Qualitative features of semantic fluency performance in mesial and lateral frontal patients

online supplementary material

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SUPPLEMENTARY MATERIAL

PART 1.

Synopsis of the mathematical relationships between the indices used in this study and other indices used in the related literature

(a) Definitions:

aSW: <u>*Absolute Switching*</u>. Number of transitions between different subcategories in the sequence of produced words.

N: <u>*Total number of words*</u> produced in the whole sequence.

rSW: <u>*Relative Switching*</u>

clu: <u>*average Cluster Size*</u>. A <u>*Cluster*</u> is defined as a group of words belonging to the same subcategory uttered one after the other. The <u>*Cluster size*</u> is the number of words that form a cluster, counted starting from the second word of the series.

(b) Relation between *aSW* and *clu*

$$N = (clu+1)\,(SW+1) \qquad (1)$$

$$rSW = \frac{SW}{(N-1)} \qquad (2)$$

$$rSW = \frac{N}{N-1}\left(\frac{1}{clu+1}\right)-\frac{1}{N-1} \qquad (3)$$

The limit of (3) when *N* goes to infinity is 1/(*clu*+1) (see Figure 1). Therefore, for high values of *N*, the following formula may be considered a simplified form of (3)

$$rSW \sim \frac{1}{clu+1} \qquad (4)$$

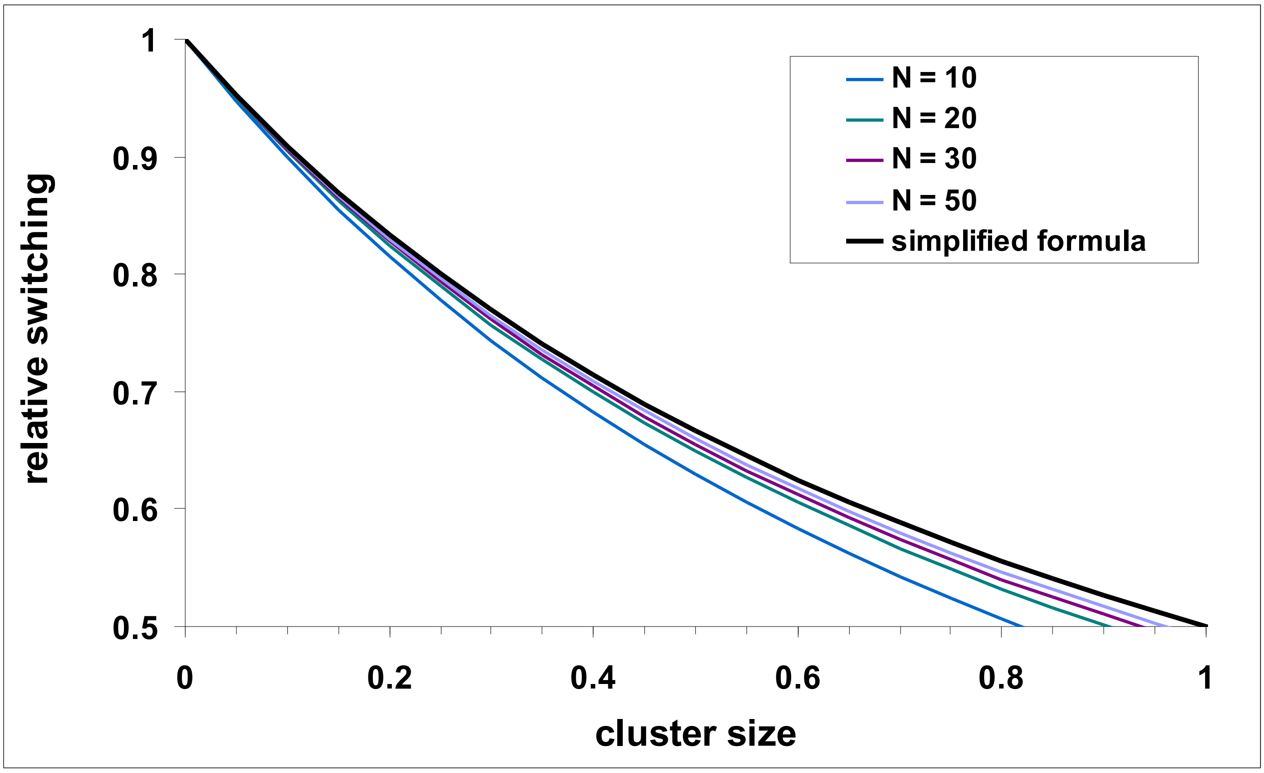

Figure 1 Relationship between average cluster size and relative switching according to the exact formula (3) for N = 10, 20, 30 and 50. The relationship determined by the simplified formula (4) is also shown. In this figure we consider the range of relative switching values that were empirically observed in the whole sample of the present study.

To test the validity of the simplified formula (4) on our real data and for the empirical range of *rSW* and *clu* values, we plotted the observed *rSW* against the observed cluster size of each participant of this study (Figure 2). This plot confirms the tight relationship between *rSW* and *clu,* which is reflected in a Pearson correlation index of – 0.98.

