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The relation of object naming and other visual speech production tasks: A large scale voxel-based morphometric study

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ABSTRACT

We report a lesion–symptom mapping analysis of visual speech production deficits in a large group (280) of stroke patients at the sub-acute stage (<120 days post-stroke). Performance on object naming was evaluated alongside three other tests of visual speech production, namely sentence production to a picture, sentence reading and nonword reading. A principal component analysis was performed on all these tests' scores and revealed a 'shared' component that loaded across all the visual speech production tasks and a 'unique' component that isolated object naming from the other three tasks. Regions for the shared component were observed in the left fronto-temporal cortices, fusiform gyrus and bilateral visual cortices. Lesions in these regions linked to both poor object naming and impairment in general visual–speech production. On the other hand, the unique naming component was potentially associated with the bilateral anterior temporal poles, hippocampus and cerebellar areas. This is in line with the models proposing that object naming relies on a left-lateralised language dominant system that interacts with a bilateral anterior temporal network. Neuropsychological deficits in object naming can reflect both the increased demands specific to the task and the more general difficulties in language processing.

1. Introduction

Recognising a specific object and saying aloud its name promptly are rather effortless for the most part. However, deficits in naming objects emerge as a frequent symptom of brain damage (Bayles and Tomoeda, 1983; Bell et al., 2001; Hodges et al., 2000; Hodges and Patterson, 2007) occurring, for instance, in at least 14% of stroke patients (e.g. Nøkleby et al., 2008; Tatemichi et al., 1994). In clinical practice, object naming is widely used as a test of language functions in bedside neuropsychological examination (e.g. in MoCA, MMSE). It is also common as a behavioural treatment approach for naming disorders, or aphasia at large, to train whole word naming to simple pictures (e.g. Conroy et al., 2009; Nickels, 2002). In this study, we examined the cognitive and neural relevance between object naming and other visual speech production tasks using a lesion–deficit mapping approach.

Deficits in object naming among neurological patients could arise at several levels of processing. Existing cognitive theories (Humphreys et al., 1999; Levelt et al., 1999) posit that naming an object requires at a minimum four processing steps to take place: 1) visual perception; 2) retrieval of semantic knowledge about the object; 3) access to the associated phonological representation; and 4) articulation. Likewise, a neuroanatomically-constrained model (Ueno et al., 2011; Ueno and Lambon Ralph, 2013) specifically highlights the interactive contribution of semantic and phonological pathways in supporting naming. Disruptions to various parts of these pathways, using computational stimulation, have been shown to affect naming and other spoken language abilities. In correspondence with the computational account, an elegant VBM study by Butler and collaborators (Butler et al., 2014) examined the common neuro-cognitive components that are shared across a number of language (including object naming) and executive function tasks. They identified three components: phonology, semantic and executive-cognition. In particular, object naming was loaded almost equally on both phonology and semantic. Also, as reported in this study, the phonological component was related to the left perisylvian regions encompassing the temporal, insula and inferior frontal cortices while the semantic component was related to the left anterior temporal area.

Evidence from neuropsychological reports suggests that object naming is supported by a large network of different brain regions along the Sylvian fissure with the left frontal and temporal lobes being

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particularly critical (Damasio et al., 2004, 1996; Hillis et al., 2006, 2001). Baldo et al. (2013) used voxel-based lesion symptom mapping to relate performance on a test of object naming to neural correlates based on the lesion maps of patients with left hemispheric stroke. Their results showed an association between naming deficits and lesions to significant portions of the left temporal cortex including the superior and middle sections and underlying white matter with an extension to the inferior parietal cortex. Similar patterns of extensive left perisylvian lesions were reported in studies using cortical electrical stimulation during neurosurgery (Corina et al., 2010) and perfusion-weighted magnetic resonance imaging (DeLeon et al., 2007). In particular, DeLeon and colleagues (2007) identified the lesions to the superior and middle temporal gyri and the anterior temporal pole to be most predictive of the lexical–semantic mapping deficits (i.e. a failure to linking concepts to phonological output) in naming. Additionally, a recently growing body of literature has emphasised the role of the anterior temporal lobe (ATL) in naming (e.g. Domoto-Reilly et al., 2012; Rogers et al., 2006). Notably patients with semantic dementia typically have prominent ATL atrophy and progressive anomia (i.e. naming impairment) (Bright et al., 2008; Jefferies and Lambon Ralph, 2006; Noppeney et al., 2007). According to Patterson and Roger (Patterson et al., 2007; Rogers et al., 2004), ATL serves as a central representation 'hub' of the brain, integrating modality-specific representations (e.g. smell, shape, colour, name) from different regions to constitute domain-general concepts (see also Lambon Ralph, 2014 for a review).

