Category* ($z = -7.593$, $p < .000$), with SR being significantly higher for nouns over verbs. There was also a significant effect of *Ambiguity* ($z = 2.334$, $p = .019$), with the higher SR for the unambiguous condition compared to the ambiguous condition. However, the interaction between *Grammatical Category* and *Ambiguity* was not significant ($z = -1.420$, $p = .156$). Importantly, the one-sample proportions T-test used to test SR against chance performance revealed that SR was significantly above chance for the noun condition (unambiguous: χ^2 (1) = 65.25, $p < .000$; ambiguous: χ^2 (1)= 28.54, $p < .000$), but not for the verb condition

(unambiguous: χ^2 (1) = 0.134, *p* = .714; ambiguous*:* χ^2 (1) = 0.55, *p* = .459). Using Cohen's d statistic, the effect size (Cohen's d) for the grammatical category difference was 0.75 and for the ambiguity was 0.19, representing large and small effects, respectively. Table 3.9 provides the logistic regression model summary based on SR results for the aphasic participants with a verb deficit.

Table 3.9. The logistic mixed model summary of selection rate for the aphasic participants with a verb deficit. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***z-value***	***Pr(>|z|)***
Intercept	-1.126	0.743	-1.515	0.130
Grammatical Category	-1.831	0.241	-7.593	**0.000 *****
Ambiguity	0.538	0.230	2.334	**0.019 ***
Frequency	0.646	0.232	2.787	**0.005 ****
Severity (WAB-AQ)	0.031	0.012	2.64	**0.008 ****
Grammatical Category x Ambiguity	-0.656	0.462	-1.42	0.156

With regard to RT, there were significant effects of *Grammatical Category* (*t* = 4.926, *p* < .000), *Ambiguity* (*t* = - 2.160, *p* = .031)*,* and interaction between *Grammatical Category* and *Ambiguity* (*t* = 2.527, *p* = .012). Responses to verbs were significantly longer than responses to nouns, and responses to ambiguous words were significantly longer as compared to responses to unambiguous words. Finally, the interaction effect between *Grammatical Category* (Nouns vs. Verbs) and *Ambiguity* (Unambiguous vs. Ambiguous) was due to significantly longer responses to nouns in the ambiguous condition compared to the unambiguous condition (t = 2.277, p = .024), but no difference between responses to verbs in the two conditions (t = -0.093, p = .926).

To assess whether the effects could be accounted for by variations of lexical factors or language severity, in the follow-up analyses length, frequency and WAB-AQ was added to the regression model for *Grammatical Category, Ambiguity,* and their interaction as predictors. Results revealed that all effects persisted, however, frequency and WAB-AQ accounted for a significant part of the variance (frequency: z= 2.787, p= .005 for SR, and t= -3.316, p= .001 for RT; WAB AQ: z = 2.640, p = .008 for SR, and z = 0.490, p = .641 for RT). Using Cohen's d statistic, the effect size (Cohen's d) for the grammatical category difference was -0.93, which is considered a large effect; however, the effect size for the ambiguity was -0.15 and this is considered a small effect. Table 3.10 provides the linear regression model summary based on RT results for the aphasic participants with a verb deficit.

Table 3.10. The linear mixed model summary of response time for the aphasic participants with a verb deficit. Significance is indicated by asterisks: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Predictor	***Estimate***	***SE***	***df***	***t-value***	***Pr(>|t|)***
Intercept	8.719	0.140	6	62.287	0.000***
Grammatical Category	0.156	0.032	452	4.926	**0.000*** **
Ambiguity	-0.067	0.031	452	-2.160	**0.031 ***
Frequency	-0.109	0.033	452	-3.316	**0.001 *****
Grammatical Category x Ambiguity	0.158	0.063	452	2.527	**0.012 ***

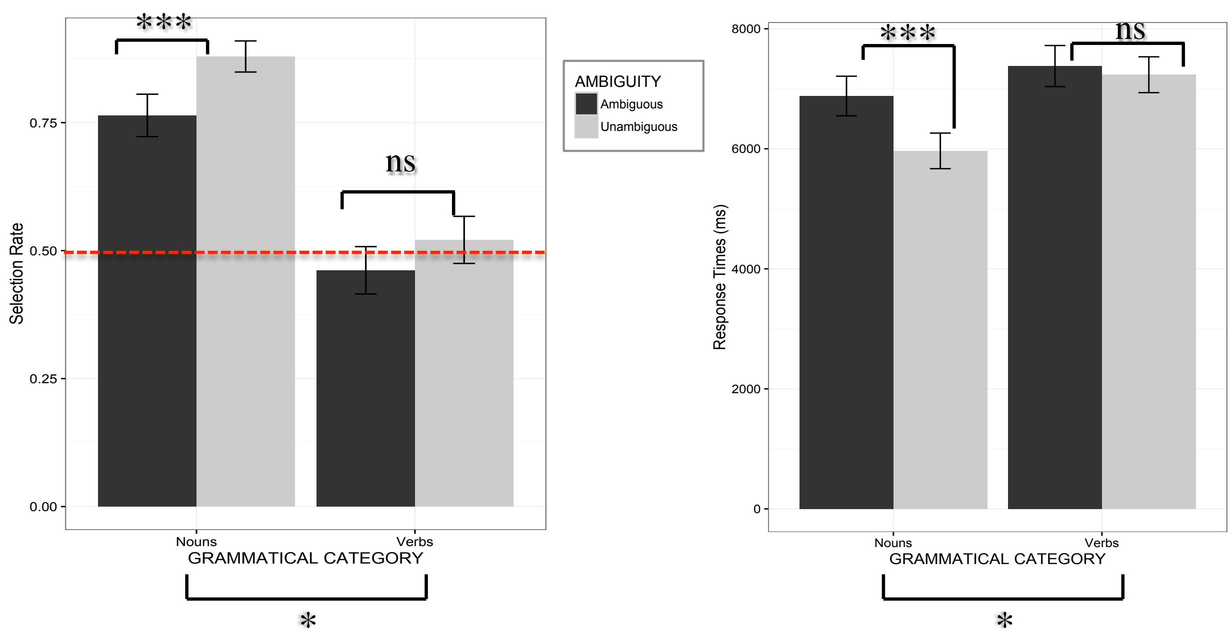

Figure 3.4. Mean selection rates (left) and response times (right) across the four conditions for the aphasic participants with a verb deficit (*** $p < .001$, *$p < .05$). Bars indicate the standard error of the mean.

Discussion

The results of this study showed a noun/verb base-form bias for ambiguous words in normal processing. Yet, aphasic participants with a verb production deficit showed a noun bias, but not a verb bias. The existence of base-form effects across categories in normal processing suggests that ambiguous words are categorically stored in the lexicon, supporting the single-entry hypothesis. The findings provide insights into the representation of ambiguous words, thus extending the knowledge of categorically ambiguous words in normal and impaired lexical processing.

Processing correlates of ambiguous words have been extensively studied within the semantic ambiguity literature. Several studies showed that both noun/verb forms of ambiguous words are initially activated and compete for selection, leading to increased computational resources (see Eddington and Tokowicz, 2015). However, theories differ on whether the two forms share the same single entry or are listed under separate entries. This study addressed this question by examining healthy and aphasic (with and without verb deficits) individuals' ability to process unambiguous and ambiguous nouns and verbs using a forced-choice response paradigm. This paradigm allowed us to identify whether participants expressed a noun/verb bias when presented with an ambiguous word, and to assess aphasic individuals' ability to covertly produce nouns and verbs.

Healthy participants showed base-form bias effects across categories: a noun bias (selection of *the*) for unambiguous and ambiguous nouns, and a verb bias (selection of *to*) for unambiguous and ambiguous verbs. These results support the single-entry hypothesis that one must process the base form before accessing the derived form. In terms of processing cost, a verb disadvantage was found only in the unambiguous condition, which substantiates previous studies showing longer response times for verbs (actions) compared to nouns (objects) (e.g., Bogka et al., 2003; Druks et al., 2006; Sereno, 1999; Tyler et al., 2001). An additional finding, the ambiguity disadvantage effect (ambiguous > unambiguous), is consistent with findings reported in the semantic ambiguity literature.

These findings align with previous studies investigating processing of homonyms (words with unrelated meanings) and polysemy (words with related meanings/senses). For example, Beretta, Fiorentino and Poeppel (2005) found distinct processing profiles for homonyms and polysemous words. First, for the homonyms, they observed longer RT and later onset of an M350 component[6] for words with more than one meaning (e.g., *bark*) relative to words with one meaning (e.g., *cage*). Second, for polysemy, they noticed shorter RT and earlier onset of an M350 component for words with many senses (e.g., *belt*) than for words with few senses (e.g., *ant*). Beretta and colleagues suggested a separate-entry model for homonymy and a single-entry model for polysemy. In consideration of Beretta et al.'s study, the ambiguous words used in the current study (e.g., *brush* and *bite*) were more like their polysemous words (e.g., *belt*), rather than their homonyms (e.g., *bark*). Essentially, the present study showed that categorically ambiguous words not only share a single entry, but they also are stored in their base form, as evident by the base-form bias effects found in the current study.

Interestingly, two distinct patterns for *aphasic participants* were noted: (1) a noun/verb base-form bias similar to that in healthy participants was found in aphasic individuals without a verb production deficit, and (2) a noun bias, but not a verb bias, across the two ambiguity conditions was found in aphasic individuals with a verb production deficit. In terms of processing cost, in contrast to healthy participants, aphasic participants with and without verb

[6] The M350 component reflects the lexical access.

deficits showed significantly longer responses to nouns in ambiguous compared to unambiguous conditions, but no significant processing difference to verbs was found between the two conditions.

These results are consistent with the large body of aphasia research demonstrating significant difficulty in naming verbs (actions), but not nouns (objects) in individuals with agrammatic aphasia in picture-naming tasks (e.g., Cappa & Perani, 2003; Thompson et al., 2012). However, very few studies so far have tested aphasic individuals' ability to retrieve ambiguous nouns and verbs, and none have controlled for the morphological complexity of both forms. In an early study, Caramazza & Hillis (1991) tested the spoken and written retrieval of noun-verb homonyms within a sentence context (e.g., There's a crack in the mirror; Don't crack the nuts in here). They found a deficit in verb retrieval in two patients (phonological in one and orthographical in the other) for noun–verb homonyms when the context required a verb, but not when the noun was needed. Similarly, Hillis and Caramazza (1995) reported on another patient, who showed an advantage for verbs over nouns with spoken output, but an advantage for nouns over verbs with written input.

However, Hillis and Caramazza's studies only tested homonyms in noun and verb contexts without controlling them for their morphological and semantic complexity in noun and verb forms. The current study systematically varied stimuli by differentiating noun-based and verb-based forms of the ambiguous words within two conditions. The representation of some ambiguous nouns and verbs contained both the base and derived forms, and for that reason, such representation could be affected by a selective base impairment.

Taken together, these data suggest that derivational processes are crucially involved in lexical access in normal processing. Importantly, aphasic individuals with verb production deficits showed selective verb deficit across unambiguous and ambiguous verbs (*bake, bite*). Also, impaired access to the base form (i.e., verbs, as in *bite*) precluded retrieval of the derived form (noun) as shown by chance performance on the binary forced-choice paradigm. This paradigm is able to capture a verb specific deficit in covert production, beyond a picture-naming test, and it could be a useful tool for future studies on word-class processing in aphasia. This is an important topic in understanding the organization of the mental lexicon and the nature of language impairments, which, in turn, may enhance ways of facilitating production of nouns and verbs in individuals with acquired language disorders.

Chapter 4

Neurocognitive Correlates of Verbs: Zero-Derivation versus Lexical-Selection costs

Abstract

Categorically ambiguous words, like *bear* and *brush,* are common in the English language. Previous research has shown such ambiguous words take longer to process and require increased activity in the left frontal and temporal cortex as compared to unambiguous words like *bake*. Two competing theories account for this processing cost: one argues that words with multiple representations require greater selection demands (*the brush* and *to brush*), while another posits that increase processing cost reflects online zero-derivation of the verb from the noun. To test these two theories, we examined the neural correlates of zero-derivation and lexical selection during verb processing by manipulating the base form of verbs. Twelve healthy young adults underwent an event-related fMRI judgment task of unambiguous verbs (*to bake*), noun-derived verbs (*to brush*), and non-derived verbs (*to bear*) as well as letters and nouns. Results revealed that verb processing elicited greater left frontal activation, while processing nouns and letters bilaterally activated temporal and occipital regions, respectively. Consistent with previous research, ambiguous verbs evoked longer response times and greater neural activation in left inferior frontal and temporal gyri than unambiguous verbs. These results are possibly due to the greater lexical-selection demands posed by the former. Importantly, non-derived verbs (to *bear*) elicited greater activity in left fronto-parietal areas and noun-derived verbs (to *brush*) elicited greater activity in bilateral temporal areas, suggesting a different representation for the two verb types. We propose that whereas ambiguous forms like *bear* correspond to two lexical items, forms like *brush* are associated with only one lexical entry, i.e. the base noun form, with the verbal form derived on-line rather than stored.

Introduction

The neural basis of verb processing has been extensively studied over the past several years with functional magnetic resonance imaging (fMRI), including a substantial body of work focused on word class distinctions (i.e., differences between noun and verb processing). Notably, results differ across studies, perhaps because verbs do not comprise a uniform category, and different representations and computations may underlie processing of various verb types. There are many different subcategories of verbs, some of which are distinguished based on semantic, argument structure, and/or morphological properties. Therefore, across neuroimaging studies, verb activation varies based on verb types and their underlying properties. Before reviewing these neuroimaging studies, the different subcategories of verbs are outlined below.

One common distinction among verbs is the property of *argument structure*. Verbs like *bake, brush* and *bear*, express an action incorporating two thematic roles in their meanings: an agent that initiates the action and a theme that is expressed by an NP-complement (two-argument verbs)[7]. In contrast, verbs like *bark* express a doable activity, but it does not take a direct object (one-argument verb)[8]. In addition, verbs like *bake* have a single action meaning, whereas verbs like *brush* and *bear* are inherently ambiguous in that they have multiple meanings and can be used as either a noun or a verb (1a, b and c). Moreover, they may refer to related or unrelated entities, i.e., *brush* carries two semantically related meanings, whereas *bear* conveys two semantically unrelated meanings.

[7] Mary bakes the cake.
Mary brushes her hair.
Mary bears the pain.
[8] Dog barks.

(1)

a. Unambiguous verb (*bake*) = action of cooking

b. Ambiguous verb (*brush*) = action of grooming/an object

c. Ambiguous verb (*bear*) = action of support/an animal

According to the Zero-Derivation theory (Don 2005; Lipka 1986), the verb's derivational status creates ambiguity in (1b): a verb *brush* is derived from a noun (the base form) to become a verb (the derived form). Thus, the derived form verb carries an object (i.e., noun) meaning as its base form. However, *bear* is not derivationally, and in turn not semantically, related with the noun *bear*. Consequently, these three verb types vary in their underlying morphological complexity (2a, b and c)[9].

(2)

a. Unambiguous verb (*bake*) = $_{V}$[bake]

b. Noun-derived verb (*brush*) = $_{V}$[$_{N}$ brush]-ø]

c. Non-derived verb (*bear*) = $_{V}$[bear] and $_{N}$[bear]

Previous neuroimaging studies that manipulated the *argument structure properties* of verbs have shown differential activation based on the number and type of the arguments that verbs encode. The neuronal activation patterns in response to verb-argument structure processing are reliably observed in posterior brain regions, such as the STG, SMG and AG (see review by Thompson and Meltzer-Asscher, 2014). In a series of fMRI lexical-decision experiments with young and older healthy adults, Thompson et al. demonstrated increased activation in bilateral SMG and AG for transitive verbs, requiring a direct object, compared to intransitive verbs that

[9] Zero-derived words are assumed to have a derivational suffix in the same way as words with explicit derivational morphemes (e.g., *classify* = [$_{V}$ [$_{N}$ class]-ify), however, this morpheme (so-called zero-morpheme) is invisible and unpronounced (e.g., *to brush* = [$_{V}$ [$_{N}$ brush]-ø]) (see Don 2005).

do not select for a direct object (Thompson et al., 2007; Thompson et al., 2010a). Similar posterior regions (STG and SMG) also have been implicated in production of verbs associated with their argument structure density (den Ouden et al., 2009).

With regard to manipulation of a *verb's semantic information*, studies have reported that the left frontal cortex is recruited under conditions of increased competition between multiple meanings (see Binder, Desai, Graves, and Conant, 2009, Eddington and Tokowicz, 2015 for reviews on semantic ambiguity). Studies of lexical ambiguity have also reported the involvement of posterior areas, such as the left inferior temporal gyrus (ITG; Rodd et al., 2005), bilateral middle temporal gyrus (MTG; Zempleni et al., 2007), right superior temporal gyrus (STG; Copland et al., 2007), as well as bilateral middle and superior frontal gyri (MFG, SFG; Mason and Just, 2007).

