SPEECH IN ALZHEIMER'S DISEASE

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ABSTRACT

This paper describes the quantification of physical characteristics of Alzheimer's patients' conversational speech. The study was conducted on a total of eight probable AD patients and eight normal controls. For each group, a total of five measurements were made from their conversational speech recordings which depended on verbal fluency and pauses in speech. The paper discusses statistical results obtained with these parameters and explains their usefulness for quantifying speech deficits in Alzheimer's disease.

INTRODUCTION

It has been found, especially in aphasia studies, that physical characteristics of speech, such as speech rate, speech tempo, pauses, etc. can be used for characterizing speech and language disorders. Feyereisen, Verbeke-Dewitte and Seron (1986) describe the process of measuring speech tempo and mean length of utterances for differentiating between Broca's, Wernické's, mixed, and recovered Broca's aphasics. They note that by making use of such physical rather than linguistic measurements, conversational performance and picture description stand out as two different tasks, which suggests that the results on one cannot be used for generalization on the other. Similar work, carried out earlier by Deloche, Jean-Louis and Seron (1979), also showed that by making use of complex measurements on speech fluency, it was possible to differentiate between aphasics and normal controls and that conversational performance is quite different from description tasks. These differences have also been pointed out by many other authors using linguistic measurements in aphasia (e.g. Benson, 1967; Kertesz and Poole, 1974; and Singh, 1996).

Although the concept of analyzing temporal variables in spontaneous speech of patients has been tested in aphasia for some time, we undertook this study with the following aims: to develop similar techniques in the case of Alzheimer's (AD) patients; to evaluate which variables are specifically important for AD patients and to understand what they represent; to compare AD and normal performance using selected parameters; and finally to discuss how this method can be used for testing the effectiveness of drug-related strategies.

SPEECH ANALYSIS

In order to evaluate patients on the basis of their conversational performance, it was decided to work on the physical characteristics of their speech. The overall procedure consisted of two steps: data collection, and data analysis. These are explained below.

Sample

A total of eight patients with a diagnosis of probable Alzheimer's disease (pAD) were recorded by a trained researcher (JG): (4 females and 4 males; age range 57-77, mean age 67.8, sd. 6.2, duration of disease 31-70 months, mean duration 48.1 months, sd. 13.2). All subjects had attended the Bristol Memory Disorders Clinic at the hospital and were diagnosed following an extensive assessment within the clinic including: medical interviews, physical examinations, neuropsychological testing, laboratory investigations and computerized tomography scanning of the head. All diagnosis were made using the DSM-III-R and NINCDS-ADRDA criteria (American Psychiatric Association, 1987; McKhann et al., 1984). The Mini mental test scores showed that subjects were suffering with a range of cognitive impairments, i.e. mild to severe (Folstein et al., 1975): patients scored in the range 3-24 (mean 15, sd. 6.8). An additional set of eight normal controls were recorded by author (SS), who were matched in terms of their age and educational background.

Each subject was recorded in a conversational setting for a period of 20-45 minutes to give a sample of roughly 1000 words. It has been noted by Andreason and Pfohl (1976) that samples below this level are usually inadequate for a reasonably valid analysis. The recording was carried out on a one-to-one basis using a clip microphone and tape-recorder. Subjects were asked to describe their hobbies, experiences and various other activities. These recordings were then used for calculating a set of speech parameters which are described below.

Method

A total of five variables were selected in this study after experimentation in order to quantify both speech fluency and planning aspects in speech. Some of these have been used in aphasia studies, and others were considered important to our understanding of speech behaviour in AD. These are:

- Verbal Rate (VR) = Text length / Total locution time (TLT), measured in words per minute including pauses
- Transformed Phonation Rate (TPR) = arc sin(PR) where PR = Total Phonation time/ Text Length where PR is phonation rate and the total phonation time (TPT) is the time spoken without pauses
- Mean Duration of Pauses (MDP) = Average pause-length in seconds = Total Pause Time/Total pauses
- Standardized Phonation Time (SPT) = Text Length/ Total Phonation Time, measured as number of words per minute, not including pauses.
- Standardized Pause Rate (SPR) = Text Length/ No. of Pauses, measured as the average number of words uttered between two pauses.

It can be observed from Table 1 that there is a considerable range of performance on most variables both in the Alzheimer and normal group. In order to establish the utility of our five measurements for discriminating between AD patients and NC subjects, it was proposed to use a non-parametric test (Mann-Whitney U test in this case) keeping in view the small sample size and no previous knowledge of the population distribution. The results are shown in Table 1, marked with asterisks, which illustrate the relative importance of variables for discriminating between AD and NC measurements. Although SPR and TPR were not found to be significantly important discriminators, at this point in our analysis it was decided to retain them for further analysis as they represent important variables in terms of their explanatory power for helping our present discussion. Their usefulness will become more evident when we discuss our PCA analysis.

