BEHAVIOURAL RESEARCH ON HUMAN WORKING MEMORY: MIXING QUALITATIVE AND QUANTITATIVE METHODS

INVESTIGACIÓN CONDUCTUAL SOBRE MEMORIA DE TRABAJO: INTEGRANDO MÉTODOS CUALITATIVOS Y CUANTITATIVOS

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ABSTRACT

The long lasting opposition between qualitative and quantitative methods for studying behaviour has been overridden by interdisciplinary work in which methods can be combined to approach animal and human behaviour, thus contributing to drawing rigorous and useful conclusions.

We show an example of this by combining a quasi-experimental design and descriptive methods to study working memory for the resolution of a spatial problem task (the Tower of Hanoi) in a neuropsychiatric hospital inpatient with amnesia and executive deficits.

Results from the quasi-experiment showed that the patient acquired strategies to solve the task with a high level of efficiency ($F_{3/35} = 7, 19, p < .01$). Qualitatively speaking, the patient developed more than one strategy to solve the problem, which indicates the presence of learning based on working memory. In the light of these findings, we discuss issues of mixed methods research and suggest the importance of developing mixed methods to study behaviour.

Key words: Behavioural research, mixed methods, Tower of Hanoi, working memory

RESUMEN

La oposición duradera entre métodos cualitativos y cuantitativos para estudiar el comportamiento ha sido anulada por el trabajo interdisciplinario en que los métodos pueden combinarse para enfocar el comportamiento humano y animal, contribuyendo así a obtener conclusiones útiles y rigurosas.

Se presenta una muestra, combinando métodos descriptivos y un diseño cuasiexperimental para estudiar la memoria de trabajo en la resolución de una tarea de problema espacial (la Torre de Hanoi), en un paciente internado en un hospital neuropsiquiátrico con amnesia y déficit ejecutivo.

Resultados del cuasiexperimento demostraron que el paciente adquirió estrategias para resolver la tarea con un alto nivel de eficiencia (F3/35 = 7, 19, p < .01). Cualitativamente el paciente desarrolló más de una estrategia para resolver el problema, lo cual indica la presencia de aprendizaje basado en memoria de trabajo. A la luz de estos resultados, se discuten métodos de investigación mixtos y se sugiere la importancia de desarrollar métodos mixtos para estudiar el comportamiento.

Palabras clave: Investigación conductual, métodos mixtos, Torre de Hanoi, memoria de trabajo.

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Introduction

What benefits can we obtain from mixing different methods in the study of behaviour? Considering that behaviour is the term which designates the actions which organisms develop in relation with their surroundings (Piaget, 1978), we might suppose that its relational complexity would deserve the best approaches we have as researchers.

Mixed methods are defined as «the collection or analysis of both quantitative and qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research» (Hanson, Creswell, Plano Clark, Petska & Creswell, 2005). The importance of combined methodologies to understand a given problem has been noted by Gersten, Baker and Lloyd (2000) in an article about effective research in special education. According to the authors, qualitative studies have considerable importance in educational research but are not enough to study intervention effectiveness, and for that reason we need to develop experimental designs: «Although qualitative studies can provide valuable insights into the process of change and enhance understanding on facets of teaching and learning, experimental group designs remain the most powerful method available for assessing intervention effectiveness» (Gersten et al., 2000).

We propose that in many cases it might be useful to develop researches with a mixed, flexible methodology in which we can use qualitative and quantitative methods in an original combination according to research objectives and problems. This work focuses on mixing methods in the study of working memory. We show one example with humans in which the combination of methods provides a more complete overview about behaviour than if we only used one or another method alone.

Understanding Memory for Learning

Since our study is focused on memory we devote this section to briefly describe it. Memory is a huge construct which includes a series of approaches, from behaviour and social systems to molecular and cellular analysis, and is studied by using a variety of methods. From the point of view of behaviour, memory can be seen at least in these stages of processing (Lezak, 1995): 1) Registration or sensory memory, 2) Immediate memory or primary memory, which includes short-term memory and working memory and 3) Long-term memory or secondary memory.

