Investigating characteristics of semantic networks of verbs in patients with Alzheimer's disease

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Abstract

Alzheimer's disease produces alterations of cognitive functions and of processes that are responsible for language and memory. In order to have a better understanding of language changes, we investigate the characteristics of the semantic networks of patients diagnosed with probable Alzheimer, focusing on verbs. The results of comparisons with networks of healthy individuals highlights some topological differences among them.

1 Introduction

It is estimated that 35.6 million people currently suffer from dementia and that in 20 years this number will reach 65.7 million of individuals[1], with an estimated overall treatment cost of 315 billion dollars per year in the world. Alzheimer's disease (AD) is responsible for more than 50% of the cases of dementia, and it is one of the pathologies that cause among other consequences, alteration of cognitive functions and of the processes that are responsible for language and memory (Mansur, Carthery, Caramelli, & Nitrini, 2005).

Although there is no consensus about the precise nature of the changes in semantic memory change (Mansur, Carthery, Caramelli, & Nitrini, 2005), based on the results of semantic memory tests such as the Hodges Battery (Hodges, Salmon, & Butters, 1992; Howard & Patterson, 1992), two main theories are proposed to explain the semantic deficits of cognitive performance on these explicit semantic tests. The first one proposes a degradation of the semantic memory itself while the second advocates for a failure to retrieve information from memory (Mansur, Carthery, Caramelli, & Nitrini, 2005; Rogers & Friedman, 2008).

In relation to the language capacity, previous studies have found a progressive deterioration of performance in phonetic-phonological, syntactic, semantic and pragmatic-discursive processes (Mac-Kay, Assêncio-Ferreira, & Ferri-Ferreira, 2003; Mansur, Carthery, Caramelli, & Nitrini, 2005; Ortiz, 2009). For instance, in the context of aphasia, which may result from a progressive neurological disease like Alzheimer's, there seems to be a preference for more general and frequent verbs to be more easily used (Barde, Schwartz, & Boronat, 2006; Breedin, Saffran, & Schwartz, 1998; Kim & Thompson, 2004; Thompson, 2003; Thompson & Shapiro, 2007), which may be due to these verbs being applicable in many distinct situations. Closely related factors such as polissemy and synonymy are also seen as an important role in the human learning process (Hills, Maouene, Maouene, Sheya, & Smith, 2009). Features like this may influence the organization of the mental lexicon arising, e.g., from the need of fast retrieval of concepts (Steyvers & Tenenbaum, 2005).

In this paper we investigate the characteristics of the semantic networks of AD patients[2], focusing on the lexical organization of verbs. For that we use psycholinguistic data from an action

[1] Figures from the Alzheimer's Disease International, 2009.

2 Due to the impossibility of detecting the presence of histological brain features in living elderly individuals, the diagnostics is of probable or possible Alzheimer Disease (McKhann et al., 1984).

naming task, comparing the output of AD patients with those from healthy individuals. We represent the data as semantic networks, which seem to play an important role in the modeling of the organization of lexical knowledge and have been used to describe access to the mental lexicon (Steyvers & Tenenbaum, 2005). We analyse the collective[3] semantic networks using statistical and topological analysis.

This paper is structured as follows: in section 2 we describe some relevant works on semantic networks. In section 3 we present the materials and methods in the experiments. In section 4 we present the results. We finish with some conclusions and future works.

2 Related Works

Semantic networks have been used in several studies of language. For instance, Steyvers and Tenenbaum (2005) analyzed the large scale structures of three kinds of semantic networks: word associations of naïve subjects (Nelson, McEvoy, & Schreiber, 1999), WordNet (Miller, Fellbaum, Gross, & Miller, 1990) and a thesaurus (Roget, 1911). All three networks have the features of small-world structure, characterized by the combination of short-average minimal path lengths (L)[4] and a high clustered neighborhood (extracted from the clustering coefficient, C, that represents the probability of two random nodes being neighbors). The results found suggest that these characteristics may be related to the cognitive need for the fast retrieval of concepts (Steyvers & Tenenbaum, 2005). Indeed, Sigman and Cecchi (2002) also found a small-world structure in a network of nouns constructed from four types of semantic relations in WordNet: hyponymy/hypernymy; antonymy; meronymy/holonymy; polysemy. However, it is only when the polysemy links are added to the network that it becomes a small world (Sigman & Cecchi, 2002). Similarly, a network constructed from synonyms from the Moby thesaurus (Motter, de Moura, Lai, & Dasgupta, 2002) also had small-world structure. In this paper we follow these works, and in particular Steyvers and Tenenbaum (2005) and Sigman and Cecchi (2002) in using topological analysis for comparing the semantic networks.

