THE RELATIONSHIP BETWEEN WORKING MEMORY AND APRAXIA OF SPEECH

Fernanda Chapchap Martins[1], Karin Zazo Ortiz[2]

Abstract – The present study aimed to verify the relationship between working memory (WM) and apraxia of speech and explored which WM components were involved in the motor planning of speech. A total of 22 patients and 22 healthy adults were studied. These patients were selected according to the following inclusion criteria: a single brain lesion in the left hemisphere, presence of apraxia of speech and sufficient oral comprehension. This study involved assessment of apraxia of speech and evaluation of working memory capacity. The performance of apraxic patients was significantly poorer than that of controls, where this reached statistical significance. The study concluded that participants with apraxia of speech presented a working memory deficit and that this was probably related to the articulatory process of the phonoarticulatory loop. Furthermore, all apraxic patients presented a compromise in working memory.

KEY WORDS: memory, working memory, speech production, motor planning of speech, apraxia, apraxia of speech.

A interrelação entre memória operacional e apraxia de fala

Resumo – O objetivo do presente estudo foi verificar a interrelação entre memória operacional e apraxia verbal e explorar quais os componentes desta memória estariam envolvidos na programação motora da fala. Foram avaliados 22 pacientes apráxicos e 22 controles. Todos os participantes foram submetidos a avaliação da apraxia de fala. Para investigar a memória operacional, foram aplicados o teste de span de dígitos na ordem direta e inversa, um teste de repetição de palavras longas e curtas e o *Rey Auditory Verbal Learning Test*, que investiga, além da alça articulatória, o buffer episódico. O desempenho dos apráxicos em todos os testes de memória foi estatisticamente significante mais baixo que o desempenho dos controles. Concluímos que indivíduos com apraxia apresentam um déficit na memória operacional e que este déficit está mais relacionado ao processo articulatório da alça fonoarticulatória.

PALAVRAS-CHAVE: memória, memória operacional, programação motora da fala, apraxia, apraxia verbal.

The first and most-used definition of working memory (WM) was devised by Allan Baddeley[1] who conceived this as a system enabling temporary storage and manipulation of information required to carry out the complex activities of language processing, learning and reasoning. In 2000, Baddeley[2] made the final additions to the WM model which currently encompasses the central executive, visuo-spatial sketchpad, phonoarticulatory loops, and episodic buffer. The phonoarticulatory loop may be divided into the phonological store and articulatory process. The former involves storage of all material from auditory code while the latter is responsible for temporary holding of this material in the memory allowing subsequent retrieval[3]. Studies have shown that WM span may vary and that factors such as phonemic similarity and word length can influence memory processing[3-5]. It was also investigated the capacity of WM during impeded retention of auditory information by the articulatory loop. Thus, articulatory suppression was introduced preventing sub-vocal rehearsal of the information. The individual had to repeat an irrelevant sound while items to be memorized were presented. Results showed that under articulatory suppression conditions, the similarity effect remained while the word length effect was lost, thereby concluding that the effects of phonemic similarity and word length originate from different components of the

Department of Speech Pathology, Universidade Federal de São Paulo (UNIFESP), São Paulo, SP, Brazil: [1]Speech Therapist, Master in Science; [2]Speech Therapist, PhD, Professor of the Speech Pathology Department, UNIFESP-EPM. Financial Support: FAPESP.

Received 10 March 2009, received in final form 6 July 2009. Accepted 24 July 2009.

Dra. Karin Zazo Ortiz – Rua Cunha 111/73 - 04037-030 São Paulo SP - Brasil. E-mail: karinortiz.fono@epm.br

articulatory loop. The word length effect most likely occurs upon retrieval of speech material promoted by the articulatory process whilst the phonemic similarity effect occurs due to the storage function of speech material facilitated by the phonological store.

