The role of executive functions in long-term memory: Case report

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Abstract

The role of executive functions in long-term memory has been studied. We describe a single-case study, consisting of a 45-year-old male patient, hospitalized for right frontal stroke. After the stroke, the patient had memory alterations in everyday activities. However, performance in short-term memory tests was not significantly altered. Long-term memory assessments included pre- and post- stroke episodic, semantic, and procedural memories. Specific skills involved in the acquisition of new learning (auditory-verbal and visual reproduction) were also evaluated, as well as executive functions. The results evidence that short-term memory was not affected. Regarding long-term memory, significant differences were observed between pre- and post-stroke knowledge, the former being better preserved, which reveals anterograde amnesia. Pre-stroke long-term memory was also affected, but only with respect to episodic knowledge, with semantic and procedural memories preserved (episodic retrograde amnesia). Executive functions were altered as well, which could have been a factor affecting the acquisition and consolidation of new learning, despite the fact that short-term memory was not significantly altered. Therefore, executive functions might be a determinant factor in the acquisition of new learning, regardless of short-term memory processes, at least partially. According to the results of the present study, alterations in these functions might lead to anterograde amnesia. This entails the need to evaluate executive functions as an intrinsic part of memory evaluation.

Keywords: anterograde amnesia, executive functions, long-term memory

Introduction

The involvement of the frontal lobes in memory processes is widely accepted, since the frontal cortex has a fundamental role in the organization, search, selection, and verification of the stored memory. Thus, although the frontal lobe is not involved in storage processes per se, it mediates memory strategic recovery, and participates in monitoring and verification processes (Shimamura, 2002). Frontal damage may affect memory in different ways: Usually, it affects short-term memory, metamemory, prospective memory and/or promotes the so-called amnesia of the source (Tirapu-Ustárroz & Muñoz-Céspedes, 2005).

In general, memory impairments as a result of frontal damage are considered to be motivated by a disorder in executive functions (Parkin, 2001). This perspective is the consolidation of the proposals of Luria (1966) about frontal functions, which were followed by Norman and Shallice (1986) until today (v. g., Álvarez & Emory, 2006; Baddeley, 2012; D'Esposito, 2007; Diamond, 2013; Miyake et al., 2000).

Conceptually, short-term memory is related to working memory (Baddeley, 1986). This kind of memory, according to the latest update of the model (Baddeley, 2000), includes different components. The phonological loop refers to a control process based on articulatory review, which is essential for the temporary maintenance of verbal material. On the other hand, the visuospatial sketchpad works in a similar way to the phonological loop, except for the fact that this system is involved in visual images. The episodic buffer allows the information from the phonological loop and the visuospatial sketchpad can be stored simultaneously and temporarily. The Central Executive System is considered a general attention system to control different processes, and it is involved in strategy selection, being this process activated when a situation is identified as novel or a nonroutine situation. Central Executive System is responsible for executive processes of anticipation, selection of objectives, planning, and monitoring, among other processes. Thus, the Central Executive System is a system controlling executive functions (which depend on the frontal lobes), with the particularity that this system does not store information. The Central Executive System is therefore responsible, at least, for the following interconnected processes (Tirapu-Ustárroz & Muñoz-Céspedes, 2005): Coding and maintenance of information when the phonological loop and/or the visuospatial sketchpad are saturated; dual execution, that is, the ability to simultaneously work with loop and sketchpad; inhibition, as the ability to inhibit irrelevant stimuli; cognitive alternation, which includes processes of maintenance, inhibition, and updating of cognitive criteria, as well as cognitive flexibility.

These components of working memory, according to Baddeley's model (2000), are functionally independent, that is, in the case of frontal damage, they may be selectively altered. In this sense, there is evidence of patients with acquired brain damage in frontal areas showing independence between different components.

Patients with specific and selective alterations of one of these components have been described. One example is the case of PV, a patient with selective damage in the phonological store of auditory working memory (Vallar & Baddeley, 1984), as well as the cases of BO and RL, both with involvement of the articulatory review processes (Waters et al., 1991). There are also cases of patients with impairment in the visuospatial sketchpad (v. g., Owen et al., 1996), as well as patients with specific alteration of the Central Executive System (v. g., Allain et al., 2001).

