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Pervasive influence of semantics in letter and category fluency: A multidimensional approach

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Abstract

We used multidimensional statistical procedures to study semantic and lexical processes underlying word retrieval in verbal-fluency performance. Forty healthy participants were given a two-choice letter task (i.e., generate items beginning with the letter ‘A’ or ‘F’, in any order) and a two-choice category task (i.e., generate animal or fruit names, in any order). Using correspondence analysis (CoA) and hierarchical clustering (HC), we found evidence of prominent semantic organization in both letter and category fluency. For example, a striking categorical segregation between animate and inanimate entities emerged during the letter task. Analysis of inter-item times revealed strong sequential priming effects in both tasks. Taken together, these results indicate that semantic facilitation is pervasive in word retrieval processes, even in the letter-fluency task, and therefore suggest that the traditional view of letter fluency as a purely phonemically based task should be revised. Finally, our findings may help explain patterns of verbal-fluency measures obtained in focal brain lesion patients.

Keywords: Semantic memory; Spreading activation; Cognitive maps; Animate/inanimate; Verbal fluency; Correspondence analysis; Cluster analysis; Cognitive processes; Frontal lobe

1. Introduction

How concepts and representations are organized in the brain is a central question in cognitive neuroscience (Barsalou, 1992; Lakoff, 1987; Rosch & Lloyd, 1978; Warrington & Shallice, 1984). Category-specific deficits after brain damage (Gainotti, Silveri, Daniele, & Giustolisi, 1995) and connectionist models of semantic knowledge (McClelland & Rumelhart, 1988) suggest that information processing involves selectively distributed systems (Mesulam, 1998). Semantic networks are commonly considered to be functionally segregated into anatomically discrete, but highly interactive, modality-specific regions (Farah & McClelland, 1992; Moore & Price, 1999; Thompson-Schill, Aguirre, D’Esposito, & Farah, 1999). Such functional organization might potentially underlie the formation of distinct conceptual categories (Barsalou, 1992; Caramazza & Shelton, 1998; Lakoff, 1987; Rosch & Lloyd, 1978; Warrington & Shallice, 1984).

One way in which semantic networks have been studied is by analyzing the pattern of responses on verbal-fluency tasks (e.g., Chan et al., 1993; Schwartz & Baldo, 2001). Fluency tasks require participants to generate as many items as possible according to a given criterion (words beginning with a certain letter or items belonging to a semantic category) within a specified time period (usually 1 or 2 min). Often administered in clinical neuropsychological assessment, letter and category-fluency tasks are thought to involve specialized cognitive abilities that tap differentially frontal and temporal cortices (Jones-Gotman & Milner, 1977; Milner, 1964; Ramier & Hécaen, 1970). Disproportionate category-fluency impairment is

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commonly associated with temporal-lobe dysfunction (Chan et al., 1993; Hodges, Salmon, & Butters, 1992; Monsch et al., 1994; Troester, Salmon, McCullough, & Butters, 1989). On the other hand, patients with focal frontal lesions may be more impaired on letter than category fluency, in the absence of major semantic breakdown (Chan et al., 1993; Monsch et al., 1994; Stuss et al., 1998). These neuropsychological observations have led to the hypothesis of a dissociation between the contributions of temporal- and frontal-lobe processes to fluency performance. In particular, discrepancies between letter- and category-fluency scores in patients with temporal-lobe deficits have been attributed to the greater demands category-fluency places on the hierarchical structure of semantic knowledge, which is believed to be primarily held in the temporal cortex (Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Chan et al., 1993; Garrard, Lambon Ralph, Hodges, Patterson, & Hodges, 2001; Hodges et al., 1992; Martin & Fedio, 1983; Monsch et al., 1992; Ober, Dronkers, Koss, Delis, & Friedland, 1986; Troester et al., 1989). Conversely, letter- and category-fluency tasks may rely on executive processes involving several brain regions, particularly the left frontal cortex (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001; Martin, Wiggs, Lalonde, & Mack, 1994; Moscovitch, 1994; Stuss et al., 1998). Importantly, no major deficit in verbal-letter fluency has been observed after right frontal or non-frontal damage (Stuss et al., 1998). While category fluency is thought to be mainly based on semantic associations and on the meaning of the words generated, letter fluency would rely more on abstract or novel rules and would require the ability to "*suppress the habit* of using words according to their meaning" (Perret, 1974, p. 324, his italics).

The cerebral correlates of verbal-fluency performance have also been assessed using functional neuroimaging techniques. In a number of studies, letter fluency has been found to activate left frontal regions, using category fluency or other control tasks as a baseline condition (Cuenod et al., 1995; Elfgren & Risberg, 1998; Frith, Friston, Liddle, & Frackowiak, 1991; Mummery, Patterson, Hodges, & Wise, 1996; Parks et al., 1988; Phelps, Hyder, Blamire, & Shulman, 1997; Pujol et al., 1996; Schloesser et al., 1998; Yurgelun-Todd et al., 1996). Furthermore, the degree of activation in the left frontal regions may predict the behavioral performance on orthographic lexical-retrieval tasks (Wood, Saling, Abbott, & Jackson, 2001). In contrast, several functional neuroimaging studies have suggested that semantic knowledge may be represented in distributed neural sites within the temporal lobes (Martin, Wiggs, Ungerleider, & Haxby, 1996; Sartori, Job, Miozzo, Zago, & Marchiori, 1993; Tranel, Damasio, & Damasio, 1997). In particular, different temporal-lobe regions are activated during retrieval of specific semantic categories (e.g., manmade manipulable objects or natural kinds; Mummery et al., 1996). Such findings accord with reports of category-specific semantic disorders after temporal lesions (Barsalou, 1992; Caramazza & Shelton, 1998; Lakoff, 1987; Rosch & Lloyd, 1978; Warrington & Shallice, 1984). Frith et al. (1995) proposed that fluency performance may actually engage reciprocal activity in dorsolateral prefrontal cortex and temporal cortex. That is, verbal fluency may require dynamic interactions between both frontal and temporal regions. In such a model, the frontal cortex plays an executive and monitoring role by actively searching and retrieving stored representations from the temporal regions. In this view, it would be expected that highly structured semantic networks within the temporal regions might exert important constraints on word retrieval processes.