Gennari, MacDonald, Postle, and Seidenberg (2007) examined the neural mechanisms involved in lexical ambiguity resolution, especially, in computing word meanings that change as a function of syntactic contexts (the/to). The authors found that ambiguous words (e.g., the/to *brush*) elicited more activity in the left IFG and posterior MTG than unambiguous words (e.g., the *tray,* to *dig*). Ambiguous words also elicited more activity in *to*-contexts than *the*-contexts in the left IFG and MTG. Gennari et al. suggested that ambiguous words require more complex processing than unambiguous words, and verbs require more complex processing than nouns. Similarly, Burton and colleagues (2009) in a 2 x 2 factorial design, with the two factors being grammatical category (nouns vs. verbs) and ambiguity (ambiguous vs. unambiguous), examined the neural correlates of lexical ambiguity using an auditory grammaticality judgment task. They demonstrated an effect of ambiguity in the left IFG, with greater activation for ambiguous words (e.g., the/to *smell*) than unambiguous words (e.g., the *song*, to *send*). Additionally, an interaction effect between ambiguity and grammatical category was observed in the left STG: for unambiguous words, the posterior left STG showed increased activity for verbs compared to nouns, while for ambiguous words in this same region, nouns showed greater activation than verbs. Finally, within the context of a lexical-decision fMRI experiment, Grindrod et al. (2014) examined the neural correlates of ambiguity modulated by syntactic similarity (noun-noun, noun-verb) and meaning dominance (balanced, unbalanced). Syntactic similarity effects were observed in the left IFG, with greater activation for noun-verb (e.g., rock-stone, rock-sway) than noun–noun (e.g., match-fire, match-game) homonyms. Meaning dominance effects were observed in the left MTG and STG, with greater activation observed for balanced than unbalanced homonyms.

To date, only one neuroimaging study has manipulated morphologically *zero-derived* verbs (Pliatsikas et al., 2014). They investigated the neural mechanism of zero-derivation by comparing neural activation patterns elicited by one-step (*bouncing*) versus two-step (*brushing*) derived verbs. The one-step verbs are directly derived from their verb base-form ([*bouncing*] -- > [$_{V}$ bounce]), whereas the two-step derived verbs are derived via zero-derivation from their base-form noun ([*brushing*] --> [$_{V}$ brush] --> [$_{N}$ brush]). Pliatsikas and colleagues found increased brain activity within the left IFG for verbs like *brushing* compare to verbs like *bouncing*, suggesting that this activation reflects morphological complexity.

However, it is unclear if increased activity within the left IFG for verbs like *brushing* (as in Pliatsikas et al., study 2014) reflects the processing cost of zero-derivation or lexical selection between noun and verb representations (as in Grindrod et al., 2014). The previously discussed ambiguity studies agree that processing ambiguous words requires increased computational resources due to greater selection demands associated with co-activation of two representations, relying mainly on the frontal cortex. However, the usage of heterogeneous ambiguous words in the aforementioned studies prevents the acceptance of this conclusion.

The neural network supporting verb processing has also been addressed by neuroimaging studies comparing verb and noun activation patterns, irrespective of the verb's properties. A detailed review and meta-analysis on neuroimaging studies which investigated the neural basis of noun and verb processing, showed a significant overlap in the neural tissue recruited for the two word classes (Crepaldi et al., 2011, 2013). For example, Crepaldi et al. (2011) in their review of 15 neuroimaging studies that reported verb-noun direct contrasts revealed that only five studies showed verb-specific activation in left frontal regions, and only two showed noun-specific activation in a left temporal region. Additionally, as a result of a meta-analysis, Crepaldi et al. (2013) reported that: nouns across different tasks elicited activation in the right ITG, and the left AG and inferior parietal lobe (IPL); verbs across different tasks elicited activation in the posterior part of the right MTG; and three clusters showed verb specificity in some tasks and noun specificity in others (in the left and right IFG and the left insula).

The goal of the present study was to identify brain regions and different patterns of activation associated with the computational and representational properties of verbs. To that end, we examined the neurocognitive mechanisms of verbs when compared to nouns, letters, and different verb types. According to Embick and Poeppel's discussion on *Computational-Representational theories* (2015), "complex ambiguous words" can be stored as whole-forms and can also be derived through computation. Take for example, the verb *brush*, which can be considered a complex word, since it can also be used to refer to an object: there are two main ways of analyzing this word.

One approach claims that the verb *brush* is derived by a morphological process that operates on an underlying base-form representation that is the noun *brush*. This is in line with the *Single Entry* (Nunberg, 1979) and *Fully Decompositional* (Taft and Foster, 1975) accounts, which suggest that base forms are stored in the mental lexicon and the derived forms arise from the base form via a morphological operation that derives one category from the other. Therefore, multiple forms such as *brush* are listed under a single lexical entry, with one being computationally derived from the other with every use**.**

Another approach relies more on memory and holds that the verb *brush* is stored as an unanalyzed whole form. This is in line with *Non-decompositional or "full-listing"* (Jackendoff, 1976) and the *Separate Entry* (Langacker, 1987) accounts, which suggest that multiple forms of *brush* are listed as separate lexical entries in the mental lexicon and that such forms do not undergo derivational processes.

To address the question of how ambiguous words are processed, the current study examined the neural mechanisms associated with processing unambiguous verbs (e.g., *to bake*), noun-derived verbs (*to brush*), and non-derived verbs (*to bear*). Using an fMRI grammaticality judgment task (GJT), this study aimed to disentangle the neural mechanisms of zero-derivation versus those engaged for lexical-selection during verb processing, while keeping the argument structure property of verbs constant. The *overall working hypothesis* was that different brain areas support different cognitive sub-processes, i.e. lexical-selection versus morphological processes.

Both the *separate-entry* and the *single-entry* approaches agree that non-derived verbs (e.g. *to bear*) involve separate lexical entries (a noun and a verb). According to the *separate-entry approach*, noun-derived verbs (e.g. *to brush*) likewise involve the listing of two separate entries. If noun-derived verbs entail separate lexical entries, we expected activation patterns similar to those seen for non-derived verbs, reflecting lexical selection demands. This cost may be reflected in frontal as well as posterior regions as seen in previous studies. Similarly, longer response times and greater neural activation for noun-derived verbs (e.g., *to brush*) and non-derived verbs (e.g., *to bear*) over unambiguous verbs (e.g., *to bake*) were expected, reflecting lexical-selection demands for the former but not the later. In contrast, according to the *single-entry approach*, if noun-derived verbs (*to brush*) are derived from a single base-form noun representation, we expected that only non-derived verbs (*to bear*) would elicit greater activation in regions involved in lexical selection. On the other hand, noun-derived verbs (*to brush*) would elicit activation in regions associated with stored noun representations.

Method

Participants

Fourteen right-handed, young healthy individuals took part in this study. All participants were monolingual English speakers with normal or corrected-to normal vision and hearing, and showed no history of psychiatric, neurological, speech, or language disorders. Participants were recruited from the Northwestern University student body and staff, as well as from residents within the greater Chicago area. All participants provided written informed consent approved by the Northwestern University Institutional Review Board. Two participants were excluded due to a technical problem with the scanner. The remaining twelve participants (7 females; age range = 19 to 28 years, *M*=24; education range = 13 to 18 years, *M*=15) were included in the analysis reported below.

Stimuli

The stimuli consisted of 63 experimental items, 42 baseline items, and 63 fillers, each repeated twice. The study included three verb conditions: 1) unambiguous verbs with a single, verbal, lexical representation (v1 = *to bake*), 2) noun-derived verbs associated with two lexical representations (a verb and a noun), which by hypothesis are derived on-line from a stored noun representation (v2 = *to brush*), and 3) non-derived verbs associated with two lexical representations (a verb and a noun) where one is not derived from the other (v3 = *to bear*). There were 21 items per condition, repeated twice. Ambiguous verbs (2-3) were selected only if the noun and verb forms had: a) identical orthographic and phonologic form (i.e., all are homographs, homophones, respectively), and b) near-equal frequency of usage (range: 0.89-1.29) as a noun and as a verb based on the Corpus of Contemporary American English (COCA; Davies, 2008).

Also, ambiguous verbs were tested for their morphological properties. Verbs in condition 2 were classified as zero-derived (ZD) in accordance with linguistic diagnostics for derived status: (a) ZD words share the same stress pattern (*brush*$_N$ *vs. brush*$_V$, *RE-cord$_N$ *vs. re-CORD*$_V$), (b) ZD words resisted some specific class of suffixes (Meyers's Root Suffixation test, 1984), and (c) ZD words follow a specific semantic distribution expressed by paraphrases (Clark and Clark's Test, 1979). For example, according to Myers's Root Suffixation Test, *brush* is categorized as a noun derived verb since it cannot take a verbal suffix that turns a verb to a noun (e.g., *brush-*ery*) or a verb to an adjective (e.g., *brush-*ive*), but it can take a nominal suffix that turns a noun to an adjective (e.g., brush-*less*). Additionally, *brush* denotes an action that crucially involves a base form (a tool) like *brush* (e.g., to brush = to act with an N, as in "*Mary brushed her hair"*; Clark and Clark's classification, 1979).

In addition, imageability ratings were collected for each verb using a rating questionnaire. Fifteen participants (10 females, M=28 years of age) were asked to rate on a 7-point Likert-scale (1 = low, 7 = high) the degree of imageability by indicating how easy it was to create a mental image for each experimental item. For example, the phrase "to brush" would be assigned a high score because it was easy to create a mental image for it. In contrast, it was more difficult to create a mental image for a phrase like "to hope", which would be assigned a low score. There were no significant differences between nouns and verbs or across the three verb conditions in orthographic length, log frequency, or imageability (see Table 4.1).

Table 4.1. Descriptive data and statistical results for lexical variables across conditions. N/A= not available.

	Length		***Frequency***		***Imageability***	
	Mean (SD)	*Statistics*	*Mean (SD)*	*Statistics*	*Mean (SD)*	*Statistics*
Condition						
v1 *(to bake)*	5.0 (1.16)	v1 vs. v2: $t\,(35) = 1.85$ ***p* = .072**	3.69 (0.53)	v1 vs. v2: $t\,(39) = 0.03$ ***p* = .975**	4.9 (1.04)	v1 vs. v2: $t\,(39) = 0.27$ ***p* = .786**
v2 *(to brush)*	4.7 (0.72)	v2 vs. v3: $t\,(39) = -1.42$ ***p* = .164**	3.69 (0.62)	v2 vs. v3: $t\,(39) = 1.32$ ***p* = .195**	4.8 (1.21)	v2 vs. v3: $t\,(31) = -1.89$ ***p* = .067**
v3 *(to bear)*	4.4 (0.80)	v3 vs. v1: $t\,(33) = 0.79$ ***p* = .429**	3.47 (0.45)	v3 vs. v1: $t\,(39) = 1.49$ ***p* = .144**	5.4 (0.66)	v3 vs. v1: $t\,(34) = -1.76$ ***p* = .087**
Verbs	4.7 (0.93)	*verbs vs. nouns:* $t\,(28) = 0.45$ ***p* = .654**	3.62 (0.54)	*verbs vs. nouns:* $t\,(33) = 1.09$ ***p* = .280**	N/A	
Nouns	4.8 (1.17)		3.77 (0.55)			

In addition to the 63 experimental stimuli, another 42 items, the letter and noun pairs, (e.g., letter (l) = bb bbbb, noun (n) = the bell) were selected and served as low-level and high-level baselines, respectively (21 each, repeated twice). Additional noun, verb and letter pairs were included as fillers (e.g., noun filler (nf) = *to belt, verb filler (vf) = *the build, letter filler (lf) = *bb sss; 21 each, repeated twice). Appendix 4.1 and 4.2 display a complete list of stimuli.

Design

A rapid event-related design was selected for this study in order to account for (a) proper randomization of stimuli, (b) randomized inter-stimulus onsets, and (c) "jittered" randomly intervening rest intervals (NULL events). The study was compromised of two runs, each including 63 experimental items, 42 baseline items, and 63 filler stimuli, all in different orders, presented during a single session, and with the order of runs counterbalanced across participants. Stimuli were randomized within each run using the OPTSEQ program (http://surfer.nmr.mgh.harvard.edu/optseq) to generate an optimized random order of all conditions. The ordering constraints were specified as follows: 1) no more than three of the same condition (v1, v2, v3 or n), 2) no more than four of the same response (match or mismatch), and 3) each condition was preceded equally by another one. In addition, randomized "jittered" NULL events (0-15 s) were inserted, using the OPTSEQ program and TR = 1.6 s. This resulted in a varied onset of successive stimulus events, with randomly intervening rest intervals. Figure 4.1 shows the first eight events of the first run.

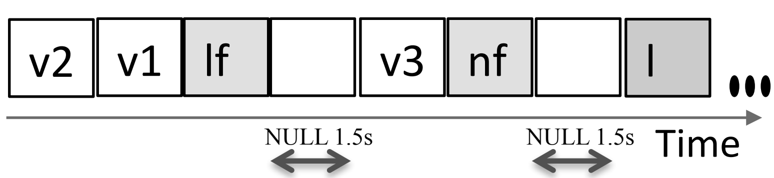

Figure 4.1. An event-related design showing the first eight events of the run 1. Notes: v1=unambiguous verb, v2=noun-derived verb, v3=non-derived verb, 1=letter pair, lf=letter filler, nf=noun filler.

Procedure

All participants performed an event-related fMRI GJT in which they decided whether a two word sequence was grammatical ('to bake') or not ('the build'), and whether two letter pairs matched (‘bb bbbb’) or mismatched (‘ff bbbb’). In each trial, the target or the filler pair was visually displayed for 2.5 seconds, preceded by a fixation cross for 0.5 second and then followed by jittered randomly intervening rest intervals (NULL events) lasting between 0-15 seconds (see Figure 4.2). Participants were instructed to use the right hand and to respond by pressing one of two buttons: for a match a left button was pressed with their index finger, and a mismatch a right button was pressed with their middle finger. Participants performed practice trials (with feedback) before entering the scanner in order to become familiar with the task. The experiment was presented using E-Prime software version 2.0.8 (Bates, Maechler, & Bolker, 2012) on a Dell desktop computer running Windows XP Professional with an Intel Core 2Duo CPU processor.

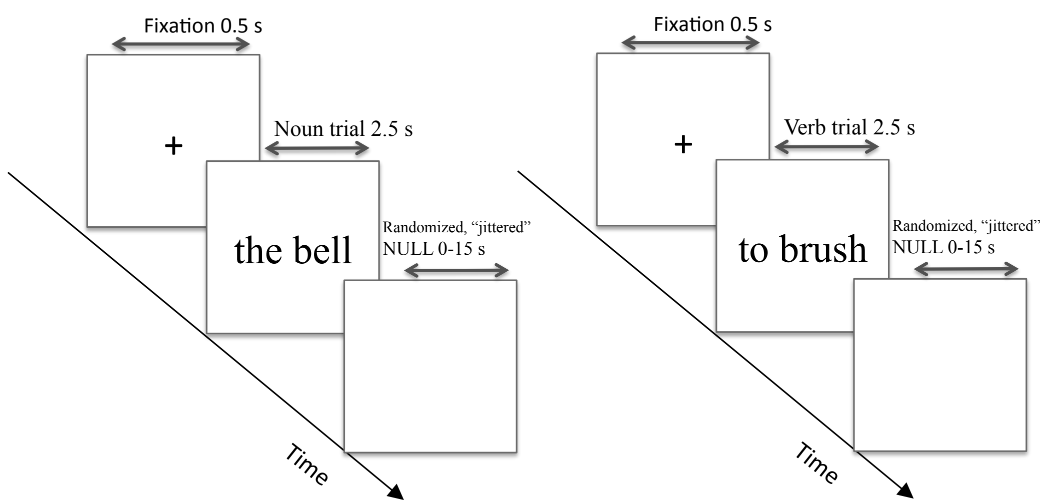

Figure 4.2. Schematic of noun (left) and verb (right) trials in the grammaticality judgment task.

Data Acquisition

A 3-T Trio Siemens Prisma scanner was used to obtain anatomical (T1-weighted) and functional scans (T2*-weighted) at the Center of Translational Imaging (CTI) at Northwestern University. The T1-weighted scan was acquired using an MP-RAGE sequence: time to repeat (TR) = 2300 ms, time to echo (TE) = 2.94 ms, flip angle = 9 degrees; matrix size = 256 × 256; field of view (FOV) = 256 mm; voxel size = 1 × 1 × 1 mm; 176 slices). Functional scans were obtained using the following parameters: TR= 1600 ms; TE = 20 ms, flip angle = 80 degrees; matrix size = 104 × 104; FOV = 208 mm; voxel size = 2 × 2 ×2 mm; 60 slices.

Data Analysis

Behavioral Data

Accuracy (proportion correct) and RT (milliseconds) were recorded on each trial. Means and standard deviations were calculated for each item and condition. To eliminate outliers from the RT data, the mean and standard deviation of RTs were calculated for each condition of the task, and any RTs above or below 2.5 standard deviations of the mean were excluded from further analysis. Accuracy and RT data were analyzed using a linear regression with mixed-effects: fixed effects for word-class or verb type, and the appropriate random effect structure (i.e., random by-participant intercepts and as well as random by-item intercepts). Regression was performed using the lme4 package running in R program (http://www.r-project.org).

Neuroimaging Data

Neuroimaging data processing and statistical analyses were performed using Statistical Parametric Mapping (SPM8) software (http://www.fil.ion.ucl.ac.uk/spm). The data were pre-processed through the web-based Northwestern University Neuroimaging Data Archive (https://nunda.northwestern.edu) and included the following steps: (a) slice-timing correction and motion correction of functional images, (b) transformation of functional images and anatomic images into the standard space, and (c) smoothing. In the first level of analysis, conditions were modeled separately for each verb type and low- and high- baseline measures (letters, nouns) using a general linear model (GLM; Friston et al., 1995). The fMRI analysis focused on five primary contrasts: (1) all verbs versus nouns (word-class effects), (2) all verbs versus letters (lexical effects), (3) overall effect of ambiguity (v2+v3>v1), (4) effect of derivation (v2>v1; v2>v3), and (5) effect of lexical selection (v3>v1; v3>v2).

