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Marklund, Petter; Sikström, Sverker; Bååth, Ramus

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Age Effects on Semantic Coherence:

Latent Semantic Analysis Applied to Letter Fluency Data

Petter Marklund*, Sverker Sikström†, Rasmus Bååth†, Lars-Göran Nilsson*

*Department of Psychology, Stockholm University, Sweden
petter.marklund@psychology.su.se, lgn@psychology.su.se

†Lund University Cognitive Science, Lund University, Sweden
sverker.sikstrom@lucs.lu.se, rasmus.arnling_baath@lucs.lu.se

***Abstract*—We investigated age-related changes in the semantic distance between successively generated words in two letter fluency tasks differing with respect to demands placed on executive control. The semantic distance was measured by Latent Semantic Analysis (LSA). The results show that older people have a larger semantic distance between successively generated items than young people, and that this effect is particularly pronounced in the more demanding fluency task. Taken together, our findings support the idea that elderly have a less distinct semantic network compared to young people while also demonstrating the feasibility of LSA as a powerful tool for delineating multifaceted aspects of semantic organization inherent in behavioural data from language production tasks.**

***Index Terms*— latent semantic ananlysis; cognitive aging; semantic coherence; letter fluency.**

I. Introduction

The lack of empirical studies looking into the semantic structure underlying successive word generation in letter fluency is striking. One exception comes from a study using a multidimensional approach which demonstrated that sequential patterns of letter fluency output are not only influenced by phonemics but also semantics [1]. To our knowledge no other study has looked at age-related changes in semantic relatedness between successive words in traditional letter word fluency tests.

Our study has three main objectives. First, to show how semantic spaces, created by latent semantic analysis (LSA), can be used as a powerful tool for analysing the semantic properties of letter fluency performance data. Second, we investigate age-related changes with respect to inter-item semantic coherence. Here we predict that as people get older the semantic representation deteriorates, leading to progressively greater 'leaps' between successively generated words. Third, depending on task demands verbal fluency might tap into different memory processes, especially with respect to requirements on control strategies during memory search and retrieval, such that a more difficult task with greater demands on monitoring (generating five letter words starting with 'm') will be more affected by age than a simpler task (generating words starting with 'a') due to age-related decline in executive functions. First we overview relevant literature on verbal fluency and semantic spaces. Then we present the results from the LSA applied to fluency data from the Betula [9] study and discuss the findings.

A. *Fluency and age-related changes in semantic processing*

One way to explore age-related decline in semantic processing is to analyze behavioural patterns on verbal fluency tasks. Fluency tasks require subjects to overtly produce as many words as possible in accordance with a specific rule. The fluency test is conduced during a limited time period (usually 60 secs). It is among the most widely used tasks in neuropsychological assessments which generally include two standard formats of the task; semantic (i.e. words from a target-category like animals) and letter fluency (i.e. items beginning with a certain letter).

Substantial age effects are typically reported for semantic fluency, but not letter fluency [2], which is somewhat surprising in view of the posited preferential involvement of prefrontal cortex (PFC) in letter fluency. However, it has been shown that the advantage of semantically guided word production over phonemically guided word production is reversed at very old age (+80 years of age), and that even mild depression in elderly can produce a deleterious effect that selectively impairs semantic fluency [3]. These findings call into questioning the validity of choosing semantic over letter fluency for investigating changes in the organization and processing of semantic LTM over the adult life span including age groups of subjects at +75 years of age. Moreover, with respect to applying LSA to fluency data with the aim to examine relationships between aging and changes in lexical-semantic information processing, the presumably much greater variability of meaning across words generated in letter fluency as compared with semantic fluency due to the narrow semantic fields probed in the latter task (because words need to be confined to a single category), strongly favours letter fluency.