Both patients and imaging data suggest that at least two independent cognitive components are involved in the ability to generate words in response to a given cue: (1) an *associative* component reflecting the semantic organization of memory stores (e.g., Cardebat, Demonet, Celsis, & Puel, 1996; Chiarello, 1985; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Tranel et al., 1997; Warrington & Shallice, 1984), and (2) an *executive* component reflecting response initiation, monitoring, and flexibility (e.g., Glosser & Goodglass, 1990; Grafman, Holyoak, & Boller, 1995; Milner, 1995; Ramier & Hécaen, 1970). The goal of the present paper is to assess the contribution of associative semantic effects in both letter and category fluency by analyzing patterns of word retrieval in healthy young participants.

Although fluency performance is traditionally measured by the number of words generated, there have been attempts to characterize other aspects of the data, such as the sequential structure and composition of individual responses (Chan et al., 1993; Schwartz & Baldo, 2001; Troster et al., 1998; Troyer, 2000). These new approaches can inform on the structure and dynamic interactions within semantic networks, as implemented in connectionist models. For example, when asked to freely generate word lists, participants tend to produce clusters of successive semantically or phonemically related words (Bousfield & Sedgewick, 1944; Estes, 1974; Gruenewald & Lockhead, 1980; Raskin, Sliwinski, & Borod, 1992; Wixted & Rohrer, 1994). Such spontaneous grouping of the words has been accounted for by a "spreading activation" model in which words are represented as interconnected nodes that altogether form structured semantic networks (Anderson & Pirolli, 1984; Collins & Loftus, 1975; Quillian, 1967). As concepts sharing many attributes are more strongly connected (Collins & Loftus, 1975; for an alternative model, see McKoon & Ratcliff, 1992), the activation of a given word may automatically activate or *prime* a local network of related associates (McClelland & Rumelhart, 1987). In verbal-fluency tasks, participants do not generate free verbal associations, but must observe certain rules that are thought to engage executive processes (e.g., generating words starting with a given letter, without repetitions; Butler, Rorsman, Hill, & Tuma, 1993; Glass & Holyoak, 1986). It remains an open question to what extent the structure of semantic memory can constrain word retrieval under controlled fluency conditions.

The present study investigated how semantic factors may influence verbal-fluency tasks using two complementary multidimensional methods, correspondence analysis (CoA) and hierarchical clustering techniques (HC). These methods allowed us to translate differences between individual word lists or "word-profiles" into distances on bidimensional maps and to identify the main semantic dimensions underlying the generation of words (Greenacre, 1994; Lebart, 1998; Schwartz & Baldo, 2001). Based on the literature reviewed above, we hypothesized that the analysis of normal fluency data might reveal similar underlying semantic structures as the ones suggested by category-specific deficits in brain-damaged patients (e.g., living and non-living).

In both letter- and category-fluency conditions, we used a two-choice task (generating names of "animals" *or* "fruits" for the category task and generating words starting by the letter "A" *or* "F" for the phonemic task; see Duchene, Graves, & Brugger, 1998). Such two-choice tasks provide more information than traditional-fluency tasks on aspects of clustering, as well as switching between subcategories. Indeed, we can easily identify "runs" of successive words belonging to either of the two possible cues within the each response (i.e., letter 'A' or 'F' in the letter task, and animal or fruit name in the category task). Our analysis focused on word-profiles generated in each tasks, as well as on the number and length of the runs. The number of runs reflects strategic-search processes (e.g., ability to switch when the current cue no longer provides new items), whereas the run length and the inter-item times are indicators of connectivity and spreading activation in semantic networks (Anderson & Pirolli, 1984; Collins & Loftus, 1975; Troyer, Moscovitch, & Winocur, 1997). These different measures enabled us to compare the degree of semantic organization operating in both category-based retrieval and more abstract letter-based retrieval of words.

2. Methods

2.1. Participants

Forty undergraduates at the University of Victoria (20 males, 20 females) were paid to participate in a series of experiments on individual differences in neuropsychological tasks. Participants had an average age of 21 years, 8 months. All participants were right-handed and spoke English as their first language. None had a history of substance abuse, psychiatric or developmental disorders, or neurological damage. The protocol was approved by the ethics committee of the university and written informed consent was obtained from each student.

2.2. Procedure

2.2.1. fluency tasks

In the two-choice letter fluency task, participants were instructed to generate as many nouns as possible beginning with the letter "A" *or* the letter "F" during 2 min. This letter task was always administered first. In the two-choice category-fluency task, administered after 20 min of unrelated neuropsychological testing, participants were asked to say as many names of "animals" *or* "fruits" as possible during 2 min. In both tasks, subjects were explicitly informed that they could switch between the two letters or between the two categories whenever and as often as they wanted. They were asked not to use names of persons, places, or brand-names, and warned not to repeat words. All subjects were tested individually. All responses were tape-recorded, digitized (using Creative WaveStudio of Sound Blaster 16; sampling rate = 44,100 Hz, sampling size = 8 bits), and the time between each successive word was determined. Parts of the letter-fluency data have been reported in a previous study (Duchene et al., 1998).

