ANALYSIS OF THE ROLE OF PREFRONTAL CORTEX IN DETERMINING AGE DIFFERENCES IN LANGUAGE PROCESSING: GRAMMATICAL NUMBER AGREEMENT BETWEEN SUBJECT AND VERB

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Abstract: *According to the frontal lobe theory of aging, this process is associated with a series of micro- and macro-structural changes at the level of the prefrontal cortex. These changes are correlated with a decline of the capacity of working memory. Until now there are no clear evidence that sustains the involvment of a unitary or distributed working memory capacity in explaining age differences in syntactic processing. The participants included in the study N=134 are Young (n=72, m=22.06, sd=3.17) and Old (n=62, m=65.95, as=5.94). The measured variable of the study, time of processing was statistically analyzed using an ANOVA 2x2x4 model, with one between subject independent variable Working memory capacity (high or low) and two within the subject variables, the Type of phrase (number agreement or disagreement) and the Region of processing (subject, verb, the word ofter the verb or the last word). The obtained result does not conform the prediction of a unitary working memory capacity of syntactic processing, sustaining the alternative, specific resources model of the working memory.*

Cuvinte cheie: *cortex prefrontal, memorie de lucru, limbaj*

Rezumat: *Conform teoriei frontale a îmbătrânirii înaintarea în vârstă este însoţită de modificări dramatice micro- şi macro-structurale ale cortexului prefrontal. Modificări structurale şi funcţionale ale cortexului prefrontal sunt corelate cu declinul memoriei de lucru. Pe baza datelor din literatura de specialiate, putem afirma că deocamdată nu există consens în ceea ce priveşte implicarea unor resurse unitare sau distribuite ale memoriei de lucru în explicarea diferenţelor de vârstă în procesarea sintactică. Participanţii incluşi în studiu N=134, au vârsta Tineri (n=72, m=22.06, as=3.17) şi Vârstnici (n=62, m=65.95, as=5.94). Timpul de procesare a diferitelor regiuni, a fost prelucrată statistic prin utilizarea procedurii ANOVA pentru un design 2x2x4, cu o variabilă independentă intersubiect, Capacitate ML (redusă sau crescută) şi două variabile independente intragrup, Tipul frazei (acord sau dezacord) şi Regiune (substativ, verb, plus1 şi ultim). Rezultatele obţinute infirmă predicţiile modelului capacităţii unice a memoriei de lucru, susţinând explicaţia alternativă dedusă pe baza modelului resurselor distribuite*

INTRODUCTION

Executive decline hypothesis is based on the frontal theory of aging, proposed by West (1996). According to this theory aging is accompanied by dramatic changes in micro-and macro-structural prefrontal cortex (Raz, 1999). Thus, there is a demyelization of neurons in prefrontal cortex, which reduces the efficiency of transmission of impulses (Berkman et al., 1993, Raz, 2000), decrease post-synaptic responsiveness to neurotransmitters, in particular a reduction of dopamine receptors (Fulop & Seres , 1994), reduce the cellular metabolism, decreases the number of synapses (Gibson, 1983), reduce the abundance of branches dendrites (Uylings, West Coleman, Brabander, & Flood, 2000) and increase the concentration of pathological structures (eg. wound tracks), especially in the frontal and temporal areas (Ferrer-Caja et al., 2002). Structural changes are accompanied by functional changes. There is a selective decline of cerebral blood flow observed in prefrontal cortex (CPF) compared with the parietal and temporal lobe and a reduction in glucose metabolism.

These losses do not affect equally all prefrontal cortical areas. Areas of the prefrontal cortex, the most significant structured and functional changes are recorded in the dorsolateral prefrontal cortex and orbitofrontal cortex (Band, Ridderinkhof, & Segalowitz, 2002). Structural and functional changes of prefrontal cortex are correlated with a decline of cognitive functions associated with the activation of these cortical areas, especially the working memory. In the literature there are some data supporting the existence of a shortfall in working memory (WM) in the elderly population (Light and Capps, 1986, Verhaeghen et al., 1993).