Individual participants' summary activation maps for the contrasts of interest were entered into a second level analysis (i.e., random effects analysis) to enable inferences at the group level. Following this second-level analysis, statistical parametric maps were generated, displaying a t-statistic at each voxel (SPM {t}) that characterized differences in activation for any condition. Second-level statistics were evaluated using a cluster-level threshold of $p < .05$, corrected for multiple comparisons using a false discovery rate (FDR), with a minimum cluster size (k) of 15. If significant cluster of activation was not seen at the FDR threshold, uncorrected clusters of activation ($p < 0.02$) were obtained.

In addition to whole-brain analysis, region of interest (ROI) analyses were conducted for the three verb conditions relative to the low-level (letter) baseline, using the Marsbar toolbox in SPM (Brett, Anton, Valabregue, & Poline, 2002). The anatomically-defined ROIs were created based on the Automated Anatomical Labeling (AAL) atlas within Marsbar, and included the bilateral inferior frontal region and inferior, superior and middle temporal regions, shown to be involved in ambiguity processing.

Results

Behavioral Results

Accuracy and RT means and standard deviations for each condition are summarized in

Table 4.2. Figure 4.3 illustrates accuracy and RT across conditions for young healthy participants. Prior to statistical analysis on RT, incorrect responses (comprising 4.9% of the data) and outliers (comprising 3.2% of the data) were removed. Participants were highly accurate on the task (0.95% correct), with 0.96% correct on verb trials and 0.98% correct on noun trials. Accuracy for verb type was highest for v1 (0.99% correct) and v2 (0.99% correct) and least accurate for v3 (0.91% correct). Also, RTs were longer for nouns (850 ± 164 ms) as compared to verbs (822 ± 197 ms). Participants were fastest in responding to v1 (789 ± 169 ms), slower for v2 (814 ± 201 ms), and slowest for v3 (868 ± 213 ms) (see Table 4.2).

Table 4.2. Mean and standard deviation of response time and accuracy across conditions for the healthy participants.

Conditions	***Response Time (ms)***		***Accuracy (% correct)***	
	Mean	*SD*	*Mean*	*SD*
unambiguous verbs	789	169	0.99	0.05
noun-derived verbs	814	201	0.99	0.08
non-derived verbs	868	213	0.91	0.29
Verbs	822	197	0.96	0.18
Nouns	850	164	0.98	0.13

Linear mixed-effect regression analysis indicated that accuracy was not significantly predicted by *word-class* ($t(83.99) = -0.947$, $p = .346$), though RT was significantly predicted, with responses to nouns being significantly longer than responses to verbs ($t(75.04) = -2.381$, $p = .019$). However, a regression analysis indicated that both accuracy ($t(63) = -4.119$, $p = .000$) and RT ($t(59.41) = 4.778$, $p = .000$) were significantly predicted by *verb type*. Participants' responses to non-derived verbs were less accurate than unambiguous ($t(496.23) = 6.980$, $p = .000$) and noun-derived verbs ($t(540.67) = 6.526$, $p = .000$). No significant difference in accuracy between unambiguous and noun-derived verbs ($t(756.17) = 1.005$, $p = .315$) was found. With regard to RT, a graded pattern in RT across the three verb conditions was observed (non-derived > noun-derived > unambiguous). Participants' responses to non-derived verbs were significantly longer compared to unambiguous ($t(777.62) = -5.953$, $p < .000$) and noun-derived verbs ($t(841.21) = -3.812$, $p < .000$), and also responses to noun-derived were significantly longer than unambiguous verbs ($t(884.08) = -1.992$, $p = .046$) (see Figure 4.3). In addition, effect sizes of RT mean differences for *Grammatical Category* (Nouns vs. Verbs) and *Verb Type* (Unambiguous vs. Noun-derived vs. Non-derived) were computed with Cohen's d. The effect size (Cohen's d) for the grammatical category difference was 0.18 and for argument structure was 0.14, which is considered a small effect by Cohen's (1988) standard. On the other hand, the effect size was large for non-derived verbs when compared to unambiguous verbs ($d = -0.414$), and medium when compared to noun-derived verbs ($d = -0.261$), whereas, a small effect size was for noun-derived verbs when compared to unambiguous verbs ($d = -0.135$).

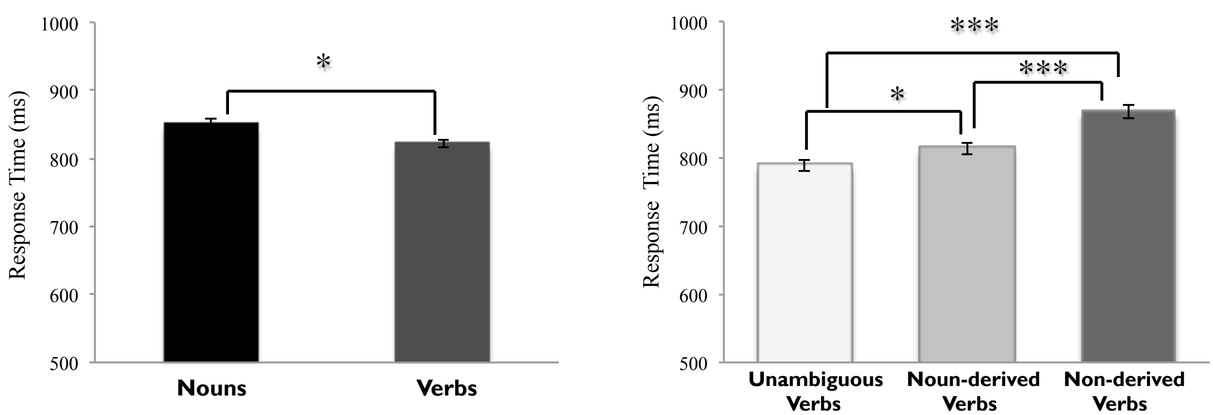

Figure 4.3. Mean response time for the noun and verb conditions (left) and across the three verb conditions (right) for the healthy participants (*** $p < .001$, *$p < .05$). Bars indicate the standard error of the mean.

Neuroimaging Results

Statistical analyses were conducted to determine first whether verb trials differed from noun (word-class effect) or letter trials (lexical effect), and secondly, whether different verb types elicited differential activation patterns (unambiguous *vs*. noun-derived *vs*. non-derived). For verb type, we examined whether there were regions supporting the overall effect of ambiguity (ambiguous > unambiguous), and whether this ambiguity network is modulated by zero-derivation (noun-derived > unambiguous, noun-derived > non-derived) or lexical selection (non-derived > unambiguous, non-derived > noun-derived).

We also consider different kinds of ambiguity resolution by examining activation patterns underlying "category and semantic competition" for verbs with multiple related and unrelated representations. For this reason, the experiment included a condition in which verbs entailed both categorical and semantic competitions (such as *to bear* (non-derived)), and verbs with primarily categorical (and less semantic) competition (such as *to brush* (noun-derived)).

<u>Word-class (verbs vs. nouns) effects</u>

The results of the verb and noun comparisons are presented in Table 4.3 and Figure 4.4. The *Verbs versus Nouns* (high-level baseline) contrast revealed a cluster of activation in the left frontal cortex: the Pars Triangularis, Opercularis and Orbitalis of the IFG, and in the left MFG and right Cerebellum. This pattern of activation was similar to what was found when each type of verb was compared separately to nouns. For each verb condition, activation within the left Pars Triangularis was significantly greater compared to the noun condition (p(FDR) < .05). For the *Nouns versus Verbs* contrast a right lateralized network including the SFG/SMA, STG, SMG, Postcentral, Rolandic Operculum, Cingulate and Precuneus was prominent, however, the left STG/Temporal pole also showed significant activation. When nouns were contrasted to each verb type, differences in activation patterns were observed. Activation patterns were consistent in the right hemisphere for nouns > unambiguous and nouns > non-derived verbs contrasts, but activity within the left hemisphere, including the FG, STG, SMG, and Pre/Post-central gyri, was found only for the latter (p(FDR) < .05). No significant activation was found for nouns > noun-derived verbs contrast.

Table 4.3. Areas of differential activation for verbs and nouns. Peak Montreal Neurological Institute coordinates, cluster sizes (*k*), maximal *t*-values, and cluster-corrected (false-discovery error rate) *p*-values are reported (voxel-wise threshold of $p < 0.05$, FDR-corrected, $k > 60$). Notes: L=left hemisphere; R=right hemisphere; AAL=Automated Anatomical Labeling atlas.

Contrast	Hemisphere	Region (AAL)	*Peak coordinates*					
			x	*y*	*z*	k	t	p(FDR-corr)
Verbs > Nouns	L	Inf and Mid Frontal	-54	22	8	517	8.71	0.000
	R	Cerebellum	10	-78	-32	66	5.14	0.015
Nouns > Verbs	L	Supp Temporal, Rolandic Operculum, Temporal Pole	-50	2	2	62	6.61	0.031
	R	Precuneus, Supp Parietal	8	-62	58	911	8.91	0.000
	R	Cingulate gyrus	4	-50	12	67	8.38	0.027
	R	Supp Temporal and Marginal gyri, Postcentral	52	-42	18	349	7.68	0.000
	R	Supp Frontal and Motor areas	14	-2	68	85	5.62	0.011

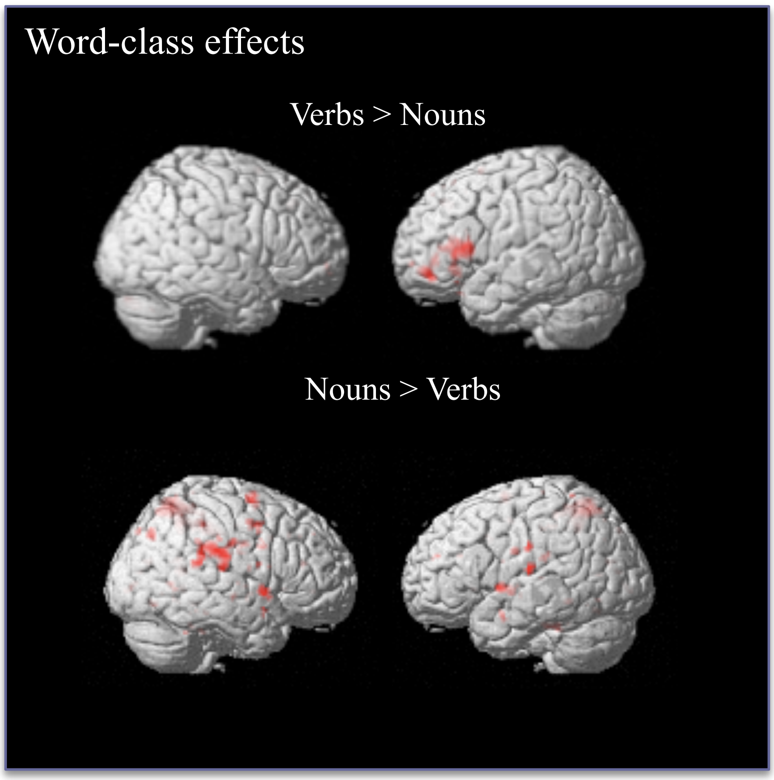

Figure 4.4. Activation maps showing increased activation for the contrasts: verbs versus nouns (top) in the left frontal cortex, and nouns versus verbs (bottom) in the bilateral temporal and the right frontal-parietal areas (p(FDR) < 0.05; k > 5).

Lexical (verbs vs. letters) effects

The results of the verb and letter comparisons are presented in Table 4.4 and Figure 4.5. The *Verbs versus Letters* (low-level baseline) revealed a cluster of activation in the left frontal cortex: the Pars Triangularis, Opercularis and Orbitalis of the IFG, and the MFG. In addition, all verbs also elicited peak activity in the left SFA, SMA, and Precentral gyrus. The opposite contrast, *Letters versus Verbs*, elicited stronger bilateral activation of the parietal-occipital network, including the left FG, SPL, middle and superior occipital gyri, precuneus and cuneus, as well as the right IPL (SMG/AG), MTG, ITG, lingual gyrus and cingulum.

Table 4.4. Areas of differential activation for verbs and letters. Peak Montreal Neurological Institute coordinates, cluster sizes (*k*), maximal *t*-values, and cluster-corrected (false-discovery error rate) *p*-values are reported (voxel-wise threshold of $p < 0.05$, FDR-corrected, $k > 5$). Notes: L=left hemisphere; R=right hemisphere; AAL=Automated Anatomical Labeling atlas.

Contrast	Hemisphere	Region (AAL)	*Peak coordinates*				
			x	*y*	*z*	k	p(FDR-corr)
Verbs > Letters	L	Inf and Midd Frontal	-42	28	-14	802	0.000
	L	Sup Frontal and Motor areas	-16	30	58	275	0.000
	L	Sup Motor Area	-4	10	62	69	0.004
	L	Precentral	-46	4	44	83	0.002
Letters > Verbs	L	Precuneus, Sup Parietal	-4	-62	54	472	0.000
	L	Fusiform, Lingual	-26	-50	-16	285	0.000
	L	Cuneus	-14	-58	20	38	0.045
	L	Midd and Sup Occipital	-30	-84	30	92	0.001
	R	Fusiform, Inf and Midd Temporal and Occipital guri	26	-48	-14	1573	0.000
	R	Inf and Supp Parietal lobes, Postcentral	46	-34	48	323	0.000
	R	Lingual Gyrus	10	-86	-6	41	0.038
	R	Midd and Sup Occipital, Angular gyrus	24	-68	38	219	0.000
	R	Supramarginal gyrus	54	-44	36	110	0.001
	R	Midd Temporal	48	-58	12	51	0.019
	R	Cingulum Mid	2	-38	44	88	0.002
	R	Precuneus	6	-74	40	109	0.001

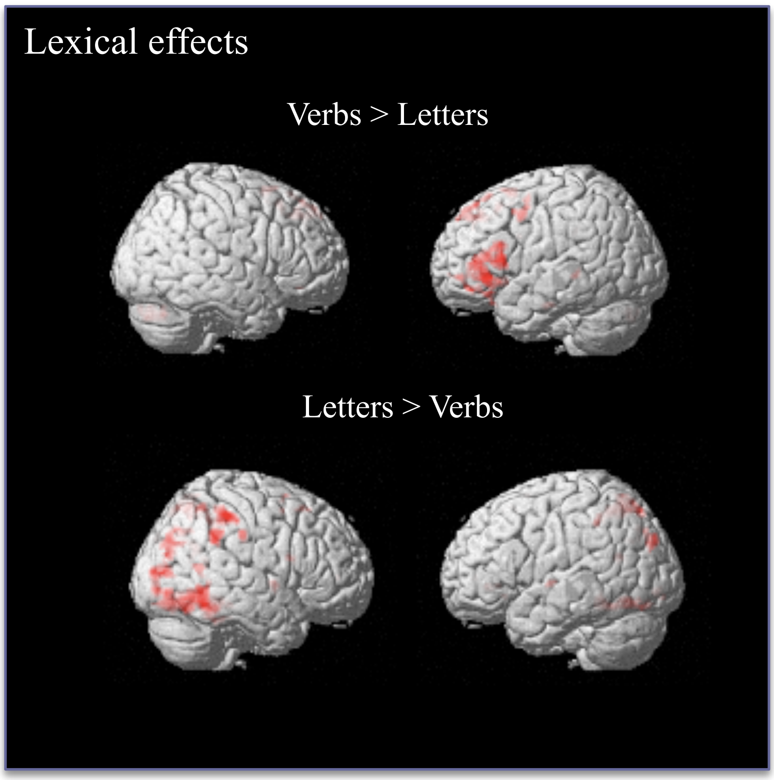

Figure 4.5. Activation maps showing increased activation for the contrasts: verbs versus letters (top) in the left frontal cortex, and letters versus verbs (bottom) in the bilateral parietal-occipital and the right temporal areas (p(FDR) < 0.05; k > 5).

Verb type (unambiguous *vs.* noun-derived *vs.* non-derived) effects

The results of the verb type (whole-brain) analysis are presented in Table 4.5 and Figure 4.6. Testing for the *effect of ambiguity* (ambiguous > unambiguous) resulted in significant clusters in the left IFG (Pars Triangularis and Opercularis), SMA, and inferior parietal (AG) and temporal areas (FG). No significant clusters emerged in the reverse comparison (unambiguous > ambiguous).

The comparison testing for the *effect of derivation* (noun-derived > unambiguous, noun-derived > non-derived) resulted in three clusters (p(unc) > .02). A cluster of activation in the left ITG/FG emerged in the noun-derived > unambiguous comparison, however, right lateralized activation in the STG and FG was found for the contrast noun-derived > non-derived. No activation differences were found for the reverse contrast (unambiguous > noun-derived).

The comparison testing for the *effect of lexical-selection*, including non-derived > unambiguous and non-derived > noun-derived, revealed a cluster of activation in the left pars triangularis of the IFG, though only the former comparison revealed additional clusters including the left MFG, IPL, and the right SFG/SMA and Cerebellum. Right lateralized activation in the STG/AG was found for the reverse contrast unambiguous > non-derived.