2.2.2. Statistical analyses

In addition to conventional analyses, we also used correspondence analysis (CoA) and hierarchical clustering (HC) procedures to explore the data. These multidimensional techniques make minimal assumptions about the underlying distribution of the data (Benzécri, 1973; Blasius & Greenacre, 1998; Greenacre & Blasius, 1994), and are straightforward and well adapted to the analysis of fluency data (Schwartz & Baldo, 2001). All analyses were computed using SPSS statistical software (SPSS, Chicago, USA).

CoA and HC require that the data are organized into *contingency* tables (Fig. 1). Two separate contingency

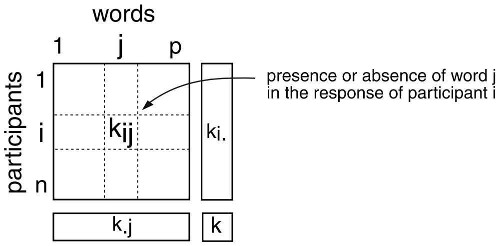

Fig. 1. Contingency table for n fluency responses (n participants): the rows ($i = 1, \ldots, n$) represent the n individual fluency responses, and the columns ($j = 1, \ldots, p$) constitute the p different words generated by the participants.

tables were built, one for the letter and one for the category-fluency data, crossing the participants (rows) by the words produced (columns). Each cell of the tables indicated if a given word was present ("1") or absent ("0") in a given individual's fluency word list ("word-profile"). CoA is a multivariate method for exploring tables in which data appear as simple counts of the responses' content. The goal of CoA is to transform such contingency tables into graphical displays, called "CoA maps" that can be interpreted using related statistics. HC is used as a complementary technique that is most valuable when CoA results are too complex to be easily interpreted or when additional verification of the CoA solution is needed (Lebart, 1994).

Both CoA and HC are based on an estimation of the similarity between each of all row-profiles (or between each of all column-profiles). For example, if two participants produce very similar word-profiles (i.e., present and absent words), their word-profiles will have an increased probability of being located close to each other on the CoA map and will be grouped in the same HC cluster (Blasius & Greenacre, 1998; Schwartz & Baldo, 2001). Furthermore, a single joint CoA map makes it possible to visualize the distances between different individuals or different groups, as well as the distances between different words: participants who generate similar *combinations* of words will be close to each other, as will words that are frequently generated *together* across participants (Greenacre & Blasius, 1994). Consequently, the geometrical distances on a CoA map are a direct function of the resemblance between the rows or between the columns within a contingency table.

Fig. 2 illustrates the complementarity between CoA and HC analyses. The main goal of CoA is to reduce the initial multidimensional cloud of data into a continuous bi- or tridimensional space, while minimizing the distortion of the original distances (Greenacre, 1994). In contrast, HC achieves successive groupings of the data based on the initial multidimensional distances, but the relative positions of the final clusters in the dendrogram are arbitrary, i.e., the clusters can be rotated at each branching (see Fig. 2). Since HC is fully compatible with CoA factorial dimensions (Lebart, 1994), we can check the spatial arrangement of CoA data and refine our interpretation of the map by identifying the items that belong to the same clusters in HC (bottom of Fig. 2).

To get reliable CoA maps and hierarchical clusters, we have to limit our analyses to relatively high-frequency words and exclude infrequent words from the contingency tables. Indeed, high-frequency words have a higher probability to co-occur within responses, whereas words generated by only one or very few participants add noise to the CoA data and may obscure potentially significant patterns shared by many word-profiles (see Greenacre, 1994). In order to perform an unbiased reduction of the data, the best solution is to keep words showing a frequency of occurrence in our population that is above a given threshold. Lexicometric studies have shown that relevant data for such multidimensional analyses must exclude single occurrences (hapax) and about one third of the lower part of the frequency distribution (cf. Lebart, 1998). We adapted this empirical rule to our data and kept 60% of items generated by more than one participant (non-unique occurrences) in each fluency task: 16 words in the letter fluency corresponding to 60.7% of non-unique occurrences (i.e., generated by more than one participant), and 23 words in the category fluency corresponding to 61.8% of non-unique occurrences. Thus, words generated by less than seven participants on letter fluency and less than 11 participants on category fluency were removed.

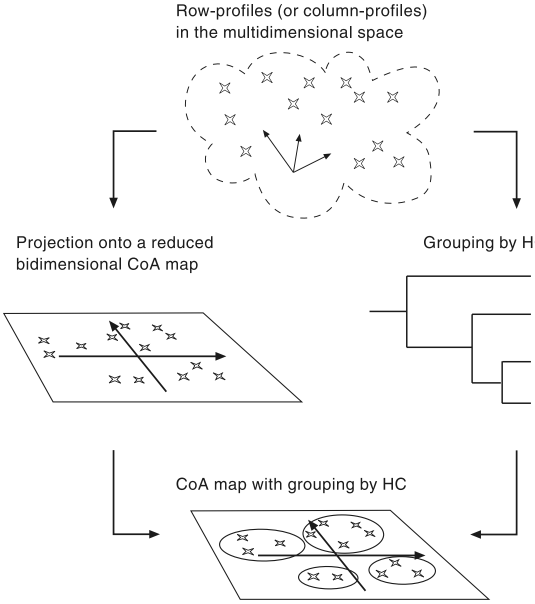

Fig. 2. Complementarity between CoA and HC. On the top, entries from the original contingency table define points in a multidimensional space; the points are symbolically represented in a cloud. On left, CoA proceeds to a flattening of the multidimensional cloud of points into a bidimensional map. The right side shows the dendrogram of the HC grouping of the data which can then be used to delineate clusters on the CoA map, as displayed on the bottom map.