According to this background, the objective of this work is to evaluate post-stroke short-term memory, and executive functions, as well as long-term memory of pre- and post-stroke knowledge, and how the possible alterations affect the acquisition of new learning.

MATERIALS AND METHOD

Patient

A 45-years old male was evaluated during the acute phase of a stroke. The patient completed secondary studies and worked as a construction worker. He was living with his wife and children. He currently lives with his wife, who is them caregiver.

Background and Medical History

May 2008: MGF was admitted to the Infanta Elena Hospital (Huelva, Spain) with a decreased level of consciousness (a score of 7 in the Glasgow Coma Scale). The patient symptoms were dizziness, sweating, vomiting, headache, dysarthria and reduced muscle tone.

Then the patient was moved to the Virgen del Rocío Hospital, in Seville (Spain). The patient needed orotracheal intubation, and a cranial tomography was performed, showing active bleeding and dilated ventricular system. The patient was admitted to the Neurosurgical Intensive Care Unit in this hospital, and another cranial tomography was performed, which revealed a right frontal hematoma. Neuroimaging also revealed decreased ventricular dilation and decreased intraventricular bleeding in the lateral ventricles and the third ventricle.

During the Intensive Care Unit stay, the patient suffered acute obstructive hydrocephalus, which was treated with external ventricular drainage. After this intervention, drainage was removed without signs of hydrocephalus or increased intracranial pressure.

The main clinical judgment was moderate-severe primary intraventricular hemorrhage (Graeb score: 7), absence of aneurysm according to a posterior arteriography, and possible cardiac arteriovenous malformation according to unclear images in the left ventricular atrium.

The progress of the patient in Intensive Care Unit was favorable and then was transferred to the neurosurgery unit. In this unit, the patient was conscious but disoriented, with agitation without neurological focus.

June 2008: Computed tomography showed intraventricular hemorrhage with ventricular dilatation and active hydrocephalus. It is also observed left lacunar infarction. Magnetic resonance imaging showed the previous hematic signals remain, without other alterations. Cerebral arteriography no evidence of aneurysm or malformation that justifies hemorrhagic symptoms. Vascularization at the level of the posteromedial choroidal artery, without early venous drainage, which could suggest a semi-thrombosed arteriovenous malformation. From this moment the patient goes to ambulatory state, that is, he goes home.

2011: A cranial Magnetic resonance imaging revealed alterations compatible with cortico-subcortical atrophy, with ischemic infarction in the right frontal region. No further vascular lesions are observed in the patient. The clinical judgment reported in this stage was moderate-severe primary intraventricular hemorrhage with negative arteriography, so there is suspicion of spontaneously thrombosed arteriovenous malformation.

2018: The patient presents ventricular dilation of the III and lateral ventricles, as revealed by Magnetic resonance imaging.

2021: The family contacted with the authors of this work requesting a neuropsychological evaluation. The patient’s main symptom is memory alterations. The patient needs help with and supervision for most activities of daily life (transport, cooking, leisure, shopping, cleaning). However, the hygiene and personal care activities are carried out without help.

2022: A neuropsychological evaluation was performed.

Procedure

From the first session, we explained to the patient and his wife all aspects and contents of the evaluation process, as well as the dates and times scheduled for each session. An informed consent was provided to the patient to voluntarily be signed. All sessions took place in the patient's own home and had a maximum duration between 20 and 30 minutes. A long interview with the family is conducted; Information is obtained about the patient's premorbid memory, mainly of the procedural type. In addition, information is obtained about the patient's past in order to evaluate premorbid episodic memory.

On the other hand, the non-standard tests that were going to be used with the patient were applied to 30 people of the same age and educational level (control group).

Instruments

Initially, cognitive impairment was ruled out using The Mini-Examination Cognitive (Lobo et al., 1979).

