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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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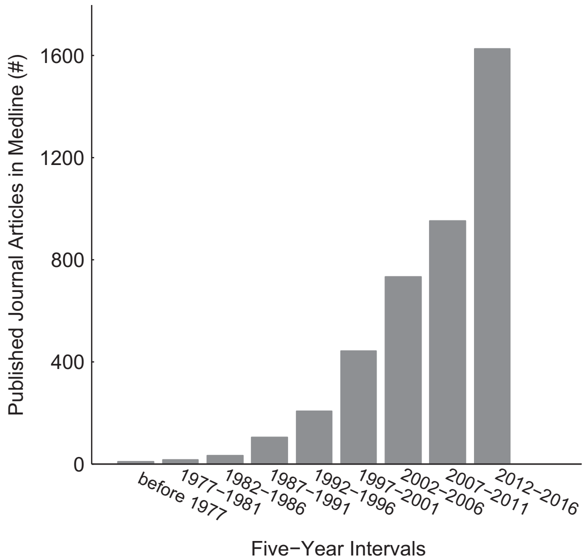

Fig. 1. Bibliometric overview of 4136 published journal articles on verbal fluency listed in PubMed (http://www.ncbi.nlm.nih.gov/pubmed; literature survey on December 31st, 2016, search phrase: verbal fluency [Title/Abstract]) between 1965 and 2016 collapsed in five-year intervals.

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 participants were excluded from further analyses as their difference score for at least one of the two fluency tasks deviated for more than 1.5 times the interquartile range from the median difference score of the sample (see 2.2; Tukey, 1977). In consequence, the final sample comprised N=69 healthy young adults (N=47 female) with a mean age (±SD) of 23.07±2.03 years (range, 19.04–26.48 years) and a mean education (±SD) of 16.10±2.14 years (range, 12 −23 years).

2.1.2. Stroke patients

For the confirmatory factor analyses (CFA) in the clinical sample, N=189 chronic stroke patients were recruited from the Department of Neurology at the University Medical Center Freiburg and tested at least 5 months post-stroke as part of a larger study on the recovery after ischemic stroke. The main patient-specific inclusion criterion was first presentation of an ischemic stroke without a hemorrhagic event. Exclusion criteria at the acute stage were age over 90 years, inability to tolerate MRI examination or clinical testing due to poor general health status, previous infarcts, previous intracerebral hemorrhage, previous traumatic brain injury, contemporary re-infarct, bilateral infarcts, major cognitive impairment (e.g., dementia), illiteracy, hearing and visual deficits, alcohol abuse, and contraindications for MRI examination such as claustrophobia or cardiac pacemaker. Every eligible participant was asked to participate and, once consented, tested at the Department of Neurology. The study was approved by local ethics authorities and conducted in compliance with the Helsinki Declaration of the World Medical Association (http://www.wma.net).

Four patients were excluded from the present analyses because of severe aphasia (i.e. patients were unable to speak) which would confound the assessment of verbal fluency. Another 9 patients were excluded because they either did not complete, or were unable to perform, the task (i.e. task abortion at the request of the patient). Given the influence of education on performance in verbal fluency tasks (Strauss et al., 2006; Tombaugh et al., 1999), another 2 patients were excluded due to an unusually low educational attainment of less than 8 years. Prior to the main analysis, individual data were inspected for outliers following the procedure described for healthy subjects. However, no further patients had to be excluded. In consequence, the final sample comprised N=174 chronic stroke patients (N=61 female) with a mean age (±SD) of 64.4±13.7 years (range, 22.4–87.5 years), a mean education (±SD) of 13.2±3.4 years (range, 8–23), and an average post-stroke duration (±SD) of 18.3±19.1 months (range, 5–73.5 months). A total of N=105 patients with left hemisphere and N=69 patients with right-hemisphere strokes were included. The stroke territory concerned in most of these cases (n=147) was that of the middle cerebral artery.

2.2. Verbal fluency task

Participants were administered a German version of the verbal fluency task employing a 2×2 factorial combination of semantic cues (categories, e.g. vegetables) and phonological cues (letters, e.g. V) that were further classified as being of an easy or hard difficulty level. This classification was based on pilot testing in a preceding study (cf. Katzev et al., 2013) and ensured that, despite differences in the general difficulty between phonological and semantic items, letter and category cues within each cell of the resulting factorial design had an almost comparable level of empirical difficulty (Supplementary Table S1). Four different items were presented for each cue type (semantic vs. phonological) and difficulty level (easy vs. hard), yielding a total of 16 items (8 categories and 8 letters). Items and presentation order were identical for all healthy participants and stroke patients and did also not differ between the two testing sessions in the healthy sample. Both participants and patients started with the semantic condition (first, items for the easy condition: vehicles/means of transport [German: 'Transportmittel'], quadrupeds ['Vierbeiner'], musical instruments ['Musikinstrumente'], professions ['Berufe']; second, items for the hard condition: fluids ['Flüssigkeiten'], toys ['Spielzeuge'], furniture ['Möbelstücke'], vegetables ['Gemüsearten']) followed by the phonological condition (first, items for the easy condition: T, B, S, K; second, items for the hard condition: V, N, D, F).

Instructions for the verbal fluency task were given orally by the experimenter (CS, LVS, PR). Participants were told that the verbal fluency task would comprise two different parts (semantic and phonological fluency) and that they were to generate as many nouns as possible within a time limit of 60 s following either a category or a letter. Task rules were explained with the help of example items. In the semantic condition, the example item was 'Lebensmittel' (English: food or groceries). First of all, participants were told that only words common in German should be said (e.g., milk, butter, bread, cheese). Second, no words should be produced twice and participants were not allowed to say proper names or brand names (e.g., Pepsi). Finally, no words beginning or ending with the same word stem were valid (e.g., *milk*, *milk* powder). For the phonological condition, additional rules were explained with the help of the example letter 'E'. Participants were told that words generated in the second part should begin with the given letter and only nouns should be said (e.g., egg, eye, elephant). That is, besides proper names and brand names, verbs, adjectives, filler words, or numbers were also not allowed for these trials.