Finally, we also examined the number and length of "runs" of successive words generated for a given cue (i.e., letter 'A' or 'F' in the letter task; animal or fruit name in the category task), and used the tape-recorded material to time the intervals between successively generated items within or between such runs.

3. Results

The results are described in four sections: (1) we compared the *total number of words* generated in the letter- and category-fluency task for each participant; (2) we analyzed the *word-profiles* of fluency responses using two complementary multidimensional techniques, CoA and HC; (3) we assessed the length and distribution of *phonemic* and *semantic runs*; and (4) we analyzed the *time intervals* between successive items, specifically comparing within- and between-run times (resp., nonwitch and switch times).

In the letter-fluency task, two response sets were omitted from data analysis, one because of frequent rule breaks and one because of technical problems with the tape recorder. In the category-fluency task, all 40 response sets were available.

3.1. Number of words generated

A paired t test indicated that participants generated significantly more words overall in the category-fluency task ($M = 39.27$, $SD = 7.58$) than in the letter-fluency task ($M = 17.18$, $SD = 4.76$), $t(37) = 15.17$, $p < .0001$. On the letter fluency, participants produced significantly more words beginning with the letter "F" ($M = 9.34$, $SD = 2.89$) than with "A" ($M = 7.84$, $SD = 2.95$), $F(1, 74) = 5.025$, $p < .05$. On the category-fluency task, participants named significantly more "animals" ($M = 12.50$, $SD = 4.42$) than "fruits" ($M = 26.77$, $SD = 6.81$), $F(1, 78) = 123.65$, $p < .0001$. This pattern of results for two-choice fluency tasks is consistent with previous findings on traditional, single-cue fluency tasks (e.g., Baldo & Shimamura, 1998; Kozora & Cullum, 1995; Martin et al., 1994; Troyer et al., 1997).

3.2. Correspondence analysis and hierarchical clustering

3.2.1. Letter fluency

CoA was used to analyze the contingency table created by cross-tabulating the 38 participants' word-profiles (rows) and the 16 most frequently generated words (columns) in the letter-fluency task. Each of these 16 words was present in at least 7 of the 38 participants' word-profiles (see Table 1).

This CoA reduced the complex multidimensional set of data to a bidimensional solution. The two main dimensions accounted for 15.5% and 14.2% of the total inertia, respectively. Importantly, the total inertia in CoA is a direct measure of the dispersion of the profiles in multidimensional space (Greenacre, 1994), and such percentages of inertia associated with the first two dimensions of a CoA correspond to highly specific and stable CoA maps (Lebart, Morineau, & Warwick, 1984).

The CoA map for letter-fluency revealed a clear semantic organization along the first dimension (horizontal axis): words on the left side of the map correspond to inanimate/functional entities, whereas words on the right side include exclusively animate/living entities (Fig. 3). Note that this segregation between animate and inanimate emerged without any a priori categorical constraint due to our analysis. Also, the task required participants to retrieve words using a letter cue only, with semantic meaning of the words being totally irrelevant to performance. The second dimension on the map was more difficult to interpret because it did not correspond to a clear semantic or phonemic dichotomy. The interpretation of the first dimension of the CoA display was further validated by statistical indicators measuring the contributions of each word to the inertia of that dimension. The ranking of these scores confirmed that the first dimension was organized along an animate versus inanimate dichotomy, with the highest contributions belonging either to the animate group of words ("ant", "anteater", and "animal") or the inanimate group ("air", "floor", and "airplane"). These words are underlined in Fig. 3.

Table 1
Total frequent word count in the letter and category fluency

Letter fluency[a]		Category fluency[b]	
Apple	29	Apple	39
Friend	18	Cat	36
Ant	16	Dog	36
Fish	13	Banana	34
Animal	11	Orange	34
Fruit	11	Bear	25
Airplane	10	Elephant	25
Food	10	Horse	25
Frog	10	Grape	23
Farm	9	Lion	23
Air	8	Monkey	23
Aardvark	8	Whale	22
Family	8	Bird	21
Anteater	7	Zebra	20
Finger	7	Giraffe	19
Floor	7	Mouse	19
		Tomato	19
		Fish	18
		Kiwifruit	18
		Pear	18
		Tiger	18
		Cow	17
		Deer	17
		Grapefruit	17
		Rat	17
		Mango	16
		Peach	16
		Pineapple	16
		Snake	14
		Gorilla	13
		Strawberry	13
		Cherry	12
		Papaya	12
		Raspberry	12
		Sheep	12
		Watermelon	12
		Ant	11
		Ape	11
		Lemon	11
		Pig	11

[a] Words generated by seven participants or more (60.7% of total non-unique occurrences).

[b] Words generated by 11 participants or more (61.8% of non-unique occurrences).