Short-term memory: Digit memory in direct order (Wescher et al., 1988), and Corsi test in direct order (Corsi, 1972); Word-list test. Digit memory in Reverse Order (Wescheler et al., 1987) and Corsi test in Reverse Order (Corsi, 1972).

Long-term memory: Evaluation was performed using ad hoc instruments for the patient. For episodic memory evaluation, a questionnaire was specifically elaborated with the help of his family, to be completed by the patient. This questionnaire included life events of the patient both before and after the brain injury. For semantic memory evaluation, a questionnaire was applied with general questions referring to both stages, before and after brain injury. A battery showing famous character images was also used, via power point slides, including well-known characters specifically of the premorbid or post-morbid stage.

For the evaluation of premorbid procedural memory, the family interview is used.

Tower of Hanoi is used for the evaluation of postmorbid procedural memory. This task was carried out for 13 consecutive days, always at the same time. During these sessions, the correct resolution of the Tower of Hanoi was shown, and then the patient was asked to execute this task.

New Learning Acquisition: Auditory-Verbal Learning Test (Rey, 1964), Visual Reproduction Test (Weschler, 1988).

Executive functions: Aleatory Number Generation (Towse & Neil, 1998); Hayling's test (Pérez et al., 2016); Five-digit test (Sedó, 2007); Zoo map test (Vargas et al., 2009); Wisconsin Card Sorting Test (Grant & Berg, 2001); Stroop Test (Golden, 2020).

In addition, the following instruments were applied:

Attention and Processing Speed: Number Key (WAIS subtest) (Weschler et al., 1988); the Letter Cancellation Test (Coners, 1995); the Trail Making Test (Reitan, 1992).

Visual perception: the Clock Drawing Test, from Luria (Ardila, 1999); the Interference Recognition Test (Poppelreuter, 1990); the Drawing Copy Test (Strub & Black, 1991).

Language: Spontaneous speech (Peña-Casanova et al., 1997); Semantic verbal fluency (García et al., 2012); Phonetic verbal fluency (García et al., 2012); the Token Test (Renzi & Faglioni, 1978); Verbal repetition: the Boston Naming Test (Kaplan et al., 2001).

Number processing and calculation: The Numerical Processing and Calculation Evaluation Battery (shortened version) (Salguero & Alameda, 2015).

Data analysis

Two complementary procedures were used for data analysis. To analyze the results of the specific scales of each test. And for non-standardized tests, our patient's performance was compared with that of the control group used a statistical test of difference of proportions (Moore & McCabe, 2001; Price, 2005)..

RESULTS

According to the results, general cognitive functioning maybe considered within normality (27/30 in Mini-Examination Cognitive).

Table 1 shows the results of neuropsychological assessment. Our results reveal that short-term memory was preserved. The scores of the Digit direct order, Corsi direct order, and Word List tests corresponded to normal values. Likewise, scores of the Reverse Order Digit and Reverse Order Corsi tests were within normal values. Therefore, this would allow us to consider that the articulatory loop and the visuospatial sketchpad are preserved.

Long-term memory was evaluated from knowlwdges before and after the stroke, in order to differentiate possible alterations in retrograde and anterograde memory, respectively. Pre-stroke information of episodic nature was significantly better preserved than that acquired after stroke ($Z = 2.15$; $p = .031$). However, it is observed that this type of memory is altered when compared with healthy subjects ($Z=7.94$; $p=.000$). Likewise, there were significant differences between pre- and post-stroke semantic memory. In particular, premorbid semantic knowledge was significantly better preserved than that after the stroke, according to the results of both memory questionnaires ($Z = 3.22$; $p = .001$) and the famous people recognition test ($Z = 3.16$; $p = .001$).

Table 1

The long-term memory tests results are consistent with the obtained in the new learning assessment tests. The patient showed auditory-verbal learning alterations, especially evocation difficulties, considering that the recognition results were significantly better than in the case of recall (Z = -4.16; p = .0003). Regarding visuospatial learning, the results show that this process was altered, including both immediate and delayed visuospatial memory. Therefore, it can be concluded that MGF has severe auditory-verbal and visuospatial learning difficulties. On the other hand, procedural learning was also affected in this patient after injury. In the different learning sessions dedicated to solving the Tower of Hanoi (13 sessions in total), the patient was unable to learn the procedure for solving the test. Throughout the sessions, the patient was able to reduce the execution time, although with help. After 13 sessions, the patient could not execute the task without help.