Based on these discoveries, some relationships between WM and speech were formed[6] and attempted to link the role of the phonoarticulatory loop of the WM with the complex process of producing speech. It was concluded that the processes of articulatory control and retrieval may be the same as those responsible for control of output of speech and the WM may play at least two roles in the cognitive sequence of producing speech. Firstly, it can provide a storage buffer for output of speech. Each level of the speech sequence, from the mental forming of the idea up to the motor execution of the phonemes, requires storage while processes necessary for translation from one level to the next are being swapped. In other words, the WM offers a short-term store for both intermediate and final articulation levels, prior to effective output of the oral emission. This function is performed by the articulatory loop. A second possibility is the contribution to the cognitive processing involved in producing speech, such as retrieving material from the lexicon, building syntactic structures and integrating these two processes. The component responsible for these two procedures is the central executive. The authors[3,6] also linked these hypotheses with some errors committed in speech. Switching of phonemes which are to appear later in the discourse by earlier phonemes indicates that the whole discourse is stored prior to its execution. Indeed, a system based on phonological information which does not require central processing would be ideal for efficient speech planning and production. According to his hypotheses, it was concluded that the processes responsible for articulatory control and sub-vocal rehearsal are in fact the same. In this case, alterations in speech production would impede the operation of subvocal rehearsal performed by the articulatory loop. This explains the correspondence between natural oral errors and errors committed in memory tests: both arise from speech output mechanisms. These results could be interpreted as suggesting that apraxic individuals, who present a disorder in motor planning of speech, fail in the subvocal rehearsal process and therefore present a working memory deficit.

The present study aimed to verify the inter-relationship between working memory and apraxia of speech, as well as to investigate which components of this memory are involved in the motor programming of speech.

METHOD

This study was carried out within the Speech Therapy Department of the São Paulo Federal University (UNIFESP), Brazil. The study was approved by the Research Ethics Committee of UNIFESP under CEP number 0382/04. Participants signed the Free and Informed Consent Term.

A total of 22 patients were studied. These patients were selected according to the following inclusion criteria: a single brain lesion in the left hemisphere and presence of apraxia of speech.

The sites of lesions were confirmed through a neurological assessment and according to imaging exams. 3 subjects presented brain lesion in the frontal region, 4 in the temporal region, 2 in the parietal region, 3 in the fronto-temporal, 5 parietal-temporal region, and 5 presented lesions in the parietal fronto-temporal region.

Apraxia of speech was diagnosed through a speech pathologist assessment and a specific protocol[7] was employed. Just patients with apraxia of speech were selected for this study.

Oral comprehension was investigated through application of the oral comprehension section of the Boston Diagnostic Aphasia Examination[8]. All individuals presenting oral comprehension to perform the test were included in the study.

Inclusion factors for controls were individual matching for gender, age and schooling with patients studied, along with absence of prior brain lesions or history of previous or current psychiatric or neurologic alterations. The control group was drawn from individuals accompanying patients frequenting the outpatient unit.

A total of 44 individuals of Brazilian nationality who were Brazilian Portuguese speakers were included in the study, comprising 22 apraxics and 22 controls. Each group contained individuals aged between 31 to 80 years, where 13 were male and 9 female. All patients presented apraxia of speech associated to aphasia.

Participants in this investigation underwent tasks assessing working memory and apraxia of speech. Given the objective of this study was to ascertain the influence of WM components on apraxia, memory tests able to assess the functionality of these components were selected, and results compared for individuals with and without apraxia of speech.

The assessment of memory comprised three different tests: the word list repetition, the digit span forward and backward, and the Rey Auditory Verbal Learning Test (RAVLT).

Word list repetition

This test consisted of two and three-syllable words, in order to verify how memory influenced processing of these prompts. The individual was instructed to repeat orally presented lists containing two to six words. Items were presented at one second intervals and the response was oral. Participants had to repeat the list in the correct order, and when failing twice on same-length words and lists the test was concluded. Individual span was determined according to the maximum number of correctly repeated words.

Digit span forward

According to Baddeley and Hitch[1], the DS tests require functioning of WM and more specifically, of the phonological loop.

Digit span backward

This task is deemed more complex than the forward DS, since the information must be processed more times prior to being retrieved, thus placing greater demands on the WM[3,9].

RAVLT

This test consists of 15 words (list A) which were read aloud by the examiner (with a one-second interval per item) five consecutive times. Each presentation was followed by the participant orally repeating as many words as they could recall from memory.