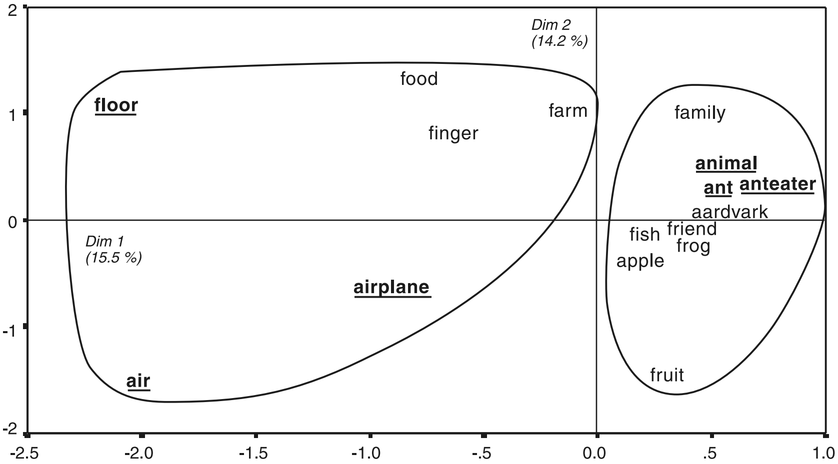

Fig. 3. Two-dimensional CoA map for the letter fluency responses (38 individual responses × 16 frequent words) displaying the words (column-profiles) as well as their grouping by HC into two separate clusters (encircled). Proximity of the words on the map reflects their co-occurrence across participants. Values on the first dimension (or factor) of the CoA analysis are represented along the horizontal axis (Dim 1); values on the second dimension (or factor) of the CoA analysis are represented along the vertical axis (Dim 2). Words with the highest contributions to the first dimension of the CoA are underlined.

HC analysis of the letter-fluency data corroborated these results. The HC solution revealed two separate main clusters, one for inanimate/functional items (i.e., "airplane", "air", "floor", "farm", "finger", and "food"), and another for animate/living beings ("animal", "family", "fish", "ant", "aardvark", "friend", "frog", "anteater", "fruit", and "apple"). These two clusters are shown as encircled areas in the CoA map (Fig. 3). Critically, the frequency with which words in the two clusters were generated did not differ, $F(1, 14) = 2.76$, $p = .12$. Thus, both CoA and HC converged to reveal highly consistent information about the structure of the dataset which would have been missed by conventional analyses.

3.2.2. *Category fluency*

A second CoA was computed for the contingency table created by cross-tabulating the 40 participants' category fluency word-profiles (rows) and the 40 most frequently generated words (columns). These 40 words represented 23 animal names and 17 fruit names that were generated by at least 11 of the 40 participants (see Table 1). The first two dimensions of the CoA analysis accounted for 10.6 and 10.0% of the total inertia, respectively (for more information about inertia in CoA, see Greenacre, 1994; Lebart et al., 1984).

Since there were more words in this analysis (thus more dimensions in the original data) than in the previous CoA on letter-fluency data, we concentrated on the highest contributions to interpret the bidimensional representation (underlined in Fig. 4). Also, with more words, those with low contribution to a given dimension may not be accurately represented along this dimension. The first horizontal dimension distinguished between the domestic and exotic items, with words belonging to the domestic or farm category (i.e., "cow", "sheep", "pig", or "horse") on the right, and words belonging to the wild or exotic category (i.e., "mango", "pineapple", and "tiger") on the left. (The same domestic vs. exotic dissociation was found when animal names and fruit names were analyzed separately). The second dimension appeared to be organized according to size, with words representing relatively large items in the upper half of the display (i.e., "watermelon", "giraffe", "elephant", and "whale") and words representing the smallest entities in the lower half of the display (i.e., "raspberry", "strawberry", "cherry", "mouse", and "rat"). This size dichotomy was however less clearly demarcated than the domestic vs. wild distinction.

HC analysis of the category-fluency data distinguished between four main clusters (Fig. 4). The first cluster appears centrally on the CoA map and contains prototypical items from both semantic categories (i.e., "cat", "dog", "apple", "orange", and "banana"). The second cluster is located on the bottom half of the map and mainly composed of wild animals (e.g., "lion", "tiger", "deer", and "whale"). The third cluster is located on the right side of the map and contains farm animals (e.g., "horse", "cow", "pig", and "sheep"). The fourth cluster appears on the top half of the display and includes exotic fruits (e.g., "papaya", "mango", and "kiwi") and jungle animals ("elephant", "giraffe", "zebra", and "snake"). These HC results confirmed the semantic organization found along the first dimension: domestic animals (Cluster 3) were clearly segregated from the more exotic items (Cluster 4). By contrast, the separation between Clusters 2 and 4 did not provide any straightforward interpretation for the second dimension of the CoA.

