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The behavioural patterns and neural correlates of concrete and abstract verb processing in aphasia: A novel verb semantic battery

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ABSTRACT

Typically, processing is more accurate and efficient for concrete than abstract concepts in both healthy adults and individuals with aphasia. While, concreteness effects have been thoroughly documented with respect to noun processing, other words classes have received little attention despite tending to be less concrete than nouns. The aim of the current study was to explore concrete-abstract differences in verbs and identify their neural correlates in post-stroke aphasia. Given the dearth of comprehension tests for verbs, a battery of neuropsychological tests was developed in this study to assess the comprehension of concrete and abstract verbs. Specifically, a sensitive verb synonym judgment test was generated that varied both the items' imageability and frequency, and a picture-to-word matching test with numerous concrete verbs. Normative data were then collected and the tests were administered to a cohort of 48 individuals with chronic post-stroke aphasia to explore the behavioural patterns and neural correlates of verb processing. The results revealed significantly better comprehension of concrete than abstract verbs, aligning with the existing aphasiological literature on noun processing. In addition, the patients performed better during verb comprehension than verb production. Lesion-symptom correlational analyses revealed common areas that support processing of concrete and abstract verbs, including the left anterior temporal lobe, posterior supramarginal gyrus and superior lateral occipital cortex. A direct contrast between them revealed additional regions with graded differences. Specifically, the left frontal regions were associated with processing abstract verbs; whereas, the left posterior temporal and occipital regions were associated with processing concrete verbs. Moreover, overlapping and distinct neural correlates were identified in association with the comprehension and production of concrete verbs. These patient findings align with data from functional neuroimaging and neuro-stimulation, and existing models of language organisation.

1. Introduction

Words can be classified into different categories; one common classification is concrete versus abstract words (such as 'to twist' and 'to exist'). Concrete concepts are more tangible, imageable and can be experienced through the senses whereas abstract words are less tangible, less imageable and they typically refer to ideas, mental or emotional states. In relation to this perspective, Paivio (1986) proposed a dual-coding theory, according to which concrete concepts benefit from dual-coding of verbal and non-verbal stores, whereas abstract concepts are represented in a verbal store only. It was assumed that the sensory and perceptual experiences associated with a concept are represented in a non-verbal store, whereas the linguistic information is stored in a verbal store. Imageability refers to the extent to which a word can conjure up a mental image and/or sensory experience. Words with high-imageability give rise to a mental image more rapidly and easily, whereas low-imageability words do so with difficulty, if at all (Paivio et al., 1968). It has been shown that concreteness and imageability are highly correlated (Paivio et al., 1968), and hence, most studies use these two terms interchangeably (though for important variations relating to high valence abstract words, see Vigliocco et al., 2014). Henceforth, the term 'concrete' is used to refer to high imageable concrete concepts, and 'abstract' for low imageable abstract concepts. The effect of concreteness on word processing has been well documented in the literature: concrete words are processed more accurate and efficiently than abstract words in healthy adults (e.g., Wiemer-Hastings and Xu, 2005), people with aphasia (e.g., Hoffman et al., 2011b; Sandberg and Kiran, 2014), and semantic dementia (e.g., Jefferies et al., 2009). This concreteness effect has also been observed in language tasks that do not place high demands on semantic knowledge,

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such as repetition (Tyler et al., 2000) and reading (Evans et al., 2012). These studies imply that the imageability of a word is a vital feature that supports different components of the language system including production and comprehension processes, not only at the semantic level, but also when the phonological or orthographic processes are activated. One classic explanation for these observations related to the greater semantic richness associated with concrete compared to abstract concepts (Jones, 1985; Paivio, 1986). Other theories emphasis on the greater context sensitivity for abstract items (Hoffman et al., 2011b), with convergent fMRI, TMS and neuropsychological data suggesting that both mechanisms are important and are supported by different neural networks (Goldberg et al., 2007; Hoffman et al., 2015; Hoffman et al., 2010).

Concrete-abstract differences have been explored almost entirely with respect to noun processing. Verbs vary extensively in their concreteness and imageability ratings. Concrete verbs are usually related to action and motion verbs (e.g., 'to drink' or 'to walk') whereas abstract ones are linked to cognitive and emotional verbs (e.g., 'to process' or 'to care'). Moreover, the majority of words used in aphasiology, neuropsychological research and clinical practice are picture-based, constraining tests to concrete items, with a main focus on nouns. As a result, the processing of abstract and concrete verbs in aphasia remains relatively unexplored. Where verbs have been investigated it has primarily been in the context of comparing them to nouns, rather than exploring processing of different types of verbs. Bird et al. showed that imageability was a strong predictor of naming performance among individuals with verb deficits compared to those without verb deficits (Bird et al., 2001b), and among individuals with post-stroke aphasia compared to healthy controls (Bird et al., 2003).