Human studies add at least two new categories: *declarative* and *non-declarative* memory. Declarative memory consists of factual and semantic memories, while non-declarative memory is an umbrella concept which designates any memory which does not need a conscious effort to be remembered, e.g. procedures, habits, priming effects and others (Gazzaniga, Ivry & Mangun, 2009; Lezak, 1995; Rosenzweig & Leiman, 1995; Squire, 2007).

In the context of neuropsychological studies the term anterograde amnesia refers to the inability to form new declarative memories after a lesion, and retrograde amnesia refers to the inability to remember information formed before a cerebral lesion; this inability can be temporally limited or affect a long period of time, depending on the injury (Squire & Bayley, 2007).

There are at least two reasons to study memory: for diagnostic or prognostic objectives. When related to prognosis, studies focus on memory for learning or, as Schacter, Norman and Koutstaal (1998) and Schacter and Addis (2007) has called it, *constructive memory*, which is not memory per se but a set of dynamic processes of memory for action. The same authors consider that constructive memory consists of information from the past which is useful for the future, and therefore it is not a fixed part of the past which is remembered but rather that an adaptive process takes place by means of which fragments of stored information are taken and reloaded in order to make it useful for new situations. The following study uses the word *memory* in the sense explained in the second place.

To explore constructive working memory it is possible to develop qualitative methods combined with experimental designs with the subject (or groups) as their own control. The subjects may be selected intentionally because of their peculiarities, e.g. a specific neurological and behavioural condition may be a key factor in a study and that may determine the selection of a given subject to work with. In this case we develop a quasi-experimental design in a case-study framework. We can call this procedure intra-subject design or single-subject design (Salkind, 1999) in which

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the individual works as their own control and receives the treatment. What we consider the «unit of analysis» in this research design is not the subject per se but each trial in the subject's performance.

Methodology

Design

We developed a case-study based on a quasi-experimental design taking the subject (an inpatient in a neuropsychiatric hospital) as their own control (paired measures: before - after) to test our hypothesis that it would be possible for a patient with anterograde amnesia and executive problems to learn new information and use it to solve a problem.

Although it has been proven that amnesic patients can learn non-declarative skills (see Bayley & Squire, 2002; Corkin, 1968; Scoville & Milner, 1957; for illustrative examples), what is not obvious is that they can learn to solve a problem because solving a problem involves working memory, which requires not only non-declarative skills but also declarative contents and executive functions. A patient with amnesia and frontal deficits would probably not learn to solve a problem by themselves. However, if it is possible to help them by developing a new learning context, some kind of improvement of their performance might be expected. This enhancement is what we are going to prove. This paper aims at proving that this enhancement is possible.

Participant

The case was an Argentinean male inpatient of 51 years of age with Wernicke-Korsakoff's disease due to chronic alcohol intake, with elementary education completed, medium to high level of vocabulary (in accordance with what can be expected from a person who has only finished their primary education), right-handed and with neither motor nor sensory problems. He showed anterograde and retrograde memory deficits and confabulation but a preserved non-declarative (procedural) memory. His daily medication was Diazepam 5 mg and Haloperidol 5 mg. His simple attention was not altered as measured by the Wechsler Adult Intelligence Test (WAIS-III) Digit Span (Wechsler, 2002) but he had problems with mental tracking measured by WAIS-III Inverse Digit Span (Wechsler, 2002) and with executive functions measured by the Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay & Curtiss, 2001).

Korsakoff's syndrome is a neurological condition due to Thiamine (Vitamin B1) deficits produced by chronic alcohol consumption, although it has also been described in other conditions of severe malnutrition such as hyperemesis gravidarum in pregnant women. As a consequence people develop a dramatic amnesia which prevents them from forming new memories; therefore they are not able to learn new information. Furthermore Korsakoff's patients show working memory deficits related to a frontal lobe dysfunction (Oosterman, de Goede, Wester, van Zandvoort & Kessels, 2011).

