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Neuroimaging the short- and long-term effects of repeated picture naming in healthy older adults

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ABSTRACT

Repeated attempts to name pictures can improve subsequent naming for aphasic individuals with anomia, however, the neurocognitive mechanisms responsible for such improvements are unknown. This study investigated repeated picture naming in healthy older adults over a period of minutes (short-term) after one repetition and a period of days (long-term) after multiple repetitions. Compared to unprimed pictures, both repeated conditions showed faster naming latencies with the fastest latencies evident for the short-term condition. Neuroimaging results identified repetition suppression effects across three left inferior frontal gyrus regions of interest: for both the short- and long-term conditions in the pars orbitalis, and for long-term items in the pars triangularis and pars opercularis regions. The whole brain analysis also showed a repetition suppression effect in bilateral pars triangularis regions for the long-term condition. These findings within the inferior frontal gyrus suggest that effects of repeated naming may be driven by a mapping mechanism across multiple levels of representation, possibly reflecting different levels of learning, and lend support to the idea that processing may be hierarchically organised in the left inferior frontal gyrus. The whole brain analysis also revealed repetition suppression for the long-term condition within the posterior portion of bilateral inferior temporal gyri, which may reflect attenuation of integration processes within this region following the learning of task-relevant information.

1. Introduction

Anomia, or naming difficulty, is the most common symptom of post-stroke aphasia. A number of tasks, such as word-picture matching and auditory repetition, have been shown to improve subsequent naming of pictures in individuals with aphasia (for review, see Nickels (2002b)). Interestingly, for some people with aphasia, repeated attempts at picture naming alone, in the absence of feedback or response correction, also appears to improve subsequent naming (Howard, 2000; Nickels, 2002a). While the neural substrates of a number of aphasia therapies have been explored (for review, see Meinzer et al. (2011)), the mechanisms underpinning improvements following repeated naming as a treatment technique have not been widely considered. Importantly, the normal language-related neural mechanisms associated with the behavioural improvement of naming in healthy adults following repetition have also not been fully explored. Such normal mechanisms have been suggested to contribute to the successful treatment of naming deficits in aphasia (Nickels, 2002a). The current study therefore aimed to investigate the neural modulation of language-related brain regions engaged by repeated picture naming in healthy older adults, to inform our understanding of the mechanisms underlying successful anomia treatment.

Behavioural facilitation or 'repetition priming' of picture naming refers to the speeding of response latencies and increase in accuracy of picture naming following earlier naming of the same

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pictures. This effect is well documented for healthy adults (e.g., Cave (1997); Cave and Squire (1992); Mitchell and Brown (1988)). However, the exact cognitive-linguistic mechanisms modulated by repetition priming for picture naming are still to be identified. Most theoretical models of spoken word production involve 'lead-in' picture identification processes required specifically for picture naming. Picture identification involves both perceptual processes and concept retrieval (Francis et al., 2008). Although controversy exists regarding the extent to which component processes are serial, cascaded and/or interactive, most models involve broadly (a) a lexical-semantic stage, where a lexical representation corresponding to the semantic concept is selected, and (b) a phonological encoding stage, where the lexical representation is mapped to its phonological word form (with phonetic encoding and articulation ensuing) (e.g., Caramazza (1997); Dell (1986); Levelt et al. (1999)).

Behavioural data from a variety of tasks suggests that facilitation over the long-term (keeping in mind that the timeframe referred to as 'long-term' can vary across studies) may result from priming/strengthening of the mappings from lexical-semantics to phonology (Wheeldon and Monsell, 1992, 1994). For example, Wheeldon and Monsell (1992) reported that prior spoken production of the name of an item in response to a definition facilitated subsequent picture naming (at lags of 60–120 intervening items/6–13 min). In contrast, the production of a heterographic homophone (a word that sounds the same but has a different meaning and spelling, e.g., *piece* and *peace*) did not facilitate naming. Thus, production of the phonological word form without the associated semantic concept was not sufficient to produce behavioural priming, implicating the mapping of lexical-semantics to phonology with facilitation over many intervening items.