Table 4.5. Areas of differential activation for the three verb conditions. Peak Montreal Neurological Institute coordinates, cluster sizes (*k*), maximal *t*-values, and cluster-corrected (false-discovery error rate) *p*-values are reported (voxel-wise threshold of $p < 0.05$, corrected and uncorrected, $k > 19$). Notes: L=left hemisphere; R=right hemisphere; AAL=Automated Anatomical Labeling atlas.

Contrast	Hemisphere	Region (AAL)	*Peak coordinates*			k	t	p(FDRcorr)	p(unc)
			x	*y*	*z*				
Ambiguity effect									
Ambiguous > Unambiguous	L	Sup Motor Area	-6	4	60	45	12.2	0.034	--
	L	Inf Frontal (Pars Triangularis & Opercularis)	-44	10	12	130	6.48	0.000	--
	L	Inf Parietal, Angular gyrus	-34	-50	46	96	11.1	0.002	--
	L	Inf Temporal, Fusiform gyrus	-40	-54	-12	65	5.86	0.010	--
	R	Cerebelum	18	-76	-24	74	7.57	0.007	--
Unambiguous > Ambiguous		None							
Derivation effects									
Noun-derived > Unambiguous (to brush > to bake)	L	Inf Frontal (Pars Triangularis)	-38	26	24	19	5.54	3.750	**0.042**
	L	Inf Temporal, Fusiform	-40	-54	-12	26	5.93	3.900	**0.020**
Noun-derived > Non-derived (to brush > to bear)	R	Supp Temporal	48	-40	18	53	7.29	0.361	**0.004**
	R	Lingual, Fusiform	18	-44	-12	39	7.27	0.503	**0.011**
Lexical- selection effects									
Non-derived > Unambiguous (to bear > to bake)	L	Inf Frontal (Pars Triangularis & Opercularis)	-44	10	12	96	7.19	0.002	--
	L	Inf Frontal, Mid Frontal	-48	46	4	63	5.18	0.012	--
	L	Inf Parietal	-34	-50	46	171	10.1	0.000	--
	R	Supp Frontal and Motor Areas	2	22	54	49	5.16	0.029	--
	R	Cerebellum	20	-76	-26	95	9.51	0.002	--
Non-derived > Noun-derived (to bear > to brush)	L	Inf Frontal (Pars Triangularis)	-46	20	32	24	5.02	0.424	**0.038**
Unambiguous > Noun-derived (to bake > to brush)		None							
Unambiguous > Non-derived (to bake > to bear)	R	Sup Temporal and Marginal/Angular gyri	56	-44	36	108	8.63	0.002	--
	R	Angular gyrus, Occipital	48	-62	26	21	5.39	0.634	**0.032**

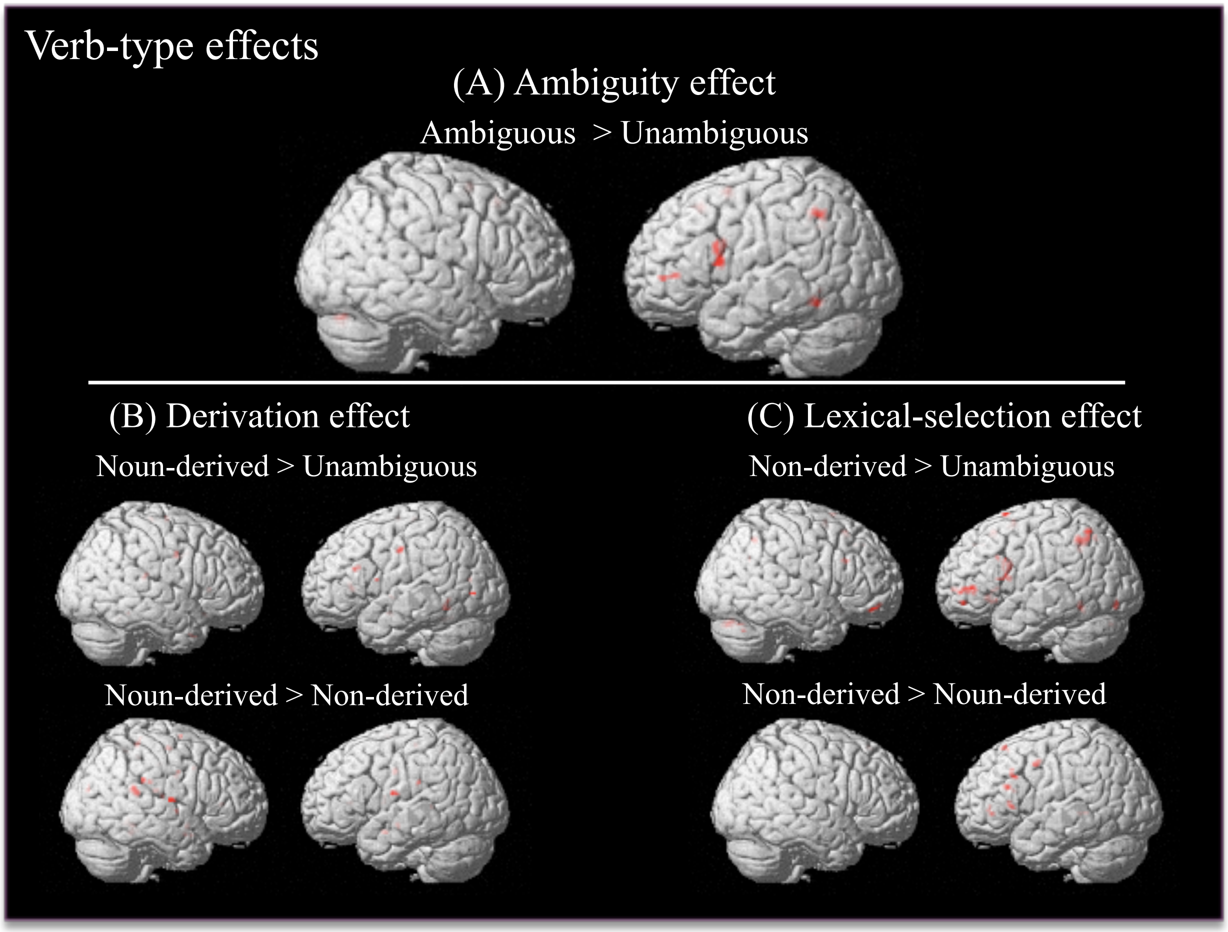

Figure 4.6. Activation maps showing increased activation for: (A) *the effect of ambiguity* in the left frontal, and inferior temporal and parietal areas (p(FDR) < 0.05), (B) *the effect of derivation* in the bilateral fusiform and the right superior temporal area (p(unc) < 0.02), and (C) *the effect of lexical-selection* in the bilateral fontal and left inferior parietal areas (p(FDR) < 0.05).

Region of interest (ROI) analysis: Verb type effects

Regions of significant activation found to be involved in processing of ambiguity were further examined using a region-of-interest (ROI) analysis. The anatomically-defined ROIs were selected using the AAL atlas within Marsbar toolbox in SPM8 and included the bilateral inferior frontal region and inferior, superior and middle temporal regions. The ROI analysis involved the extraction of the blood-oxygen level-dependent (BOLD) signal from each ROI. Therefore, we obtained the mean parameter estimates of the BOLD signal (using SPM mat file from second–level analysis) for the contrast of interest (each verb type vs. low-level baseline) for each ROI.

As shown in Figure 4.7, the ROI analysis revealed that the previously observed (whole-brain) ambiguity effect in the left IFG (see Figure 4.6) was driven by increased activation for noun-derived and non-derived relative to unambiguous verbs (p = .026; p = .008, respectively). Specifically, the left pars triangularis of the IFG exhibited increased activation for non-derived verbs compared to unambiguous (p = .008) and noun-derived verbs (p = .050), and also for noun-derived verbs compared to unambiguous verbs (p = .022). Regarding the temporal regions, the left ITG showed a significant response for the noun-derived and non-derived verbs compared to unambiguous verbs (p = .037; p = .005, respectively). In contrast, the right STG exhibited greater decreased activation for non-derived compared to unambiguous (p = .022) and noun-derived verbs (p = .015). However, neither the left STG nor the right IFG and ITG showed a significant response between the three verb types (p > .05).

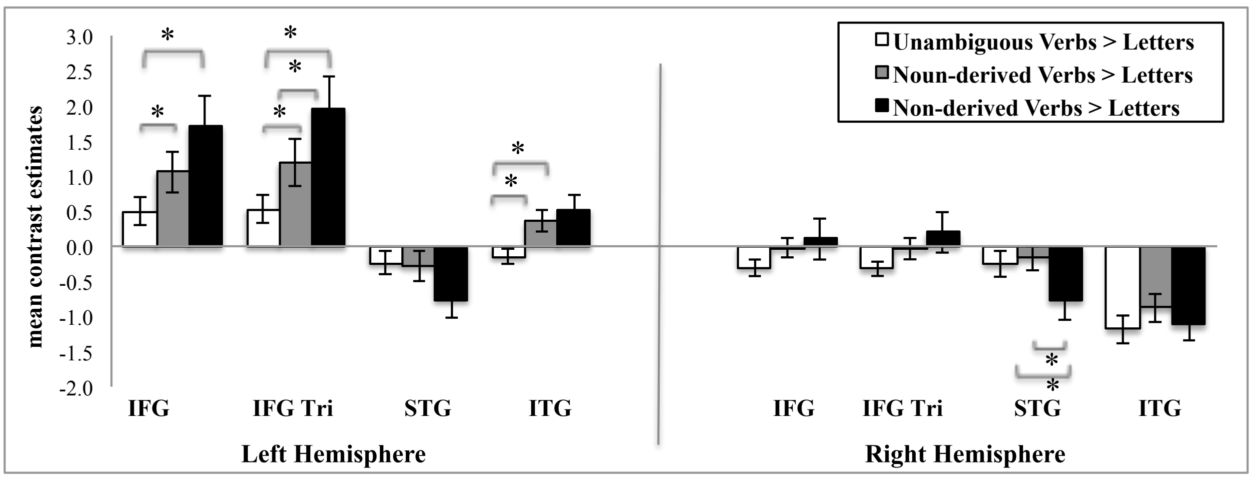

Figure 4.7. Region-of-interest (ROI) results for the three verb conditions relative to the low-level (letter) baseline for the inferior frontal area and inferior and superior temporal areas, bilaterally. Bars represent the standard error of the mean.

Discussion

The present study investigated the neurocognitive mechanisms of verbs (compared to nouns and letters) using an fMRI Grammaticality Judgment Task (GJT). In particular, two competing theories of representation and processing of complex ambiguous verbs, like *brush,* were tested. According to one theory (separate-entry), verbs like *brush* are stored as atomic forms, separately from their corresponding noun, while the other theory (single-entry) suggests that such verbs are derived through computation from the noun. Thus, we compared behavioral and neural patterns to unambiguous verbs (*to bake*), noun-derived verbs (*to brush*), and non-derived verbs (*to bear*). Consistent with previous studies of word processing, verb processing elicited greater left frontal activation, while processing nouns and letters bilaterally activated temporal-parietal and occipital regions respectively. Also, ambiguous forms (*brush* and *bear*) evoked longer response times and greater neural activation in the left inferior frontal and temporal gyri than unambiguous forms (*bake*). Crucially, we observed distinct frontal and temporal neural activation patterns for non-derived vs. noun-derived verbs, suggesting separate and single entry representations, respectively, as explained in further detail below.

Previous studies on healthy individuals, investigating processing correlates of nouns and verbs, have demonstrated a verb disadvantage over noun (e.g., Bogka et al., 2003; Druks et al., 2006; Sereno & Jongman, 1997; Sereno, 1999). In contrast to previous studies, the current study showed that response times to nouns were significantly longer compared to verbs. Differences between the results of the present study and previous ones are perhaps due to the fact that unlike other noun-verbs studies, which mainly employed lexical-decision and picture-naming tasks, this study used a GJT. The task-dependent differences between noun and verb retrieval were demonstrated by Berlingeri et al. (2008). Berlingeri et al. tested the task-by-grammatical-class interaction using the picture-naming task (PNT) and the grammatical-class switching task (GCST). They found faster responses to nouns in the PNT, but faster responses to verbs in the GCST.

Regarding the different verb types, we compared behavioral responses to unambiguous verbs (e.g., *to bake*), noun-derived verbs (e.g., *to brush*), and non-derived verbs (e.g., *to bear*). A gradual increase in the response time was observed: non-derived verbs take longest to process; noun-derived verbs take less time to process; and unambiguous verbs take the least amount of time to process. In addition, responses to non-derived verbs were significantly less accurate compared to unambiguous verbs and noun-derived verbs. These results replicated the previous findings of an ambiguity disadvantage: ambiguous words with multiple representations are recognized more slowly than unambiguous words with only one representation (e.g., Rodd et al., 2002). Importantly, the results demonstrate a significant advantage for verbs that are morphologically related to nouns, compared to verbs that are unrelated to nouns in both response time and in accuracy, which is comparable to the results reported by Rodd et al. 2002 and Berretta et al. 2005. Both studies manipulated homonymy and polysemy in a 2 x 2 factorial design and found that the ambiguity advantage was entirely due to polysemy (words with multiple related word senses, *twist*), and that homonymy (words with multiple unrelated meanings, *bark*) actually delay word recognition.

To summarize the behavioral results, the present study replicated previous findings: an overall ambiguity disadvantage (ambiguous > unambiguous) and semantic relatedness advantage (noun-derived > non-derived). While previous studies investigating ambiguity used a lexical-decision task and included both types of ambiguous words interchangeably, the present study separately tested noun-verb ambiguous words with and without a derivational relation, focusing on the verbal reading of the word by using the minimal syntactic context "to".

Turning to the neural correlates, we found a *word-class effect*, with verbs eliciting greater activation in the left IFG and MFG when compared to nouns, and nouns bilaterally activating the STG and the right SFG/SMA and SPL. Significantly, verb specific frontal activation was observed regardless of verb type. Although previous research examining the neural substrates of nouns and verbs has reported inconsistent findings (Crepaldi et al., 2011, 2013), the present results are consistent with studies that found left frontal activation for verbs and the left temporal activation for nouns (e.g., Cappa and Perani, 2003; Gainotti et al., 1995; Shapiro et al., 2005). While the left IFG activation is thought to represent and process verb-specific information, left STG activation reflects stored conceptual knowledge (e.g., Gainotti et al., 1995; Price, Moore, Humphreys, & Wise, 1997).

To further identify the network of brain regions involved in verb processing, the neural responses to verbs were also compared with the letter-processing baseline (*lexical effect*). Verbs elicited more extensive left frontal activation, including not only the IFG and MFG, but also the SFG/SMA. In contrast to verbs, letters activated bilateral occipital and parietal areas. The left-hemisphere activation in frontal regions for verbs compared to letters is consistent with prior neuroimaging studies of word processing (e.g., Davis, Meunier, & Marslen-Wilson, 2003). Overall, the present study systematically varied the baseline measures and still reliably observed verb-related activity in the left IFG across two baselines (nouns, letters).

Regarding the analysis by the verb type, we first identified the neural network involved in processing ambiguous forms compared to unambiguous verbs, and then determined whether verbs morphologically related and unrelated to nouns modulate this network, using whole-brain and ROI approaches. Three main findings emerged from the whole-brain analysis.

The first finding was the overall *ambiguity effect* observed in the left IFG, SMA, IPL/AG and ITG/FG. Ambiguous forms elicited greater activation in these areas than unambiguous verbs. This result is consistent with previous fMRI studies of semantic ambiguity, which highlighted the importance of the left frontal and posterior temporal cortex in the process of ambiguity resolution (e.g., Binder et al., 2009; Eddington and Tokowicz, 2015; Rodd et al., 2011). While the left IFG plays a role in the initial semantic selection process that is triggered by verbs with multiple representations (Thompson-Schill, Bedny & Goldberg, 2005), the role of the posterior temporal areas is implicated in other aspects of semantic ambiguity, such as the long-term storage of and access to information associated with lexical representations (e.g., Lau, Phillips, & Poeppel, 2008).

Secondly, we found that different verb types modulate the overall ambiguity network. The activation pattern for non-derived verbs like *to bear* compared with unambiguous verbs like *to bake* revealed the distributed network involving the left IFG, MFG, and IPL, and the right SFG/SMA, while *to bear* over noun-derived verbs like *to brush* involved only left IFG. This activation pattern suggests greater demands on selection mechanisms, referred to here as a *lexical-selection effect*. For example, to recognize the verb *to bear*, subjects required extra resources in order to resolve ambiguities and maintain multiple representations, thus activating SFG/SMA areas within the right hemisphere (Mason & Just, 2007; Rodd et al., 2005). It is also suggested that the left MFG activity increases as the strength of association between the words decreases (Thompson-Schill, Bedny & Goldberg, 2005), which is the case for *to bear* in the current study. Finally, a parallel activation found in the IFG and IPL suggests that these regions could oscillate together during visual verb processing. These results are consistent with co-activation within the left IPL, which are shown to be anatomically connected and functionally related to the IFG (Klepousniotou, Gracco, and Pike, 2014).