During trials either the corresponding category or letter was displayed on a computer screen and acoustic cues indicated the beginning and end of the 60 s response interval. The total number of correct words for each item was recorded and served as outcome measures for data analyses.

2.3. Data analyses

Analyses were conducted using SPSS Statistics 23 and AMOS 23 (IBM Corp., Armonk, NY, USA). To first investigate whether semantic and phonological fluency indeed measured two distinct sets of cognitive processes, an exploratory factor analysis (EFA) was carried out on the data of the healthy sample. In particular, semantic and phonological items entered a principal component analysis. As semantic and phonological fluency can be expected to share at least some cognitive processes such as language, working memory, and attention, it was hypothesized that the extracted factors may be correlated and, accordingly, an oblique rotation (Promax, Hendrickson and White, 1964) was used instead of an orthogonal rotation (Field, 2005). The number of factors was determined using Horn's parallel analysis and Velicer's minimum average partial (MAP) test (Horn, 1965; O'Connor, 2000; Velicer, 1976). In Horn's parallel analysis, factor extraction is based on the comparison of raw data eigenvalues with random data eigenvalues. Raw data eigenvalues that are larger than the random data eigenvalues are retained as factors (cf. Horn, 1965). Factor extraction of the MAP test is based on the matrix of partial correlations with a rule to stop factor extraction (cf. Velicer, 1976). To validate the factor structure derived from the EFA in the healthy sample, a confirmatory factor analysis (CFA) was then performed in the sample of stroke patients using AMOS Version 23.

3. Results

3.1. Exploratory factor analysis (EFA) in healthy participants

A principal component analysis was conducted on the verbal fluency data of healthy young adults (cf. 2.1.1) using Promax rotation. Before the analysis, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were inspected. Both the KMO measure of .868 and a significant Bartlett's test of sphericity ($\chi^2(120)=539.954$, $p < .001$) indicated that the implementation of the analysis was appropriate. Velicer's minimum partial (MAP) test as well as Horn's parallel test suggested the extraction of two factors. Note that the same decision would have been obtained by the default criterion

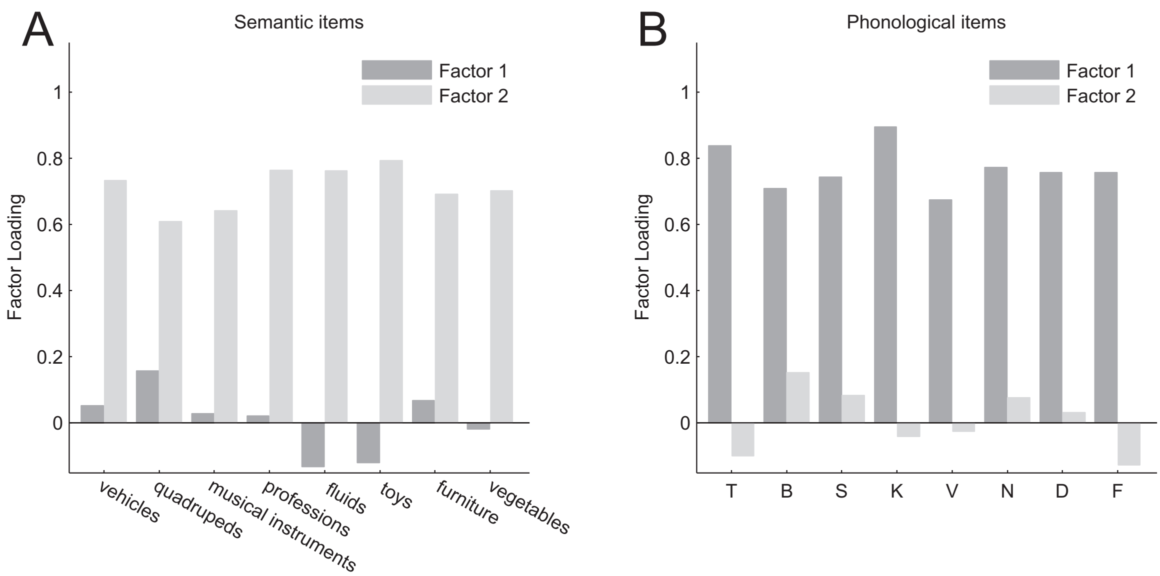

Fig. 2. Factor solutions of the exploratory factor analysis in healthy young adults illustrating the pattern matrix (A) for the semantic items and (B) for the phonological items.

implemented in SPSS (i.e. eigenvalues > 1) as well as by the inspection of the scree plot (Supplementary Fig. S1).

As is illustrated in Fig. 2, the results of the EFA revealed that the first factor had strong loadings from the items T, B, S, K, V, N, D, and F and accounted for 42.5% of variance in the verbal fluency data. The second factor had strong loadings from vehicles, quadrupeds, musical instruments, professions, fluids, toys, furniture, and vegetables and accounted for further 13.5% of incremental variance. Both factor 1 and 2 were correlated by r=.508, thus indicating a common share of explained variance of about 25.8%. Depicting the different two factors' unique and common shares of explained variance in a Venn diagram (Fig. 3) demonstrates that 56.1% of variation in inter-individual differences in verbal fluency could be accounted for by two partly correlated factors, presumably reflecting unique as well as overlapping cognitive processes for semantic and phonological fluency.

