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Are semantic and phonological fluency based on the same or distinct sets of cognitive processes? Insights from factor analyses in healthy adults and stroke patients

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ABSTRACT

Verbal fluency for semantic categories and phonological letters is frequently applied to studies of language and executive functions. Despite its popularity, it is still debated whether measures of semantic and phonological fluency reflect the same or distinct sets of cognitive processes. Word generation in the two task variants is believed to involve different types of search processes. Findings from the lesion and neuroimaging literature further suggest a stronger reliance of phonological and semantic fluency on frontal and temporal brain areas, respectively. This evidence for differential cognitive and neural contributions is, however, strongly challenged by findings from factor analyses, which have consistently yielded only one explanatory factor.

As all previous factor-analytical approaches were based on very small item sets, this apparent discrepancy may be due to methodological limitations. In this study, we therefore applied a German version of the verbal fluency task with 8 semantic (i.e. categories) and 8 phonological items (i.e. letters). An exploratory factor analysis with oblique rotation in N=69 healthy young adults indeed revealed a two-factor solution with markedly different loadings for semantic and phonological items. This pattern was corroborated by a confirmatory factor analysis in a sample of N=174 stroke patients. As results from both samples also revealed a substantial portion of common variance between the semantic and phonological factor, the present data further demonstrate that semantic and phonological verbal fluency are based on clearly distinct but also on shared sets of cognitive processes.

1. Introduction

Verbal fluency (e.g., Benton, 1968; Borkowski et al., 1967; Milner, 1964) is one of the most frequently used neuropsychological measures of language abilities and executive functioning (Chouiter et al., 2016; Lezak et al., 2004; Moscovitch, 1994; Shao et al., 2014; Strauss et al., 2006). This is particularly indicated by the vast and increasing number of more than 4100 publications listed in PubMed (http://www.ncbi.nlm.nih.gov/pubmed; Fig. 1) that have assessed verbal fluency in a wide variety of clinical as well as healthy populations (for reviews, see Abwender et al., 2001; Alvarez and Emory, 2006; Costafreda et al., 2006; Henry and Crawford, 2004; Martin and Fedio, 1983; Metternich et al., 2014; Sarkis et al., 2013).

Verbal fluency is typically studied by requiring the subject to generate as many words as possible for a given category cue (semantic fluency) or letter cue (phonological fluency) within a pre-set time interval (e.g. 60 s; Lezak et al., 2004; Strauss et al., 2006). In general, semantic fluency is usually easier than phonological fluency (Lezak et al., 2004) and both are assumed to differ in the type of search processes required for successful retrieval (Katzev et al., 2013). That is,

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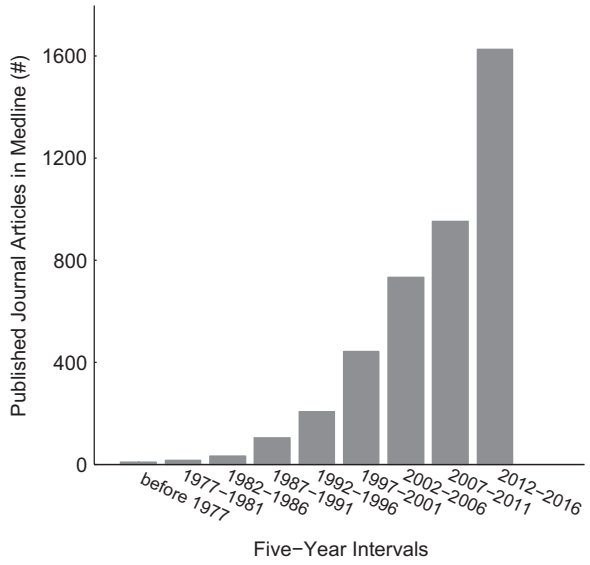

Fig. 1. Bibliometric overview of 4136 published journal articles on verbal fluency listed in PubMed (http://www.ncbi.nlm.nih.gov/pubmed; literature survey on December 31st, 2016, search phrase: verbal fluency [Title/Abstract]) between 1965 and 2016 collapsed in five-year intervals.

phonological fluency is believed to involve a serial search based on systematic syllabification of initial letters (Mummery et al., 1996; Rende et al., 2002). By contrast, semantic fluency is most likely driven by association chains and spreading activations within cue-related subcategories (Gruenewald and Lockhead, 1980), thus requiring additional control processes such as generating and actively shifting between semantic sub-categories (Rosen and Engle, 1997; Troyer et al., 1997; Reverberi et al., 2006), as well as selecting appropriate items from competing alternatives (Thompson-Schill et al., 1998).