Clustering and switching have been postulated to constitute two separable component processes contributing to verbal fluency performance [4]. Clustering refers to the number of words successively generated from the same semantic or phonemic subcategory, and switching corresponds to the number of shifts that take place between clusters. In a study examining age differences in the utilization of clustering and switching during fluency performance it was found that elderly subjects produced larger cluster sizes on letter fluency [4] . This age effect might have reflected a greater vocabulary in the older subjects which tentatively allowed them to retrieve a larger number of words with similar characteristics (e.g., words sharing the same initial two letters) before switching than their younger counterparts. Importantly, clustering during letter fluency was defined by phonemic similarity between successive words in the study by Troyer and coworkers [4] and hence clustering based on semantic similarity was disregarded. Previous studies examining patterns of clustering and switching based on semantics have almost exclusively focused on category-based (semantic) fluency tasks. We know of only one prior study, conducted by Schwartz and coworkers [1], that looked at the influence of semantic memory on letter fluency. Using multidimensional statistical approaches to evaluate semantic and phonemic relationships between generated items they demonstrated that conceptual knowledge and semantic organization indeed appears to play a crucial role in guiding word retrieval in letter fluency tasks. However, since two-choice fluency tasks were used in that study, which allowed subjects to generate items beginning with either of two initial letters (letter fluency) or belonging to either of two different categories (semantic fluency) [1] it is difficult to know to what extent these findings generalize to traditional single letter fluency tasks.

Letter fluency tasks can be designed to require more or less executive control related to cognitive monitoring. In this study we examine whether a letter fluency task with low monitoring demands (generating words starting with 'a') differs from a task with high monitoring demands (generating five letter words starting with 'm') in terms of age-associated changes in the semantic organization of sequential word output.

High and low monitoring tasks are relevant to study because they depend on different brain regions known to show dissociable changes with advanced age. High monitoring fluency tasks are believed to be more heavily dependent on executive functions associated with the PFC, whereas a low monitoring fluency task may be linked to inferior temporal lobe regions. Age-related changes in PFC are much more pronounced than in inferior temporal cortex.

If age-accompanying changes in coherence is differentially exhibited on a letter fluency task with less executive requirements it is plausible that they reflect changes in the structure of conceptual LTM stores. On the other hand, if age-related changes in coherence are greater on a letter fluency task that depends more on executive control processes like monitoring it might conceivably indicate deterioration of frontal lobe functioning with advanced age rather than decremental changes with respect to inferior temporal regions harbouring lexical-semantic representations.

B. Investigating Fluency with Semantic Spaces

Semantic spaces is a useful tool used to measure to semantic distances between words, however, little work has been done applying it to word fluency test. Semantic spaces can be automatically generated by several computational methods applied to large text corpora. One of the most prominent methods for creating semantic spaces is Latent Semantic Analysis. It was originally developed as a document retrieval method to improve upon word matching approaches [5] but soon found use in cognitive science and computer assisted educational research (see [6] for a review of different application areas of LSA). The original LSA algorithm is highly data-driven and does not use syntactic information such as word order or what word class a word belongs to. This implies that LSA disregards much of the information in the corpus. On the other hand, this make LSA a very flexible algorithm, e.g., it can to be applied on corpuses of any language without modification.

The end product of an LSA of a corpus is a high dimensional semantic space where each word is represented as a vector in this space. The number of dimensions (n) has to be chosen properly. The optimal value depends on the chosen corpus and the purpose of the semantic space, where $n = 100$ is a good starting point [7]. Given a semantic space one can use the distance between two words as a measure of how related they are, one would e.g. expect to find dog close to puppy but far from puppet. It is possible to compare sentences or whole documents in the same way, as a document can be represented in the semantic space by the sum of the vectors of the words in the document. The dimensions of a semantic space are not normally assigned any specific meaning, the meaning of a word is solely defined by it's relation to other words.

LSA has been proposed as a model of language, and then especially as a model of the acquisition of the meaning of words [6]. One virtue of LSA is that it is not only an explanatory model, it is also an performing model, that is; it can perform some tasks normally requiring several years of human experience. An example of such a task is completing the synonym part of the Test of English as a Foreign Language (TOEFL), where the test taker is required to select the best synonyms for a number of given words. In this task LSA performs far better than the average test taker [8].

A semantic space as created by LSA can be used for measures other than semantic distance. Most importantly here, the distance measure can be used to define a measure of text coherence, or the average semantic distance between successive words.

II. Method

Data from two letter fluency tasks employed in the Betula study was used for the LSA analyses. In one task (letter A) participants were instructed to name as many words as possible beginning with the letter A while in the other task (letter M5) they were required to generate as many words as possible beginning with the letter M, with the additional restriction that word length was 5 letters.