The activation pattern for noun-derived verbs like *to brush* compared with unambiguous verbs like *to bake* revealed the left ITG/FG, while *to brush* compared with non-derived verbs like *to bear* involved right STG and FG. This activation pattern may suggest that *to brush* is lexically stored as a noun, therefore, reflecting retrieval of the stored noun representation, referred to here as a *derivation effect*. To generate a verb from the corresponding noun involves activation of visual attributes of the object, which may rely more on posterior bilaterally temporal areas. This finding further suggests top-down accessing of visual information (Vitello et al., 2014). However, these results are inconsistent with those reported by Pliatsikas et al. study (2014).

Whereas, Pliatsikas et al. found increased brain activity within the left IFG for derived verbs like *brushing*, the present study showed derived verbs to be activated in the posterior rather than frontal areas of the brain. It should be noted that the test used to categorize derived verbs differed across studies. To classify derived verbs, Pliatsikas et al., used the 9-point scale questionnaire and categorized them based on primacy of object and action meaning, whereas we used linguistic tests designed explicitly to categorize zero-derived words (Myers's Root Suffixation 1984 and Clark & Clark 1979 Tests). Unlike linguistically controlled tests used in our study, the rating questionnaire used by Pliatsikas et al., could not distinguish the directionality of derivation. For instance, verbs like *trim* and *brush* were both used as an example of derived verbs, whereas only the latter is consider a verb derived from a noun according to the linguistic tests. Thus, it is possible that increased activity within the left IFG in Pliatsikas et al. reflected the cost of lexical-selection, but not zero-derivation, as suggested by the semantic ambiguity literature.

In addition to the whole-brain results discussed above, we also reduced the search volume using an ROI approach and analyzed the neural responses to each verb type relative to the low-level (letter) baseline within ROIs implicated in ambiguity processing. The ROI results revealed the gradual activation within the left pars triangularis of the IFG and ITG for three verb types (non-derived > noun-derived > unambiguous). However, deactivation within the right STG and ITG was greater for non-derived, lesser for unambiguous, and the least for noun-derived verbs. The ROI results confirmed that the role of left IFG might become increasingly necessary as semantic relations between noun and verb forms of the ambiguous word become weaker.

A multi-voxel pattern analysis (MVPA) can be performed on the fMRI dataset, in addition to the standard GLM analysis which was performed. While the conventional univariate analysis measures involvement of a region in a certain process (localization), MVPA measures representational content via pattern information (Raizada & Kriegeskorte, 2010). MVPA uses a machine-learning algorithm to train a classifier to distinguish between experimental conditions, and thereby associate patterns of activation across voxels to each experimental condition. MVPA is sensitive to fine-grained spatial pattern differences in the absence of regional-average differences, which is important for analysis of subtle linguistic processes. Thus, MVPA will allow us to detect differences between verb conditions with higher sensitivity than conventional univariate analyses.

Overall, this study demonstrated greater activation for verbs (compared to nouns and letters) in the left frontal cortex, previously presented in other studies of verb processing. Moreover, using well-controlled verb set, consisting of either single or multiple (noun-verb) representations, the results showed a behavioral and neural processing cost for verbs with multiple representations. Interestingly, the two distinct neurocognitive processing profiles for verbs with multiple lexical representations were observed. This is exemplified by the difference in response times and activation patterns between verbs like *to bear* and *to brush* in the current study using an fMRI GJT. The neurocognitive processing difference between *to bear* and *to brush* can be explained in terms of the structure of their lexical representations: in the former the two co-activated lexical representations compete for selection, while the latter are derived on-line from the noun rather than stored. These findings contribute to our understanding of the neurocognitive basis of word processing.

Chapter 5. General Discussions and Conclusions

This dissertation investigated the cognitive and neural distinction between nouns and verbs by studying the processing of categorically ambiguous words. The two forms (noun/verb) of the ambiguous word could be listed, according to two competing representational theories, under a single lexical entry or separately in the mental lexicon. Across three studies, similarities and differences are addressed as to the way noun/verb forms are represented and processed in healthy and aphasic individuals. The overall hypothesis is that different (or additional) cognitive and neural mechanisms are implicated in the representation and processing of each type of form.

5.1. Summary of dissertation studies

Study 1, *The role of Argument Structure and Zero-Derivation in Lexical Processing,* addressed the question of whether argument structure or morphological properties of lexical entries impact word access, specifically, when the word has two lexical representations. Healthy young participants performed a grammaticality judgment task (GJT) on word pairs (e.g., the/to *brush, bite*) that varied in argument structure (experiment 1), or morphology (experiment 2), while controlling for length and frequency (see Figure 2.2). We hypothesized that complexity in terms of argument structure and/or morphology could affect the processing of nouns and verbs, in line with previous work on argument structure and semantic complexity (see 1.1.2 section).

This study resulted in two findings, which highlighted factors underlying processing costs:

i. Experiment 1 revealed a grammatical category effect (*nouns* > *verbs*). Contrary to previous studies, processing cost was associated with nouns more than verbs even when nouns and verbs were matched on argument structure. Thus, the higher complexity of verbs does not necessarily explain differential processing of *categorically ambiguous* nouns and verbs.

ii. Experiment 2 revealed a zero-derivational morphology effect (*derived forms* > *base forms*), suggesting that the morphological properties of words affect lexical processing both within and across grammatical categories, accounting for the overall category effect in the current study.

Previous studies on healthy individuals, investigating noun and verb processing have demonstrated a disadvantage of verb over noun processing in terms of response times. However, numerous factors are involved in lexical retrieval. The contribution of the present study is the systematic examination of the role of two factors, argument structure and morphology, in word-class processing using categorically ambiguous nouns and verbs. The present study provides evidence that the critical property distinguishing two forms (noun, verb) of an ambiguous word is zero-morphology, whether it denotes a base or derived form. Accordingly, the study demonstrates that processing derived forms of ambiguous words requires activation of the base form, which results in greater processing demands. Yet, one could argue that the morphological effect in this study relates not to derivation per se, but instead reflects the cost of semantic ambiguity (i.e., co-activation of the multiple meanings). However, if these results reflect ambiguity cost, this cost would also emerge in the opposite direction, slowing processing time for base forms, as well as derived forms. Therefore, semantic ambiguity alone cannot capture the differences between noun and verb forms of ambiguous words in this study (see Figures 5.1 and 5.2 on the implications of these data for models of word recognition). To further understand the morphological computations underlying word-class processing, we next examined how healthy and aphasic individuals process base and derived forms of categorically ambiguous words.

Study 2, *The role of Zero-Derivation in Normal and Impaired Lexical Processing,* tested the base-form bias effects in unambiguous (*bell, bake*) and ambiguous nouns and verbs (*brush, bite*) in healthy and aphasic individuals, using a forced-choice response paradigm. The single-entry hypothesis postulates that if noun and verb forms of ambiguous words like *brush* and *bite*, are listed under a single lexical entry, with one being derived upon the other, then a difference in selection rates of *the* and *to*, respectively can be expected. Conversely, separate-entry hypothesis suggests that if ambiguous words like *brush* and *bite*, entail separate lexical entries for noun and verb forms, and no morphological process is involved, then no difference in selection rates of *to* and *the* can be expected.

In terms of representation (reflected by selection rates), two key findings emerged:

i. For both healthy and aphasic participants without verb deficits, a noun bias (selection of *the*) for noun-based words, and a verb bias (selection of *to*) for verb-based words, was found. This base-form bias effect found in both participant groups supports the single-entry hypothesis, in that words like *brush* and *bite* are listed under a single lexical entry, nominal and verbal, respectively.
ii. Aphasic participants with a verb deficit showed a noun bias, but not a verb bias. Furthermore, impaired access to the base verb form precluded retrieval of the derived noun form (as in *bite*). This finding suggests that derivational processes per se are not impaired but, instead, the retrieval of verb-derived nouns is affected by a selective verb production deficit.

In terms of processing (reflected by response times), the following findings emerged:

i. Across two groups of participants (healthy and aphasic), the present study revealed that processing cost was associated with verbs more so than nouns, and with ambiguous words more so than unambiguous words, suggesting that lexical complexity is reflected in processing time across groups.

ii. Compared to the unambiguous condition, the ambiguous condition yielded a larger processing time for nouns, while less or no time difference was observed for verbs between the two conditions.

This study contributes to research on normal lexical processing by providing empirical evidence that zero-derivational processes are crucially involved in lexical access. These data also suggest that people possess implicit morphological knowledge about basic versus derived forms when processing ambiguous words. The processing cost for verbs compared to nouns exhibited for aphasic and healthy participants is consistent with previous data on healthy individuals, and also with the few published noun-verb studies of aphasic individuals in which reaction time data were obtained (e.g., Bogka et al., 2003 and Székely et al., 2005 with healthy English speakers; Matzig et. al., 2009 with aphasic speakers). The present study also extends knowledge about word-class deficits in aphasia to categorically ambiguous words using a novel experimental paradigm, in place of picture-naming, which has been used as the primary task in previous studies of word processing in aphasia. Overall, these findings contribute to current theories of lexical processing (see sections 5.2. and 5.3). Having addressed the psycholinguistic dynamics of zero-derivation, we next asked if this morphological process relies on a spatially defined neural network.

Study 3, *Neurocognitive Correlates of Verbs: Zero-Derivation versus Lexical-Selection costs,* examined the neurocognitive mechanisms responsible for computational and representational properties of verbs (compared to nouns and letters) using functional magnetic resonance imaging (fMRI) and a grammaticality judgment (GJT) task. Specifically, this study addressed the question of whether distinct neural mechanisms are engaged for morphological and lexical-selection processes, and whether, in turn, multiple representations of verbs like *brush* and *bear*, support a single- or separate-entry hypothesis. As such, response times and neural activation patterns to unambiguous (e.g., *bake*), noun-derived (e.g., *brush*) and non-derived verbs (e.g., *bear*), were compared. We hypothesized that different brain areas support the different cognitive sub-processes, i.e. morphological versus lexical-selection processes.

In terms of neurocognitive correlates, two key findings emerged:

i. The word-class effect (*nouns versus verbs*) revealed increased processing times for nouns compared to verbs, with left lateralized fontal lobe activation for verbs and bilateral temporal lobe activation for nouns. These data support the claim that verbs and nouns are processed by separable neural systems, i.e., frontal versus temporal, lateral versus bilateral, as originally hypothesized by Gainotti et al. (1995). Also, the greater processing cost for nouns observed (which was also found in Study 1) may partially reflect previously described task-dependent differences during noun and verb processing (e.g., Berlingeri et al., 2008; Burton et al., 2009).

ii. The verb-type effect (*ambiguous versus unambiguous*) revealed increased processing times for ambiguous verbs despite their derivational status. Compared with unambiguous verbs (*bake*), ambiguous verbs like *brush* and *bear* required both greater processing time and additional left frontal-temporal network activation. Among ambiguous verbs, non-derived verbs (*bear*) required greater processing time and yielded more distributed left lateralized frontal lobe activation than noun-derived verbs (*brush*). These noun-derived verbs instead elicited bilateral temporal lobe activation.

Taken together, these data provide insight into the neurocognitive processing system with the primary focus on categorical ambiguity. Crucially, the data identify a mechanistic dissociation between the processing of non-derived and noun-derived verbs. Non-derived verbs require domain-general cognitive control and selection processes of two distinct lexical entries (e.g., Binder, 2004; Thompson-Schill, et al., 1997), while noun-derived verbs require lexical access of the base-form (noun). These two processes are implemented in distinct neural substrates: left fronto-parietal for non-derived verbs and bilateral temporal for noun-derived verbs.

5.2. Implications for models of lexical/sentence processing

This section discusses the implications of these findings for several prominent models of word production, lexical processing and sentence processing. Can serial and/or interactive models of lexical processing account for the findings derived from the three studies? That is, do such processing models account for differential processes engaged for ambiguous and unambiguous words?

Briefly, **the serial model of word spoken production** (see Levelt, Roelofs, & Meyer, 1999; Chapter 1) assumes that production of a word proceeds through stages of conceptual preparation, grammatical (lexical selection), morphological and phonological encoding, phonetic encoding, and articulation. In parallel there occurs output monitoring involving the speaker's normal speech comprehension mechanism. In this model, one or more lexical concepts and the associated lemmas are activated. Once a lemma has been selected, the corresponding sublexical units begin to be activated. If several lemmas are selected more or less at the same time, then several sublexical units are activated in parallel and selected sequentially (Meyer, A. S., 1996). Accordingly, in a production task, it can be hypothesized that the concept node of 'brush' activates the two lemma nodes of *the brush* and *to brush.* Although, multiple stored representations are activated in parallel, the selection of the most likely representation is governed by lexical factors (e.g., frequency, semantic congruency). However, this was not the case in the current studies, as demonstrated by base-form bias effects (Study 2), even after controlling for those lexical factors known to affect word processing.

The interactive activation model of visual word recognition (see Chapter 1 for more detailed description) assumes distributed lexical representations, where each word is represented as a unique pattern of activation across orthographic, phonological and semantic units. In the case of ambiguous words with multiple lexical candidates, the input is associated with multiple representations. These competing representations interfere with each other, which increases the time it takes for a stable pattern of activation to be accomplished (Rodd et al., 2000). Additionally, the semantic (higher) level of representation can feed back and induce constraints on the orthographic/phonological (lower) level of representation. According to this model, the word is selected from the multiple candidates through competition and inhibitory connections.

Though interactive models do not specifically refer to category ambiguity, one can assume that these cases are treated in the same way as semantic (multiple meanings) ambiguity. In interactive systems, the two forms of ambiguous words are retrieved. Therefore, both forms (noun, verb) of the categorically ambiguous word are activated during the recognition process, and competition between the noun and verb forms should have a similar influence on word recognition when the ambiguous word is used as a noun or a verb, provided the two forms do not differ on other dimensions, e.g. frequency (as indeed was the case in the current study).

However, this was not borne out in the current studies, as demonstrated by delayed recognition for derived over base forms (Study 1), and base-form bias effects (Study 2). That is, healthy participants showed a noun bias (i.e., selection of *the*) for unambiguous (*bell*: 98%) and ambiguous nouns (*brush*: 59%), and a verb bias (i.e., selection of *to*) for unambiguous (*bake*: 97%) and ambiguous verbs (*bite*: 65%). The greater processing speed observed for derived forms of the ambiguous word in Study 1 (*derivational morphology effect*) corresponded to greater selection rates of *the/to* for the base form of the ambiguous words in Study 2 (*base-form bias effect*) (e.g., longer response time for *to brush*; greater selection rate for *the brush*). This pattern cannot be explained solely as a result of co-activation and competition between different representations of words in the interactive activation system.

In **the constraint-based lexicalist model of sentence parsing** (Boland & Blodgett, 2001; see also MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell, Tanenhaus, & Garnsey, 1994), when a parser encounters a point of ambiguity during sentence processing, there are three distinct stages: (1) *generation* of syntactic structures, (2) *selection* of a single structure, and (3) *reanalysis*. At the first stage, a word will generate several alternative syntactic forms that compete for selection. Then, during the second stage, discourse constraints can be used to select among those alternatives. Thus, discourse constraints cannot influence the set of syntactic alternatives that is generated, but can guide selection of the most likely syntactic structure. The constraint-based account by Boland and Blodgett (2001) clearly draws a distinction between syntactic generation and syntactic selection during sentence parsing. Finally, reanalysis is done if the structure initially selected is incorrect. However, similar to word processing models, competing selection between the noun and verb forms should have a similar influence on word recognition when the ambiguous word is used as a noun or a verb.

We therefore see that all models predict a symmetrical behavior of the noun and verb meaning of an ambiguous word (provided they are controlled for relevant lexical factors), in contrast to the findings in the current experiments. No model takes into account the derivational status of the two categories. The question remains as to how these forms are represented and, in turn, how the processing system selects from multiple categories.

There are two possible scenarios for processing ambiguous words. Considering a view of semantic ambiguity resolution and above models, if two forms of an ambiguous word are represented as separate semantic nodes, then no differences in response times or selection rates would be expected for the verb and the noun. However, if morphology is considered, in that one form is derived from the other form, then asymmetry in processing two forms would be expected. Morphology-based accounts advocate that ambiguous words are represented both as whole-forms and derived words (Giraudo & Grainger, 2000; Taft, 1994; see also Marslen-Wilson, Tyler, Waksler, & Older, 1994 on semantically transparent forms like dark-darkness). Therefore, ambiguous words could be stored as single entries and could be either derived from a noun (*the base form*) to become a verb (*the derived form*) (e.g., [$_{N}$ *brush*] -- > [$_{V}$ *brush*]) or from a verb to become a noun (e.g., [$_{V}$ *bite*] -- > [$_{N}$ *bite*]).

Given the above accounts, a plausible account of how the human mind processes categorically ambiguous words must consider representation and processing differences of two (noun/verb) forms. Here, **the word-class processing model** is delineated as distinguishing between the noun/verb forms of an ambiguous word. The model consists of four types of independent but highly interactive processes: (1) the lexical access which takes place in the *lexicon* unit (2) the phrase structure building (triggered by context *the/to*) in the *syntax* unit, (3) the process of lexical reanalysis, and (4) the lexical formation rule in the *morphology* unit. Each of the four processing stages performs its own computation, but also interacts with the others in a bidirectional fashion. Inputs and outputs are not modality-specific and can be provided either visually or auditorily (see Figure 5.1).