Instructions were repeated before each trial in order to minimize forgetting of the task. Following completion of five trials, a second list containing another 15 words (List B) was read and subsequently repeated by the participant. Immediately after this distracter, the individual was instructed to spontaneously repeat the words recalled from List A, where this procedure was repeated after 20 minutes. This final recall is influenced by the episodic buffer of the WM, as the task calls for long-term memory. It is important to note that these final recalls are not preceded by repeat readings by the examiner. Target words with articulation errors were scored as correct. After delayed recall, the recognition test was applied. The 15 words from list A was pooled with a list of another 15 words which were either phonologically or semantically similar, or presented no similarity to the lists given initially. The examiner read this list of 30 items and the patient was instructed to identify which items belonged to the original list and which were "new". As responses were limited to yes or no, and individuals use the phonoarticulatory retrieval component only to compare the given prompt against that stored.

Regarding learning analyses, the method developed by Ivnik et al.[10] in MOANS (Mayo's Older Americans Normative Studies) was employed, which standardizes scoring as follows:

Total Learning (TL): total learning is established by summing up words recalled over the five trials; Learning Over Trials (LOT): calculated based on TL, adjusted for the first trial, that is, LOT = TL – (5 × number of words obtained in the first trial). The RAVLT assesses a range of cognitive skills such as attention, different components of working memory and learning[10-13].

Statistical analysis

Differences amongst means for continuous data were tested using parametric as well as their corresponding non-parametric tests, which without exception produced similar results. Then, only results from parametric tests shall be presented.

Comparison of performance in immediate digit recall, word group repetition and RAVLT tests between normal and apraxics were tested using the paired Student (t) test as they were individual matched.

A probability (p) of less than 0.05 was considered as statistically significant, except when a potential problem of multiple comparisons was identified. In this event, Bonferroni's correction was employed. All tests were two-tailed. A ninety five per cent Confidence Interval (CI) was calculated for differences amongst means. All analyses were carried out using SPSS (Statistical Package for the Social Sciences) 11.5.1 for Windows.

RESULTS

A total of 44 participants were evaluated: 22 patients with apraxia of speech and 22 healthy volunteers individually matched for gender, age and schooling. 13 were male and 9 female. Concerning schooling, 14 patients had 1 to 4 years of schooling, 5 had studied between 5 and 8 years, and only 3 had greater than or equal to 9 years of formal education.

Performance on cognitive tests

Table shows the performance of the control group and the apraxic group on tests assessing cognitive functions. We should consider the immediate retrieval as the first recall of list A.

Table. Comparison of performance of apraxic individuals and controls on cognitive tests acording to the Paired Student (t) test.

	Apraxics		Controls					
	M	SD	M	SD	95% CI	t	DF	p
Comprehension test	7	2.5	9.4	2	–3.6 to –1.1	–3.9	21	0.001*
Short word span	2.6	0.8	4.5	0.7	–2.3 to –1.4	–8.8	20	<0.001*
Long word span	2.6	0.7	4.3	0.8	–2.2 to –1.2	–7.2	20	<0.001*
Digit span forward	3.3	1.1	5.4	1	–2.7 to –1.5	–7.3	21	<0.001*
Digit span backward	2.3	0.7	4.4	1.2	–2.4 to –1.6	–10.7	21	<0.001*
RAVLT								
Immediate retrieval	3.5	2.8	7.6	3	–5.6 to –2.7	–6.0	20	<0.001*
Delayed retrieval	4.1	2.8	7.6	3.1	–5.1 to –1.9	–4.5	20	<0.001*
Learning	8.6	5.5	15.9	5.6	–10.7 to –3.7	–4.3	20	<0.001*
Recognition	24.1	3.2	28	1.6	–5.0 to –2.4	–5.9	20	<0.001*

M: Mean; SD: Standard deviation; CI: Confidence interval; DF: Degree of freedom; p<0.005 after bonferroni's correction; *statistical significance.

The paired Student t test was used to compare performance of patients with apraxia of speech versus their respective controls. Across all tests applied, performance of apraxics was significantly poorer than that of controls, where this reached statistical significance.

DISCUSSION

The data presented in this study might suggest that individuals with AOS typically have WM impairments. Initially, some considerations could be done concerning lesion data. The lesion site related to the motor programming functions of speech and to WM, in view of the fact that all lesion patients presented apraxia of speech and were assessed for difficulty in carrying out tasks involving the WM.