PRINCIPAL COMPONENTS ANALYSIS

PCA is one of the multivariate methods of analysis for identifying a set of principal components which explain the variance in data (see Jollife (1986) for details). The results showed that the first principal component PC1 contrasts variables VR, SPT, SPR and TPR against variable MDP. This implies that a high PC1 score can be obtained through low scores on all variables except MDP. All measurements except SPT depend to some extent on pauses, however, MDP is the only variable that quantifies their average duration. The MDP measurement quantifies the time taken to re-plan sentences rather than their fluency (a large number of short pauses or a small number of large pauses will both yield equivalent pause time, however, in the latter case more subconscious effort goes into the planning aspect of speech). All other measurements quantify the fluency aspect of speech, namely the speech rate. In summary, PC1 contrasts variables that depend upon the planning aspect of language with those that depend upon its fluency (speech rate in some form) and explains 66.9% of variation in the original data.

PC2 contrasts variables VR and SPT against variables MDP, SPR and TPR. A high PC2 measurement will be obtained through high VR and SPT measurements and low MDP, SPR and TPR measurements. The first two, VR and SPT, are primarily concerned with the speech rate and describe the number of words spoken per minute, whereas the last three variables taken together describe the distribution of pauses in the sample: MDP describes their mean duration; SPR describes on average the number of words spoken between two pauses and TPR which is the sine of the ratio PR can be used to derive the proportion of speech time spent in pauses. PC2 describes 27.6% variance in the data.

At this point the importance of retaining SPR and TPR variables in the analysis becomes clear. Although they are less important than other variables on the PC1 axis, they are considerably important for explaining variance on the PC2 axis. The plot of PC1 and PC2 scores is shown in Figure 1. The plot shows that A's (AD patients) are more dispersed along the PC1 axis rather than on the PC2 axis, the opposite being true for B's (normal controls). It should be observed that there are virtually two separate clusters for normal and Alzheimer subjects.

DISCRIMINANT ANALYSIS

In order to identify the relative importance of differentiating variables, and determining a classification rate for recognizing AD and NC patterns as belonging to two separate classes, a linear discriminant analysis was performed. The results were obtained with ($p = 0.004$, $\chi^2 = 17.25$ and d.f. = 5).

It was found that variables VR, SPT and MDP have higher discriminant loadings indicating their relatively higher importance in the pattern discrimination process. This supported our earlier results with the Mann-Whitney analysis, and PCA analysis that the first three variables contribute most to PC1 scores which explain most of the variance in data.

Figure 2 shows all sixteen subjects plotted against their discriminant scores. In Figure 2, each AD patient is represented by four 1's and each NC subject is represented by four 2's. As it can be seen, there is distinct discrimination between the two groups on the basis of all variables on the X axis. A classification summary for the above analysis resulted in a 100% correct classification. We must remind ourselves here that the function generated is tested here on the same data which was used for generating it. This may lead to over-optimistic results and hence a more rigorous technique called cross-validation should be employed (see Fu (1994) for a description of the technique). Cross-validation using leave-one-out method takes the sample of size *n*, and generates the function using *n-1* entities of the sample and tests it on the remaining one which was taken out. The process will repeat for a total of *n* times and an average of misclassifications will indicate the success of discriminant process. Using this technique with our data, a classification rate of 87.5% was achieved.

The results show that AD patients are significantly different from normals in terms of their speech measurements. The discriminant scores axis in Figure 2 seems to represent the severity of disorder in terms of word finding problems and planning deficiency. Patients who achieve a high positive discriminant score, and are therefore further away from the normal spectrum of scores, would have a smaller speech rate (measured as TPR) with more long pauses, and will spend more time reorganizing their language into speech output.

DISCUSSION

In this paper we set out to quantify the physical characteristics of patients with AD and to demonstrate the usefulness of such measurements for classifying them from normal adults. There are several benefits from doing so such as: quantifying the degree of speech disorder in AD patients as evident through their conversational speech; the formulation of sensitive outcome measures which can quantify the degree of deficit; and the identification of those areas of deficit that need most attention.

It seems from Table 1 that VR, SPT and MDP are significantly different at the 5% significance level across groups AD and NC. It is surprising to note here that TPR (transformed phonation rate) does not play a significant part as in the case of discriminating between aphasics and normals (see Dongen et al. (1994)). Also, SPR (average number of words between pauses) is not an important discriminator. These are important findings. It implies that the length of pauses is more important than their number which directly controls SPR, and also that the ratio of TPT to TLT is not of critical importance as previously thought.