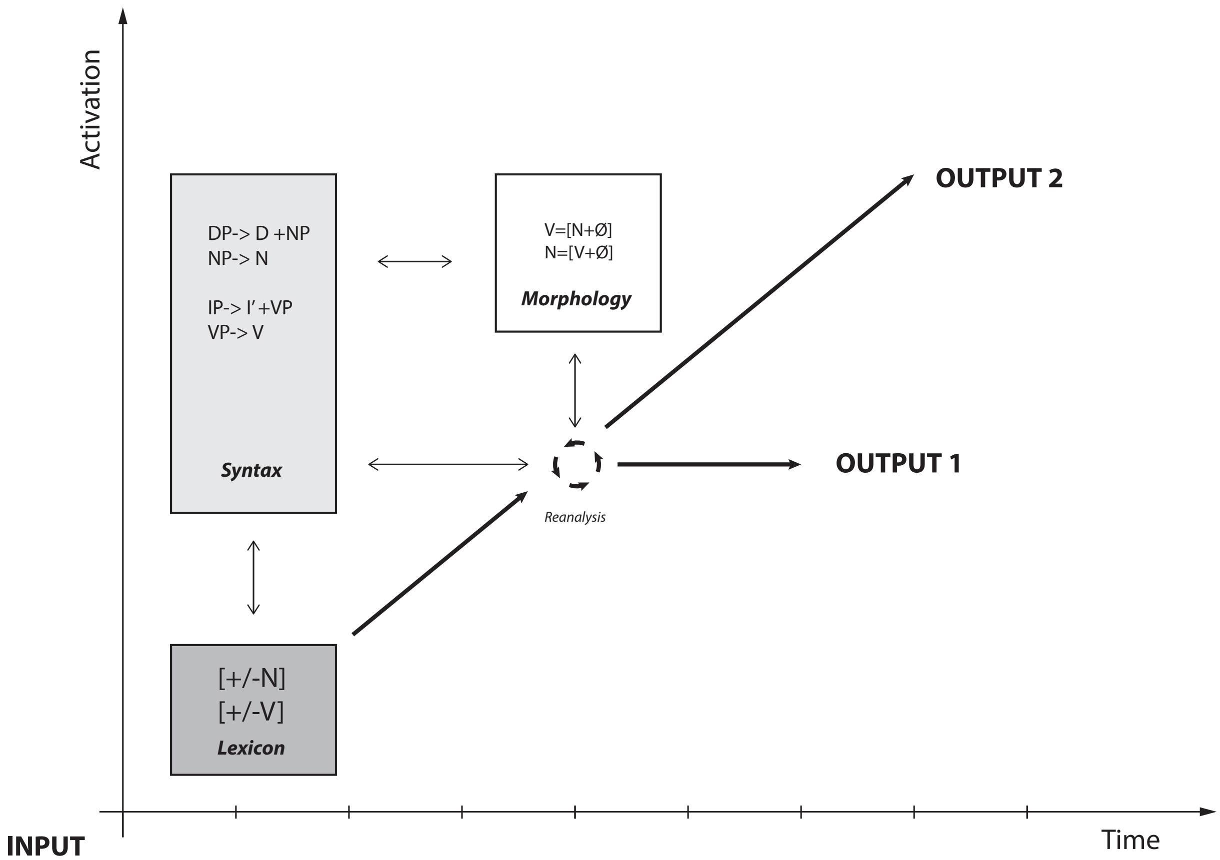

Figure 5.1. A schematic view of the word-class processing model.

In this model, first the lexical items that set up the syntactic contexts are processed. "the" projects the nominal phrase, (determiner phrase (DP)), and "to" projects the verbal phrase (inflectional phrase (IP)) (**Step 1**). Next the base-form of a lexical item is accessed from the lexicon (**Step 2**). The parser attempts to integrate the lexical item into the existing syntactic context. When the base form of the lexical item is a noun and there is a verbal syntactic structure, then there is a mismatch between the category of the lexical item and the category of the terminal node that the lexical item could be inserted (**Step 3**). Upon encountering this mismatch between the category of the lexical item and the terminal node, the parser initiates a reanalysis, and converts the category of the lexical item from a noun to a verb, by means attaching the zero-morpheme (ø) (**Step 4**). Finally the lexical item that underwent the zero-derivation process is integrated into the syntactic structure (**Step 5**). Accordingly, when processing a verb from the corresponding noun (*brush*) or a noun from the corresponding verb (*bite*), a direct link from the derived form to the base form is generated, sharing both nominal and verbal properties. Figure 5.2 illustrates the time course of how the structure of zero-derived verbs is built and integrated into the syntactic context.

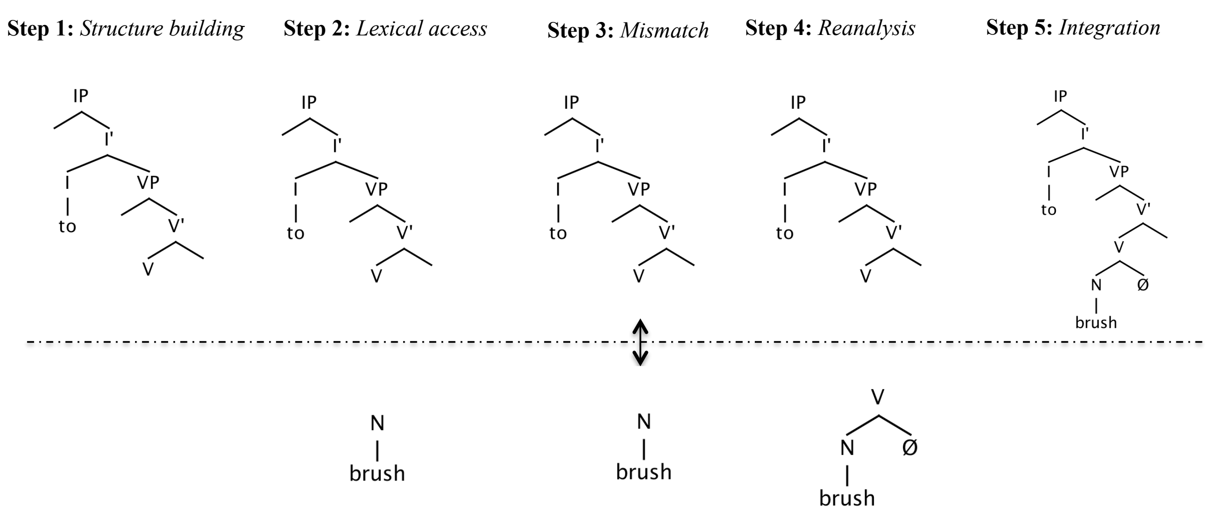

Figure 5.2. The time course of zero-derived verbs.

Let us briefly provide an example of different ways in which three types of noun-verb pairs are processed in the proposed framework. In the pairs *to brush-the brush* and *to bite-the bite*, the noun and the verb, respectively are considered as basic inputs. Accordingly, the noun-derived verb *to brush* necessarily implies the use of *the brush*, while *to bite* does not involve the use of *the bite*. Similarly, the verb-derived noun *a bite* necessarily implies a biting event, while noun *the brush* does not involve the brushing event (see Don, 2005). Conversely, in pairs such as *to bear-the bear*, neither a noun nor a verb necessarily implies the use of other.

Within the proposed model, when people encounter the word *brush* they access lexical representation from the lexicon (base-form noun), and accordingly project a nominal structure. If the word appears in a nominal syntactic structure of the word (NP or DP), then the word is integrated into an existing nominal syntactic structure without any further processes (output 1). However, if the word *brush* appears in the verbal syntactic context "to", then the activated nominal base-form needs to be reanalyzed to accommodate the verbal node. The base-form noun undergoes the process of zero-derivation, in that a verbal zero-suffix is attached yielding the derived form (output 2). Similarly, when people encounter the word *bite,* they access lexical representation from the lexicon (base-form verb), and accordingly project a verbal structure. If the word appears in a verbal syntactic structure of the word (VP or IP), then the word is integrated into an existing verbal syntactic structure without any further processes. However, if the word *bite* appears in the nominal syntactic context "the", then the activated verbal base-form needs to be reanalyzed to accommodate the nominal node. The base-form verb undergoes the process of zero-derivation, in that a nominal zero-suffix is attached yielding the derived form (output 2).

According to the experimental results, derived forms have a more complex structure and are less accessible than base forms, because when an ambiguous word is encountered in its base form, only the base lexical form is accessed and the minimal (simplest) structure (nominal: $[_{DP}[_{D'}$ the $[_{NP}[_{N'}$ brush]]]] or verbal: $[_{IP}[_{I'}$ to $[_{VP}[_{V'}$ bite]]]]) is always produced (output 1). On the other hand, when the derived form is built, both the derived form and the base form are built, producing a more complex derived structure (noun-derived: $[_{IP}[_{I'}$ to $[_{VP}[_{V'}[_{N}$ brush+ø]]]]] or verb-derived: $[_{DP}[_{D'}$ the $[_{NP}[_{N'}[_{V}$ bite+ø]]]]]). Thus, processing derived forms of an ambiguous word entails more complex computations than base forms, involving more widespread activation; therefore, more time is required for a derived word to be processed. This accounts for the pattern of results obtained in Study 1 and 2.

Lastly, when people encounter the word *bear,* they access multiple lexical representations from the lexicon (a noun and a verb), and project both structures. Thus, irrespective of the syntactic context (the or to), both the noun and verb representations are activated, and the lexical form that is not compatible with the given syntactic context needs to be inhibited. The processing of non-derived multiple forms of an ambiguous word entails more complex computations than those of base or derived forms, likely due to co-activation of multiple syntactic frames and an inhibition process (e.g., top-down control), and thus extra resources are needed for the word to be processed. In turn, a graded processing cost for the three noun-verb pairs (non-derived multiple form > derived form > base form) observed in Study 3 could reflect differential mental processes as highlighted above. Thus, although the proposed model predicts increased processing difficulty whenever the simplest structure needs to be reanalyzed (as in a derived form), in the non-derived form, the cost of selection process is greater than reanalysis process.

The new empirical evidence presented in this thesis was used to evaluate models of word recognition as well as parsing model, and showed that none of them can fully capture performance differences between two forms. The interactive model of word processing coupled with insights from morphology can best explain the results from current studies (as proposed in the model outlined above). As such, the model proposed here incorporates insights from several influential models, yielding a word-class processing model that could account for the current results. Yet, more data are needed to address the time course of lexical access of the two forms (noun/verb) and elucidate whether multiple lemmas activate two forms in parallel, and how generation and selection processes are accomplished. Nevertheless, the results of current studies add to the growing body of evidence indicating that explicitly derived words have structured representations, and that morphology influences lexical processing (Marslen-Wilson, Tyler, Waksler, & Older, 1994; Lehtonen, Monahan, & Poeppel, 2011).

Turning to the neural underpinning of lexical category processing as reflected in the results of Study 3, interactive models of word recognition predicts two effects of ambiguity, both of which were observed: a processing cost for ambiguous over unambiguous words and a processing benefit for ambiguous words with related meanings compared to unrelated meanings. In the case of ambiguous words, multiple semantic candidates are elicited since both a noun and a verb alternative are available for selection. However, for unambiguous words, only a noun or a verb representation is activated and available to be selected. Therefore, on this model, interference between different representations of an ambiguous word would delay their recognition relative to an unambiguous word.

The *ambiguity effect* from the current study supports this claim, as reflected by ambiguous verbs (such as *brush* and *bear*) eliciting longer response times when compared with unambiguous verbs (*bake*). The interactive model further claims that unrelated representations are stored in different parts of semantic space and compete with each other for activation, while multiple senses or related representations are stored within a single region of the semantic space and combine to form a single stable pattern of activity (see Rodd, Gaskell & Marslen-Wilson, 2004 for a detailed discussion of this). The *verb-type effect* from the current study supports this claim, as reflected by longer response times for non-derived ambiguous verbs like *bear* compared to noun-derived verbs like *brush*.

However, the two verb types also recruited neural resources in distinct brain regions. The behavioral and neural separation for the two verb types could be due to the fact that the study focused on categorical ambiguity, only including noun-verb ambiguous stimuli. In the domain of categorical ambiguity, two competing accounts have been proposed to explain verb-type-specific processing cost. One account posits separate lexical entries (i.e., *the* brush and *to* brush for the noun-derived verb *brush*), and argues that greater selection demands are required for lexical items with multiple entries (e.g., Grindrod et al., 2014; Jackendoff, 1976). The other account assumes that only the noun is stored, and processing cost reflects online zero-derivation of the verb from the noun (e.g., Pliatsikas et al., 2014). Accordingly, if noun-derived verbs entail separate lexical entries, as assumed in the first account, activation patterns similar to those seen for non-derived verbs would be expected, reflecting lexical selection demands. In contrast, if noun-derived verbs are formed from a single stored noun representation, then non-derived verbs would elicit greater activation compared to noun-derived verbs in regions involved in lexical selection. The increased activity found within the left frontal cortex for non-derived verbs (e.g., *bear*) compared to noun-derived verbs (e.g., *brush*) suggest the existence of multiple entries for the former, but not for the latter. This supports the hypothesis that verbs like *brush* are derived on-line from the noun rather than stored independently.

These results are consistent with the neural interactive model by Carreiras, Armstrong, Perea, and Frost as shown above (2014; see Chapter 1), as well as with the neuroanatomical model for semantic processing posed by Lau, Phillips and Poeppel (2008). The effect seen for non-derived verbs like *bear* in the left frontal and parietal areas likely reflects selection/retrieval and semantic integration processes, respectively. Whereas the effect found for noun-derived verbs like *brush* in the bilateral temporal cortex reflects lexical access. While non-derived verbs like *bear* required top-down control of co-activated, distinct noun and verb representations and, hence engender inhibition of the unintended form, noun-derived verbs like *brush* entail activation of the stored noun-derived object (e.g., tool) only, which triggers morphological processes required to derive the verb form, and no inhibition is required.

5.3. Implications for word-class impairments in aphasia

Some studies focusing on verb production deficits in aphasia have investigated whether categorically ambiguous words affect verb production in individuals with agrammatic aphasia, and have yielded inconsistent results. While some show a facilitative effect of semantically and phonologically related nouns on verb retrieval (e.g., Jonkers and Bastiaanse 1996, 1998; Kambanaros and van Steenbrugge, 2006; Kemmerer and Tranel, 2000; Park et al., 2013), others have found no facilitation effect on the retrieval of words (e.g., Caramazza and Hillis, 1991, Hillis and Caramazza, 1995). Caramazza and Hillis (1991) showed that in naming tasks some aphasic individuals are able to produce a particular phonological form as a noun (e.g., a *crack*) but not as a verb (e.g., to *crack*), or vice versa. These findings suggest that when processing ambiguous words, the ability to retrieve the phonological form of one category does not necessarily facilitate the retrieval of another category.

Conversely, in their early English study, Kemmerer and Tranel (2000) found that some aphasic participants produced instrumental verbs (e.g., *brush*) significantly better than non-instrumental verbs (e.g., *sew*) in a picture-naming task. Similarly, Park et al., (2013) examined effects of conceptual (instrumentality) and lexical form (homonymy) relationships between nouns and verbs on verb production and discussed how these relationships might influence the response to treatment in three individuals with Broca's aphasia. The stimuli included verbs that use an instrument and those that do not (e.g., *to sweep* vs. *to yawn*), verbs that have the same lexical form of a noun (e.g., homonymous verb: *to hammer*), and verbs that are phonologically related (e.g., *to grind – a grinder*) and unrelated to nouns (e.g., *to lean*). Participants in the Park et al. study were required to produce verbs in sentences in response to picture stimuli before and after a four-week Constraint-induced aphasia therapy. Participants produced more accurate instrumental than non-instrumental verbs both pre- and post-treatment, and homonymous verbs compared to phonologically related and unrelated before treatment.

These data suggest that differences in the production of verbs like *brush* and verbs like *sew* in aphasia, may be interpreted in light of the differences in their underlying representations. Verbs like *brush* are categorically ambiguous, having both noun and verb forms, which are closely related, and stored as a unit, while no apparent connection between noun and verb form exist in verbs like *sew*. Thus, verbs like *brush,* which necessarily implies the use of a noun (tool) may be easier to retrieve for aphasic individuals than verbs not entailing a noun representation.

While most previous studies of word class deficits in aphasia, featuring categorically ambiguous words, have examined whether aphasic individuals with a verb deficit also present with verb related to nouns deficits (such as *to brush – the brush*), the current study examined verbs and related nouns that denote not just a concrete entities (e.g., *brush*) but also events (e.g., *bite*). Importantly, previous studies have not considered the fact that the relation between some noun and verb forms is derivational, that is, one form is derived from the other. Study 2 included two groups of aphasic participants, one with and one without verb deficits, based on their noun and verb production abilities, and tested them on morpho-semantically and phonologically related noun and verb forms by taking into account the directionality of morphological derivation. The results showed that aphasic participants without a verb deficit, similar to healthy participants, showed base-form bias effects: a noun bias (selection of *the*) for noun-based words, and a verb bias (selection of *to*) for verb-based words. In contrast, agrammatic aphasic participants with a verb deficit demonstrated only a noun bias for noun-based words, but demonstrated chance performances on verb-based words. These results persisted even after the inclusion of additional lexical factors, such as length and frequency, as well as language severity, in our analysis. Although these lexical factors significantly contributed to the ability of agrammatic aphasic participants to retrieve verbs, these factors could not account for the performance of participants on the study task.