In the present study, 82% of patients presented lesions in the frontal and/or parietal regions. Patients with apraxia of speech can present lesions in the fronto-parietal circuits, the frontal lobe and vicinity[14-16]. In addition to these studies, there have also been reports on subcortical regions and right hemisphere lesions being associated with apraxia of speech[17,18].

Considering WM, it is not possible to affirm that it is located in any one specific region of the brain, since its processing occurs in a distributed and dynamic manner. Activation of pre-frontal dorsolateral, inferior frontal gyrus and parietal lobe areas of the córtex were also reported. Articulatory retrieval must be situated in the Broca region, left inferior frontal cortex, while the phonological store was more related to the left parietal region[19,20.] It was also found the involvement of the superior cerebellar hemisphere together with the Broca area, during articulatory control and activation of the right inferior cerebellar hemisphere associated to the inferior parietal lobe during storage of phonological material[21]. Results from studies using imaging exams to investigate apraxia of speech, together with studies investigating WM, leads us to the observation that a number of the same areas act in both processes.

The two key areas activated during WM and motor programming of speech, are the inferior frontal and left parietal regions. The praxia circuit which begins in parietal regions and runs toward the frontal region[13] coincides with the site of some WM operations, such as phonological storage and phonoarticulatory retrieval, respectively[20].

Recently, the functional architecture of WM through functional Magnetic Resonance Imaging (fMRI) was investigated and it was observed similar activated regions for WM and speech production[21]. Results indicated that both rehearsal and storage of verbal information activates a network comprising ventrolateral premotor cortex, dorsal premotor cortex, the planum temporal, inferior parietal lobe, the anterior insula and subcortical structures. So, these regions appear to provide resources for the representation and maintenance of information, and which are similar for the production of speech.

In spite of these findings, we are increasingly seeing that the relationship between a given function and a restricted area of the brain is relative. Communication through cortical and subcortical pathways between lobes makes brain processing dynamic, whereby communication of several regions is responsible for a given function, rather than an isolated area.

Performance on cognitive tests

Table shows that the control group presented better performance on all cognitive tasks.

Working memory tests

The word repetition test requires the individual to memorize the items presented auditively and to repeat them in the same order.

Drawing from studies on WM, its components along with length and similarity effects[3,8] the word length effect would be expected in the current study in controls, yet not apraxics. Nevertheless, apraxic patients in fact presented identical mean values (Table) for short and long word repetition, demonstrating the absence of the length effect. In controls however, although the mean span for short words was greater than long words, this difference was not statistically significant (Table 1). Analysis of the words used in the test revealed that the length difference between short and long words was small. Baddeley et al.[1,5] used monosyllabic words and compared their span with five-syllable words. Some authors[23] also found the word length effect in long-term memory tests and considered monosyllabic words as short words. Perhaps the use of words with a greater difference in length could have evidenced the length effect in controls. In fact, phonemic complexity interferes in the length effect[24,25], in a way that the greater phonemic complexity of the material, the more limited the information retrieval process becomes. However, it is also known greater phonemic complexity leads to more errors being committed by apraxic individuals.

The results obtained in the present study (Table) show a statistically significant difference between the performance of controls and apraxics over all memory tests: long and short word repetition and forward and reverse digit span.

Given that the word repetition tests present material having a greater semantic load than that of digits, we would expect a better performance of participants with deficit in the phonoarticulatory loop during word repetition than during digit span tests, such as previously observed[26]. It was compared verbal short-term memory with pleasant and neutral words and concluded that pleasantness have a facilitation effect on both immediate serial recall and immediate serial recognition. But this finding does not exclude the participation of phonoarticulatory loop in words serial recall, it just shows that semantic load helps during memorizing. The involvement of the phonoarticulatory loop is evident in both the DS and word repetition. Belleville et al.[27]conducted a study on a patient presenting WM alteration, more specifically in the phonoarticulatory component. Memory tasks were applied using semantic and phological material. The patient presented a significant deficit in memorizing the phonological information and, although memorizing of semantic information was superior, the individual did not use phonological characteristics of the words to assist in recall. Thus, the patient's performance with regard to the semantic material could have been improved if the subject had employed the phonological characteristics as an additional cue for memory, by means of the phonoarticulatory loop. In view of this, although the digit items used in the current study present purer phonologic information than the words, which for their part carry more significant semantic load, the phonoarticulatory loop is in fact activated in the memorizing of both stimuli.