Using cue-word monitoring paradigm allowed the investigation of sensitivity to grammatical mistakes in elderly. The results indicate a general increase in time and error rate of aging people, but have not revealed a difference in sensitivity to such errors (Waldstein & Baum, 1992). The word by word reading of ambiguous sentences did not reveal differences in the processing of disambiguation area between young and old (Kemtes & Kemper, 1996), although older people were more powerful affected by the off-line component of evaluation. These data sustains that age does not affect psycholinguistic processes itself (assessed by on-line paradigms) it affects the ability to operate effectively with meanings already developed (skill assessed off-line tasks). The studies presented support the involvement of a specific WM ability in syntactic analysis, whose capacity is not affected by age (Waters & Caplan, 1996, Waters & Caplan, 2005).

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At the opposite pole lie those studies supporting the involvement of a general WM capacity in syntactic processing. Thus, Zurif, Swinney, Prather, Wingfield, and Brownell (1995) found that elderly have poorer results in tasks involving processing sentences whose components position was changed. For example, in sentences like The tailor finished the gown which the actor from the theater needed to play tomorrow the meaning of the word gown may only get a thematic role only after the link with the word needed was established (in canonical form, needed the gown ...). In such tasks the elderly have a reduced sensitivity regarding the relationship between the separated components. King & Just (1991) and Stine-Morrow, Loveless & Soederberg (1996) found similar results. In both studies there were significant differences between elderly and young subjects in processing syntactically ambiguous phrases compared with those non-ambiguous. The existence of a general WM capacity involved in syntactic processing is supported by data provided by studies on aphasic patients. In their case it was found that the diversity of symptoms can be explained by differences in the degree of deficit of the WM capacity (MacDonald, Just & Carpenter, 1992). The data show a significant correlation between the decline of the ML ability and grammatical deficit (Zurif, Swinney, Prather, Wingfield & Brownell, 1995, Carpenter, Miyake & Just, 1994). Data provided by cognitive neuroscience indicates that this relationship can be explained by the common substrate of these functions, syntactic processing and WM capacity (Kemtes & Kemper, 1996 Kemper, 1988). Summarizing the presented empirical data, we can say that: i)until now there is no consensus regarding the involvement of a unitary or distributed resources WM capacity in explaining age differences in syntactic processing, ii) there is a convergence of studies which suggests a similarity in performance of older and aphasic patients in lexical disambiguation tasks. The similarity is explained by the decline of nervous system that characterizes aging (West, 1996). Taking these data as a starting point, the aim of our experimental study is to verify the prediction of the two models of WM in a language context that was poorly investigated until now, namely determining the number agreement between subject and predicate.

If the integration of syntactic information involves maintaining their components in an activated state until extraction of meaning from the phrase is executed, then distancing syntactically related components will lead to a decline in detection the presence of syntactic errors. But this effect will particularly affect elderly subjects, explained by their reduced WM capacity (Spencer & Raz, 1995). Maintenance in an active state of all syntactic features of a verb allows early detection of violations of rules of number agreement. Elderly subjects will show longer processing times for verb, an experimental effect that will be present only in long incorrect sentences. For young people interaction between variables listed above will not reach significance.

MATERIAL AND METHOD

Number of participants enrolled in the study was N = 134, divided into two categories based on age, young (n = 72) and elderly (n = 62). The average age of participants in youth category was m = 22.06 (s = 3.17) in the category was older was, m = 65.95 (s = 5.94). RST test score in young class was, m = 36.66 (s = 7.25) while in the older was, m = 26.624 (s = 7.19). Subjects of both age groups were randomized into two groups; one read the short version of the task other the long one. Each participant had normal vision or corrected to normal.