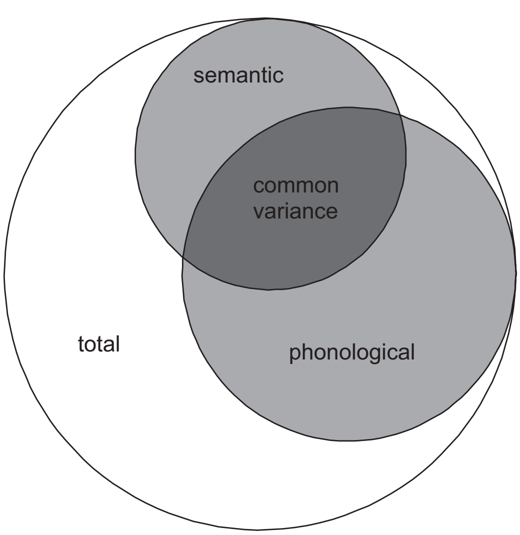

Fig. 3. Venn diagram depicting the two factors' unique and common shares of explained variance for the variation in inter-individual differences in the verbal fluency task. The white circle, labeled with 'total', depicts the total variance (100%) of the data for the verbal fluency task in healthy young adults. The two light grey circles, labeled with 'phonological' and 'semantic', depict their respective proportions of explained variance (phonological [factor 1]=42.5%; semantic [factor 2]=28.1%). The dark grey area labeled 'common variance' depicts the explained common variance of both factor 1 and factor 2 (14.5%). Therefore, the unique variance explained by factor 1 (phonological) is 42.5–14.5%=28.0% and by factor 2 (semantic) is 28.1–14.5%=13.6%. Total explained variance by the two factors is 14.5%+28%+13.6%=56.1%.

3.2. Confirmatory factor analysis (CFA) in stroke patients

Based on the results of the EFA, a confirmatory factor analysis (CFA) was used to validate these findings in an independent sample of N=174 stroke patients (cf. 2.1.2). More specifically, we hypothesized that items for semantic and phonological fluency load on two different (but partly correlated) latent factors and that, consequently, a CFA model including such a two-factor solution fits the data significantly better than a model with a one-factor solution.

In detail, model 1 comprised a two-factor model with the 16 items assigned either to the phonological or to the semantic factor (See Supplementary Fig. S2). All semantic and phonological items significantly loaded on their corresponding factor, with loadings ranging from .659 to .908. The correlation between the two factors was r=.875, indicating about 76.6% of shared variance. The indices for goodness of fit (GFI) and for adjusted goodness of fit (AGFI) were well above the acceptable level of .85 (Table 1; Schermelleh-Engel et al., 2003). Other model fit indices such as χ^2 and χ^2/df, the comparative fit index (CFI), and the root-mean-square error of approximation (RMSEA) also suggested a very good fit of the data to the model (Table 1).

In order to test whether the two-factor model 1 was superior to a one-factor solution, in model 2 the correlation between factor 1 and factor 2 was set to 1 to constrain the two factors to be exactly the same. For model 2, the GFI and the AGFI were markedly lower as compared to model 1 (Table 1). Furthermore, all other model fit indices (i.e., χ^2, χ^2/df, CFI, and RMSEA) suggested that the null hypothesis of a good model fit be rejected. The comparison between both models further indicated that the two-factor solution in model 1 was significantly better than the one-factor solution in model 2 by a change in χ^2(df=1) of 131.571 ($p < .001$). Taken together, the CFA hence confirmed that, despite their overlapping variance, semantic and phonological verbal fluency also measure distinct sets of cognitive processes.

Finally, for direct comparability, we repeated the EFA approach in the stroke sample. Results were essentially the same as for the healthy young adults, yielding a two-factor solution with all semantic items loading on one factor and all phonological items loading on the other (see Supplementary Fig. S3).

As the stroke sample comprised several patients with aphasia who possibly performed worse in both the semantic and phonological verbal fluency due to a general language impairment, we further repeated the

Table 1
Results of the confirmatory factor analysis (CFA) for the clinical sample of 174 stroke patients.

	χ^2	DF	p-value	χ^2/DF	TLI rho2	CFI	GFI	AGFI	RMSEA
Model 1	93.565	103	.736	.908	1.005	1.000	.936	.916	< .001
Model 2	225.137	104	< .001	2.165	.938	.946	.809	.750	.082

Note: DF=degrees of freedom; TLI=Tucker-Lewis index; CFI=comparative fit index; GFI=goodness-of-fit index; AGFFI=adjusted goodness-of-fit index; RMSEA=root mean square error of approximation.

above CFA in a subsample of n=134 stroke patients without signs of aphasia in the acute phase, so as to rule out any potential bias. The results of this analysis were highly comparable to those obtained in the whole sample (see Supplements).

To further understand the increased correlation between the semantic and phonological factor in the stroke patients (r=.875) as compared to the healthy controls (r=.508), partial correlation was computed. Specifically, available data on the patients' Montreal Cognitive Assessment score (MoCA; Nasreddine et al., 2005) was used as control variable, as this test reflects a measure of the general cognitive status. When controlling for the MoCA, a considerably reduced correlation between the two factors (r=.575) was revealed, thus closely matching the findings in the healthy controls. However, it should be noted that the MoCA also includes verbal fluency as a sub-test. To additionally control for this issue, partial correlation was re-computed using a MoCA score excluding the verbal fluency sub-test. Again, a substantially reduced correlation between the two factors (r=.616) was observed. The same results were obtained when repeated in the sample of patients without signs of aphasia (r=.553). Taken together, a large proportion of the increased common variance of the two factors in stroke patients can be explained by their general cognitive status. The unique and common shares of explained variance of the two factors are depicted in a Venn diagram (Fig. 4).