The poor performance of apraxics on both the DS and word repetition appears to indicate that these individuals present a deficit in WM. Some studies[8,23] found a significant reduction in length presented by apraxics and an absence of word length effect, akin to results found in healthy adults under articulatory suppression conditions. And observed that the alteration in material retrieval found in apraxics involves the articulatory planning stage of speech production.

The reduced capacity of WM in apraxics must be related to the loss of subvocal rehearsal capacity in such individuals. This pertains not to the motor aspect of subvocalization, but instead its "mental" processing, independently of any motor compromise. If reduced span were related to motor rehearsal, normal individuals with articulatory suppression would not present the same results as apraxics, since they have no motor compromise[8]. It can therefore be concluded that WM capacity depends on speed of mental processing of subvocalization. It was also reported[28] that the information retrieval process performed by the phonoarticulatory loop takes place during the same stage as articulatory planning. However, this may suggest that this stage, compromised in apraxics, also implies an alteration in WM.

Gathercole and Baddeley[6] attempted to link the role of the phonoarticulatory loop of WM with the complex process of producing speech. Following a bibliographical review, they concluded that the processes of articulatory control and retrieval may be the same as those responsible for control of output of speech. So, deficits in oral production would interfere in the process of subvocal rehearsal performed by the articulatory loop. The authors suggested that subvocal retention of information in this loop involves the same processes as used in motor programming of speech.

Investigations about which components of WM influence apraxia are able to confirm that the main system involved is the phonoarticulatory system, more specifically its articulatory process. The role played by the phonologic store and episodic buffer are hypothesized based on the results obtained in the RAVLT test applied in this study.

Results shown in Table demonstrate that although apraxics presented capacity to learn, this learning was not as successful as the learning experienced by the normal individuals.

The immediate recall task, the first to elicit recall of list A, is considered similar to the word repetition task discussed earlier.

Delayed recall can reveal, besides the phonoarticulatory loop, episodic buffer involvement. During delayed recall, the individual uses both the phonoarticulatory loop as well as the episodic buffer to retrieve the material stored in long-term memory.

In fact, during learning, the phonoarticulatory loop appears to promote the entry of more permanent structures which are stored in a mental lexicon. Then, the true function of this component is the learning of new words. This last task occurs secondary to learning[28]. The learning of familiar words requires the participation of the phonoarticulatory loop, although it is mediated by the use of preexisting knowledge. However, it was also suggested report that this involvement of long-term memory also occurs in word repetition[29].

Thus, in this test the individual uses prior knowledge stored in long-term memory to facilitate word memorization and consequently aid learning. The viability of this connection between working memory and long-term memory is provided for by the episodic buffer[2]. The poor performance of apraxics in delayed recall may suggest that, apart from functional compromise of the phonoarticulatory loop outlined earlier, it is pertinent to investigate whether the episodic buffer is not also compromised.

This finding can be best discussed using results obtained in the recognition task. Poor performance was again found in the apraxic group compared to controls, where this reached statistical significance. However, it is noteworthy that the phonoarticulatory loop is not in such demand for the recognition task as it is in other recalls in the RAVLT because the stimulus is provided and its function is only to compare to the stimuli stored in the episodic buffer, and not to retrieve it.

In relation to apraxics, comparison of the mean number of words retrieved in delayed recall, with the mean number of words recognized (Table 1), we may conclude that these individuals presented better performance in recognition, thus demonstrating that the episodic buffer is not influencing apraxia of speech.

This may suggest that the poor overall performance on the RAVLT is largely due to compromise of the phonoarticulatory loop responsible for rehearsal, and that this system is the main component involved in apraxia of speech.

Based on our study findings, we have verified that apraxics present reduced WM capacity suggestive of phonoarticulatory loop dysfunction. The data presented might suggest that individuals with AOS typically have WM impairments.

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