The quality of speech output is important to measure in Alzheimer's disease as it gives an indication about the type and the severity of the deficit, as well as ties such evaluations with others which are usually recorded. Speech is a dynamic process and several language and non-language factors are concurrently active. In this paper we have been able to distinguish between normal and AD subjects on the basis of two such factors: the fluency in speech (as evident through the rate of speaking), and the distribution of pauses in speech. This is an important discovery. In different subjects, these factors may be different from the norm to varying extent. We have found that AD patients' speech deficits are considerably dependent on their planning impairments, as evident through their longer pause duration. Furthermore, we have discovered that the variables which have been suggested as highly important for differentiating between dysphasic and normal adults, i.e. SPT and TPR, are not critically important as shown in Table 1.

The results produced in our study are mutually supportive. The three analyses done on our multivariate data, i.e. Mann-Whitney, PCA and Discriminant Analysis, all support the importance of the first three variables as statistically significant, and confirm that normal subjects and AD patients form two separate clusters when classified through the variables proposed by us. All these variables have been standardized to the corresponding text lengths and are therefore comparable across transcripts.

The evaluation of conversational speech and language in AD is highly important. Our analysis can be used with larger samples to develop a more comprehensive taxonomy of Alzheimer's Disease, which at present weakly classifies patients as early onset (EO) and late onset (LO). Similar classifications can be achieved in affective disorders. It has been demonstrated by Newman and Mather (1938) that using linguistic features in free speech, it is possible to classify patients belonging to different varieties of affective disorders such as manics and depressives. This classification, and several related ones, can also be attempted using the physical characteristics of free speech now that it has been demonstrated both in aphasia, and in AD (this paper), that this can be attempted through reliable measures which quantify different levels of performance. Speech analysis is also important to quantify the degree of deficit during the course of a therapeutic programme. In diseases which are drug-related, assessments may be made to rank AD severity in different patients. Also, the present approach provides a technique to monitor patient progress through a series of assessments at regular intervals. We should recommend that the proposed technique should be studied with a larger sample, exploring more variables that quantify the degree of speech deficit. Such analyses can be used in conjunction with other conversational analyses in language disorders (Singh, 1996).

SUMMARY

In this paper we have proposed a new technique for quantifying the degree of speech deficits in AD patients as in their conversational speech. The overall process consists of interviewing AD subjects and normal controls, data transcription and data analysis. The transcripts are used in the calculation of various features of AD speech, e.g. pauses, and can also be used to do a linguistic analysis. A total of eight AD patients and eight normal subjects were interviewed and analyzed. The paper establishes the usefulness of analyzing physical characteristics of speech for AD patients through various statistical analyses such as non-parametric analysis, Principal Components Analysis, and Discriminant Analysis. These analyses yield mutually supportive results which confirm AD patients as deficient in the planning aspect of their conversational speech and shows differences in their speech fluency. The frequency distribution and average length of pauses was also found to be different between the two classes. The paper recommends similar analysis with a larger sample and its integration with other linguistic methods of analyzing AD patients.

REFERENCES

American Psychiatric Association (1987). *Diagnostic and Statistical Manual of Mental Disorders*, Washington D.C.

Andreason, N.J. & Pfohl, B. (1976). Linguistic Analysis of Speech in Affective Disorders, *Arch. Gen. Psychiat.*, 33, 1361-1367.

Benson, D. F. (1967). Fluency in Aphasia: Correlation with Radioactive Scan Localization, *Cortex*, 3, 373-392.

Deloche, G., Jean-Louis, J. & Seron, X. (1986). Study of Temporal Variables in the Spontaneous Speech of Five Aphasic Patients in Two Situations: Interview and Description, *Brain and Language*, 8, 241-250.

Dongen, H. R. V., Paquier, P. F., Raes, J. & Creten, W. L. (1994). An Analysis of Spontaneous Conversational Speech Fluency in Children with Acquired Aphasia, *Cortex*, 30, 619-633.

Folstein, M. F. & Folstein, S. E. 91975). Mini-Mental State. A practical method for grading the cognitive state of patients for the clinician, Journal of Psychiatric Research, 12, 189-198.

Fu, L. (1994). *Neural Networks in Computer Intelligence*, Singapore:McGraw-Hill.

Henderson, A., Goldman-Eisler & Skarbeck, A. (1966). Sequential Temporal Patterns in Spontaneous Speech, *Language and Speech*, 9, 207-216.

Jollife, I.T. (1986). *Principal Components Analysis*, New York: Springer-Verlag.