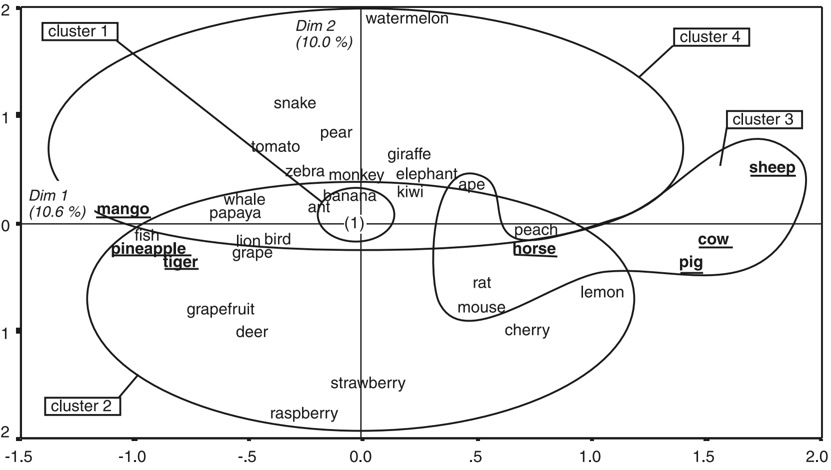

Fig. 4. Two-dimensional CoA map for the category fluency responses (40 participants × 40 frequent words) showing the location of the words (column-profiles), as well as their grouping by HC into four separate clusters (encircled). Values on the first dimension (or factor) of the CoA analysis are represented along the horizontal axis (Dim 1); values on the second dimension (or factor) of the CoA analysis are represented along the vertical axis (Dim 2). Words with the highest contributions to the first dimension of the CoA are underlined. (1) = apple, orange, cat, dog, bear, gorilla.

Analysis of variance revealed that words in Cluster 1 were generated more frequently than words in other clusters, $F(1,38) = 84.20$, $p < .0001$, but there was no difference in the frequency with which words were generated between the three remaining clusters, $F(2,32) = 0.76$, $p = .47$. This suggests that the differential spatial arrangement of these word categories on the CoA map did not simply result from quantitative differences relative to their frequency.

3.3. Phonemic vs. semantic runs

The two-choice fluency procedure enabled us to study the semantic organization in participants' word-profiles in another way, namely, by analyzing sequential grouping of words within fluency responses. Participants' word-profiles were decomposed into successive runs of phonemically or semantically related words. In the letter-fluency task, *phonemic runs* were defined as successive words beginning with the same letter (i.e., A-runs and F-runs). In the category-fluency task, *semantic runs* were defined as successive words from the same category (i.e., animal-runs and fruit-runs). For example, the following word-profile from a participant has 55 words forming five successive semantic runs:

lion - tiger - bear - zebra - giraffe - elephant - frog - snake - boa constrictor - dog – cat *[animals];* apple - orange - apricot - pear - lemon - lime - cherry - strawberry - blackberry - raspberry *[fruits];* lynx - lemur - monkey - ape - chimpanzee - gorilla - mouse - rat - chipmunk - squirrel - rabbit - duck *[animals];* grapefruit - mango - grape *[fruits];* leopard - jaguar - horse - cow - sheep - goat - chicken - bird - seagull - parrot - elk - deer - moose - buffalo - fish - salmon - cod - shark - whale *[animals].*

3.3.1. Run length and number

The length of a run is the number of successive animal or fruit names in the category fluency, or the number of successive words beginning with the same letter in the letter fluency. In the example above, there were five runs (three animal-runs and two fruit-runs) and the length of these five runs, respectively, consisted of 11 animals, 10 fruits, 12 animals, 3 fruits, and 19 animals.

The mean run length was significantly larger in the category than in the letter-fluency task (10.49 vs. 3.11, respectively), $F(1,76) = 61.14$, $p < .0001$ (see Fig. 5). From a connectionist perspective (Anderson & Pirolli, 1984; Collins & Loftus, 1975; Troyer et al., 1997), this result indicates that links within semantic categories like animals and fruits are tighter than phonemic links,

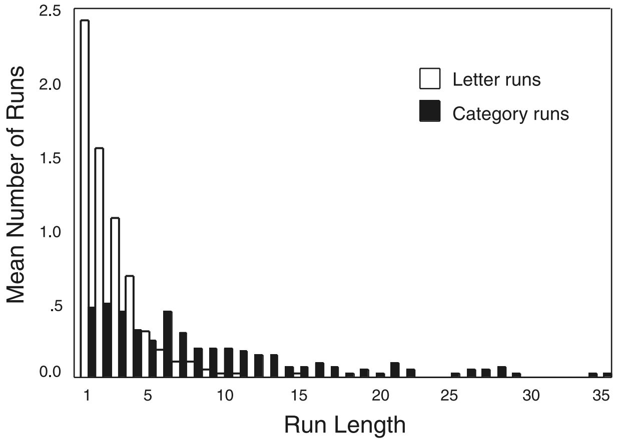

Fig. 5. Distribution of run length within the two-letters and two-categories fluency tasks. The height of the bars corresponds to the mean number of runs of a given size in the individual responses.

resulting in a quicker spreading activation between semantic nodes of a given category than between words beginning with the same letter.

Conversely, the number of runs was significantly greater in the letter than in the category-fluency task (6.63 vs. 4.68, respectively), $F(1,76) = 13.77$, $p < .001$. This pattern contrasts with the fact that the total number of words was greater in the category-fluency condition, suggesting more efficient search processes (i.e., the ability to switch between cues) during category fluency performance. Our analysis of length and number of runs demonstrates that a strategy based on semantic category cues may be more effective for generating uninterrupted series of related words, as compared with a phonemic strategy.

3.3.2. Bigrams

To further assess whether the runs involved phonemic or semantic influences on the generation of successive words rather than purely random processes, we analyzed the composition of all pairs of successive words (or bigrams) in 2×2 contingency tables. A first analysis compared the number of "A–A", "A-F", "F–A", and "F–F" bigrams generated in the letter-fluency condition (Table 2). A second analysis compared the number of "animal–animal", "animal–fruit", "fruit–animal", and "fruit–fruit" bigrams generated in the category-fluency condition (Table 2).

