



Noun and verb processing in aphasia: Behavioural profiles and neural correlates

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ABSTRACT

The behavioural and neural processes underpinning different word classes, particularly nouns and verbs, have been a long-standing area of interest in psycholinguistic, neuropsychology and aphasiology research. This topic has theoretical implications concerning the organisation of the language system, as well as clinical consequences related to the management of patients with language deficits. Research findings, however, have diverged widely, which might, in part, reflect methodological differences, particularly related to controlling the psycholinguistic variations between nouns and verbs. The first aim of this study, therefore, was to develop a set of neuropsychological tests that assessed single-word production and comprehension with a matched set of nouns and verbs. Secondly, the behavioural profiles and neural correlates of noun and verb processing were explored, based on these novel tests, in a relatively large cohort of 48 patients with chronic post-stroke aphasia. A data-driven approach, principal component analysis (PCA), was also used to determine how noun and verb production and comprehension were related to the patients' underlying fundamental language domains. The results revealed no performance differences between noun and verb production and comprehension once matched on multiple psycholinguistic features including, most critically, imageability. Interestingly, the noun-verb differences found in previous studies were replicated in this study once un-matched materials were used. Lesion-symptom mapping revealed overlapping neural correlates of noun and verb processing along left temporal and parietal regions. These findings support the view that the neural representation of noun and verb processing at single-word level are jointly-supported by distributed cortical regions. The PCA generated five fundamental language and cognitive components of aphasia: phonological production, phonological recognition, semantics, fluency, and executive function. Consistent with the behavioural analyses and lesion-symptom mapping results, both noun and verb processing loaded on common underlying language domains: phonological production and semantics. The neural correlates of these five principal components aligned with existing models of language and the regions implicated by other techniques such as functional neuroimaging and neuro-stimulation.

1. Introduction

1.1. Behavioural status of noun and verb processing in aphasia

The assessment and treatment of individuals with aphasia secondary to acquired brain injury, such as stroke, provide us with a window into the behavioural and neural systems underpinning language. Several aphasiological studies have investigated the effect of word class (particularly nouns and verbs) in individuals with aphasia. Typically, the aphasia clinical profile involves greater difficulties with verb processing (compared to nouns), both during comprehension and production. This verb processing deficits potentially undermining lexical retrieval,

sentence comprehension and production, and ultimately connected speech production and the engagement in conversations. Several competing linguistic explanations have been proffered to account for word class effects in aphasia. The lexical account claims that nouns and verbs are stored separately in the mental lexicon and the noun-verb dissociation results from selective damage to accessing either the noun or the verb lexicon at the lexical stage of word production (Hillis and Caramazza, 1995; Miceli et al., 1988; Miceli et al., 1984). The semantic account proposes that verbs are more difficult because they are semantically more complex. Verbs tend to be lower in imageability (the degree to which a word can generate a mental image and/or sensory experience) than nouns, and have less perceptual features (Bird et al.,

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2000; Breedin et al., 1998; McCarthy and Warrington, 1985). The syntactic account suggests that greater verb deficits are a consequence of the syntactic complexity of verbs given their syntactic role in sentences (Kim and Thompson, 2000; Thompson, 2003). Some researchers argue that it is difficult for this account to explain noun and verb dissociation observed during single-word production (Berndt et al., 1997a), although the proponents of the syntactic account would argue that syntactic structures associated with verbs are engaged even when the verb was produced in isolation (Kim and Thompson, 2000). Lastly, the morphological account suggests that verbs are more difficult to process because they are morphologically more complex, as they carry a greater number of inflectional morphemes in most languages (Badecker and Caramazza, 1991; Tsapkinis et al., 2002). Though this account is challenged by studies revealing noun-verb dissociation in languages with no morphological differences between nouns and verbs, such as Chinese (e.g., Bates et al., 1991).

The pattern of results and the associated theories concerning the noun-verb literature in aphasia have been inconsistent. Some researchers have emphasised a noun-verb double dissociation (e.g., Miceli et al., 1988; Miceli et al., 1984), whereas more recent studies have shown greater verb deficits compared to nouns (e.g., Luzzatti et al., 2002; Mätzig et al., 2009). Differential noun-verb processing has also been compared with aphasia classifications, proposing a potential association between fluent aphasia with noun deficits, and non-fluent aphasia with verb deficits (e.g., Bates et al., 1991; Hillis and Caramazza, 1995; Laiacona and Caramazza, 2004; Zingeser and Berndt, 1988). This view has been challenged, however, by studies showing greater verb deficits compared to nouns among: (i) individuals with fluent aphasia (e.g., Berndt and Haendiges, 2000; Jonkers and Bastiaanse, 1998), and (ii) individuals from both fluent and non-fluent aphasia groups (e.g., Bastiaanse and Jonkers, 1998; Berndt et al., 2002; Jonkers and Bastiaanse, 1996; Luzzatti et al., 2002; Mätzig et al., 2009). An extensive theoretical review by Vigliocco et al. (2011) demonstrated that all reports on patients with large noun-verb dissociation in the literature up to 2011 could be accounted for by three main factors: (i) task, whether it tackles lexical retrieval or sentence processing and phrasal construction; (ii) cross-linguistic differences between the use of nouns and verbs in sentences, in term of morphological markers and syntactic complexity; and (iii) semantic distinctions between nouns and verbs. The importance of semantic differences between nouns and verbs has also been emphasised in a recent review, which notes that cross-linguistically nouns refer to objects and verbs usually predict actions and events (Kemmerer, 2014).