Neuroimaging studies have added to our understanding of picture naming facilitation by providing information regarding which brain areas are important for the component processes involved in word production. Processes that are lexical-semantic or phonological in nature have been linked with different neural regions that are largely left lateralised, although picture naming overall appears to recruit a more distributed bilateral network (Indefrey and Levelt, 2004). The mid to posterior sections of the middle temporal and inferior temporal gyri, the angular gyrus, and the anterior and mid sections of the inferior frontal gyrus are commonly implicated in lexical-semantic processing, while the posterior section of the superior temporal gyrus, the supramarginal gyrus and the posterior section of the inferior frontal gyrus have been implicated in phonological processing (see meta-analyses by Indefrey and Levelt, 2004; Price et al., 2005; Vigneau et al., 2006). Regions within the inferior frontal gyrus have also been linked to executive control functions, with anterior-mid sections (pars orbitalis and pars triangularis) and the posterior section (pars opercularis) commonly associated with lexical-semantic and phonological control processes, respectively (for reviews, see Bookheimer (2002); Poldrack et al. (1999); Price (2012)). Facilitation from repeated naming may thus arise through priming of any of the various sub-processes of spoken naming mediated by different or overlapping neural regions.

Studies involving repeated presentation of various tasks including word-stem completion, object classification and picture naming, most often report decreases in neural activation within these regions, traditionally termed 'repetition suppression' (Henson, 2003). Repetition suppression is generally thought to reflect neural computational savings, although the exact mechanisms are unclear. Repetition priming paradigms using a range of tasks suggest that such savings may stem from (a) a neural "sharpening" of the cortical representation of a repeated stimulus (see Henson (2003) for review); or (b) by-passing of the neural systems involved during prior presentation due to rapid stimulus-response learning (Dobbins et al., 2004; Horner and Henson, 2008); or (c) both (Race et al., 2008). On the other hand, increased activation or "repetition enhancement" is thought to reflect increased or additional processing upon repetition of a task (Henson, 2003).

Previous neuroimaging studies have investigated long-term repeated picture naming in healthy adults over periods of several days or weeks (Meister et al., 2005; van Turennout et al., 2003, 2000) but they have been confounded by the use of covert picture naming during scanning, precluding analysis of behavioural responses, and are limited in scope by the use of whole brain analyses, rather than also defining specific neural regions of interest. Nonetheless, these studies have consistently reported repetition suppression effects in bilateral occipitotemporal regions (including the posterior inferior temporal gyrus) and the left inferior frontal gyrus. Inferior temporal and occipitotemporal regions demonstrate relatively consistent suppression effects over both the short- and long-term that increase in magnitude with the number of naming repetitions (Meister et al., 2005; van Turennout et al., 2003, 2000). In contrast, repetition suppression effects in the left inferior frontal gyrus appear to be more variable across these studies, with short- and long-term effects differentially modulated by time between exposures, number of exposures and neuroanatomical region within the gyrus (either anterior pars orbitalis and mid pars triangularis, or the more posterior pars opercularis) (Meister et al., 2005; van Turennout et al., 2003, 2000).

A qualitative difference in the effects found for occipitotemporal and inferior frontal regions suggested that long-term repetition priming might be driven by two distinct mechanisms. Firstly, by more efficient processing of visual object-form features in occipitotemporal areas and secondly, by priming of semantic and/or phonological representations, or possibly a stimulus-response learning mechanism resulting in more efficient name retrieval, in the inferior frontal region (Meister et al., 2005; van Turennout et al., 2003, 2000).

Rather than repeated picture naming, a different task at first exposure can be used in an attempt to target a specific process of word production. Recently, we reported the findings of two studies investigating the neurocognitive mechanisms underlying the short-term facilitation (within minutes following a single prior exposure) and long-term facilitation (within days following multiple prior exposures) of picture naming. Prior to picture naming within the scanner, one study used an auditory repetition task where the target name was presented auditorily and repeated aloud by participants (Heath et al., 2012a). The second study used a semantic task, with participants required to respond by button press to a yes–no question regarding a semantic feature of the target (Heath, et al., 2012b). Unlike previous research using repeated picture naming (Meister et al., 2005; van Turennout et al., 2003, 2000), these two studies, which employed different tasks across presentations of the same stimuli, did not find significant repetition suppression in the inferior frontal gyrus. However, repetition suppression in the middle temporal gyrus was associated with facilitation over the long-term in both studies. This repetition suppression was suggested to reflect more efficient lexical-semantic processing, possibly lexical selection (Heath et al., 2012a; Heath et al., 2012b). Additionally, in the auditory repetition study there was decreased posterior superior temporal gyrus activity for long-term items relative to short-term items, suggesting repetition suppression and more efficient activation and retrieval of phonological representations (Heath et al., 2012a).

The current study extends our previous work by examining the neural correlates of the facilitation associated with repeated picture naming, a task more representative of standard word finding treatment. It also improves on previous repetition priming studies that have relied on covert verbal responses (Meister et al., 2005; van Turennout et al., 2003, 2000). The silent production of