The fact that processing concrete and abstract words can be differentially impaired suggests that there might be important, graded variations in their cognitive and neural representations. It has been argued that concrete concepts rely on sensory experiences, and thus visual and other sensory information contribute to their semantic representation (Paivio et al., 1968). On the other hand, the meaning of abstract words is more context-dependent (Schwanenflugel and Shoben, 1983) and as such might be more reliant on semantic-executive control processes (Hoffman et al., 2011b; Noppeney and Price, 2004). Accordingly, damage to the visual and sensory association regions within the ventral language pathway and particularly left temporal lobe could be expected to affect concrete but not abstract knowledge (Noppeney and Price, 2002); whereas, damage to the executive control network, including the left prefrontal cortex, could result in deficits with abstract knowledge (Hoffman et al., 2010).

A number of neuroimaging experiments have investigated differences between concrete and abstract concepts using fMRI, PET and TMS on healthy adults (e.g., Binder et al., 2005; Goldberg et al., 2007; Hoffman et al., 2015; Hoffman et al., 2010; Noppeney and Price, 2004; Perani et al., 1999; Sabsevitz et al., 2005). Studies found strong involvement of the left inferior frontal gyrus for abstract over concrete word processing. A number of other language-related regions including the left superior temporal gyrus and temporal pole have been related to abstract word processing over concrete words (Binder et al., 2005; Noppeney and Price, 2004; Perani et al., 1999; Sabsevitz et al., 2005). In contrast, the involvement of temporal (posterior inferior temporal gyrus, medial anterior temporal lobe and left inferior temporal pole) and parietal regions (posterior inferior parietal areas and angular gyrus) have been shown to be activated for processing concrete over abstract words (Binder et al., 2005; Noppeney and Price, 2002; Sabsevitz et al., 2005). Findings from these neuroimaging studies are generally consistent with the view proposing that the representation of concrete concepts are boosted by temporal and occipital areas that underpin sensory processing and visual object recognition, whereas abstract concepts rely more on frontal regions related to semantic-executive control (Breedin et al., 1998; Hoffman et al., 2015; Noppeney and Price, 2002).

To date, most functional neuroimaging experiments have utilised noun items. Few studies have investigated the neural correlates associated with low-imageability emotion and cognitive verbs in comparison to concrete motion verbs in healthy adults (Grossman et al., 2002; Rodríguez-Ferreiro et al., 2011). Where data are available, these studies have shown that processing both concrete and abstract verbs recruit left and right inferior frontal gyri. Even though these studies employed different tasks (reading versus semantic judgment), direct contrasts indicated that abstract verbs generated greater activation in the left inferior frontal gyrus and temporal regions (middle temporal gyrus or posterior-lateral temporal areas), while concrete verbs lead to greater activation in more posterior temporal regions. The authors of these studies suggested that abstract verbs engage semantic processes more strongly in comparison to concrete verbs. To the best of our knowledge, the cognitive and neural correlates of concrete and abstract verb processing have not been investigated and compared in post-stroke aphasia – and thus this was a key target for the current study.

We also considered the effect of word frequency as it has been widely implicated in healthy adult language processing (e.g., Balota and Chumbley, 1984) and in some studies on aphasia (e.g., Cuetos et al., 2002; Nickels and Howard, 1995). Other aphasiological studies, particularly those on semantic aphasia, however, have shown an absent or reversed frequency effect (e.g., Hoffman et al., 2011a; Hoffman et al., 2011b). Again, the evidence to date has been mainly based on noun processing. Those studies that have explored verbs have shown an absent of frequency effect in word retrieval or sentence production tasks among patients with brain-injury (Kemmerer and Tranel, 2000), and aphasia (Bastiaanse et al., 2009; Bastiaanse et al., 2016). This might indicate that word frequency is not a factor that affects verb processing.

A review of the available neuropsychological and aphasiological assessment batteries suggests that there is a dearth of comprehensive tests to assess verb comprehension. While some tests have been specifically designed to assess verb deficits, they either tackle production but not comprehension, such as the Object and Action Naming Battery (OANB: Druks and Masterson, 2000), or they focus on syntactic impairments and sentence processing, such as the Northwestern Assessment of Verbs and Sentences (Thompson, 2011).

In the current study, a new neuropsychological test battery was developed to probe the semantic comprehension of verbs. This battery includes a synonym judgment test and a picture-to-word matching test. These tests are relatively challenging, leading to sensitive assessment of verb comprehension at single-word level. From a clinical perspective, this battery offers a new and important supplement to the existing clinical assessment tools. In particular, the abstract conditions of the synonym judgment test have the potential to detect mild comprehension deficits in cases that usually pass the typical (noun-based) clinical assessments but report comprehension deficits at the level of everyday functional communication (such as conversations or reading complicated notes, as insurance letters). Thus the key aims of this study were to investigate differences in the comprehension of concrete and abstract verbs for a large cohort of patients with chronic post stroke-aphasia, and further identify the neural correlates associated with verb processing using lesion-symptom mapping.

2. Methods

2.1. Constructing the battery

Two novel neuropsychological tests were developed to examine single-word concrete and abstract verb comprehension. First, a verb synonym judgment test was constructed. This test consists of 80 verb stimuli split evenly into four conditions: concrete high-frequency verbs