Reading Span Task (RST) - task assesses working memory capacity (Just & Carpenter, 1992). The task included 60 pairs of words structured in five series. Each set includes three rows of such pairs. The difficulty of the series gradually increases correlated with the number of words that had to be retained and the number of phrases that had to be processed (series length varied between 2 and 6). A correct answer involves deciding upon the grammatical correctness of a sentence and retention the word which follows each phrase (for a detailed description of the task see Just & Carpenter, 1992).

Sensitivity Test to Number Disagreement (STND) – the long form and the short form consisted of 40 test sentences and 40 filler sentences. Grammatical agreement / disagreement in number, was established between subject and copulative verb as follows: agreement in 20 sentences (10 SS type, singular subject and singular verb and 10 PP type, plural subject and plural verb) and disagreement in 20 sentences (10 SP type, singular subject and plural verb and 10 PS type, plural subject and singular verb). Based on this rules we have generated four types of sentences: The restaurant near the hut is frequented by tourists (SS); The restaurants near the hut are frequented by tourists (PP); The restaurant near the hut are frequented by tourists (SP) and The restaurants near the hut is frequented by tourists (PS). The distance between subject and verb was always three words (which amounted to between 15 to 20 characters), for short phrases and eight words long phrases (totaling 35-40).

The dependent variable of the experiment resulted in subtracting the predicted value from the recorded one (prediction was made for each subject using regression analysis using as criterion variable the processing time and as predictors the type of processed region of the phrase and the length of the processed region, for a detailed description of approach see Lorch & Myers, 1990). The regions that were taken into account were: noun (... hut ...), verb (...is...), the word which follows the verb, called plus1 (... frequented ...) and last word (... tourists). Based on the time registered for each phrase we had calculated an average processing time on the correct phrase (SS and PP type) and incorrect sentences (SP and PS type). Processing time of different regions was statistically analyzed using ANOVA procedure using a 2x2x4 design, with WM Capacity as between-subject independent variable (with two levels, low or high) and two within subjects independent variables, Sentence Type (with two levels, agreement or disagreement) and Region (with four levels, noun, verb, plus1 and last word). The threshold for statistical significance was set to 0.05.

RESULTS AND DISCUSSIONS

Statistical analyzes were performed separately on the short and long version of the task. Descriptive results obtained for the short version are presented in Table 1.

Analysis of variance revealed an effect of the Sentence Type, $F(1, 71) = 184.03$, $p < 0.05$, $\eta^2 = .81$. This shows that the presence of disagreement in the phrases lead to a significant increase in time of processing compared with those without disagreement (difference of 37.6 ms). A relevant finding of the study is the effect of Region, $F(3, 213) = 121.58$, $p < 0.05$, $\eta^2 = 0.63$, which means that significant differences are recorded during processing of the various regions of the phrase. Comparisons of the regions shows that the verb is processed with 44.93 ms slower than the expected value, while the noun and the word following the verb are processed faster than the expected value (-20.56 and -12.27 ms ms).

Statistical comparisons indicate significant differences between the time of processing for all four regions. More important, Region effect is not manifested in the same way in the two types of sentences, $F(3, 213) = 166.68$, $p < 0.05$, $\eta^2 = 0.7$. The processing time is much greater in sentences containing agreement, compared to those containing disagreement.

Table no. 1. Descriptive data from the two groups while reading the short phrases (N = 72)

Sentence type	Region	Young (N=38)			Old (N=35)		
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error
Agreement	Noun	-14.78	15.88	2.58	-32.15	4.27	25.26
	Verb	-5.12	20.99	3.40	-16.38	3.88	22.94
	Plus 1	-26.07	12.40	2.01	-42.41	3.71	21.93
	Last word	10.53	23.36	3.79	-0.83	6.20	36.68
Disagreement	Noun	-9.18	17.69	2.87	-26.14	3.38	20.01
	Verb	96.14	53.48	8.68	105.09	6.77	40.08
	Plus 1	13.17	23.48	3.81	6.20	6.72	39.76
	Last word	2.17	23.70	3.85	-11.76	5.00	29.55