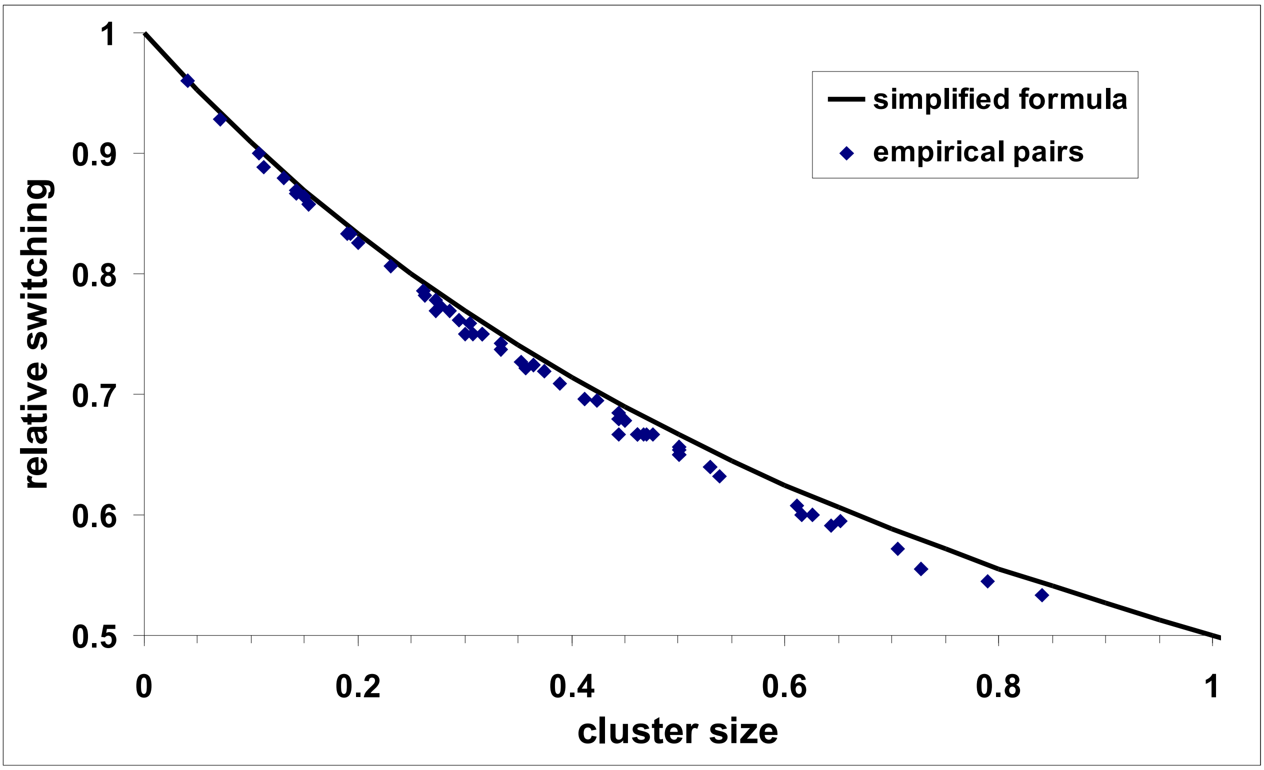

Figure 2 Relative switching is plotted against average cluster size. Blue diamonds: empirical values from single individuals. Solid curve: function connecting *aSW* and *clu* as computed from the simplified formula (4).

SUPPLEMENTARY MATERIAL

PART 2.

Relationship between some of the cognitive hypotheses considered and the behavioural measures analysed in this study.

The cognitive constructs considered in the main text as accounts of the impairment shown by frontal patients on semantic fluency are:

A. *Initiation deficit*

B. *Switching deficit*

C. *Strategic deficit*

We will consider how the above types of deficit are reflected in the following domains of observation:

(i) the overall *number of words* uttered, and

(ii) the *order* of the produced words with reference to the semantic structure of the category "fruit".

(i) Number of produced words

All of the three deficits at issue (see above) should impair the search in the semantic store, so that a longer time will be necessary to find a given number of words. As a consequence, patients suffering from any of these cognitive deficits should generate, *under time constraint*, a shorter series of words. If unlimited time is granted, the patients are expected to produce the same number of words as controls (i.e. all the words belonging to the category) since they do not suffer from any semantic impairment .

(ii) Order of words

A. *Initiation deficit*. This deficit is defined as a slowing down of all the processing stages involved in the task. If the whole process is simply slowed down, with its qualitative characteristics being preserved, no *qualitative* alterations of the sequence are expected. However, the sequence produced should be *shorter* due to the time constraints.