Material and Procedure

We used a commercial version of the Tower of Hanoi (TOH, by Ruibal S.R.L), a test which involves the function of planning (Anderson & Douglass, 2001; Lezak, 1995; Newman, Carpenter, Varma & Just, 2003; Riccio, Wolfe, Romine, Davis & Sullivan, 2004; Spreen & Strauss, 1998). The instrument is illustrated in Figure 1. The tower has three axes, A, B and C, and the task consisted in moving the discs or rings (which usually are four or five) from axis A to axis C, keeping the same arrangement in which they are piled: from the biggest –at the bottom of the pile– to the smallest –at the top of the pile–. Two are the main rules: (a) not to pile a bigger disc on a smaller one and (b) to move only one disc at a time.

Procedure was as follows: 1.- Pre-test: single application of the TOH with 5 rings; 2.- Treatment: 11 sessions along three months in which we developed prompting to help the patient to solve the Tower by a very gradual increase of the number of discs (from 2 to 5); and 3.- Post-test: double application of the TOH two months after having finished the treatment sessions: 1) learned direction (practised execution: similar to pretest and treatment) and 2) inverse direction (non-practised execution). Number of trials per level of complexity was not identical for the four levels (see below) because the criteria for the patient to advance to the following level of complexity was not a fixed number of trials but to sucessfully outpass the previous level.

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Figure 1. The patient working with the Tower of Hanoi

The treatment followed the theoretical framework of dynamic assessment (Bacigalupe, Lahitte & Tujague, 2011).

The quantitative variables we tested were: movements (the number of movements the subject performed to solve the tower) and complexity (the number of rings with which the patient was working in a given trial).

There were four levels of complexity according to the number of rings used in the problem, from two (the simplest) to five (the most complex condition).

The quantity of movements per level of complexity in a given trial gave rise to the level of efficiency, which was the proportional increase of movements in relation to the increase of levels of complexity. The level of efficiency could range from low (the increase of movements unproportionally surpassed the increase in the level of complexity) to high (the increase of movements was proportional to the increase in the level of complexity).

The qualitative variables we analyzed were: strategy (the sequence of movements the subject used to solve the tower, including the characteristic working memory features such as online maintenance of items –in this case items were, for example, previous movements, objectives and sub-objectives– and manipulation of them) and progression (the level of complexity the subject reached through the treatment).

To assess transference of learning we tested the subject with Raven's Progressive Matrices Test (Paidos, 1993; Spreen & Straus, 1998) both at the pre-test and the post-test stages.

Data analysis

Complete performances were analysed by the One-way analysis of variance (ANOVA) single factor. Data were transformed into normal distribution using the square-root function. We analyse the minimun significant difference (Tuckey HSD).Qualitative results were retrieved from observational methods of *in vivo* and videotaped sessions.

We obtained the Raven's Progressive Matrices score following the normative data shown in Table 5-13. Standard Progressive Matrices: Smoothed Summary Norms for Adults in the United States of America (Spreen & Strauss, 1998). Besides we use ANOVA to analyse statistical differences between the first and the second application of the test.

Ethic Note

Ethical norms were followed on conducting the research (Universal Declaration on Bioethics and Human Rights, 33rd UNESCO's General Conference, 2005; Helsinki Declaration, 18th World Medical Assembly, Finland, 1964 and its amendments). Inpatient verbal informed consent was obtained and institutional authorization was granted as well.

Results

Quantitative Analysis: Efficiency

Patient's performance with the Tower of Hanoi complete trials showed significant differences ($F_{3/35} = 7, 19$, $p < .01$). It was the two-ring level which showed the difference (Tuckey HDS, Homogeneous Subsets) with respect to the three, four and five-ring levels (Table 1).