χ^2 analyses revealed significant effects for both comparisons, $\chi^2(1) = 54$ for letter fluency, $p < .0001$, and $\chi^2(1) = 927$, $p < .0001$ for category fluency. These results clearly indicate that the choice of a particular word was not independent of the immediately preceding word, but potentially affected by its phonemic or semantic characteristics. This influence can be referred to as a *sequential priming* effect (Ratcliff & McKoon, 1995). In addition, such *sequential priming* was much larger in the category than in the letter-fluency condition (Mann–Whitney $U = 116.5$, $p < .0001$).

3.4. Inter-item times

In this study, we could also analyze the dynamic characteristics of word generation since fluency responses were tape-recorded. We distinguished between non-switch and switch inter-item times: *non-switch times* were defined as the time-lag between two successive words belonging to the same letter or category run; and *switch times* were defined as the time-lag between two successive words belonging to two different runs. A small percentage (<5%) of the inter-item times were not calculable because of interfering sounds on the recording (e.g., coughing or sneezing). Also, we excluded outlier inter-item times that were above two standard deviations from the mean for each condition (two non-switch and two switch times in the letter task; one non-switch and one switch time in the category task). In the following, time data are presented in seconds.

Inter-item times were analyzed in a 2×2 ANOVA, with Inter-Item Condition (non-switch or switch) and Fluency Task (letter or category) as within-subjects variables. There was a main effect of Inter-Item Condition, $F(1,144) = 106.54$, $p < .0001$, confirming that switch times ($M = 6.32$, $SD = 2.67$) were generally longer than non-switch times ($M = 2.88$, $SD = 1.46$). There was also a main effect of Fluency Task, $F(1,144) = 16.38, p < .0001$, as words were generated at a slower pace in the letter task ($M = 5.27$, $SD = 3.31$) than in the category task ($M = 3.97$, $SD = 2.99$). More critically, the Inter-Item Condition × Fluency Task interaction was significant ($F(1,142) = 6.36$, $p < .05$), indicating that non-switch times were shorter in the category-fluency task, whereas switch times were comparable across the category and letter tasks (see Fig. 6). These effects further evidence a rapid access between items sharing similar semantic characteristics relative to items with similar phonemic features.

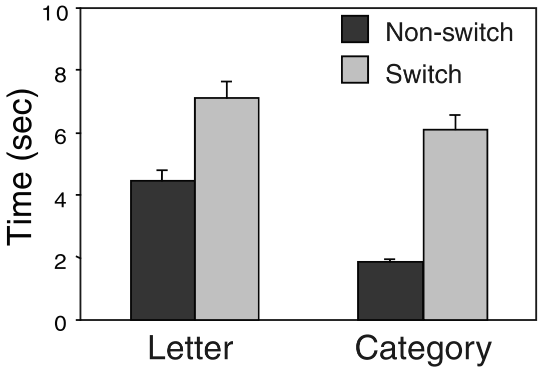

Fig. 6. Mean non-switch and switch times in the two-letters and two-categories fluency tasks (error bars = standard error).

Table 2
Distribution of phonemic and semantic bigrams

Letter fluency				
Bigram type	A–A	A–F	F–A	F–F
N	166	116	98	235
Category fluency				
Bigram type	An–An	An–Fr	Fr–An	Fr–Fr
N	972	71	76	412

Note. A, word starting with the letter 'A'; F, word starting with the letter 'F'; An, animal name; Fr, fruit name.

4. Discussion

Our results highlight several useful contributions of a multidimensional statistical approach to verbal fluency data. Fluency tasks are widely used in clinical neuropsychology and fluency performance is traditionally measured by the number of words generated in a given time period. While this measure provides an indication of overt productive capacity, it fails to capture other cognitive aspects that may underlie the generation and choice of words in fluency tasks. In the present study, we showed that novel statistical techniques can provide a richer characterization of underlying cognitive components. Specifically, we found that responses during both letter and category fluency showed evidence of semantic organization. Predominant influences of semantic organization were also revealed by sequential priming and switching times within runs of successive related words. In addition, the semantic organization of the words on the CoA maps reflected well-known neuropsychological dissociations, purportedly related to specific underlying cerebral substrates (e.g., animate vs. inanimate entities), even in the letter-fluency task where subjects were not explicitly required to use any category-based strategy.

Semantic clustering in category-fluency tasks has already been showed in previous studies (e.g., naming farm animals, then wild animals, then sea animals, etc., on an animal category task; cf. Troyer, 2000; Troyer et al., 1997). Here, using correspondence analysis (CoA) and hierarchical clustering (HC), we confirmed and extended these results. We found that response patterns on a two-choice category-fluency task reflected groupings according to size, domesticity, and prototypicality. More critically, semantic influences were also evidenced in the letter-fluency condition. CoA and HC showed that participants' responses in the letter task were organized along an animate-inanimate dichotomy (i.e., "airplane", "air", "floor", "farm", vs. "family", "fish", "ant", and "aardvark"). The multidimensional statistical procedures applied to fluency responses therefore clearly demonstrated a pervasive role of semantic constraints on the words produced, not only in the category fluency, but also in the letter-fluency task. To our knowledge, such an effect of semantic organization in the letter-fluency performance has not previously been reported.