Can the performance of aphasic individuals with and without verb deficits inform models of ambiguous word representation and processing? Greater selection rates of *the* and *to* found for ambiguous nouns (*brush*) and verbs (*bite*), respectively, in aphasic participants without a verb deficit support a single-entry hypothesis, suggesting that ambiguous words are categorically stored as base forms, and that derived forms are computed on-line rather than stored. Moreover, impaired access to the base form (i.e., verbs, as in *bite*) prevents retrieval of the derived form (i.e., noun) in aphasic participants with a verb deficit. Our findings suggest that noun and verb forms of ambiguous words like *brush* and *bite* have the same single entry representation, rather than having separate entries.

What does the performance patterns of agrammatic aphasic individuals tell us about the underlying mechanism(s) associated with differential deficits in verb and noun processing? The nature of word-class deficits in aphasia has been, and continues to be, greatly debated past. As outlined in the introduction, several possible interpretations of verb deficits have been advanced, including *lexical* (e.g., objects versus actions) and *syntactic* (e.g., argument structure, grammatical category) hypotheses. Results of the current set of studies are not consistent with a *lexical hypothesis*, which claims that verb production deficits result from impaired semantic representations. The lexical hypothesis assumes that verbs refer to actions, and that verb deficits arise as a consequence of damage to or loss of functional-motor features (e.g., Vinson & Vigliocco, 2002). On this account, patients with verb deficits should not select the action reading of ambiguous nouns like *brush*. However, this pattern was not forthcoming in the present data set, that is, findings from Study 2, as reflected by a difference between processing of unambiguous nouns (*bell*) and ambiguous nouns (*brush*). In the case of unambiguous nouns, our agrammatic aphasic individuals almost exclusively selected base (object) form since this is the only interpretation available for selection. However, in the case of ambiguous nouns, selection of both object and action reading was frequent, suggesting that both base (object) and derived (action) forms are accessed. Also, the presence of processing cost (longer RT) for ambiguous nouns (*brush*) compared to unambiguous nouns (*bell*) confirms that participants access both object and action interpretations, when processing ambiguous nouns.

Moreover, if semantic factors (multiple meanings) influence processing performance of verbs, then patients with verb deficits (i.e., agrammatic aphasic participants) should show dissociated impairment on different verb types (i.e., ambiguous versus unambiguous). The present study demonstrated that our agrammatic aphasic participants showed difficulty in retrieving both types of verbs, suggesting a grammatical category specific deficit. In addition, our agrammatic aphasic participants showed difficulty with derived nouns, supporting the view that the mental lexicon includes one (shared) word form entry for both the noun and verb form of an ambiguous word.

The findings of this study are consistent with the idea that verb deficits are grammatical category specific deficits (e.g., Caramazza and Hillis, 1991), but also suggest that, when controlling noun-verb homonyms for a derivational morphology, aphasic participants with impaired verbal base also present with impairment on verb-derived nouns. Agrammatic aphasic participants demonstrated a difference between processing nouns and verbs across the two ambiguity conditions by showing the base-form bias effect only for the noun category, but not for the verb category. Also, the presence of processing cost (longer RT) for ambiguous nouns (*brush*) compared to unambiguous nouns (*bell*) but not between two types of verbs (*bake* and *bite*) confirms that aphasic participants with a verb selective deficit are unable to access the base category with the verbal status thus showing no difference in ambiguous versus unambiguous condition. Though we cannot precisely define where the deficit resides, the findings appear to align best with a grammatical-category deficit hypothesis.

Lastly, the findings from this study are discussed according to the interactive activation model. The findings are inconsistent with the interactive model, which argues that lexical processing involves spreading activation across semantic and phonological levels, allowing feed-forward and backward flow of information between the two levels. With regard to derived forms, this situation would predict that successful activation of a noun or verb representation that is semantically and morphologically related to each other would facilitate the verb retrieval in the current study. However, there was no effect of noun-verb relatedness in our aphasic participants with a verb deficit, since they performed poorly on both ambiguous (noun-related) verbs like *bite*, and unambiguous verbs like *bake*. On the basis of previous noun/verb homonym studies, semantically and phonologically related event nouns do not produce a facilitative effect on verb retrieval, as instrument nouns do.

The word-class processing model proposed above can capture performance differences between nouns and verbs. According to this processing model, such differences are consistent with the claim that the base-form of an ambiguous word is lexically represented, while the derived form is not. This model can account for the patterns of impairment observed in participants with aphasia, as individuals with a verb deficit may show impaired lexical access to the base (verb) form in the *lexicon* unit, which, in turn, precluded connection between the lexicon and morphology units.

In conclusion, aphasic participants with a verb production deficit demonstrated selective verb deficits that affected both unambiguous and ambiguous verbs (*bake, bite*). Also, impaired access to the base form (i.e., verbs, as in *bite*) precluded retrieval of the derived form (noun) as shown by chance performance on a binary forced-choice paradigm. Therefore, verb deficits cannot be explained by reduced activation or selective loss of semantic, morphological and phonological representation. Further research with a large and more diverse sample of patients is needed to clarify the nature of the impairment.

5.4. Limitations and future studies

Study limitations

Because this thesis pioneers zero-derivational studies in both normal and impaired lexical processing, there are several expected limitations. One important limitation of the studies in this thesis is that the dependent measures (i.e., response time and selection rate) precluded examination of the temporal dynamics of noun and verb processing. Future studies are needed to examine the dynamics of the time course of events that lead to response patterns exhibited. This limitation can be addressed by using more fine-grained temporal measures, such as electroencephalography (EEG) and magneto-encephalography (MEG). Both, EEG and MEG are time-sensitive measures with a temporal resolution in the range of milliseconds, and can reveal the internal representations and processes that subserve complex word recognition, which is not possible via behavioral and neural investigations alone.

Using such methods one could examine why ambiguous nouns and verbs are more difficult when encountered in their derived compare to their base forms, by considering syntactic, semantic or morphological factors. Future studies could address this question by contrasting EEG or MEG responses to morphologically versus semantically complex ambiguous words. Different EEG/MEG components are predicted to reflect distinct cognitive processes (morphological vs. lexical-semantic vs. syntactic reanalysis). Furthermore, if implicit (zero) morphology causes difficulty in retrieving nouns and verbs (as shown in *brush* versus *bite*, see Chapter 2), then the same argument could be made for explicit morphology (*criticize* versus *construct*). Other morphological processes such as Gerund Nouns (e.g., *painting* versus *opportunity*), De-Adjectival Verbs (e.g., *beautify* versus *tripping*), De-Verbal Adjectives (*amazing* versus *fantastic*) could also be tested in future studies. These studies of word-derivation will add to the growing body of research supporting the existence of morphologically structured lexical representations.

Biologically, distinct fMRI activation patterns identified in this thesis in response to noun versus verb processing do not tell us how the brain represents and computes the two word-classes. Use of MEG will disentangle rapidly unfolding sub-processes underlying the computation of the two word-classes. Furthermore, one could use Dynamic Causal Modeling (DCM) to examine how noun and verb areas coalesce into effective noun- and verb-specific cortical networks. Researcher could use these basic findings to study lexical impairments in aphasia at the biological level. Understanding disruptions within these cortical networks and how they reorganize during the aphasia recovery process will guide clinical practices and potential novel treatment approaches.

Future studies

Among studies of noun and verb processing in healthy and aphasic subjects, few have investigated lexical retrieval of semantically and phonologically related noun/verb (N/V) pairs. Crucially, this thesis attempted to differentiate between two types of N/V pairs: nouns derived from verbs, and verbs derived from nouns. Understanding how the word-derivation influences lexical retrieval will have significant implications for theories of lexical processing and will better elucidate the nature of word-class impairments in aphasia. The following enumerates potential studies on categorically ambiguous words embedded in simple sentence contexts using EEG in healthy and aphasic subjects, as well as possible treatment study in aphasia.

EEG Study in healthy individuals. Future studies could investigate the nature of processing cost for ambiguous nouns and verbs and the influence of morphological complexity on on-line processing of syntactic ambiguities associated with N/V pairs in healthy subjects. This experiment could test if different EEG components are sensitive to different types of linguistic processes (morphological and/or semantic). The experiment could use a self-paced sentence listening paradigm, such as:

(1a) The teacher told the principal that the students' brush is dirty.
(1b) The teacher told the principal that the students brush the hallways.
(2a) The curator told the principal that the tourists' visit is expensive.
(2b) The curator told the principal that the tourists visit the museum.

In addition, the following filler stimuli could be added along with the comprehension question:

(3a) The teacher told the principal that the students' lunch is expensive.
(3b) The teacher told the principal that the students clean the hallways.

Comprehension Question: Was students' lunch expensive?

It could be hypothesized that the derivational property of N/V pairs would have an on-line influence on whether participants expect a verb or compliment continuation of the sentence. If morphological complexity of the word affects lexical access, increasing processing cost is expected for nouns and verbs when derivation is required vs. when it is not (1b & 2a vs. 1a & 2b). On the other hand, if semantic complexity of the word (lexical-semantic selection) affects lexical access, lexical processing of derived nouns and verbs will be influenced by expectations regarding the grammatical category of the item that follows within the sentence (1a vs. 2a and 1b vs. 2b). It is predicted that noun-base ambiguous words would cause participants to experience processing difficulties when the sentence is resolved with a verb interpretation of the ambiguous words, and vice-versa for verb-base ambiguous words. Given that EEG responses from 300-500 ms post-stimulus are sensitive to rule-based combinatorial processing (LAN) and responses around 400 ms reflect semantic processing (N400), it is predicted that online processing of derived versus base forms will elicit divergent EEG patterns.

EEG Study in aphasia. Another important area of future research is to understand the time course of word-derivation in agrammatism and anomia. A future study could examine if agrammatic and anomic aphasic subjects show equal retrieval impairments of N/V pairs including: (1) noun-derived verbs (e.g., *brush*), (2) verb-derived nouns (e.g., *visit*), and (3) morphologically related and unrelated pairs (e.g., *seal*). Namely, the ability to retrieve N/V pairs in sentence contexts, and associated EEG components could be identified. For example, a sentence completion task could be used, such as:

(1) The boy's hair was messy.
He needed to _____/a _____ his hair/for his hair (brush).

(2) The boy didn't feel well.

He needed to _____/a _____ the hospital/to the hospital (visit).

(3) The boy was at the post-office.

He needed to _____ /a _____ the letter/for the letter (seal).

The boy was at the zoo.

He needed a _____ for the circus show (seal).

If grammatical category influences lexical retrieval in aphasia, agrammatic aphasic subjects with verb retrieval deficits will have difficulty retrieving nouns that are derived from verbs in the noun-frame (visit (2)). Consequently, anomic aphasic subjects with noun retrieval deficits will have difficulty retrieving verbs in the verb-frame (brush (1)). Moreover, dissociated impairment is expected for *seal* (3) in two groups of aphasic subjects. Agrammatic aphasic subjects will have difficulty retrieving morphologically related N/V pairs (*seal* as an official document). Anomic aphasic subjects will have difficulty retrieving morphologically unrelated N/V pairs (*seal* as an animal).

Treatment study in aphasia. Treatment studies, examining recovery patterns in subjects with aphasia also are informative for both understanding theories of lexical access and noun-verb impairments in aphasia. A future study could examine the effects of treatment focused on one category (e.g., Verb (V)) on generalized improvement to other category (e.g., Noun (N)) in aphasic subjects. This experiment could use a factorial design 2 N/V impairment (+, -) x 2 N/V treatment (+, -), and the experimental control could be either untreated participants or untreated items within the same participant. If training to name one category generalizes to another category then *one* word form entry can be assumed. In contrast, no naming improvement for the untrained category would support the assumption of two separate entries. Crucially, it is expected that training to name more complex derived forms will generalize to simple base forms (in line with *The Complexity Account of Treatment Efficacy* (CATE); Thompson, Shapiro, Kiran & Sobecks, 2003). Therefore, treatment of the verb-derived noun form (e.g., *a bite*) would facilitate production of the verb form (e.g., *to bite*) and treatment of the noun-derived verb form (e.g., *to brush*) would facilitate production of the noun form (e.g., *a brush*). This was found by Blanken (1989) and Biefdermann et al. (2002) in German studies on homophones. For example, in the study by Biedermann et al., (2002), two individuals with aphasia showed generalization from treatment to one pair of homophones to the other (e.g., *ball* (the dance) -> *ball* (the game); *flowe*r -> *flour*), but not to phonologically (e.g., *vase* -> *nose*) and semantically (e.g., *window* -> *door*) related stimuli. Similarly, Park et al., (2013) in English found that three individuals with Broca's aphasia produced more accurate instrumental than non-instrumental verbs (e.g., *to sweep* vs. *to yawn*) pre- and post-treatments. These findings manifest effects of noun-verb relatedness on verb production, supporting the existence of *one* word form entry for some N/V pairs. However, classification of N/V pairs based on noun-verb morphological relations has not been addressed among the above-mentioned studies. Our findings suggest that deficits in accessing ambiguous nouns and verbs for production are influenced by word's morphological complexity.

5.5. Conclusions

This dissertation investigated the representation and processing of categorically ambiguous nouns and verbs in English as a means of providing insight into the domains of semantic ambiguity and morphology. Using a form of grammaticality judgment task, we compared words that are identical on the surface but that vary at other levels of representation (*brush, bite, bear*). Each form (noun/verb) of the ambiguous word could be listed, according to two competing representational theories, disjunctively under a single lexical entry or separately in the mental lexicon.

Across three studies, findings indicated that ambiguous words like *brush* and *bite* (which are morphologically-related noun and verb forms) behave as if they are stored via a single base-form entry, while ambiguous words like *bear* (which are morphologically-unrelated noun and verb forms) correspond to separate lexical entries (a noun, a verb). In the case of processing correlates, the behavioral findings suggest that ambiguous words in their derived form are more complex than in the base forms, despite their orthographical and phonological identity. Accordingly, derived forms induced greater processing cost and, therefore, delayed recognition when compared to base forms (Study 1). Additionally, base forms were selected more frequently compared to derived forms across noun and verb categories in both healthy and aphasic participants without verb deficits, while decreased selection rates of the verbal base form occurred in aphasic participants with a verb selective deficit (Study 2). Studies 1 and 2 provided behavioral evidence for processing cost of categorically ambiguous words when used in their derived forms compared to base forms.

In the case of neural correlates, two distinct neural mechanisms are involved in recognition of verbs morphologically related to nouns (*brush*) and verbs unrelated to nouns (*bear*). The activity observed in the bilateral temporal areas for *brush* and the left frontal-parietal areas for *bear* suggest a link with morphological or semantic complexity, respectively (Study 3). Though finer-grained temporal measures are needed to tease these two processes apart, these studies contribute to existing theories on the neurocognitive basis of word processing.

Lastly, with respect to word-class processing, both Studies 1 and 3 showed that nouns have longer processing times than verbs, however, Study 2 showed longer processing times for verbs than nouns. Also, a distinct frontal and temporal neural basis for verbs and nouns, respectively, were observed. These word-class findings implicate separable cognitive and neural systems in processing of each word-class.

Overall, this work is important for informing mechanisms associated with normal as well as impaired lexical processing. The knowledge of morphological processing of ambiguous words can elucidate the interaction between noun and verb deficits. For instance, a noun deficit can be caused by a verb specific deficit. Therefore, it is possible to facilitate production of verbs through treatment that emphasizes verb-derived nouns. Taken together, these data advance current neurocognitive models of word-class processing, understanding of word-class deficits and corresponding treatment possibilities in stroke-induced aphasia.

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Appendix 2.1.

Experiment 1. Experimental Stimuli

	Noun and Verb Stimuli for 'Match' Condition	Noun and Verb Stimuli for 'Mismatch' Condition
1	Answer	Brush
2	Claim	Cover
3	Control	Frame
4	Limit	Guide
5	Love	Iron
6	Praise	Match
7	Protest	Measure
8	Regret	Paint
9	Repair	Play
10	Rescue	Recruit
11	Reward	Reserve
12	Search	Roast
13	Support	Seal
14	Tackle	Stamp
15	Taste	Store
16	Torture	Switch
17	Visit	Trace

Experiment 1. Filler Stimuli

	Fillers (unacceptable trials)	
	"to N"	"the V"
1	Blouse	Achieve
2	Bucket	Adopt
3	Carrot	Bake
4	Celery	Bathe
5	Corn	Bring
6	Crime	Consume
7	Deer	Criticize
8	Elephant	Deliver
9	Frog	Destroy
10	Glove	Donate
11	Goal	Earn
12	Grape	Eat
13	Jacket	Erase
14	Justice	Explore
15	Kite	Grow
16	Lamp	Imitate
17	Law	Inspect
18	Lid	Juggle
19	Mood	Kneel
20	Mouse	Learn
21	Myth	Live
22	Panda	Locate
23	Peach	Marry
24	Sandal	Pray
25	Scarf	Pursue
26	Skill	Quit
27	Song	Remain
28	Spider	Resist
29	Stapler	Sew
30	Sweater	Sing
31	Sword	Solve
32	Tray	Speak
33	Victory	Teach
34	Zebra	Write

Appendix 2.2.

