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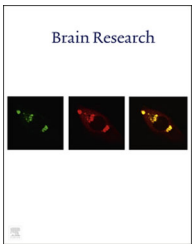

Research Report

The processing of lexical ambiguity in healthy ageing and Parkinson's disease: Role of cortico-subcortical networks

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ABSTRACT

Previous neuroimaging studies showed that correct resolution of lexical ambiguity relies on the integrity of prefrontal and inferior parietal cortices. Whereas prefrontal brain areas were associated with executive control over semantic selection, inferior parietal areas were linked with access to modality-independent representations of semantic memory. Yet insufficiently understood is the contribution of subcortical structures in ambiguity processing. Patients with disturbed basal ganglia function such as Parkinson's disease (PD) showed development of discourse comprehension deficits evoked by lexical ambiguity. To further investigate the engagement of cortico-subcortical networks functional Magnetic Resonance Imaging (fMRI) was monitored during ambiguity resolution in eight early PD patients without dementia and 14 age- and education-matched controls. Participants were required to relate meanings to a lexically ambiguous target (homonym). Each stimulus consisted of two words arranged on top of a screen, which had to be attributed to a homonym at the bottom. Brain activity was found in bilateral inferior parietal (BA 39), right middle temporal (BA 21/22), left middle frontal (BA 10) and bilateral inferior frontal areas (BA 45/46). Extent and amplitude of activity in the angular gyrus changed depending on semantic association strength that varied between conditions. Less activity in the left caudate was associated with semantic integration deficits in PD. The results of the present study suggest a relationship between subtle language deficits and early stages of basal ganglia dysfunction. Uncovering impairments in ambiguity resolution may be of future use in the neuropsychological assessment of non-motor deficits in PD.

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1. Introduction

Lexical ambiguity depicts an inherent feature of everyday language. A homonym, a special case of lexico-semantic ambiguity, is one of a group of words that share exactly the same spelling and the same pronunciation but have distinct, unrelated meanings. The word 'bank' for example can be referred to a monetary institute or to the edge of a river. The conflict between multiple representations is thereby often resolved on the basis of both meaning dominance (Moritz et al., 2001; Twilley et al., 1994) and contextual sources of information (Dixon and Twilley, 1999; Gorfein et al., 2000). Based on previous experience and biased by the context in which a homonym occurs, we are able to choose the appropriate meaning often even without being aware that a word is ambiguous. However, in specific circumstances lexical ambiguity may lead to severe discourse comprehension deficits.

Effects of aging were observed within various aspects of language processing. Whereas word finding performance decreases during the course of healthy ageing (Abrams et al., 2007; Albert et al., 2009; Baltes and Lindenberger, 1997; Bowles et al., 1987; Burke and Shafto, 2004; Kavé et al., 2010) global semantic and lexical knowledge appears to be fairly well preserved (Goral et al., 2007; Miller et al., 2009; Park et al., 2002; Salthouse, 2009).

In addition to basic components that include vocabulary, syntax and the phonologic-orthographic system, there are higher-level aspects of language which enable us to select strategies, make choices and inhibit competing outputs. Harley et al. (2011) delineated the idea of so-called deliberative processes that, opposed to automatic processes, require language planning, reflecting about language and making judgements about linguistic representations. They concluded that these processes rely on the integrity of fronto-striatal loops and were preferentially susceptible to deterioration with age. For instance, ageing was associated with increasing difficulties in the inhibition of competing information (De Beni et al., 2007; Uekermann et al., 2008).

One consistent finding across functional imaging studies that investigated general effects of cognitive ageing is that brain activity, particularly in the frontal lobes, tends to be less lateralised in older adults. This finding was primarily interpreted as being compensatory and has been conceptualised in a model called "Hemispheric Asymmetry Reduction in Old Adults" (HAROLD) (Cabeza, 2002; Cabeza et al., 1997). Wingfield and Grossman (2006) summarised age-related changes in the domain of language processing and concluded that contralateral frontal regions may particularly contribute to the stability of language which was underlined by more recent neuroimaging studies investigating word retrieval in healthy and pathologically ageing individuals (Wierenga et al., 2010, 2008).

There is consensus that semantic word processing substantially relies on proper engagement of left prefrontal and left temporo-parietal cortices (Binder and Desai, 2011; Bonner et al., 2013; Price, 2012). Likewise, context-driven lexical ambiguity resolution was found to require bilateral inferior frontal (Rodd et al., 2005; Zempleni et al., 2007) and inferior parietal cortices (Balthasar et al., 2011; Chan et al., 2004; Hoenig and Scheef, 2009; Weis et al., 2001). While frontal activation was supposed to subserve successful meaning selection and inhibitory control mechanisms, it was argued that inferior parietal activation might represent a substrate for access to word form knowledge. The latter was congruent with a previous fMRI study where left and right inferior parietal activations (BA 39, 40) were associated with accurate ambiguity resolution in the younger human brain (Ketteler et al., 2008). Furthermore, we showed that subcortical structures (i.e. caudate nucleus, thalamus) were activated during successful meaning selection. Caudate activity was also reported to be involved in comprehension of ambiguous sentences (Mason and Just, 2007) and in control of word interference (Ali et al., 2010).

Chenery et al. (2008) developed the hypothesis of an integrated basal ganglia thalamocortical circuit responsible for enhancement and suppression of lexically ambiguous words. Following prior considerations on cortico-subcortical pathways in language processing (Ullman, 2006), they investigated lexico-semantic impairments in PD and outlined the role of dopamine depletion that may contribute to discourse comprehension difficulties in this population (Angwin et al., 2009; Arnott et al., 2011; Copland et al., 2009b). Besides PD there are many other patient groups documenting language deficits possibly linked to disturbed cortico-subcortical networks (Ketteler et al., 2012; Legg et al., 2005; Nadeau and Crosson, 1997; Teichmann et al., 2008; Titone et al., 2000).

The present study aimed at unveiling the contributions of healthy ageing and PD on neural pathways that underlie the neurocognitive process of disambiguating a homonym. We hypothesised that access to semantic concepts stored within temporo-parietal regions is regulated and controlled by fronto-subcortical structures of the brain. The first question was whether previous findings showing a participation of prefrontal, temporo-parietal and subcortical brain areas during ambiguity resolution in young could be replicated in healthy elderly participants. Moreover, based on ideas of the HAROLD model, we explored if there was an additional recruitment of homologous cortical and subcortical brain areas or not. Second, by investigating ambiguity resolution in early PD we aimed to gain further insights into subcortical language processing. We assumed that proper execution of our task demands basal ganglia integrity and will be hampered in PD. Our results might help to elucidate mechanisms of higher-level language processing such as the resolution of lexical ambiguity in the healthy and pathologically ageing brain.

2. Results

2.1. *Behavioural data*

Across groups, participants produced fewer correct responses in the homonym, the dominant-distractor and the subordinate-distractor compared to the distractor-only condition (main effect of condition $F(3,57)=16.13$, $p<0.0001$; see Fig. 1A). Within the PD group there was a detectable decrease in accuracy rates between conditions, i.e. less hits in the dominant-distractor and the subordinate-distractor compared to the homonym condition