In many neuropsychological studies of object naming (e.g. Baldo et al., 2013; DeLeon et al., 2007), patients have been restricted to those only with left hemispheric damage. This limited the ability to draw inferences about potential contributions of particular regions in the rest of the brain to a given function. For example, Brambati et al. (2006) examined the anatomical organisation of object naming using voxel-based morphometry (VBM) in patients with a range of neurodegenerative diseases. They reported a link between overall naming performance and bilateral atrophy in the superior and inferior temporal gyri, anterior fusiforms and hippocampi, in additional to some left-sided atrophy. Similarly, studies using functional imaging show activations in extensive brain regions during object naming (Garn et al., 2009; Léger et al., 2002; Okada et al., 2000; Spitzer et al., 1998). Price and colleagues (2005) conducted a meta-analysis of the functional imaging studies on object naming in healthy individuals. This meta-analysis study identified regions primarily along the occipito-temporal cortices on the left; however, greater involvement of the right hemisphere was also noted when object naming was compared with baseline conditions controlling for perceptual processing and speech production. In the current study, we performed the whole brain correlation analysis using VBM.

Object naming is very similar to other speech production abilities such as reading as they both require speech response driven by visual inputs. Interestingly, however, there is limited comprehensive account of how object naming is distinguished from other visual speech production tasks at the neuronal level. Only a few fMRI studies have directly contrasted the neural activation of object naming to single word reading (Bookheimer et al., 1995; Moore and Price, 1999; Price et al., 2006). For example, Moore and Price's (1999) study found shared mechanism in the inferior temporal cortex (among other regions) which responded more to both words and objects relative to viewing meaningless visual stimuli. Compared with word reading, increased activation during object naming was observed in the anterior fusiform. The authors (Moore and Price, 1999) explained that the anterior part of fusiform has been linked to semantic processing, with object naming being more dependent on semantic processing than reading. Functional imaging studies of other speech production tasks alone such as sentence production in picture description (e.g. Grande et al., 2012) highlight the involvement of a large bilateral network which includes both the anterior (e.g. inferior frontal gyrus, anterior part of superior and middle temporal gyri) and posterior (e.g. temporo-parietal and occipital cortices) regions of the left hemisphere. However, there is a lack of neuropsychological data directly comparing performance on object naming with a series of visual speech production tasks using a common set of patients.

The present study used performance data from a stroke sample on a clinical cognitive screen (BCoS; Humphreys et al., 2012). The BCoS assesses language abilities including object naming as well as reading and picture description (see the Behavioural Measures subsection and the Supplementary material S1, for detailed description). All these tasks assess identification of visual stimuli and generation of spoken responses. Despite the similarities, each task potentially has its specific demands. To increase the demands on recognition and semantic processing, the object naming task in BCoS includes low frequency object items. In contrast, the sentence production (picture description) task is designed to assess primarily syntactic and morphological processing while demands on recognition and semantic/name retrieval of the target objects were made minimal (by using very frequent object items, e.g. 'book', and also by actually providing the name of the target objects alongside the picture stimulus to the participant). The sentence reading task requires the participant to read aloud a sentence containing some relatively low frequency and exception words (i.e.'irregular words' as described in Coltheart et al., 2001). This task would tap the lexical and non-lexical phonological processing. Finally, BCoS also assesses nonword reading, which can only be achieved by non-lexical phonological processing and not aided with semantic knowledge. Table 1 outlines the potential cognitive–language processes underlying these four visual speech production tasks. We speculate that the object naming task may have greater demands on recognition and semantic knowledge of objects relative to other tasks tested in the present study.

In a large sample of sub-acute stroke patients, we examined the lesions associated with impaired object naming and then in relation to other visual speech production tasks (in order to isolate regions specific to object naming). As another approach, we also performed a principal component analysis in order to identify the shared and unique mechanisms of object naming and the other language tasks. We applied a fully-automated voxel-based correlational method to assess the relationship between the performance on the language tasks (based on the raw and PCA scores) and the density of grey and white matters (based on patients' clinical CT scans).

2. Methods

2.1. Subjects

All patients were recruited from the stroke units of 12 hospitals in the West Midlands, UK, as part of the Birmingham University Cognitive Screen trial (BUCS; http://www.bucs.bham.ac.uk). The broad inclusion criteria of the trial were that the patient should be at the sub-acute stage (<120 days post-stroke), physically stable and well enough to maintain concentration for around an hour to complete the cognitive assessment (judged by a trained assessor of the multi-disciplinary stroke team). No restrictions were placed according to aphasic type or severity. The sample of this present study was made up of 280 patients (141 males, average age: 70.88 years ± 14.06std, ranging between 26 and 93 years) selected from the BUCS database of 532 cases with clinical CT scans available. As previously estimated in the patient group of the BUCS trial, 41.4% had middle cerebral artery (MCA) stroke, 10.4% posterior cerebral artery stroke and 13.4% due to other affected vascular territories (Chechlacz et al., 2014a). For the present study, we excluded patients whose CT scans were of poor quality (n = 37), or if the scans showed abnormally large ventricles (n = 4). To control for the potential confounding effect due to the presence of abrupt high intensity signals, we also eliminated cases with haemorrhage (n = 42). We further excluded patients who were non-right-handed (n = 54), or who were scanned more than 120 days post-stroke (n = 1) or on the same day