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A computational analysis of semantic structure in bilingual verbal fluency performance

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ABSTRACT

Groups of English monolingual and English–French bilingual participants completed letter and category fluency tasks, either only in English (monolinguals) or in English, French, free-switch and forced-switch conditions (bilinguals). Response patterns were modeled using a semantic space approach that estimates the weight of frequency and semantic similarity information in determining output patterns. Overall, semantic similarity had a stronger influence on output patterns than did frequency. In the forced English–French switching condition, the weight of similarity information was reduced and the weight of frequency information was increased, suggesting that the increased executive demands related to language switching result in alterations in the semantic structure of fluency output. Moreover, the frequency and similarity model parameters were negatively correlated in all tasks, indicating that they may be in competition during verbal fluency tasks.

Introduction

Bilingualism is extremely prevalent, with more than 50% of the world's population being bilingual or multilingual (Grosjean, 2008). Recent research has demonstrated differences in cognitive function between bilinguals and monolinguals, with bilinguals exhibiting lower performance than monolinguals in language-related tasks, but better performance on tasks of executive control (for a review, see Bialystok, 2009; Bialystok, Craik, & Luk, 2008). Verbal fluency tasks are among the most commonly used measures to assess language function in neuropsychological testing. These tasks require the participant to generate as many words as possible according to a specific criterion within a given time period (typically 1 min). Most commonly, the criterion is either a phonemic cue (e.g., words starting with the letter F) or a category (e.g., animals). Verbal fluency requires both language and executive function; the subject must organize verbal retrieval and recall, initiate responses, monitor prior responses, and inhibit inappropriate responses (Henry, Crawford, & Phillips, 2004). However, the demands on semantic knowledge vary depending on the criterion. Category fluency intrinsically requires rapid access to semantic knowledge. Letter fluency, in contrast, can be performed without access to semantic knowledge (Rohrer, Salmon, Wixted, & Paulsen, 1999), although output is typically influenced by semantic organization to some extent in healthy adults (Schwartz, Baldo, Graves, & Brugger, 2003).

One influential approach to analyzing fluency output examines measures of clustering and switching (Troyer, Moscovitch, & Winocur, 1997; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998). Clustering refers to the grouping together of items from a given subcategory; for example, a participant may produce a subgroup of farm

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animals, and then switch to African animals, and so on throughout the test period. By examining the number of clusters and the number of switches between clusters that a participant makes, a measure of the semantic coherency of the output can be measured. This approach has been successfully used to examine deficits in verbal fluency in various disorders, including Alzheimer's and Parkinson's disease (Troyer, Moscovitch, Winocur, Leach, et al., 1998), Huntington's disease (Ho et al., 2002), amyotrophic lateral sclerosis (Lepow et al., 2010), and traumatic brain injury (Zakzanis, McDonald, & Troyer, 2011). Based on data from patients with frontal and temporal lobe lesions, it has been claimed that clustering in normal fluency output reflects temporal lobe function, strongly related to semantic representations, while switching is related to frontal lobe function (Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998).

However, the traditional clustering procedure suffers from a number of drawbacks. First, a clustering analysis relies on subjective judgments of category membership, which brings into question issues of reliability and validity. Second, it does not allow a fine-grained analysis of fluency output, because a binary decision is made on each item (i.e., whether the item is a member of given category or not). Most category structures are more continuous than this, and so this need for a binary decision on each word may not accurately reflect actual category structure. Third, the procedure cannot differentiate between a deficit in switching and general decline in processing speed (Mayr, 2002), which recent research suggests is one of the major contributors to fluency performance (McDowd et al., 2011).

Research into verbal fluency across languages indicates that language of administration can affect performance. For example, higher fluency output is observed in Vietnamese relative to Spanish, possibly because animal names are typically monosyllabic in Vietnamese and multisyllabic in Spanish (Kempler, Teng, Dick, Taussig, & Davis, 1998). Moreover, bilinguals—both younger and older—typically exhibit lower category fluency performance relative to monolinguals, even when the task is administered in the participant's native language (Bialystok et al., 2008; Gollan, Montoya, & Werner, 2002; Portocarrero, Burright, & Donovick, 2007; Rosselli et al., 2002). In balanced French–English bilinguals, similar performance across languages has been reported (Roberts & Le Dorze, 1997), and in Spanish–English bilinguals and English monolinguals, similar animal subcategories and semantic associations were produced in all groups and languages (Rosselli et al., 2002). In letter fluency, some studies report lower performance in bilinguals than monolinguals (Bialystok et al., 2008; Gollan et al., 2002), while others report similar performance in the two language groups (Portocarrero et al., 2007; Rosselli et al., 2000). Vocabulary size also affects fluency performance in bilinguals: those with relatively higher vocabularies outperform those with lower vocabularies on letter (but not category) fluency (Luo, Luk, & Bialystok, 2010).

A few studies have examined bilingual fluency output in terms of semantic variables. A greater number of subcategory exemplars—that is, increased semantic clustering—was observed in the native language in French–English and Spanish–English bilinguals (Roberts & Le Dorze, 1997; Rosselli et al., 2002). Salvatierra, Rosselli, Acevedo, and Duara (2007) also found more semantic clusters (defined as two or more consecutive items from the same subcategory) in Spanish than in English, both in normal older adults and in patients with Alzheimer's disease (AD). However, de Picciotto and Friedland (2001) found no differences across language conditions in Afrikaans–English bilingual older adults and AD patients. It should be noted, however, that these studies did not provide detailed information about the semantic clusters produced by participants, nor how the output was coded.

Gollan et al. (2002) tested Spanish–English bilingual college students using both an English-only and a free-choice condition (i.e., the participant could say words in both languages, using whichever words came to mind). Surprisingly, performance did not improve in the both-languages condition relative to the English-only condition, although participants did make use of both languages. The authors interpret these results in terms of both interference between languages in bilinguals, and weaker links between semantic and phonemic representations in bilinguals relative to monolinguals. These weaker links are postulated to result from reduced use of word forms in both languages, relative to monolingual speakers of that language. This reduced use also leads to differences in frequency effects in bilinguals and monolinguals. For example, bilinguals differ from monolinguals in a semantic association task when the strongest associate is of low frequency (e.g., in response to "bride" they produce "dress", while monolinguals produce "groom"), but perform similarly to monolinguals when the associate is of high frequency (Antón-Méndez & Gollan, 2010). In picture naming, bilinguals show the greatest disadvantage in low-frequency items, although this effect is weaker in older adults in the non-dominant language (Gollan, Montoya, Cera, & Sandoval, 2008). This "weaker-links hypothesis" (Gollan et al., 2008) predicts that use of frequency information should differ between bilinguals and monolinguals in verbal fluency tasks.

In order to disentangle the different mechanisms potentially contributing to the effects of bilingualism on verbal fluency, Sandoval, Gollan, Ferreira, and Salmon (2010) conducted a time-course analysis of fluency output in monolinguals and bilinguals. They found that bilinguals' lexical retrieval during the fluency task was delayed relative to monolinguals; bilinguals produced more cognates and lower-frequency items than monolinguals; and cross-language intrusion occurred when bilinguals were tested in the non-dominant language, but not when testing was in the dominant language. These results were taken to indicate that between-language interference plays a major role in the verbal fluency disadvantage observed in bilinguals.

In the present paper, we use a novel approach to explore the effects of frequency and semantic relatedness on fluency output in bilinguals, employing similarity structure learned from a distributional model of lexical semantics. Distributional models do not use the traditional approach to coding semantic similarity based on hand-coded relationships between words (e.g., Collins & Quillian,