4. Discussion

Results of the exploratory factor analysis (EFA) in the healthy sample and the subsequent confirmatory factor analysis (CFA) in the stroke sample both indicated that a two-factor solution, in which all semantic items load on one factor and all phonological items load on the other, best described the variation of inter-individual differences in both verbal fluency types and that this solution was significantly superior to a one-factor solution. The present results hence constitute first evidence from factor-analytic approaches that semantic and phonological verbal fluency indeed measure two distinct sets of cognitive processes. In this respect, the present data close an existing gap in the literature by resolving the discrepancy between the results from previous factor analyses favoring a one-factor solution (Ardila et al., 1994; Unsworth et al., 2011; Whiteside et al., 2016) and the evidence from the lesion and neuroimaging literature suggesting a two-factor solution (see e.g., Birn et al., 2010; Gourovitch, 2000; Henry and Crawford, 2004; Indefrey and Levelt, 2004; Wagner et al., 2014; for overviews).

At first glance, the present results contradict those found in previous factor analyses. However, the preference of a one-factor solution in these studies (Ardila et al., 1994; Bizzozero et al., 2013; Unsworth et al., 2011; Whiteside et al., 2016) might be due to several methodological reasons (see Introduction; i.e. limited and partly disparate number of items for semantic and phonological verbal fluency; potential bias by inclusion of other cognitive constructs in the analyses). Furthermore, as the present results emphasize both common and distinct shares of variance in semantic and phonological fluency, they rather seem to extend the findings from these previous studies by complementing prior evidence for common cognitive processes with additional evidence for distinct sets of cognitive processes.

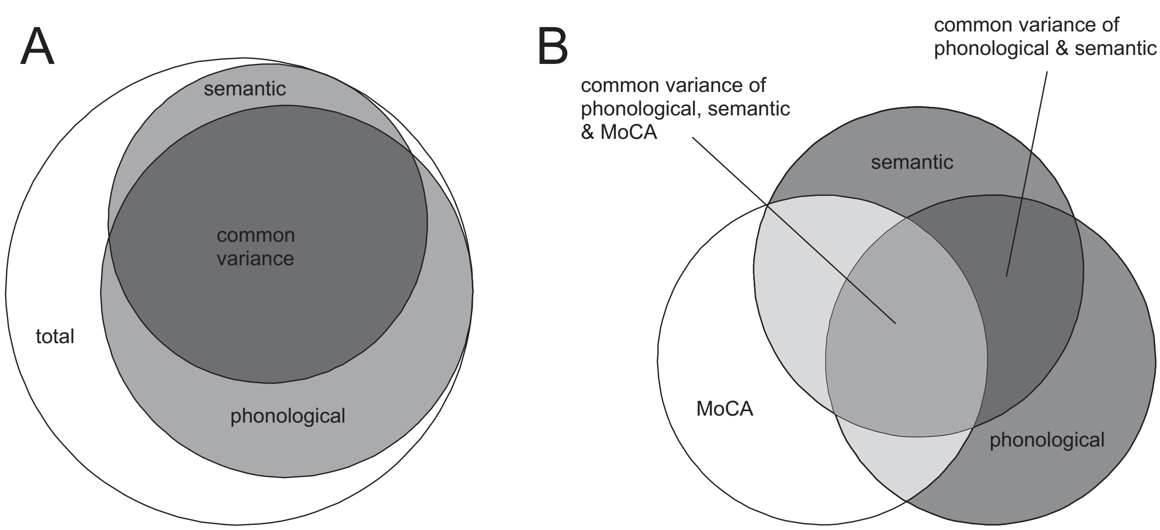

Fig. 4. Venn diagram depicting the two factors' unique and common shares of explained variance in stroke patients for the variation in inter-individual differences in (A) the verbal fluency task and (B) the MoCA. (A) The white circle, labeled with 'total', depicts the total variance (100%) of the data for the verbal fluency task in stroke patients. The two light grey circles, labeled with 'phonological' and 'semantic', depict their respective proportions of explained variance of the verbal fluency data (phonological [factor 1]=63.6%; semantic [factor 2] =47.3%). The dark grey area, labeled 'common variance', depicts the explained common variance of both factor 1 and factor 2 (40.9%). Therefore, the unique variance explained by factor 1 (phonological) is 63.6–40.9%=22.6% and by factor 2 (semantic) is 47.3–40.9% =6.4%. Total explained variance by the two factors is 40.9%+22.6%+6.4%=69.9%. (B) The white circle, labeled with 'MoCA', depicts the total variance (100%) in MoCA scores of stroke patients. The dark grey area, labeled with 'common variance of phonological & semantic', depicts the shared variance of both factor 1 and factor 2 (58.5%). The lighter grey area, labeled with 'common variance of phonological, semantic & MoCA', depicts the share of common variance of factor 1 and factor 2 and MoCA scores (39%). The unique variance of MoCA scores explained by factor 1 (phonological) is 40.5–39%=1.5% and by factor 2 (semantic) is 53.4–39% =14.4%. Note that the amount of variance (i.e. the size of each circle) of MoCA scores, factor 1 (phonological), and factor 2 (semantic) was set to be equal for visualization purposes.

However, the present findings cannot answer the question regarding the nature of cognitive processes that are required for both fluency sub-tasks and the type of processes that are exclusively involved in either semantic or phonological fluency.

With regard to common cognitive processes, working memory, self-monitoring, cognitive flexibility as well as sustained attention have been frequently associated with both types of verbal fluency (Baldo et al., 2006; Rosen and Engle, 1997; Robinson et al., 2012; Schwartz et al., 2003; Troyer et al., 1998). For instance, executive control processes for constant monitoring of words already said and semantic sub-categories or letters already processed as well as switching between sub-categories/letters is required for successful retrieval in both semantic and phonological fluency (Henry and Crawford, 2004).