A. The Betula Study

The Betula study is an ongoing large-scale longitudinal study of memory and health [9]. At the first wave of data gathering that took place 1988-1990 the study encompassed

1000 subjects partitioned into 100 subjects in each of 10 age cohorts (35, 40, 45, 50, 55, 60, 65, 70, 75, and 80 years). These subjects have been followed over the last 20 years during which they have been tested on a comprehensive cognitive test battery once every fifth year. All participants had Swedish as native tongue. The cognitive tests of the Betula study include several measures of episodic and semantic long-term memory (LTM). Semantic memory is indexed by a test of verbal knowledge and four different verbal fluency tasks: (i) words beginning with letter A, (ii) five-letter words beginning with M, (iii) occupation words beginning with letter B, and (iv) five-letter animal words beginning with S. Here we used the data from two of the fluency tasks (i and ii) collected at four test occasions (t1, t2, t3, and t4), five years apart, with the aim to use LSA to investigate changes in semantic memory processes occurring with advanced age. The age cohorts between 35-75 were grouped into three groups: 35-45 (young), 50-60 (middle-age), and 65-75 (old). Age cohort 80 was discarded as it did not contain enough subjects tested at t4.

B. Measuring Semantic Coherence with LSA

A 150-dimensional semantic space was created from a corpus consisting of more than 100,000 articles taken from the 100 largest Swedish newspapers in 2007. The space was created using the Infomap software package[1] and further semantic analyses were then conducted using the LSALAB software[2].

Semantic similarity between two words is defined as the cosine of the angle of the two corresponding word vectors. This means that the similarity of two identical words is 1 and that the minimum similarity between two words is -1. This measure of semantic similarity is then used to define a measure of semantic coherence. The coherence of a list of subject generated words is calculated as the mean of the similarities between adjacent words in the list. This method of measuring coherence have successfully been used to predict the effects of coherence on text comprehension [10]. The intuition behind this measure is that low coherence values are given to lists of words were the semantic category is often changed while high coherence values are given to lists of words where category changes are few and/or small. This implies that the coherence of a list of words is dependent on the order of the words. "Hus, Skola, Böcker, Författare" (Eng. "House, School, Books, Author") is an example of a coherent list as "House" is related "School", "School" to "Books", and so forth. This list yields a coherence value of 0.34. A list containing the same words but in a less coherent order; "Skola, Författare, Hus, Böcker", consequently yields a lower coherence value of 0.18.

Coherence values were calculated for all lists of produced words from both fluency tests. One problem is that a subject generated list might contain words that are not present in the semantic space. This was solved by not including these lists in the subsequent analysis. Another issue is that the number of produced words of each subject varied greatly. Therefore only the first four produced words were used to calculate coherence values and lists with fewer than four words were omitted from the analysis.

[1]http://infomap-nlp.sourceforge.net/index.html

[2]http://www.lucs.lu.se/sverker.sikstrom/LSALAB_intro.html

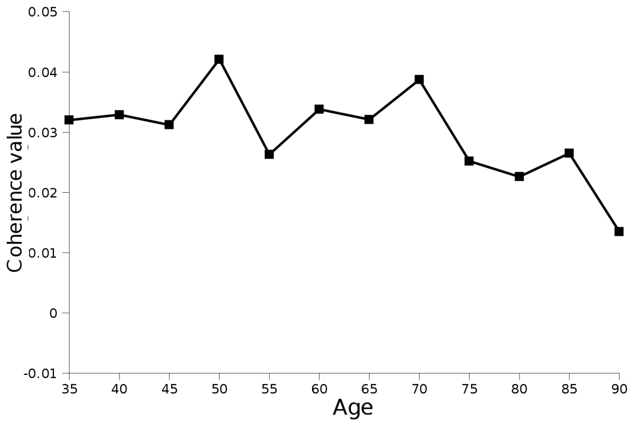

Figure 1. Mean Coherence value for the A task.

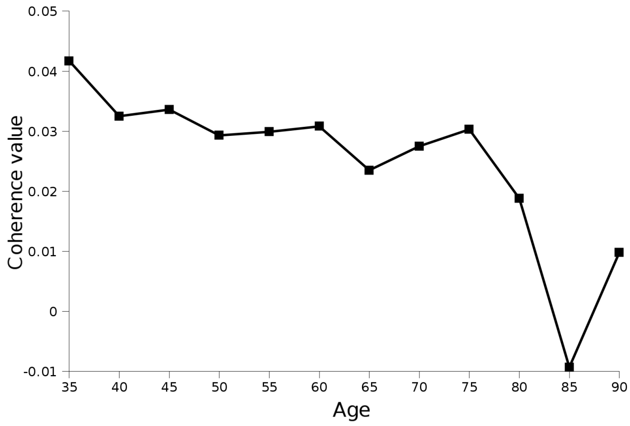

Figure 2. Mean Coherence value for the M5 task.