The focus of the current study was lexical processing and the semantic distinction between nouns and verbs rather than sentence processing and the morpho-syntactic disparities, and this was addressed using single-word tasks. There are three potential reasons for the inconsistent findings concerning the noun-verb differences at single-word level in the literature, which were tackled in the present study by developing a new set of matched materials to assess both production and comprehension of nouns and verbs. The first issue identified in the literature is variation of psycholinguistic features between noun and verb items utilised in different studies and the challenge of adequate control over these variables. In early studies, noun and verb items were not matched on any psycholinguistic variables (e.g., Bates et al., 1991; Hillis and Caramazza, 1995; Miceli et al., 1984). Other studies matched the noun and verb items on word frequency (e.g., Bastiaanse and Jonkers, 1998; Berndt et al., 2002; Berndt and Haendiges, 2000; Berndt et al., 1997a; Berndt et al., 1997b; Jonkers and Bastiaanse, 1996, 1998; Laiacona and Caramazza, 2004), age-of-acquisition (Druks and Carroll, 2005; Mätzig et al., 2009), frequency and length (e.g., Miceli et al., 1988; Zingeser and Berndt, 1988), age-of-acquisition, frequency and familiarity (e.g., Luzzatti et al., 2002), and frequency, familiarity, length and visual complexity (e.g., Shapiro and Caramazza, 2003). These studies failed to control for other variables, in particular, word imageability, which often has a strong effect on performance in aphasia,

and it has been suggested that the relative verb deficits ceases to exist once imageability was controlled for (Bird et al., 2000). A second potential issue in the literature is that the vast majority of studies focused on production. Only few studies have investigated comprehension (e.g., Berndt et al., 1997b; Miceli et al., 1988). Finally, the third potential factor relates to the fact that the majority of the studies in the literature are single case (e.g., Druks and Carroll, 2005; Hillis and Caramazza, 1995; Shapiro and Caramazza, 2003; Zingeser and Berndt, 1988) or case-series studies (e.g., Bastiaanse and Jonkers, 1998; Berndt et al., 2002; Bird et al., 2000; Miceli et al., 1988; Miceli et al., 1984), with only few group studies (Jonkers and Bastiaanse, 1996; Luzzatti et al., 2002). With small samples it is possible, of course, to end up with divergent data, and it is much harder to relate performance on nouns and verbs to the variation of aphasiological presentation not only in terms of aphasia classification but to more specific components of aphasia (e.g., phonological abilities, semantics, fluency and so on).

In the current study, these methodological challenges were addressed by investigating noun and verb processing using a noun-verb set matched on multiple psycholinguistic variables simultaneously including word imageability, frequency, familiarity, age-of-acquisition, length and visual complexity. A set of matched materials was developed to assess both production and comprehension on a large cohort of patients with chronic post-stroke aphasia, including a wide range of aphasia classifications beyond Broca's and anomic aphasia.

1.2. Neural correlates of noun and verb processing

Noun-verb differences have also been linked to the neuroanatomical bases of noun and verb processing. One view posits an, at least, partially segregated representation of noun and verb processing, with verb processing mainly supported by the left frontal cortex (left inferior and superior frontal gyri and pre-frontal cortex), and noun processing largely supported by left temporal regions (primarily middle fusiform gyrus, anterior and lateral temporal regions). These effects have been shown in both production and comprehension, and evidence for this view comes from neuropsychological (e.g., Damasio and Tranel, 1993; Daniele et al., 1994), functional neuroimaging (e.g., Shapiro et al., 2006; Shapiro et al., 2005), cortical stimulation mapping studies (e.g., Lubrano et al., 2014) and repetitive transcranial magnetic stimulation (Cappelletti et al., 2008). The noun/verb stimuli in these studies, however, were matched on frequency and length, or were not matched on any psycholinguistic variables. In contrast to this view, there is evidence that wide cortical regions jointly correlate with noun and verb processing, including the left frontal, parietal and temporal lobes. This view is supported by neuropsychological studies showing that verb deficits can result from lesions outside the left frontal lobe including left posterior temporal regions, parietal lobe, posterior lateral temporal-occipital junction, basal ganglia, insula, and/or extensive lesions involving fronto-temporal perisylvian area (e.g., Aggujaro et al., 2006; Kemmerer et al., 2012; Luzzatti et al., 2006; Tranel et al., 2001). Several functional neuroimaging studies also suggested common but distributed neural correlates of noun and verb processing, with activation observed in wide, overlapping set of brain regions within left frontal, temporal and parietal regions (e.g., Li et al., 2004; Siri et al., 2008). A review of the neural correlates of noun and verb processing in functional neuroimaging studies showed that the majority of regions that were selectively activated for one word class in some studies were found to be selectively activated for the other word class in different studies (Crepaldi et al., 2011). The authors argued that these inconsistencies suggest that the neural correlates of noun and verb processing are not segregated. A subsequent meta-analysis on functional neuroimaging studies suggested a distributed network correlating with noun and verb processing, including frontal, temporal and parietal regions (Crepaldi et al., 2013).

Some caution is needed when interpreting some of the earlier neuropsychological results, as most of them did not utilise accurate

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