Therefore, the results of the long-term memory tests along with the learning tests are convergent, in the sense that they reveal anterograde amnesia, which affects the acquisition and consolidation of new knowledge from the stroke.

In addition, the results of the executive function tests revealed that these processes were altered. Inhibitory processes were apparently altered according to the scores obtained in the Aleatory Number Generation test, especially the verbal inhibition processes (Hayling test, part B) and those evaluated in the Five-Digit Task (part 3). The results revealed deficits in the inhibition of automatic responses. These results were confirmed with the Stroop test, which showed that the patient is unable to inhibit automatic responses. The cognitive flexibility processes also seemed to be severely affected, as shown by the results obtained in the Five Digits Task (part 4), in which the difficulties of the patient in changing the previous judgement during the task were evident. This limitation was also observed when using the Wisconsin Card Sorting Test, in which the patient was not able to detect the correct criterion and therefore no category could be completed. Regarding the planning processes, which were evaluated using the Zoo Map test, the results revealed that these were also affected because the patient could not successfully perform any of the test versions. The results of the different tests of evaluation of the functions are convergent in the sense that they show that the executive functions of MGF are altered after the stroke.

The following processes, which were evaluated complementary, were preserved: visual perception, language, and numerical processing and calculation. However, we have observed an alteration in attention and processing speed.

In summary, after the stroke, the patient retains the short-term memory, as well as premorbid semantic and procedural long-term memory but premorbid episodic memory is impaired. The long-term memory episodic, semantic and procedural for knowledges following the stroke was affected, possibly due to the difficulties in the acquisition of new learning as a consequence of the alteration of executive functions (table 2).

Table 2

DISCUSSION

In this work, different cognitive processes were evaluated in a patient (MGF) to determine the functional effects of frontal brain damage. The results show that short-term memory is preserved, but the patient presents alterations in the acquisition of new learning and executive functions, i.e., the patient shows anterograde amnesia. In addition, the patient presents retrograde amnesia but that exclusively affects his premorbid episodic memory.

These results can be explained in terms of the Baddeley working memory model (Baddeley, 2000). The patient of the present study maintains both the articulatory loop and the visuospatial sketchpad. However, the Central Executive System, as evaluated via executive functions tests, seems to be altered. Thus, different components of the Central Executive System were shown to be affected, such as inhibitory processes, cognitive flexibility, and planning. These limitations are critical and prevent the acquisition and consolidation of new learning after lesion, including verbal and visuospatial information, and procedural learning. These limitations were confirmed by the results obtained in the long-term memory evaluation. Premorbid semantic and procedural memory is preserved in this patient, and premorbid episodic memory is alteraded; the deficits in long-term memory were evident after injury, affecting episodic, semantic, and procedural memory. Therefore, our results are in line with the assumptions of the Baddeley model (Baddeley, 2000), that is, the different components of working memory are susceptible to be selectively and independently damaged after frontal damage. This is consistent with some studies described in the literature that include specific alterations in the Central Executive System, but with the articulatory loop and the visuospatial sketchpad being preserved (v. g., Allain et al., 2001), that is short term memory. Thus, our results confirm the double dissociation between the "slave" components of the model and the Central Executive System. Moreover, unlike the results in our patient, other studies have described alterations only in the articulatory loop (v. g., Waters et al., 1991) or the visuospatial sketchpad (v. g., Owen et al., 1996) after frontal damage.

Therefore, our patient presents episodic retrograde amnesia and anterograde amnesia that affects all types of knowledge, despite the fact that short-term memory tests are within normality. To explain these results, it is necessary to consider that these alterations in the patient's long-term memory are due to the important executive deficit that he presents. This is consistent with previous studies that evidence the fundamental role of executive functions in memory functioning (v. g., Álvarez & Emory, 2006; Baddeley, 2012; D'Esposito, 2007; Diamond, 2013; Luria, 1966; Miyake et al., 2000; Parkin, 2021).

