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Research report

Semantic fluency: Cognitive basis and diagnostic performance in focal dementias and Alzheimer's disease

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ABSTRACT

Semantic fluency is widely used both as a clinical test and as a basic tool for understanding how humans extract information from the semantic store. Recently, major efforts have been made to devise fine-grained scoring procedures to measure the multiple cognitive processes underlying fluency performance. Nevertheless, it is still unclear how many and which independent components are necessary to thoroughly describe performance on the fluency task. Furthermore, whether a combination of multiple indices can improve the diagnostic performance of the test should be assessed.

In this study, we extracted multiple indices of performance on the semantic fluency test from a large sample of healthy controls ($n = 307$) and patients ($n = 145$) suffering from three types of focal dementia or Alzheimer's Disease (AD). We found that five independent components underlie semantic fluency performance. We argue that these components functionally map onto the generation and application of a search strategy (component 2), to the monitoring of the overall sequence to avoid repetitions (component 3) and out-of-category items (component 4), and to the full integrity of the semantic store (component 5). The integrated and effective work of all these components would relate to a "general effectiveness" component (component 1). Importantly, while all the focal dementia groups were equally impaired on general effectiveness measures, they showed differential patterns of failure in the other components. This finding suggests that the cognitive deficit that impairs fluency differs among the three focal dementia groups: a semantic store deficit in the semantic variant of primary progressive aphasia (sv-PPA), a strategy deficit in the non-fluent variant of primary progressive aphasia (nfv-PPA), and an initiation deficit in the behavioural variant of fronto-temporal dementia (bv-FTD). Finally, we showed that the concurrent use of multiple fluency indices improves the diagnostic accuracy of semantic fluency both for focal dementias and for AD. More generally, our study suggests that a formal evaluation of fine-grained patterns of performance would improve the diagnostic accuracy of neuropsychological tests.

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1. Introduction

The semantic fluency test (Bousfield & Sedgewick, 1944) requires a subject to generate as many words as possible from a given semantic category (e.g., "fruits") within a limited time, usually 1 min. Semantic fluency is a simple yet powerful test. For clinical purposes, the test has the benefit of being very fast and easy to administer, while still being highly sensitive to detecting cognitive impairment and brain damage (Henry & Crawford, 2004). For research purposes, semantic fluency provides a unique window on the fundamental ability to explore and extract information from our semantic and lexical store.

Several cognitive functions may be involved in semantic fluency. First, when performing the task, subjects should generate and then follow a *strategy* to explore the semantic store efficiently. Typically, healthy subjects explore a semantic category (e.g., fruits) by exploiting its internal organisation. They tend to generate items by clustering them into subcategories, e.g., soft fruits, dry fruits, citrus fruits. Second, subjects need to *flexibly switch* between different subcategories or items and *select* a target item among alternative competitors. Third, subjects need to extract entries from semantic memory, and fourth, they need to monitor and check the output to avoid producing repetitions or items out-of-category. Finally, they need to keep an "active" state during task execution to cope with the limited amount of time available for production (Gruenewald & Lockhead, 1980; Reverberi, Laiacona, & Capitani, 2006; Rosen & Engle, 1997; Unsworth, Spillers, & Brewer, 2011; Wixted & Rohrer, 1994).

A deficit in any of the above-mentioned cognitive abilities may produce an impaired fluency performance. As a consequence, the raw performance in semantic fluency is not cognitively specific. Thus, it is unsurprising that an impairment on the semantic fluency task has been reported following damage to several brain structures: the left temporal lobe, for its role in semantic memory storage; the lateral frontal cortex, for its role in strategy generation, flexibility, and selection; and the medial frontal cortex, for its role in behavioural initiation and activation (Baldo & Shimamura, 1998; Henry & Crawford, 2004; Laisney et al., 2009; Robinson, Shallice, Bozzali, & Cipolotti, 2012; Stuss et al., 1998; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998).

The cognitive opacity of the overall production score curtails the usefulness of the semantic fluency test in clinical settings and hinders the understanding of the cognitive and neural basis of semantic fluency. In recent years, several proposals were made for improving the specificity of the indices used to assess fluency performance, mainly by devising scoring procedures grounded on more detailed cognitive models of the task. Ideally, these new indices should be able to selectively measure each of the cognitive processes underlying semantic fluency. "Clustering" and "switching" are well-known examples of indices devised for this purpose (Moscovitch, 1992; Troyer, Moscovitch, & Winocur, 1997; Troyer et al., 1998). The clustering index is the average size of the produced subcategory clusters, while the switching index counts the number of times a subject switches from an old subcategory to a new subcategory. Clustering is thought to specifically measure the integrity of the semantic store, a measure related to the temporal lobe functions, while switching measures the integrity of strategic search processes, cognitive flexibility, and shifting, i.e., cognitive functions related to the frontal lobes (Troyer et al., 1998). Other laboratories have further contributed with alternative theoretical interpretations of these fluency indices by testing the new indices in several different pathological groups, or by proposing different indices, such as the "order index" and the "number of subcategories index" (e.g., Abwender, Swan, Bowerman, & Connolly, 2001; Fagundo et al., 2008; Ho et al., 2002; Mayr, 2002; Price et al., 2012; Reverberi et al., 2006; Troster et al., 1998).

Notwithstanding this major theoretical and empirical effort, whether these new indices indeed provide more information compared with the mere total number of new words still needs to be formally evaluated. Specifically, it remains unclear whether each of the above-mentioned indices measures one (or a few) underlying cognitive processes, whether the new indices are more accurate in distinguishing healthy controls from patients or in distinguishing among different patient groups, and whether the combined use of two or more indices can increase the amount of information conveyed by each index when used alone.

To further investigate and evaluate these issues, this study pursued three related aims. First, we wanted to assess how many and which independent components would be necessary to thoroughly describe semantic fluency performance. Second, we wanted to assess whether considering this larger set of fluency indices would allow for a better understanding of the cognitive basis of fluency impairment in three focal dementias. Third, we systematically evaluated nine fluency indices to understand whether any of them, alone or in combination with others, can better discriminate between patients and healthy controls and among different patient groups.

In this study, we considered two main patient groups: focal dementias and Alzheimer's Disease (AD). First, we focused on relatively rare but cognitively focal syndromes: semantic dementia, which has been recently reclassified as the semantic variant of primary progressive aphasia (sv-PPA; Gorno-Tempini et al., 2011); the behavioural variant of fronto-temporal dementia (bv-FTD); and non-fluent variant of primary progressive aphasia (nfv-PPA). These clinical syndromes constitute excellent models to study semantic fluency because they are characterised by a focal impairment on one or more of the cognitive functions involved in semantic fluency. Sv-PPA presents with a progressive loss of general semantic knowledge, involving multiple modalities (e.g., words, visual percepts, sounds, and tastes). Sv-PPA patients generally show language problems consisting of anomia and semantic paraphasias, which are associated with an impairment in understanding single words, in the absence of phonological and syntactical problems (Hodges, Patterson, Oxbury, & Funnell, 1992; Patterson, Nestor, & Rogers, 2007; Snowden, Goulding, & Neary, 1989; Warrington, 1975). Nfv-