As an example, consider a healthy participant who produces the following sequence:

AABBBCCDDDEEEE

where each single letter stands for a produced item, and different letters stand for different subcategories.

After a lesion causing an initiation deficit s/he might generate the following series:

AABBBCC (omitting DDDEEEE).

By assuming that the starting end of each series has roughly the same structure as the final end, one can expect that both patients with a pure initiation deficit and healthy participants will produce sequences with a similar semantic structure.

B. *Switching deficit*. This deficit is defined as a specific difficulty to abandon a perused subcategory and pass to a new subcategory while the participant is searching within the semantic store. Patients with this type of deficit would stick to a particular subcategory and would explore it for a *longer* than healthy controls, thus producing a higher number of consecutive words that are members of a same subcategory.

For example, consider a healthy participant who produces the following sequence:

AABBBCCDDDEEEE.

After a lesion causing a switching deficit s/he might generate the following series:

AAAABBBBCCC

On the average, these patients are expected to produce sequences characterised by a decreased number of switches, or - equivalently - by larger clusters.

C. *Strategic deficit*. In this case, patients are unable to follow the exploration strategy used by most healthy participants, i.e. they do not explore a category on the basis of its sub-categorical architecture. Patients suffering from this deficit are expected to abandon a given subcategory *earlier* than healthy participants do. They will produce sequences with a looser semantic organisation, with smaller semantic clusters and a relative increase of the number of switches.