Table no. 2. Descriptive data registrered by the two groups in the covering of the long phrases (N=61)

Sentence type	Region	Young (N=34)			Old (N=27)		
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error
Agreement	Noun	1.33	20.71	3.55	-23.03	30.15	5.80
	Verb	34.00	29.89	5.13	49.56	40.65	7.82
	Plus 1	-32.04	19.63	3.37	-38.56	31.11	5.99
	Last word	22.48	35.24	6.04	6.42	57.33	11.03
Disagreement	Noun	13.98	40.00	6.86	-13.74	30.83	5.93
	Verb	161.84	96.05	16.47	161.40	82.40	15.86
	Plus 1	16.51	33.35	5.72	29.95	40.74	7.84
	Last word	17.51	40.45	6.94	6.27	70.62	13.59

Regarding the involvement of WM capacity in the grammatical number agreement processing, we have not observed any statistically significant effect which might support it's participation in this process. Capacity calculated values for the effect of WM, and its interaction with Sentence Type x Region, are all non-significant, $F < 1$. The experimental effects recorded during correct and incorrect sentences processing seems to be the same for both group of subjects.

Regarding the results for the long version of the task, we had identify an effect of Sentence Type, $F(1.59) = 164.41$, $p < .05$, $\eta^2 = 0.73$, the sentences containing number disagreement were processed more slowly (with 46.69 ms slower) than those that do not include such errors (see Table 2). We had also recorded an statistically significant effect of Region, $F(3, 177) = 96.61$, $p < .05$, $\eta^2 = .62$. The processing time of the verb is slower in average with 101.7 ms than the expected value, while the time needed to processing the *noun* and the *following word* and the *last word* do not differ significantly from the expected value (-5.36, -6.03 and 13.17 ms). The presence of a statistically significant interaction, $F (3, 177) = 60.07$, $p < .05$, $\eta^2 = 0.5$ shows that the effect of region is not manifested equally in both types of sentences, the processing time of different regions of the sentence being longer only in sentences containing number disagreement. We had not found any statistically significant effect which might suggests differences in the implication of WM capacity in syntactical analysis in the two age groups.

Finally we included in the analysis simultaneously the data from the two versions of the task using an analysis of variance with four variables, 2x2x2x2, two between independent variables: Task type (short or long), WM capacity (high or low) and two within independent variables: Sentence Type (agreement or disagreement) and Region (verb or neutral). The result do not indicates the presence of a statistical interaction between the four variables, $F(1, 390) = 1.8$, $p > 0.05$, which confirms the results already discussed.

CONCLUSIONS

The results makes possible to refute the prediction made on the model of general WM capacity (Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996), supporting an alternative explanation derived on a distributed resource model (Waters & Caplan, 1996). The general resources WM model implies a significant difference between age groups due to the fact that the elderly suffer a decline at the level of this cognitive component. Deficits of storage mechanisms and maintenance in an active state of grammatical features of the subject phrase should affect the time need to detect the presence of disagreement (King & Just, 1991, Carpenter, Miyake & Just, 1994). The presence of such an effect would be sustained by a statistical significant of interaction between WM capacity, Task type and Region. The obtained results failed to shown such a second order interaction. More than that, the calculated indicator of the effect size confirms the fact that the lack of significance is not due to a methodological artifact, such as low statistical power of the test.

Lack of interaction between the WM capacity and the variables manipulated in this experiment, support the hypothesis of involvement of a specific resources WM capacity in the mechanism of processing grammatical number agreement. According to this model, the WM capacity measured by Reading Span Task assess only general verbal resources that is not assigned to specific syntactical processing mechanisms (Waters & Caplan, 1996, Caplan & Waters 1999, Waters & Caplan, 2004). Age differences between the WM scores are not associated with differences in processing syntactic tasks.

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