In addition to these shared cognitive processes, different or specific processes are required for one fluency task but not the other. These may be related to the different search strategies required for semantic and phonological fluency (Unsworth et al., 2011). Whereas semantic fluency is based on search through conceptual or semantic memory and hence is dependent on an intact integrity of semantic memory, phonological fluency is based on search through lexical or phonological memory that is dependent on proper syllabification (Henry and Crawford, 2004; Mummery et al., 1996; Rende et al., 2002). Moreover, semantic verbal fluency is based on a serial search process in which, for the initially specified category, a first step is to search for sub-categories and then for members of these particular sub-categories. In phonological fluency successful retrieval is based on systematic syllabification of initial letters and hence, automatic retrieval influenced by semantic association chains needs to be suppressed (Katzev et al., 2013). Since knowledge is organized in semantic networks, which further promotes the retrieval strategy by semantic (sub-)categories, semantic fluency is commonly easier than phonological fluency. In close relation, studies using a dual-task methodology also found evidence for dissociable cognitive processes underlying semantic and phonological fluency. For instance, Moscovitch (1994) demonstrated that only letter fluency was impaired when participants engaged in a concurrent finger-tapping task that presumably utilizes the frontal lobes, thus further arguing for differences in the neural correlates of the two types of fluency (also see below). Rende et al. (2002) used a dual-task paradigm to test which sub-components of working memory (e.g. phonological loop, visuospatial sketchpad, and central executive) are differentially involved in semantic and phonological fluency, respectively. They found that a concurrent task that primarily involved the phonological loop (e.g. articulatory suppression) resulted in decreased performance only in the phonological fluency task, whereas a concurrent task primarily involving the visuospatial sketchpad (e.g. cube comparison) resulted in decreased performance only in the semantic fluency task (Rende et al., 2002). In addition, a concurrent task that involved frequent switching between mental sets (e.g. arithmetic switching) and thus presumably engaged the central executive equally decreased both semantic and phonological fluency (Rende et al., 2002). These findings are in line with the proposed differences in search strategy for the two types of verbal fluency in that they demonstrate dissociable recruitment of working memory processes by semantic versus phonological fluency and reverberate the shared recruitment of executive control processes presumably needed for both types of verbal fluency. On a statistical level, this is reflected by the results of this study of a two-factor solution with partial correlation between the two factors.

Considering the neural basis of semantic and phonological verbal fluency, several functional neuroimaging as well as lesion and behavioral studies showed that semantic and phonological verbal fluency can be attributed to the temporal and frontal lobes, respectively (Baldo et al., 2006, 2010; Benton, 1968; Costafreda et al., 2006; Gourovitch et al., 2000; Henry and Crawford, 2004; Thompson-Schill et al., 1998). However, other regions such as parietal cortex, insula, putamen, and cerebellum have also been implicated in both types of verbal fluency (Baldo et al., 2006; Indefrey and Levelt, 2004; Schweizer et al., 2010). Thompson-Schill et al. (1997) suggested that the left inferior frontal gyrus (LIFG) is critical for the selection processes, whereas Robinson et al. (2012) suggested that fluency tasks with greater selection demands from multiple competing responses will be impaired following LIFG damage. Katzev et al. (2013) tested this assumption and demonstrated that differences in activation of sub-regions within the LIFG can be attributed to differences in task demand and individual ability (Katzev et al., 2013; Robinson et al., 2012; Thompson-Schill et al., 1997; see Costafreda et al., 2006 for a review on the role of LIFG in verbal fluency; see also Wagner et al., 2014), further indicating that distinct sets of cognitive processes are required for the two types of verbal fluency tasks. Also studies investigating qualitative features of the verbal fluency task such as clustering and switching (Troyer et al., 1997) found differential involvement of areas within the frontal lobe (Reverberi et al., 2006; Schwartz and Baldo, 2001), corroborating the current study and previous findings.

With regard to the present findings in the clinical group, the higher correlation between the two factors for stroke patients as compared to the healthy participants suggests that the patients probably exhibited deficits in those cognitive processes that are required for both semantic and phonological fluency such as working memory and attention (Mok et al., 2004; Patel et al., 2002; Tatemichi et al., 1994). This is supported by the considerably reduced correlation between the two factors when controlling for the MoCA score (see Section 3.2), which measures a patient's general cognitive status. However, the MoCA score also represents inter-individual differences that are due to differences in age or level of education but independent of the effects of the stroke. Although the MoCA score is partially controlled for these variables, both specific and unspecific cognitive impairments are quantified with this test. In close relation, the patient sample was considerably older as compared to the group of healthy controls, which may imply that age-related decrements in processing speed, executive function, working memory, and access to lexico-semantic operations, irrespective of stroke severity, were likely to be present in this group and may have augmented the shared variance between the two factors (Baciu et al., 2016; Rosen and Engle, 1997; Salthouse, 2009). In this respect, a negative correlation between age and performance in the verbal fluency task in the stroke sample ($r=-.342$) indicated that younger patients performed better than older patients, further corroborating these assumptions.

There are several limitations of the present study. Firstly, the two samples differed with respect to various socio-demographic variables. Specifically, the healthy sample consisted of young and mainly female university students, whereas the stroke sample comprised older and mainly male patients with a broad variation in educational attainment. These differences might be due to the fact that, at least in our experience, women are more likely to voluntarily participate as healthy control subjects in research studies. By contrast, due to age- and sex-related differences in the incidence of stroke (Appelros et al., 2009; Petrea et al., 2009; Reeves et al., 2008; Roquer et al., 2003; Wyller, 1999), stroke patients at an average age of 64 years, as recruited in our sample, are more likely to be male. Furthermore, the difference between the two groups concerning education can be attributed to the recruitment of healthy young adults from among university students, whereas no such restrictions applied to the stroke sample. As age, education, and gender have been reported to influence performance in semantic and phonological fluency (e.g., Loonstra et al., 2001; Strauss et al., 2006; Tombaugh et al., 1999; van der Elst et al., 2006), it can be assumed that the two samples also differed with respect to their overall verbal fluency ability and probably also with respect to general language abilities. However, as the results from the exploratory factor analysis in the young healthy adults and the confirmatory factor analysis in the older stroke sample converged on the same conclusion, the different characteristics of the two samples may in turn be taken as an indication for the generalizability of the present findings.