It is now possible to systematically explore the relationships connecting the cognitive hypotheses listed above with the following three different performance indices:

1. *Number of words produced*
2. *Number of absolute switches*
3. *Relative number of switches*

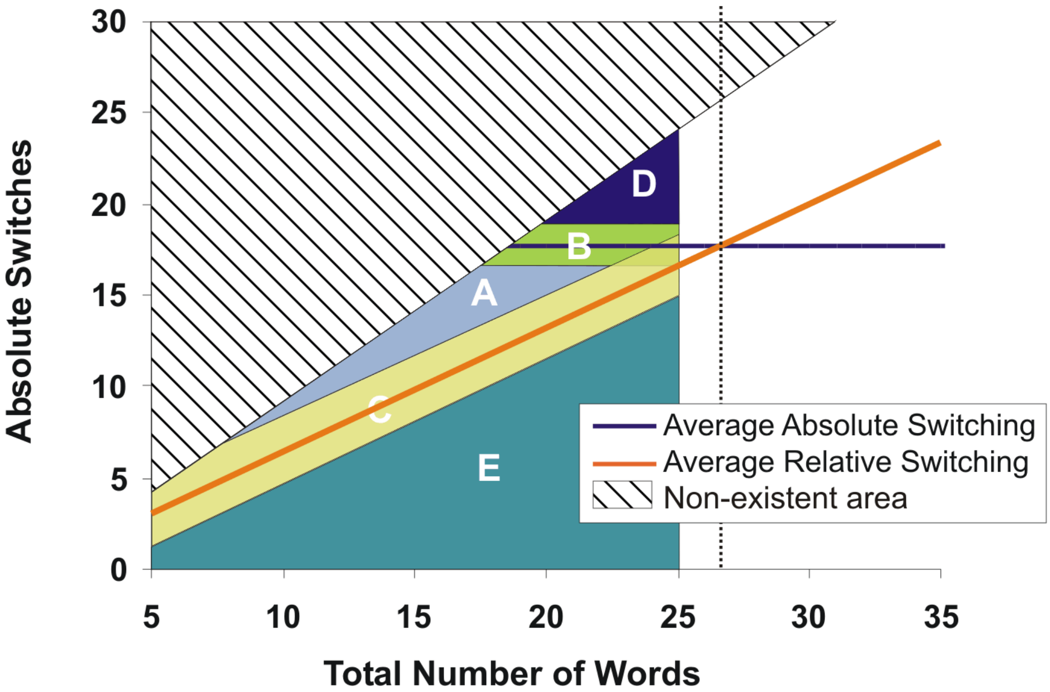

Figure 3 The surface defined by *absolute switching* and *total number of words* is partitioned into relevant subregions by some straight lines based on empirical observations (see caption and text). Each partition line is flanked with narrow stripes of different colour (for instance, the red C line is embedded in an ochre stripe and the blue B line in a green stripe). These stripes have different colours for graphical reasons, but they might also be viewed as reasonable (not formally derived) confidence areas around the partition lines.

Figure 3 shows the surface defined by two variables (absolute switching index and total number of words). This surface is partitioned on the basis of straight lines estimated on grounds of the Control Group's data set (present study). The B line, parallel to the abscissa, marks the mean absolute switches of the control group (17.7). The dotted vertical line, parallel to the ordinate, marks the mean total number of words produced by controls (27.1). The C line was constructed on the basis of the mean relative switches of the control group (0.67) and can be viewed as the absolute number of switches expected for each value of total number of words.

In the construction of Figure 3, the mean absolute switching, the mean total number of words and the mean relative switching obtained from the control group were considered as constant values. A, B, C, D, E are different subregions of the area containing pathological performances (as defined only on grounds of the number of uttered words); these subregions are separated by the lines corresponding to the absolute and relative switching of the Control Group.

Table 1 describes the behaviour of three performance indices (Total number of words, Absolute switching, and Relative switching) in the subregions A to E.

Table 1 Behaviour of the performance indices for each subregion of Figure 3.

Subregion	Number of words	Absolute Switching	Relative Switching
A	↓	↓	↑
B	↓	=	↑
C	↓	↓	=
D	↓	↑	↑
E	↓	↓	↓

↑ increase of the index; ↓ decrease of the index; = no effect expected

Because all the types of deficit considered in this section (see above) cause a decrease of the total number of produced words, the group performance of any type of patients is expected to fall in areas A, B, C, D or E of the surface represented in Figure 3.