Semantic networks have also been using in cross-linguistic investigations like that of Parente et al. (2011) who compared the semantic networks of Brazilian Portuguese speakers and Mandarin Chinese in a verb naming task, in the context of language acquisition (Parente et al., 2011). In this work we also use a verb naming task but this time to investigate possible changes in the semantic networks of AD patients.

3 Materials & Methods

Participants for the verb naming task consisted of 46 individuals divided into 2 groups:

•Alzheimer's Disease (AD) group: 23[5] patients diagnosed with probable Alzheimer's disease (Mild AD), with Mean age = 75.6 years; SD = 6.7 and

•Healthy Elderly (HE) group: 23 healthy individuals with Mean age = 72.4 years; SD = 8.2.

In addition, a third group of participants was also considered for evaluation purposes:

•Healthy Young Adult (HYA) group: with 75 adults (Mean age = 21.69; SD = 3.25).

The experimental materials consisted of 17 movies showing destruction or division actions which always included an agent, an instrument and an object (e.g. sawing a log and cutting paper) (Duvignau & Gaume, 2004; Tonietto et al., 2008). The participants were asked to name the action portrayed, and the answer given by each participant for each movie was recorded. These actions were selected according to criteria of easiness of understanding. All responses that contained verb were considered valid, if the verb was related to the main action (excluding e.g. "to eat" for the action of sawing a log) and if the answer was not metalinguistic (excluding e.g. "I don't know") or non-verbal.

For each of the elderly groups (AD and HE) one semantic network was created, where every distinct verb uttered by a participant of the group was represented by a node in the network. A link

3 Collective networks are modeled using a group of individuals, rather than only one.

4 A minimal path length is the minimal distance between two nodes in the network.

5 The size of this sample is compatible with that of other works with Alzheimer's disease: some report from 5 to 11 patients, and others have from 20 to 26 patients (Bell, Chenery, & Ingram, 2001; Chan, 1997; Garrard, Lambon Ralph, Patterson, Pratt, & Hodges, 2005; Laisney et al., 2009; Peraita, Daz, & Anllo-Vento, 2008; Rogers & Friedman, 2008). This is partly due to the difficulties of finding a larger sample of participants with the same level of the disease (in this case Mild level).

between two nodes (verbs) was added to the network if the two verbs were uttered for the same action. The result was a clique formed by all verbs given for a movie, and the different cliques became connected due to the polysemy of some of the verbs, which were produced for more than one movie.

A comparison of the two groups is done in terms of their structure, through topological analysis, and also of their content. Table 1 shows some relevant topological measures, where:

•$<k>$ is the mean degree of the network;
•L is average minimal path length;
•D is the diameter of the network (with a maximum of L nodes);
•C is the clustering coefficient and

More details about each of these measures can be found in (Barabási & Albert, 1999; Watts & Strogatz, 1998).

4 Results

The results are discussed in terms of two comparisons. In the first we compare the semantic networks of the two groups with each other. The results are further evaluated by first determining the expected differences that would arise from a variation in the participants (using the HYA group) and comparing with the observed differences between the two elderly groups (AD and HE).

4.1 Elderly Groups

Sharing the same global features of the other language networks, these show a small world structure: they have a small average of minimal path lengths and high clustering coefficients.

Apart from their diameters, the two networks considerably differ in all other measures. First of all, the AD group produced more distinct verbs for describing the actions, which suggests lower agreement for describing the actions and is reflected in a slightly larger number of nodes than the HE group. As a consequence, although a larger number of edges would be expected with more nodes in the AD group and their mean connectivity ($<k>$) of the HE, the observed increase was considerably larger than that.