In line with these proposed differences in cognitive processing during semantic and phonological fluency, the extant lesion and neuroimaging literature suggests a dissociation in the neural resources, with semantic fluency relying more on temporal brain areas and phonological fluency relying more on frontal brain areas. As such, patients with lesions in frontal regions reveal greater deficits in phonological fluency as compared to healthy controls or patients with non-frontal lesions, whereas patients with lesions in temporal regions show greater deficits in semantic verbal fluency (Baldo et al., 2006, 2010; Borkowski et al., 1967; Jurado et al., 2000; Szatkowska et al., 2000; Thompson-Schill et al., 1998; Troyer et al., 1998; see Henry and Crawford, 2004, for a meta-analytic review). Furthermore, greater task-related activation in frontal brain areas is associated with phonological fluency, whereas greater activation in temporal regions is associated with semantic fluency (e.g. Birn et al., 2010; Demonet et al., 1992; Gourovitch, 2000; Meinzer et al., 2009; Schlösser et al., 1998).

The potential dissociation between the cognitive processes involved and their underlying neural correlates associated with semantic and phonological verbal fluency is strongly challenged by findings from factor-analytic approaches: Several studies have suggested that semantic and phonological fluency primarily measure the same set of cognitive processes, given that inter-individual variation in performance in phonological and semantic fluency items consistently loads on a single factor (Ardila et al., 1994; Bizzozero et al., 2013; Unsworth et al., 2011; Whiteside et al., 2016). Potential limitations of these previous factor analyses may lie in the very limited and partly disparate number of items used in assessing semantic and phonological fluency. For example, Whiteside et al. (2016) as well as Bizzozero et al. (2013) used three phonological letters (F, A, S, and F, P, L, respectively) but only one semantic category (animals), while Unsworth et al. (2011) used two semantic (animal, supermarket) and two phonological letters (F, S). Likewise, Ardila et al. (1994) used four phonological letters (F, A, S, M) but only two semantic categories (animals, fruits). In addition to the limited and disparate number of items, all previous studies compared measures of semantic and phonological verbal fluency in relation to other cognitive constructs, such as tests of executive function, language, working memory capacity, or processing speed (Ardila et al., 1994; Bizzozero et al., 2013; Unsworth et al., 2011; Whiteside et al., 2016). However, semantic and phonological verbal fluency can be expected to share common cognitive processes at least to some extent due to the general procedure of the fluency task, particularly in comparison to other cognitive functions. Thus, statistical models including a variety of other cognitive constructs lack a direct and unbiased comparison of verbal fluency sub-tasks and may not allow firm conclusions to be drawn about whether semantic and phonological fluency measure distinct or common cognitive processes.

In this study, we addressed these potential limitations and investigated whether an exploratory factor analysis (EFA) reveals a two-factor rather than a one-factor solution (i) if explicitly tested in an analysis restricted to measures of phonological and semantic fluency and (ii) if this analysis is based on a larger and equal number of phonological and semantic items. To this end, we used a German version of the verbal fluency task with 16 items (8 categories and 8 letters; cf. Katzev et al., 2013). In a first exploratory step we analyzed verbal fluency data from a sample of healthy young adults (N=69) in an EFA and demonstrated that semantic and phonological items indeed load on two separate factors, hence suggesting distinct sets of cognitive processes for semantic and phonological fluency. Furthermore, verbal fluency is often assessed in clinical populations with language and/or executive function deficits (Baldo et al., 2006, 2010; Birn et al., 2010; Henry and Crawford, 2004), so that analyses on the nature of verbal fluency processes is also highly relevant for neuropsychological studies. Thus, to probe the generalizability of results to a common clinical population, in a second confirmatory step we verified the results of the EFA using confirmatory factor analysis (CFA) in an independent sample of N=174 stroke patients.

2. Methods

2.1. Participants

2.1.1. Healthy subjects

For the exploratory factor analyses (EFA) in healthy young adults, N=75 students were recruited from the University of Freiburg via information leaflets. All participants were right-handed and had normal or corrected-to-normal vision. Further inclusion criteria were age between 19 and 26 years, and German as a native language. Exclusion criteria were current or historical psychiatric or neurological illness, use of psychotropic medication, less than 8 years of education, and color blindness. Color blindness constituted an exclusion criterion, because the Tower of London-Freiburg version (TOL-F; Kaller et al., 2016) was also administered to each participant (cf. Köstering et al., 2015). Exclusion criteria were assessed using an in-house questionnaire on socio-demographic data. All students participated twice in the same measurements with a re-test interval of one week. Written informed consent was obtained before participation. The experiment was conducted in compliance with the Helsinki Declaration of the World Medical Association (http://www.wma.net) and local ethical standards. Before participation, subjects were screened with respect to inclusion and exclusion criteria. One of the participants was excluded after the first session because of signs of depressive symptoms (score of 17) as measured with the Beck Depression Inventory-II (BDI-II; Beck et al., 1996).

Prior to the main analysis, individual data were inspected for outliers. Specifically, the difference between the total number of words produced at the first and second sessions were separately computed for the two fluency tasks (i.e. semantic and phonological fluency). Five