III. RESULT

The mean coherence values for the A and M5 task are shown in figures 1 and 2. In Figure 2 the value at age 80 seems to be an outlier, this could be explained by that this age group held few participants. We measured the change in coherence across age testing the hypothesis that the coherence decreases with increasing age. A one-way ANOVA showed a decrease in coherence as a function of age for the M5-task (p=0.021, one-tailed test) and to a lesser extent for the A- task (p=0.045, one-tailed test). Thus, these results indicate that the semantic distance between successively generated words diminish with age, and that this effect is particularly strong in the letter fluency task that is more demanding for the central exective. There was no significant difference in how fast the coherence diminished across age for the two tasks.

With respect to overall performance a significantly greater number of items was produced in the A task as compared with the M task. Collapsed across age groups the mean number of generated words (SD) was 11.2 (4.6) in the A task and 5.5 (2.9) in the M5 task at t1 ($p < 0.0001$). In accordance with a bulk of evidence showing increases in semantic knowledge as a function of age a positive change in scores over time was demonstrated for both fluency tasks. Over the 15 years passing from t1 to t4 an increase from 12.2 (4.3) to 13.5 (4.8) words or 1.3 items in the A task and a lesser increase from 6.1 (2.9) to 6.9 (3.2) in the M5 task was observed for the young group which showed the largest change. In the oldest group there was a consistent decline in performance over time for both tasks.

IV. Conclusion and Future Work

The results from our study indicates that as people get older, they generate words with a larger semantic distance relative to when they were young. This might indicate that older people have a less fine-grained semantic representation than young people, forcing them to generate successive words that are less associated with the previously generated word. This effect becomes more robust with greater demands on executive functions as evidenced by the larger age effect on the M5 task.

To our knowledge no other study has used semantic spaces to measure coherence in letter fluency tests. Therefore it is not directly possible to compare our results with existing data. Perhaps the data that are most similar to the current study comes from Troyer and coworkers [4] who found that elderly subjects produced larger cluster sizes on letter fluency. However, their clustering index was based on phonemic similarities between consecutive words and hence did not involve semantic relatedness. Moreover, traditional measures of clustering reflecting distinct semantic classes do not measure the semantic distance between different classes, and it may be the case that these distances are larger for older than for young subjects. This may be a topic for further research in this field.

The finding that age-associated decline in semantic coherence was greater when word generation relied more on executive demands (the M5 task) indicates that age-related changes in PFC function also contribute to the observed patterns. As advanced aging is strongly associated with deterioration in PFC and a related decline in general executive functioning (e.g., [11]) it is plausible that fluctuations in monitoring processes responsible for delimiting LTM search to five-letter words might yield spurious retrieval of words not abiding to this constraint. This would in turn require response inhibition and rejection of some of the retrieved items. Assuming that word generation in letter fluency is partly guided by retrieved semantic information related to the most recently accessed item, error detection associated with illicit retrieval should not only lead to inhibition of the overt response but putatively also cause suppression of the defining characteristics of that item in LTM, both in terms of its phonemic and semantic properties. As a consequence the closest neighbours to the rejected word in semantic space would also be inhibited due to something akin to automatic deactivation of semantic associates, which might be considered as the reversal of automatic spreading of semantic activation. Following this line of reasoning, each instance of such error detection would be expected to give rise to a large leap in semantic space preceding retrieval of the next word which leads to a lower score on the coherence measure with advanced age.

The present results show that semantic space provides opportunities to introduce new measures for verbal fluency tasks. This may potentially have great impact on future research in this field. Beyond the coherence measure used here, there are a great number of other putative constructs that would be possible to measure with semantic space in fluency tests. For example, a semantic space can be used to generalize a word norm defined for a limited number of words to all words in the space. A word norm being a semantic variable such as abstractness or valence (for an example of the use of the latter see [12]). A semantic category of words, e.g., tool or animal words, can also be generalized to the whole space yielding a method to discern the "toolness" or "animalness" of any word in the space. Semantic spaces are a versatile technique that can be used to investigate a wide range of semantic phenomena.

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