Second, the mean and standard deviation presented by $<k>$ indicate that AD's nodes have a consistently higher degree of connectivity (k) than those in HE. One possibility for a larger k is the use of more polysemic verbs by the AD group, since for every action that a verb is used to describe, it becomes connected to all other verbs also used to describe the action, forming a clique. Therefore, for each new context in which a verb is used, its degree increases by the size of the clique. If we assume that more connected verbs are also more generic, this would be consistent with the tendency of aphasic patients to use more general verbs (Barde, Schwartz, & Boronat, 2006; Breedin, Saffran, & Schwartz, 1998; Kim & Thompson, 2004; Thompson, 2003; Thompson & Shapiro, 2007).

Third, with a larger number edges between the nodes and a higher mean connectivity, the average minimal path length (L) would be expected to be smaller in the AD group than in the HE. However, the opposite is found, which is an indication that the differences between the two networks go beyond the use of a larger vocabulary and less agreement between in the AD group, but that they are structurally different too

Variable	Alzheimer	Controls
n (verbs)	46	40
Edges	243	140
$<k>$	10.57 (SD 6,55)	7.00 (SD 4,56)
L	1.94	1.57
D	4	4
C	.829	.789

Table 1: A summary of the semantic networks

In Figure 1, we can see the two networks in which the size of a node is shown in direct proportion to its degree (normalized). The image suggests the a larger number of highly connected nodes, or hubs, in the AD network.

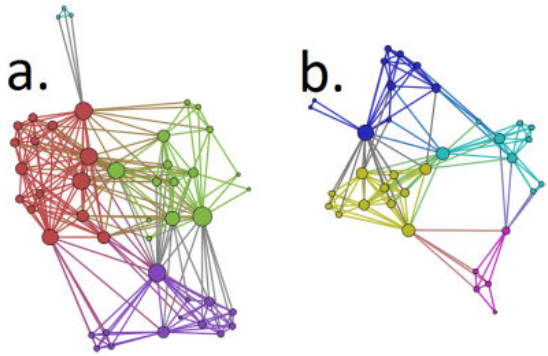

Figure 1: The Alzheimer's (a) and controls (b) semantic networks.

4.2 Adults and Elderly Groups

In order to verify the degree of variation expected from different groups of participants, and whether this variation could explain the differences found between the two elderly groups, we also created 30 subgroups of 23 participants randomly selected from the 75 in the HYA group. For each subgroup we generated a semantic network using the same method than for the elderly groups. Table 2 shows the mean and standard deviation of the topological features of the 30 groups. In addition this table also shows the module of the difference of statistics between the AD and the HE networks. All the differences are larger than the standard deviation of the adult's samples. This indicates that intra-group variations are not enough to explain the differences found between the elderly groups.

	Adults Sample		|AD-Controls|
Variable	**Mean**	**SD**	
n (verbs)	38.57	1.305	6
Edges	334	20.85	103
$<k>$	9.405	0.355	3.57
L	2.137	0.05	0.37
D	4.567	0.504	0
C	0.817	0.012	0.04

Table 2: Characterization of Sample of Adults. Including the difference between Alzheimer and controls networks.

5 Conclusions and Future Work

In this paper we presented an investigation of the lexical organization of verbs in the context of Alzheimer's disease patients. We looked at characteristics of the semantic network of verbs produced by AD patients in an action naming task, comparing with that of healthy individuals. We analysed the collective semantic networks using statistical and topological analysis, and found interesting divergences. In particular there seemed to be less agreement among the AD patients for the lexical choice to describe a given action. In addition, there were also indications of structural differences between the networks which may arise from modifications in the lexical organization caused by AD.

However, more detailed investigation of these possibilities needs to be conducted before more definite conclusions can be reached. We also plan to analyze qualitative differences among hubs between the networks. Finally we intend to inspect other statistical features of complex networks, particularly those related to network vulnerability (Criado, Flores, Hernández-Bermejo, Pello, & Romance, 2005), that are associated to network performance and helps to measure the response of complex networks subjected to attacks on vertices and edges.

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