A second limitation concerns the procedure of the verbal fluency task, which was in part different from other studies. Letter and category cues are commonly given orally but were visually presented in the present study. This difference is, however, unlikely to have biased the results, as all participants were able to read. Another difference from commonly applied procedures is that only nouns were allowed for responding to the phonological fluency condition. This task rule was adopted from Katzev et al. (2013) who used frequency estimations for German nouns (exclusive of compound nouns) with given initial letters derived from the Mannheim Corpus of the German language as an indication of the expected difficulty level of individual letter cues. In consequence, instructions for the phonological condition restricted correct answers to nouns only, and as the present study used the same items as Katzev et al. (2013), this restriction was also applied here (see also Heim et al., 2008, 2009). This difference in the task procedures may have resulted in increased item difficulty and increased task demands for phonological cues compared to the common assessment of phonological fluency. However, given that previous evidence from the lesion, neuroimaging, and cognitive literature already suggested a potential dissociation between semantic and phonological verbal fluency in the underlying neural and cognitive processes (Baldo et al., 2006, 2010; Benton, 1968; Costafreda et al., 2006; Gourovitch et al., 2000; Henry and Crawford, 2004; Thompson-Schill et al., 1998), it seems unlikely that the present findings of a two-factor solution are artificially introduced by restricting the phonological fluency to nouns only. Yet, future studies should explicitly compare the impact of different types of instructions for phonological fluency on the number of words generated and on the factor-analytic pattern of relationships between semantic and phonological fluency.

5. Conclusion

Taken together, these findings considerably expand previous studies that investigate whether semantic and phonological verbal fluency measure the same or distinct sets of cognitive processes by providing explanations for inconsistent findings between the extant neuroimaging and lesion literature and results from factor-analytic approaches. Both EFA and CFA with a large number of items revealed that semantic and phonological verbal fluency measure both clearly distinct but also shared sets of cognitive processes. Further studies may aim at investigating the nature of these distinct and common cognitive processes and whether the observed sharing of unique and common variance of the verbal fluency task for the two factors can be attributed to circumscribed neural networks. Although specific cognitive subfunctions involved thus remain to be fully characterized, it is now clear that semantic and phonological fluency are not sufficiently described by assuming one cognitive process.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuropsychologia.2017.02.019.

References

Abwender, D.A., Swan, J.G., Bowerman, J.T., Connolly, S.W., 2001. Qualitative analysis of verbal fluency output: review and comparison of several scoring methods. Assessment 8 (3), 323–338.

Alvarez, J.A., Emory, E., 2006. Executive function and the frontal lobes: a meta-analytic review. Neuropsychol. Rev. 16 (1), 17–42.

Appelros, P., Stegmayr, B., Terént, A., 2009. Sex differences in stroke epidemiology. A Syst. Rev. 40 (4), 1082–1090.

Ardila, A., Rosselli, M., Bateman, J.R., 1994. Factorial structure of cognitive activity using a neuropsychological test battery. Behav. Neurol. 7 (2), 49–58.

Baciu, M., Boudiaf, N., Cousin, E., Perrone-Bertolotti, M., Pichat, C., Fournet, N., Chainay, H., Lamalle, L., Krainik, A. 2016. Functional MRI evidence for the decline of word retrieval and generation during normal aging. Age (Dordr), 38(1), 3.

Baldo, J.V., Schwartz, S., Wilkins, D., Dronkers, N.F., 2006. Role of frontal versus temporal cortex in verbal fluency as revealed by voxel-based lesion symptom mapping. J. Int. Neuropsychol. Soc. 12, 896–900.

Baldo, J.V., Schwartz, S., Wilkins, D.P., Dronkers, N.F., 2010. Double dissociation of letter and category fluency following left frontal and temporal lobe lesions. Aphasiology 24 (12), 1593–1604.

Beck, A.T., Steer, R.A., Brown, G.K. 1996. Beck depression inventory.

Benton, A.L., 1968. Differential behavioral effects in frontal lobe disease. Neuropsychologia 6 (1), 53–60.

Birn, R.M., Kenworthy, L., Case, L., Caravella, R., Jones, T.B., Bandettini, P.A., Martin, A., 2010. Neural systems supporting lexical search guided by letter and semantic category cues: a self-paced overt response fMRI study of verbal fluency. Neuroimage 49 (1), 1099–1107.

Bizzozero, I., Scotti, S., Clerici, F., Pomati, S., Laiacona, M., Capitani, E., 2013. On which abilities are category fluency and letter fluency grounded? A confirmatory factor analysis of 53 Alzheimer's dementia patients. Dement Geriatr. Cogn. Dis. Extra 3 (1), 179–191.

Borkowski, J.G., Benton, A.L., Spreen, O., 1967. Word fluency and brain damage. Neuropsychologia 5 (2), 135–140.

Chouiter, L., Holmberg, J., Manuel, A.L., Colombo, F., Clarke, S., Annoni, J.M., Spierer, L., 2016. Partly segregated cortico-subcortical pathways support phonologic and semantic verbal fluency: a lesion study. Neuroscience 329, 275–283.

Costafreda, S.G., Fu, C.H., Lee, L., Everitt, B., Brammer, M.J., David, A.S., 2006. A systematic review and quantitative appraisal of fMRI studies of verbal fluency: role of the left inferior frontal gyrus. Hum. Brain Mapp. 27 (10), 799–810.

Demonet, J.F., Chollet, F., Ramsay, S., Cardebat, D., Nespoulous, J.L., Wise, R., Frackowiak, R., 1992. The anatomy of phonological and semantic processing in normal subjects. Brain 115 (Pt 6), 1753–1768.