Consider now the empirical dimension "Order of words". The effects on the word order predicted by the three hypotheses discussed in this study can be represented in the framework of Figure 3, and the correspondences between these hypothetical types of deficit and the subregions of Figure 3 are displayed in Table 2.

Table 2 Allocation of the types of deficit into the subregions of Figure 3.

Hypothetical Type of Deficit	subregion of Figure 3
Initiation deficit	C
Switching deficit	E
Strategic deficit	A, B, D

Hence a new table can be obtained (Table 3) by replacing subregions A to E of Table 2 with the rows of Table 1 corresponding to each subregion.

Table 3 Predicted behaviour of the experimental indices for each of the cognitive hypotheses considered in this study

	Number of Words	Absolute Switching	Relative Switching
Initiation deficit	↓	↓	=
Switching deficit	↓	↓	↓
Strategic deficit	↓	↓/=/↑	↑

↑ increase of the index; ↓ decrease of the index; = no effect expected

Table 3 shows that, within the set of measures considered in this section, only Relative Switching can discriminate among the three causal hypotheses at issue. Therefore the Relative Switching index is more appropriate than the Absolute Switching count in the present theoretical framework.

SUPPLEMENTARY MATERIAL

PART 3.

Details about the construction of the ***Order index***

The observed semantic fluency production of subject *i* can be viewed as a point p_i in a three-dimensional space: the dimensions of this space are *N* (the number of produced words), *SC* (the number of touched subcategories) and *aSW* (the absolute number of switches).

Point p_i can be found only in a subregion of the overall space, because both the number of switches and the number of subcategories cannot be greater than the number of produced words. Using symbols:

$aSW_i < N_i$ and $SC_i \leq N_i$

Given N_i and SC_i, the range of possible values of aSW_i is

$(SC_i - 1) \leq aSW_i \leq (N_i - 1)$

In other words, the number of switches ranges between a minimum corresponding to the number of touched subcategories minus 1 and a maximum corresponding to the number of produced words minus 1. These constraints are graphically represented in Figure 4.

In order to make the *aSW* values of different participants comparable, one should calculate the distance of aSW_i from its maximum, and divide this difference by the range of the possible aSW_i values. In symbols, the Order Index can be calculated:

$$\frac{(N_i - 1) - aSW_i}{(N_i - 1) - (SC_i - 1)}$$

This new variable equals 1 when aSW_i is minimal, i.e. $(SC_i - 1)$, equals 0 when aSW_i is maximal, i.e. $(N_i - 1)$, and is intermediate in the remaining cases.