Thus, it can be concluded that working memory is not a unitary construct, and some of its components can be selectively altered. The deterioration of the Central Executive System could cause a significant inability to acquire and/or consolidate new learning, which results in anterograde amnesia, even though the articulatory loop and the visuospatial sketchpad are preserved. On the other hand, preserving short-term memory does not seem to rule out possible anterograde amnesia. This possibility would confirm that the articulatory loop and the visuospatial sketchpad are “slave” components of executive functions. This involve that if these components are altered, even though the subcomponents are conserved, the acquisition of new learning is prevented.

The overall results of this study suggest the need to evaluate executive functions, or Central Executive System, in Baddeley´s terminology (2000), when evaluating different memory processes after brain damage. Thus, executive functions evaluation should be considered an integral part of memory evaluation.

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Table1. Neuropsycological assessment results according to the different domains of each function.

Domain of function	Scores	Standardized range
Memory		
Short-term memory ◦ Digit Direct Order ◦ Corsi Direct Order ◦ Word list test ◦ Reverse Order Digit ◦ Reverse Order Corsi	 7 6 6/15 4 5	 Average Average Average Average Average
Long term Memory		
Premorbid Knowledge ◦ Episodic ◦ Semantic ○ Questionnaire ○ Famous characters ○ Total Procedural Premorbid Posmorbid (Hanoi Tower) ○ Day 1 with help ○ Day 13 with help ○ Day 13 without help	 11/21 (52.3%) 9/11 (81%) 12/15 (80%) 21/26 (80.7%) 3'30'' 2' He doesn't respond	 Impaired (Z=7,94; p=.00) Average (Z=1.02; p=.30) Average (Z=1.32; p=.18) Average (Z=1.67; p=.09) Preserved (according interview with family) Impaired Impaired Impaired
New learning acquisition		
Auditory-verbal Test ◦ Inmediate ◦ Final Acquisition ◦ Delayed ◦ Recognition: ○ Success ○ Omissions ○ Inclusion	 10 7 0 11 1 7	 Average Impaired Impaired Impaired
Visual Reproduction Test ◦ Inmediate ◦ Delayed	 0/9 0	 Impaired Impaired
Executive functions		
Aleatory Number Generation	5 digits	Impaired
Hayling Test ◦ Part A (verbal initiation) ◦ Part B (verbal inhibition)	 4 points 15 points	 Impaired Impaired
Five Digits Test ◦ Part 1 (reading)	 50	

◦ Part 2 (counting) ◦ Part 3 (election) ◦ Part 4 (alternation) Inhibition Flexibility	50 8 32 -42 -18	 Impaired Impaired
Zoo Map Test	Not performance	Impaired
Wisconsin Cards Sorting Test	0 categories	Impaired
Stroop Test ◦ Interference	 -14,7	 Impaired
Attention and processing speed		
Number key	PD: 29; percentile 9	Impaired
Letter cancellation test	0 error	Average
Trail Making Test	Without help: not performance With help: 5 minutes	Impaired Impaired
Visual Perception		
Clocks of Luria	3/4	Average
Interference Recognition Test	10/10	Average
Drawing Copy Test	12/12	Average
Language		
Spontaneous speech		Average
Semantic verbal fluency	17	Average
Phonetic verbal fluency	28	Low Average
Token Test	34/36	Average
Repetition	10	Average
Boston Denomination Test	26	Average
Number processing and calculation		
Numerical understanding	18/18	Average
Numerical recoding	16/16	Average
Arithmetic signs	5/6	Average
Calculation and numerical reasoning	40/40	Average
Numerical lexical knowledge	8/8	Average
Numerical sequence	20/20	Average

Table 2. Summary of the evaluation of the patient's long-term memory.

Memory	Premorbid	Posmorbid
Semantic	Preserved	Altered
Episodic	Altered	Altered
Procedural	Preserved	Altered