Elst, Van Der, Van Boxtel, W., Van Breukelen, M.P., G. J, Jolles, J., 2006. Normative data for the animal, profession and letter M naming verbal fluency tests for Dutch speaking participants and the effects of age, education, and sex. J. Int. Neuropsychol. Soc. 12 (01), 80–89.

Field, A., 2005. Discovering Statistics Using SPSS 2nd ed.. SAGE Publications Inc, London.

Gourovitch, M.L., Kirkby, B.S., Goldberg, T.E., Weinberger, D.R., Gold, J.M., Esposito, G., Berman, K.F., 2000. A comparison of rCBF patterns during letter and semantic fluency. Neuropsychology 14 (3), 353–360.

Gruenewald, P.J., Lockhead, G.R., 1980. The free recall of category examples. J. Exp. Psychol.: Hum. Learn. Mem. 6 (3), 225–240.

Heim, S., Eickhoff, S.B., Amunts, K., 2008. Specialisation in Broca's region for semantic, phonological, and syntactic fluency? Neuroimage 40 (3), 1362–1368.

Heim, S., Eickhoff, S.B., Amunts, K., 2009. Different roles of cytoarchitectonic BA 44 and BA 45 in phonological and semantic verbal fluency as revealed by dynamic causal modelling. Neuroimage 48 (3), 616–624.

Hendrickson, A.E., White, P.O., 1964. Promax: a quick method for rotation to oblique simple structure. Br. J. Stat. Psychol. 17, 65–70.

Henry, J.D., Crawford, J.R., 2004. A meta-analytic review of verbal fluency performance following focal cortical lesions. Neuropsychology 18 (2), 284–295.

Horn, J.L., 1965. A rationale and test for the number of factors in factor analysis. Psychometrika 30, 179–185.

Indefrey, P., Levelt, W.J., 2004. The spatial and temporal signatures of word production components. Cognition 92, 101–144.

Jurado, M.A., Mataro, M., Verger, K., Bartumeus, F., Junque, C., 2000. Phonemic and semantic fluencies in traumatic brain injury patients with focal frontal lesions. Brain Inj. 14, 789–795.

Kaller, C.P., Debelak, R., Kostering, L., Egle, J., Rahm, B., Wild, P.S., Blettner, M., Beutel, M.E., Unterrainer, J.M., 2016. Assessing Planning Ability Across the Adult Life Span: Population-Representative and Age-Adjusted Reliability Estimates for the Tower of London (TOL-F). Arch. Clin. Neuropsychol. 31 (2), 148–164.

Katzev, M., Tuscher, O., Hennig, J., Weiller, C., Kaller, C.P., 2013. Revisiting the functional specialization of left inferior frontal gyrus in phonological and semantic fluency: the crucial role of task demands and individual ability. J. Neurosci. 33 (18), 7837–7845.

Köstering, L., Nitschke, K., Schumacher, F.K., Weiller, C., Kaller, C.P., 2015. Test-retest reliability of the Tower of London Planning Task (TOL-F). Psychol. Assess. 27 (3), 925–931.

Lezak, M.D., Howieson, D.B., Loring, D.W., 2004. Neuropsychological Assessment. Oxford University Press, New York.

Loonstra, A.S., Tarlow, A.R., Sellers, A.H., 2001. COWAT metanorms across age, education, and gender. Appl. Neuropsychol. 8 (3), 161–166.

Martin, A., Fedio, P., 1983. Word production and comprehension in Alzheimer's diseáse:

the breakdown of semantic knowledge. Brain Lang. 19 (1), 124–141.
Meinzer, M., Flaisch, T., Wilser, L., Eulitz, C., Rockstroh, B., Conway, T., Crosson, B., 2009. Neural signatures of semantic and phonemic fluency in young and old adults. J. Cogn. Neurosci. 21 (10), 2007–2018.
Metternich, B., Buschmann, F., Wagner, K., Schulze-Bonhage, A., Kriston, L., 2014. Verbal fluency in focal epilepsy: a systematic review and meta-analysis. Neuropsychol. Rev. 24 (2), 200–218.
Milner, B., 1964. Some effects of frontal lobectomy in man. In: Warren, J.M., Akert, K. (Eds.), The Frontal Granular Cortex and Behavior. McGraw-Hill, New York, 313–334.
Mok, V.C.T., Wong, A., Lam, W.W.M., Fan, Y.H., Tang, W.K., Kwok, T., Hui, A.C.F., Wong, K.S., 2004. Cognitive impairment and functional outcome after stroke associated with small vessel disease. J. Neurol. Neurosurg. Psychiatry 75, 560–566.
Moscovitch, M., 1994. Cognitive resources and dual-task interference effects at retrieval in normal people: The role of the frontal lobes and medial temporal cortex. Neuropsychology 8 (4), 524.
Mummery, C.J., Patterson, K., Hodges, J.R., Wise, R.J., 1996. Generating 'tiger' as an animal name or a word beginning with T: differences in brain activation. Proc. R. Soc. B: Biol. Sci. 263 (1373), 989–995.
Nasreddine, Z.S., Phillips, N.A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., Chertkow, H., 2005. The Montreal Cognitive Assessment, MoCA: abrief screening tool for mild cognitive impairment. J. Am. Geriatr. Soc., 53(4), pp. 695–699.
O'Connor, B.P., 2000. SPSS and SAS programs for determining the number of components using parallel analysis and velicer's MAP test. Behav. Res. Methods Instrum. Comput. 32 (3), 396–402.
Patel, M.D., Coshall, C., Rudd, A.G., Wolfe, C.D., 2002. Cognitive impairment after stroke: clinical determinants and its associations with long-term stroke outcomes. J. Am. Geriatr. Soc. 50, 700–706.
Petrea, R.E., Beiser, A.S., Seshadri, S., Kelly-Hayes, M., Kase, C.S., Wolf, P.A., 2009. Gender differences in stroke incidence and poststroke disability in the framingham heart study. Stroke 40 (4), 1032–1037.
Reeves, M.J., Bushnell, C.D., Howard, G., Gargano, J.W., Duncan, P.W., Lynch, G., Lisabeth, L., 2008. Sex differences in stroke: epidemiology, clinical presentation, medical care, and outcomes. Lancet Neurol. 7 (10), 915–926.
Rende, B., Ramsberger, G., Miyake, A., 2002. Commonalities and differences in the working memory components underlying letter and category fluency tasks: a dual-task investigation. Neuropsychology 16 (3), 309–321.
Reverberi, C., Laiacona, M., Capitani, E., 2006. Qualitative features of semantic fluency performance in mesial and lateral frontal patients. Neuropsychologia 44 (3), 469–478.
Robinson, G., Shallice, T., Bozzali, M., Cipolotti, L., 2012. The differing roles of the frontal cortex in fluency tests. Brain 135 (7), 2202–2214.
Roquer, J., Campello, A.R., Gomis, M., 2003. Sex differences in first-ever acute stroke. Stroke 34 (7), 1581–1585.
Rosen, V.M., Engle, R.W., 1997. The role of working memory capacity in retrieval. J. Exp. Psychol.: Gen. 126 (3), 211–227.
Salthouse, T.A., 2009. Major Issues in Cognitive Aging. Oxford University Press, New York.
Sarkis, R.A., Busch, R.M., Floden, D., Chapin, J.S., Kalman Kenney, C., Jehi, L., Ruggieri, P., Najm, I., 2013. Predictors of decline in verbal fluency after frontal lobe epilepsy surgery. Epilepsy Behav. 27 (2), 326–329.
Schermelleh-Engel, K., Moosbrugger, H., Müller, H., 2003. Evaluating the fit of structural equation models: test of significance and descriptive goodness-of-fit measures. Methods Psychol. Res. – Online 8 (2), 23–74.
Schlösser, R., Hutchinson, M., Joseffer, S., Rusinek, H., Saarimaki, A., Stevenson, J., Dewey, S., Brodie, J.D., 1998. Functional magnetic resonance imaging of human brain activity in a verbal fluency task. J. Neurol. Neurosurg. Psychiatry 64 (4), 492–498.
Schwartz, S., Baldo, J., 2001. Distinct patterns of word retrieval in right and left frontal lobe patients: a multidimensional perspective. Neuropsychologia 39 (11), 1209–1217.
Schwartz, S., Baldo, J., Graves, R.E., Brugger, P., 2003. Pervasive influence of semantics in letter and category fluency: A multidimensional approach. Brain Lang. 87 (3), 400–411.
Schweizer, T.A., Alexander, M.P., Susan Gillingham, B.A., Cusimano, M., Stuss, D.T., 2010. Lateralized cerebellar contributions to word generation: a phonemic and semantic fluency study. Behav. Neurol. 23, 31–37.
Shao, Z., Janse, E., Visser, K., Meyer, A.S., 2014. What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. Front. Psychol. 5, 772.
Strauss, E., Sherman, E.M.S., Spreen, O., 2006. A Compendium of Neuropsychological Tests. Oxford University Press, New York.
Szatkowska, I., Grabowska, A., Szymanska, O., 2000. Phonological and semantic fluencies are mediated by different regions of the prefrontal cortex. Acta Neurobiol. Exp. (Wars.) 60, 503–508.
Tatemichi, T.K., Desmond, D.W., Stern, Y., Paik, M., Sano, M., Bagiella, E., 1994. Cognitive impairment after stroke: frequency, patterns, and relationship to functional abilities. J. Neurol. Neurosurg. Psychiatry 57, 202–207.
Thompson-Schill, S.L., Swick, D., Farah, M.J., D'Esposito, M., Kan, I.P., Knight, R.T., 1998. Verb generation in patients with focal frontal lesions: a neuropsychological test of neuroimaging findings. Proc. Natl. Acad. Sci. 95 (26), 15855–15860.
Tombaugh, T.N., Kozak, J., Rees, L., 1999. Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. Arch. Clin. Neuropsychol. 14 (2), 167–177.
Troyer, A.K., Moscovitch, M., Winocur, G., 1997. Clustering and switching as two components of verbal fluency: evidence from younger and older healthy adults. Neuropsychology 11 (1), 138–146.
Troyer, A.K., Moscovitch, M., Winocur, G., Alexander, M.P., Stuss, D., 1998. Clustering and switching on verbal fluency: the effects of focal frontal- and temporal-lobe lesions. Neuropsychologia 36 (6), 499–504.
Tukey, J.W., 1977. Exploratory Data Analysis. Addison-Wesley, Reading, MA.
Unsworth, N., Spillers, G.J., Brewer, G.A., 2011. Variation in verbal fluency: a latent variable analysis of clustering, switching, and overall performance. Q J. Exp. Psychol. (Hove) 64 (3), 447–466.
Velicer, W.F., 1976. Determining the number of components from the matrix of partial correlations. Psychometrika 41 (3), 321–327.
Wagner, S., Sebastian, A., Lieb, K., Tuscher, O., Tadic, A., 2014. A coordinate-based ALE functional MRI meta-analysis of brain activation during verbal fluency tasks in healthy control subjects. BMC Neurosci. 15, 19.
Whiteside, D.M., Kealey, T., Semla, M., Luu, H., Rice, L., Basso, M.R., Roper, B., 2016. Verbal fluency: language or executive function measure? Appl. Neuropsychol. Adult 23 (1), 29–34.
Wyller, T.B., 1999. Stroke and Gender. The Journal of Gender-specific Medicine: JGSM: the Official Journal of the Partnership for Women's Health at Columbia, 2(3), pp. 41–45.