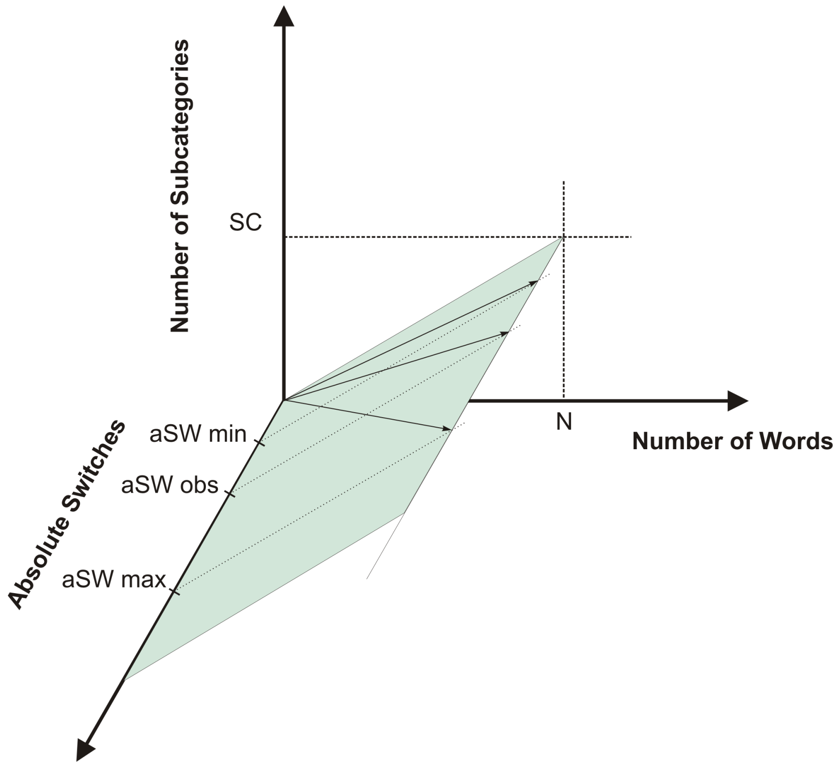

Figure 4 In this three-dimensional space each empirical observation is represented as a vector with coordinates N, SC, and aSW obs. On the coloured plane, defined by two empirical values of N and SC, three vectors are shown that represent the observed value of aSW (aSW obs), along with its theoretical minimum and maximum values.

Figure 5 shows a bi-dimensional representation of the coloured surface of Figure 4. From this figure one can better see how the Order Index is computed. The vector on the left side represents the theoretical minimum of the absolute number of switches (given a total number of words and a number of subcategories), the vector on the right side represents its maximum, and the middle vector represents the actually observed value. Angles a', b' and c' can be easily obtained given d and segments a, b, and c, that are directly observed. If a series is highly ordered, the number of absolute switches will tend to its theoretical minimum, and (c' – b') / (c' – a') will approach 1.

To avoid non-linearity problems, we have calculated the order index on the angles underlying the segments reported above, considered as sides of triangles centred on the origin of our three-dimensional space.

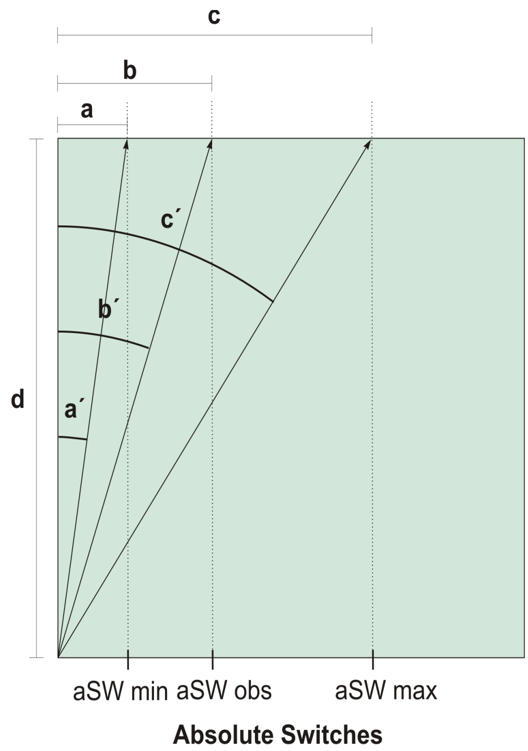

Figure 5 Bi-dimensional representation of the coloured surface of Figure 4.

A spreadsheet file (both in Microsoft Excel and in Open XML standard) is available in the on-line supplementary material which carries out the computation of the angular and linear Order Index from N, SC and a SW automatically. The procedure implemented in the file is based on the following formulas:

$$a' = \arctan\left(\frac{SC}{\sqrt{SC^2+N^2}}\right)$$

$$b' = \arctan\left(\frac{SW}{\sqrt{SC^2+N^2}}\right)$$

$$c' = \arctan\left(\frac{N-1}{\sqrt{SC^2+N^2}}\right)$$

$$Order\ Index = \frac{c'-b'}{c'-a'}$$