Kertesz, A. & Poole, E. (1974). The Aphasia Quotient: The Taxonomic Approach to Measurement of Aphasia Disability, *Canadian Journal of Neurological Sciences*, 1, 7-16.

Kreindler, A., Mihailescu, L. & Fradis, A. (1980). Speech Fluency in Aphasics, *Brain and Language*, 9, 199-205.

McKhann, G., Drachman, D., Folstein, M. F., Kaltzman, R., Price, D., & Stadlan, E. M. (1984). Clinical Diagnosis of Alzheimer's Disease: Report of the NINCDS-ADRDA Work Group under the auspices of Department of Health and Human Services Task Force on Alzheimer's Disease, *Neurology*, 34, 939-944.

Newman, S. & Mather, V. G. (1938). Analysis of Spoken Language of Patients with Affective Disorders, *American Journal of Psychiatry*, 94, 913-942.

Singh, S. (1996). Computational Analysis of Conversational Speech of Dysphasic Patients, *Ph.D. Dissertation*, University of the West of England, Bristol, U.K.

TABLES AND FIGURES

Subjects	*AD Subjects*				*Normal Controls*			
Variable	Mean	St. dev	Min.	Max.	Mean	St. dev	Min.	Max.
(VeR)*	113.86	27.24	67.46	163.86	158.65	25.91	115.31	190.85
(SPT)*	132.65	24.69	87.76	174.32	188.38	22.28	156.51	221.80
(MDP)*	2.76	.47	1.90	3.30	1.78	.43	1.20	2.50
(SPR)	40.18	22.10	16.00	88.23	36.68	22.34	17.08	72.33
(TPR)	1.03	.11	.88	1.22	1.01	1.14	.83	1.23

* Mann-Whitney test found these variables to be significant discriminators at the 5% significance level. For both SPR, and TPR, $p = 0.63$.

Table 1. Temporal measures for AD and normal elderly controls, desrciptive statistics

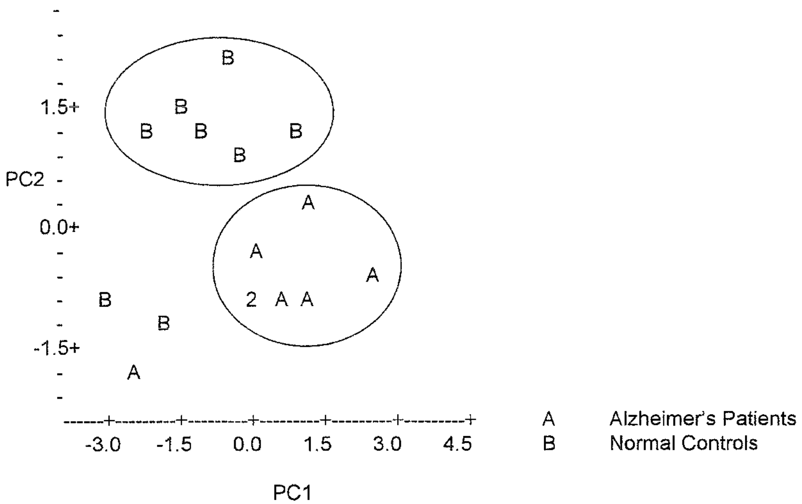
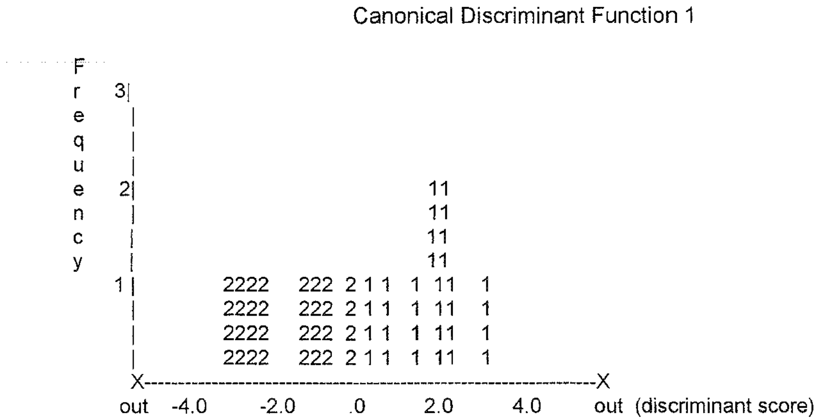


Figure 1 PCA Analysis of Alzheimer's Patients and Normal Controls



1 = normal controls
2 = AD
A stack of 4 1s, or 2s represents a single subject.

Figure 2 All-groups Stacked Histogram