Furthermore, the semantic organization of our data on the CoA maps (both during category and letter fluency) accords with known neuropsychological dissociations and neuroimaging findings. For example, the distinction between animate and inanimate-functional entities observed on the letter fluency CoA map, echoes clinical reports of selective impairments for these semantic categories (Caramazza & Shelton, 1998; Warrington & Shallice, 1984), as well as related behavioral and FMRI findings in healthy subjects (Garrard et al., 2001; Leube, Erb, Grodd, Bartels, & Kircher, 2001). Moreover, a clear distinction between animate and inanimate entities emerged even during a letter-fluency task, usually thought to require word retrieval according to a phonemic rule only. It is worth noting here that there was no a priori categorical constraint imposed on the CoA and HC analyses. Several explanations have been put forth to account for category-specific dissociations in brain-damaged patients: (a) a high degree of regional neuroanatomical segregation subserving separate conceptual categories (Caramazza & Shelton, 1998); (b) independent contributions of visuo-perceptual and functional attributes in identification processes (De Renzi & Lucchelli, 1994; Warrington & Shallice, 1984); (c) different patterns of interconnections between perceptual and functional properties (Moss, Tyler, & Jennings, 1997); and (d) semantic dissociations based only on familiarity effects (Funnell & Sheridan, 1992). Neuroimaging studies have provided further support for a neuroanatomical segregation, as differential patterns of activation are observed for different conceptual categories (e.g., living vs. non-living), although neuroanatomical loci are far from being consistent across studies (Damasio et al., 1996; Martin et al., 1996; Moore & Price, 1999; Mummery et al., 1996; Perani et al., 1999; see review Tyler & Moss, 2001).

Our CoA performed on category fluency data also suggested marked semantic distinction between domestic and wild animals. Such a domestic/wild animals dichotomy has previously been found in normal control subjects, while its disappearance may be associated to a semantic breakdown in patients with schizophrenia (Aloia, Gourovitch, Weinberger, & Goldberg, 1996) and in Alzheimer patients (Chan et al., 1995). The present CoA results therefore lend support to the existence of some elementary semantic constraints based on domesticity and prototypicality. Taken together, these findings also indicate that our current model of the normal human brain must account for both a functional segregation between categories and their integration into an organized semantic system.

According to the "spreading activation" theory, activity within semantic networks spreads instantaneously between close nodes, and decays exponentially as the distance between nodes increases (Anderson & Pirolli, 1984). The semantic effects observed in our study would be consistent with such a spreading facilitation, operating in both the category- and letter-fluency tasks. This suggests that associative components in semantic networks (thought to be stored in temporal cortex) may impose automatic influences on word retrieval controlled by strategic executive processes (thought to involve frontal cortex). From this perspective, two factors may contribute to these automatic semantic influences on verbal-fluency tasks: (1) the structure of memory networks will cause two words to be conjointly activated as a function of their semantic proximity; (2) the time pressure imposed by the task demands will limit the search process to closely connected and readily activated words. Consequently, even in a phonemic task requiring a relatively abstract letter-based retrieval strategy, words sharing semantic features will have a higher probability of occurring within the same response.

On a methodological level, combining CoA and HC provided an efficient method for extracting information about the semantic organization of responses generated in fluency tasks. Unlike multidimensional scaling which uses the number of words separating each possible pair of words as an index of their semantic distance (e.g., Aloia et al., 1996), CoA can rely on partially overlapping word lists, rather than on the temporal succession of the words. This independence vis-à-vis the temporal dimension is an advantage when studying semantic patterns in fluency data, since items from a subcategory may be dispersed in individual word lists rather than merely grouped in successive pairs. For example, one participant generated nine words in the letter fluency task, with five anatomy words appearing every other word: "arm - floor - foot - flag - finger - food - forearm - football - artery". Given this possible dispersion of related words, CoA offers an appropriate solution for assessing semantic proximity in fluency responses by computing distances between words as a function of their co-occurrence (presence-absence pattern) within individual responses. Further, CoA is not affected by the limitations associated with other multidimensional techniques (e.g., multidimensional scaling, MDS; see Aloia et al., 1996; Chan et al., 1993), such as the fact that successive words are semantically neither equidistant nor symmetrical (contrary to the metric hypotheses used in MDS; see Schwartz & Baldo, 2001).

In this study, we used a two-choice fluency procedure because it allows an easy and objective delineation of word runs, and therefore facilitates analyses of sequential effects in fluency. Comparisons of the temporal intervals within and between runs of related words during the fluency tasks showed that switch times were comparable for letter and category fluency (i.e., switching between 'A' and 'F' exemplars and between animals and fruits). By contrast, there was a significant benefit for non-switch times in the category-fluency task (i.e., naming consecutive animals or fruits was faster than naming consecutive 'A' and 'F' words), consistent with the suggestion that the generation of related concepts is facilitated by semantic associations. Thus, the retrieval of items can be primed or activated by preceding semantically related words (cf. Bousfield & Sedgewick, 1944; Gruenewald & Lockhead, 1980), especially in the category fluency task. This analysis may help distinguishing structural (i.e., CoA maps) and dynamic (i.e., runs analyses) aspects in fluency performance, potentially of interest in neuropsychological patients. Future studies might also involve using statistical analyses similar as those described here, combined with detailed semantic and phonemic distinctions within the word lists (e.g., Troyer, 2000).

In sum, we have demonstrated that fluency tasks involve several cognitive dimensions that may be efficiently assessed by a combination of statistical methods. First, the present study shows that analyzing data collected during brief, timed tasks like verbal fluency can disclose the structure of conceptual knowledge and representations within intact cognitive systems (e.g., revealing basic categorical distinctions). Second, the multidimensional results suggest that fluency responses may be constrained by the semantic features of the words generated, not only during category fluency, but also during letter fluency. These statistical methods might usefully be applied to compare patterns of words fluency across different groups of patients whose global performance (i.e., total word count) might not necessarily differ.

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