Experiment 2. Experimental Stimuli

	Base Noun and Derived Verb	Derived Noun and Base Verb
1	Brush	Answer
2	Buckle	Attack
3	Comb	Blame
4	Cover	Chase
5	Crack	Claim
6	Drill	Damage
7	Filter	Hug
8	Hook	Kick
9	Iron	Kiss
10	Label	Limit
11	Lock	Load
12	Mark	Offer
13	Match	Praise
14	Paint	Promise
15	Play	Protest
16	Recruit	Request
17	Seal	Rescue
18	Stamp	Reward
19	Switch	Support
20	Test	Visit

Experiment 2. Filler Stimuli

	Fillers (unacceptable trials)	
	"to N"	"the V"
1	Barn	Achieve
2	Bell	Bake
3	Bone	Build
4	Bucket	Carry
5	Candle	Carve
6	Car	Crave
7	Desk	Deliver
8	Fork	Detect
9	Guitar	Discuss

10	Helmet	Erase
11	Kite	Follow
12	Lamp	Invent
13	Lid	Locate
14	Pillow	Observe
15	Stapler	Promote
16	Statue	Propose
17	Sword	Pursue
18	Tent	Save
19	Tray	Stir
20	Wallet	Destroy
21	Blouse	Adopt
22	Glove	Bathe
23	Jacket	Donate
24	Purse	Eat
25	Sandal	Explore
26	Shirt	Get
27	Deer	Grow
28	Frog	Imitate
29	Horse	Inspect
30	Mouse	Juggle
31	Shark	Kneel
32	Squirrel	Learn
33	Zebra	Marry
34	Apple	Quit
35	Carrot	Resist
36	Celery	Sew
37	Corn	Sing
38	Grape	Solve
39	Lemon	Speak
40	Peach	Teach

Appendix 3.1

Experimental Stimuli

	Unambiguous Condition		Ambiguous Condition	
	Nouns	**Verbs**	**Nouns**	**Verbs**
1	Barn	Adopt	Brush	Answer
2	Bell	Carve	Buckle	Attack
3	Bucket	Deliver	Comb	Blame
4	Celery	Destroy	Cover	Chase
5	Deer	Detect	Crack	Claim
6	Desk	Discuss	Drill	Damage
7	Frog	Eat	Filter	Hug
8	Grape	Erase	Hook	Kick
9	Guitar	Explore	Iron	Kiss
10	Helmet	Follow	Label	Limit
11	Jacket	Imitate	Lock	Load
12	Lemon	Inspect	Mark	Offer
13	Lid	Invent	Match	Praise
14	Pillow	Learn	Paint	Promise
15	Sandal	Locate	Play	Protest
16	Shirt	Observe	Recruit	Request
17	Stapler	Promote	Seal	Rescue
18	Tray	Propose	Stamp	Reward
19	Wallet	Pursue	Switch	Support
20	Zebra	Resist	Test	Visit

Appendix 3.2

Filler Stimuli

	Adjective Fillers		Adverb Fillers	
	"too/so"	**"very/from"**	**"too/so"**	**"very/from"**
1	Civil	Absurd	Abruptly	Actively
2	Fresh	Acute	Absolutely	Badly
3	Gentle	Adverse	Broadly	Brightly
4	Glad	Cheap	Curiously	Certainly
5	Huge	Clever	Fully	Commonly
6	Immune	Clumsy	Greatly	Deeply
7	Odd	Cute	Happily	Early
8	Polite	Dizzy	Largely	Hardly
9	Proper	Dumb	Legally	Heavily
10	Robust	Harsh	Literally	Lately
11	Rude	Honest	Mutually	Loudly
12	Shallow	Lazy	Newly	Nicely
13	Simple	Mad	Normally	Poorly
14	Sincere	Petite	Rarely	Quickly
15	Tall	Sad	Recently	Rapidly
16	Ugly	Silly	Regularly	Sharply
17	Vague	Soft	Seriously	Suddenly
18	Valid	Strict	Strictly	Tightly
19	Vast	Stupid	Usually	Widely
20	Weak	Urgent	Virtually	Wildly

Appendix 4.1

Experimental Stimuli

	Verbs						Nouns	
	Unambiguous verbs (v1)		***Noun-derived verbs (v2)***		***Non-derived verbs (v3)***		***Unambiguous nouns (n)***	
1	to	adopt	to	brush	to	bear	the	barn
2	to	bake	to	buckle	to	boil	the	bell
3	to	buy	to	comb	to	bug	the	bone
4	to	cancel	to	cover	to	cast	the	bucket
5	to	carry	to	crack	to	check	the	candle
6	to	carve	to	dress	to	clutch	the	car
7	to	clean	to	drill	to	duck	the	desk
8	to	crave	to	filter	to	fare	the	fork
9	to	delete	to	frame	to	figure	the	scarf
10	to	detect	to	hook	to	fly	the	guitar
11	to	donate	to	label	to	groom	the	helmet
12	to	eat	to	land	to	peer	the	kite
13	to	erase	to	load	to	place	the	lamp
14	to	hire	to	lock	to	ring	the	lid
15	to	imitate	to	mark	to	root	the	pillow
16	to	invent	to	pump	to	sink	the	stapler
17	to	locate	to	rake	to	slip	the	statue
18	to	pour	to	stamp	to	stem	the	sword
19	to	resist	to	store	to	stick	the	tent
20	to	sew	to	switch	to	train	the	tray
21	to	wipe	to	test	to	watch	the	wallet

Appendix 4.2

Filler Stimuli

	Fillers (word pairs)				Fillers (letter pairs)			
		Mismatch		***Mismatch***		***Match***		***Mismatch***
1	to	apple	the	build	aa	aaaaa	ll	aaaaa
2	to	belt	the	deliver	bb	bbbb	ff	bbbb
3	to	blouse	the	destroy	bb	bbbbbb	tt	bbbbbb
4	to	carrot	the	detect	cc	cccc	ll	cccc
5	to	celery	the	discuss	cc	cccccc	ww	cccccc
6	to	corn	the	follow	dd	dddddd	gg	dddddd
7	to	deer	the	grab	ee	Eee	rr	eee
8	to	frog	the	inspect	ff	Fff	mm	fff
9	to	glove	the	learn	gg	ggggg	ss	ggggg
10	to	grape	the	observe	hh	hhhh	cc	hhhh
11	to	horse	the	promote	ii	iiiiii	aa	iiiiii
12	to	jacket	the	propose	ll	llllll	ss	llll
13	to	lemon	the	propose	ll	Llll	bb	llllll
14	to	mouse	the	pull	mm	mmmm	cc	mmmm
15	to	peach	the	pursue	pp	pppp	ee	pppp
16	to	purse	the	save	rr	rrrrrr	pp	rrrrrr
17	to	sandal	the	serve	ss	Sss	bb	sss
18	to	shark	the	sing	ss	sssss	tt	sssss
19	to	shirt	the	stir	tt	Tttt	ii	tttt
20	to	squirrel	the	teach	tt	Ttttt	dd	ttttt
21	to	zebra	the	throw	ww	wwww	hh	wwww

CURRICULUM VITAE
Sladjana Lukic

5415 North Sheridan Road, Apt 807
Chicago, IL 60640 USA

Telephone (cell): 773 322-3074

E-mail: **sladjanalukic2015@u.northwestern.edu**

EDUCATION

2010 – 2016 **Ph.D.,** Communication Sciences & Disorders Cognitive Science Specialization, Northwestern University, Evanston, IL

Dissertation: "Neurocognitive Correlates of Nouns and Verbs: Zero-Derivation and Lexical-Semantic Processes"

Committee: Dr. Cynthia Thompson (Advisor), Dr. Steven Zecker, Dr. Masaya Yoshida (Department of Linguistics), Dr. Todd Parrish (Department of Radiology), Dr. Aya Meltzer-Asscher (Tel-Aviv University, Israel)

2014 **M.A**., Communication Sciences & Disorders, Non-Clinical Northwestern University, Evanston, IL

Qualifying Research Project: "The role of Argument Structure and Zero-Morphology in Lexical Processing"

Committee: Dr. Cynthia Thompson (Advisor), Dr. Masaya Yoshida (Department of Linguistics), Dr. Mark-Jung Beeman (Department of Psychology), Dr. James Booth (University of Texas, Austin)

2012 Certificate in Cognitive Science, Language and Cognition Interdisciplinary Program, Northwestern University

2003 **B.Sc. and M.A.,** University of Belgrade (FASPER) Speech and Language Pathology, Dr. Slavica Golubovic (Advisor)

GRANTS & FELLOWSHIPS

- **The Joseph Levin Foundation Scholarship**. Dissertation Year Fellowship. One year full tuition and stipend, *2015-2016*
- **The Joseph Levin Foundation Scholarship.** Dissertation Year Fellowship. One year full tuition and stipend, *2014-2015*
- **Language and Cognition Program Assistantship.** One year full tuition and stipend, *2011-2012*
- Northwestern University **Graduate Assistantship Awards**. Full tuition and stipend, *2010-2014*
- Northwestern University **Graduate Research Ignition Grant** ($2000). School of Communication,

2015

- Northwestern University **Graduate Research Grant** ($3000). Graduate School, *2014*
- Northwestern University **Graduate School Travel Grant** ($800). School of Communication, *2015*
  The Clinical Aphasiology Conference, Monterey, CA.
- **Society of the Neurobiology of Language Travel Award** ($600), *2016*
- **The National Institute on Deafness and Other Communicative Disorders (NIDCD) Student Fellowships (**$1500), *2016*
  The Clinical Aphasiology Conference (CAC) in Charlottesville, VA.
- **The National Institute on Deafness and Other Communicative Disorders (NIDCD) Student Fellowships (**$1500), *2011*
  The Clinical Aphasiology Conference (CAC) in Ft. Lauderdale, FL.
- **Best Student Presentation Award**, Academy of Aphasia Annual Meeting, Lucerne, Switzerland, *2013*
- **Woman's Travel Awards** from Berlin School of Mind and Brain, Humboldt-University, *2009*
- University of Belgrade Scholarship, Serbia, *2003*

PUBLICATIONS

1. McNorgan, C., Chabal, S., O'Young, D., **Lukic, S**., & Booth, J. R. (2014). Task Dependent Lexicality Effects Support Interactive Models of Reading: A Meta-Analytic Neuroimaging Review. *Neuropsychologia*, 67: 148-158.

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2. **Lukic, S**., Bonakdarpour, B., Price, C., & Thompson, C. K. (in preparation). Verb, verb argument structure, and sentence production lesion-deficit patterns in aphasia.

3. **Lukic, S**., Yoshida, M., and Thompson, C. K. (in preparation). The role of Zero-Derivation in normal and impaired lexical processing.

4. **Lukic, S**., Yoshida, M., and Thompson, C. K. (in preparation). The role of Argument Structure and Zero-Derivation in lexical processing.

5. **Lukic, S.,** Meltzer-Asscher, A., Parrish, T., and Thompson, C. K. (in preparation). Neurocognitive correlates of verbs: Zero-Derivation versus Lexical-selection costs.

CONFERENCE PRESENTATIONS

1. **Lukic, S.,** Yoshida, M., & Thompson, C. K. (October, 2016). The Role of Zero-Derivation in Lexical Processing. Front. Psychol. Conference Abstract: *54th Annual Academy of Aphasia Meeting*.

2. **Lukic, S.,** Meltzer-Asscher, A., Parrish, T., & Thompson, C. K. (August, 2016). Neurocognitive Correlates of Verbs: Zero-Derivation versus Lexical-Selection costs. *Society for the Neurobiology of Language*. London, England, UK.

3. **Lukic, S.,** Yoshida, M., & Thompson, C. K. (May, 2016). The Role of Zero-Derivation in Lexical Processing. *Clinical Aphasiology Conference*. Charlottesville, VA, USA.

4. **Lukic, S.,** Wang, X., Parrish, T., Caplan, D., Kiran, S., Rapp, B., & Thompson, C.K. (October, 2015). Right hemisphere gray matter volume in left hemisphere stroke-induced aphasia: A voxel-based morphometry (VBM) study. *Society for the Neurobiology of Language.* Chicago, IL, USA.

5. **Lukic, S**., Europa, E., Mack, J. E., Mameledzija, M., Rogalski, E., Mesulam, M., & Thompson, C. K. (May, 2015). Neural mechanisms of grammatical production: Voxel-based Morphometry Study of Primary Progressive Aphasia. *Clinical Aphasiology Conference*. Monterey, CA, USA.

6. **Lukic, S.,** Europa, E., Mack, J. E., Mameledzija, M., Rogalski, E., Mesulam, M., and Thompson, C. K. (May, 2015). Neural mechanisms of grammatical production in Primary Progressive Aphasia (PPA): Voxel-based Morphometry Study. *The 21st Annual Alzheimer Day.* Chicago, IL, USA.

7. **Lukic, S.,** Europa, E., Mack, J. E., Mameledzija, M., Rogalski, E., Mesulam, M., & Thompson, C. K. (March, 2015). Neural mechanisms of grammatical production: Voxel-based Morphometry Study of Primary Progressive Aphasia. *Chicago Chapter of the Society for Neuroscience.* Chicago, IL, USA.

8. **Lukic, S**., Bonakdarpour, B., den Ouden, D. B., Price, C., & Thompson, C. K. (October, 2013). Neural mechanisms of verb and sentence production: a lesion-deficit study. *Procedia - Social and Behavioral Sciences*, 94, 34-35. Presented at the Academy of Aphasia Conference. Lucerne, Switzerland.

9. **Lukic, S**., King, M. C., Wieneke, C., Mesulm, M., Weintraub, S., & Thompson, C. K. (May, 2011). Noun and verb production and comprehension in Stroke- Induced and Primary Progressive Aphasia: An Introduction to the Northwestern Naming Battery Performance. *Clinical Aphasiology Conference.* Ft. Lauderdale, FL.

10. **Lukic, S**., Bonakdarpour, B., den Ouden, D. B., & Thompson, C. K. (November, 2010). Posterior perisylvian lesion volumes in agrammatism and associated sentence deficit patterns. *Berlin Brain Days in Berlin, Germany*.

11. Riley, E. A., den Ouden, D. B., **Lukic, S.,** & Thompson, C. K. (June, 2010). Neural mechanisms of verb argument structure training in agrammatic aphasia. *The Annual Meeting of the Organization for Human Brain Mapping.* Barcelona, Spain.

12. Riley, E. A., den Ouden, D. B., **Lukic, S.,** & Thompson, C. K. (May, 2010). Neural mechanisms of verb argument structure training in agrammatic aphasia. *Clinical Aphasiology Conference.* Isle of Palms, South Carolina, USA.

13. Riley, E. A., den Ouden, D. B., **Lukic, S**., & Thompson, C. K. (October, 2009). Neuroplasticity and Recovery from Aphasia: Treatment - Induced Recovery of Verbs and Sentence Production. *Academy of Aphasia Conference.* Boston, MA, USA.

14. Bonakdarpour, B., **Lukic, S.,** Garibaldi, K., den Ouden, D. B., Fix, S. C., & Thompson C. K. (2008). Posterior perisylvian lesion volumes in agrammatism and associated sentence deficit patterns. *Academy of Aphasia, Turku, Finland, American Speech and Hearing Association Convention (ASHA) in Chicago, IL, USA.*

RESEARCH EXPERIENCE

2010-2016	Aphasia and Neurolinguistics Research Laboratory, Northwestern University Principal Investigator: Dr. Cynthia K. Thompson
2015	Neuroimaging Research Laboratory, Northwestern University Principal Investigator: Dr. Todd Parrish
2012-2015	Syntax Laboratory, Department of Linguistics, Northwestern University Principal Investigator: Dr. Masaya Yoshida
2011	Developmental Cognitive Neuroscience Laboratory, Northwestern University Principal Investigator: Dr. James R. Booth
2008-2010	Aphasia and Neurolinguistics Research Laboratory (*Research Assistant)* Principal Investigator: Dr. Cynthia K. Thompson

CLINICAL EXPERIENCE

2008-2011	Aphasia and Neurolinguistics Research Laboratory, Northwestern University *Research Assistant*
2003-2005	VeRa Institute for Voice, Speech and Audiology, Belgrade, Serbia *Speech-Language Pathologist*

TEACHING ASSISTANT

Northwestern University, Department of Communication Sciences & Disorders

2016	Acquired Neurolinguistic and Neurocognitive Disorders (CSD- 495) with Angela Roberts, Ph.D.
2011-2015	Language Science (CSD-452) with Cynthia K. Thompson, Ph.D.
2014	Vocal Physiology and Pathology (CSD-493) taught by Nathan Waller, Ph.D.
2013	Diagnostic & Remedial Approaches for Children with Learning Problems (CSD-376) with Doris Johnson, Ph.D.
2013	Voice Disorder (CSD-448) with Christopher Allen Atkins, Ph.D.
2013	Clinical Writing (CSD-448) with Christopher Allen Atkins, Ph.D.
2012	Language Development (CSD-392) with Molly Losh, Ph.D.
2010	Statistics in Communication Sciences & Disorders (CSD-304) with Dr. Denise Drane, Ph.D.

TECHNICAL SKILLS

- PROGRAMMING LANGUAGES:

  MatLab, R-program, Statistical Parametric Mapping (SPM8, SPM12), Voxel-Based Morphometry (VBM), MRIcron, Non-Parametric Mapping (NPM)
- EXPERIMENTAL APPLICATIONS:

  SPSS, SuperLab, E-Prime, Praat, Audacity
- EXPERIMENTAL METHODOLOGY:

  Functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Lesion-symptom mapping, Linguistic and neuropsychological tests
- STATISTICAL METHODOLOGY:

  Multi-level modeling (MLM), Voxel–Lesion Symptom Mapping (VLSM), Multivariate Lesion-Symptom Mapping Using Support Vector Regression (SVR-LSM), Optseq, Brunner Munzel Test