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Table 1
Multiple Comparisons Tukey HSD

	(I) complexity	(J) complexity	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	two-ring level	three-ring level	-.52617*	.11962	.001
		four-ring level	-.47423*	.12804	.004
		five-ring level	-.39652*	.11598	.008
	three-ring level	two-ring level	.52617*	.11962	.001
		four-ring level	.05194	.11496	.969
		five-ring level	.12965	.10135	.582
	four-ring level	two-ring level	.47423*	.12804	.004
		three-ring level	-.05194	.11496	.969
		five-ring level	.07770	.11117	.897
	five-ring level	two-ring level	.39652*	.11598	.008
		three-ring level	-.12965	.10135	.58
		four-ring level	-.07770	.11117	.897

* The mean difference is significant at the 0.05 level

This means that patient´s performance was homogeneous in the three, four and five-ring levels (the number of movements did not increase disproportionately to the increasing number of rings) so performance efficiency was relatively high (Figure 2).

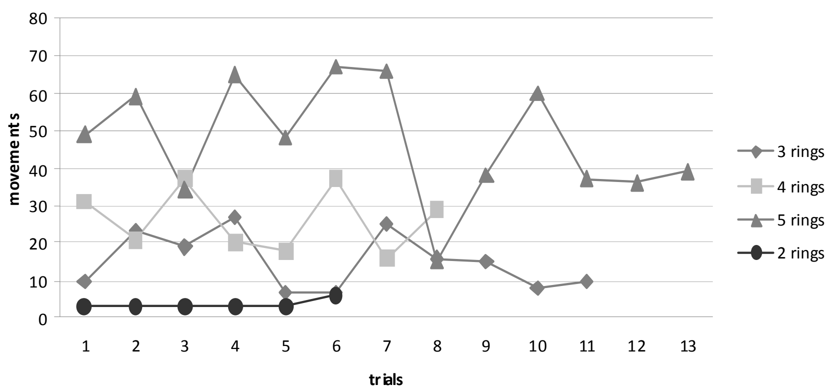

Figure 2. Comparative quantity of movements by complexity by trials. Each curve represents one of the four levels of complexity. Rombi: execution in the two-ring level of complexity along six trials; squares: execution in the three-ring level of complexity through eleven trials; triangles: execution in the four-ring level of complexity along eight trials and circles: execution in the five-ring level of execution along therteen trials.

Qualitative Analysis: Strategy and Progression

The patient reached the most complex level of the problem. In fact, he surpassed it, solving the tower with six rings successfully. Still, we do not include a six-ring level of complexity in our data analysis because it was not included initially in the design, and there were only two trials with six rings during the last training session.

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We registered more than one strategy of problem solving in the subject's performance. For example, in the simplest level of complexity the subject could solve the tower by means of the following two strategies, composed of three or six steps:

Sequence of three steps, simplest level of complexity:

1. First by moving the smallest ring form axis A to axis B,
2. Then by moving the biggest ring from axis A to axis C,
3. Finally by moving the smallest ring from axis B to axis C.

Sequence of six steps, simplest level of complexity:

1. First by moving the smallest ring to axis C,
2. Second by moving the biggest ring to axis B,
3. Third by moving the smallest ring to axis B,
4. Fourth by moving the smallest ring to axis A,
5. Fifth by moving the biggest ring to axis C,
6. Finally by moving the smallest ring to axis C as well.

Although the online maintenance of the final objective was mainly preserved during the execution of the test, the possibility to posit sub-objectives to achieve the final goal was dramatically disturbed during the pre-test.

During the treatment the patient was able to learn the rules and respect them, and progressively could posit sub-objectives and manipulate them to develop strategies to solve the tower. He was able to learn from his own experience, thus avoiding previous movements which violate the rules.

It is interesting to note that on day 10 of the treatment the patient achieved the best strategy of solution with four rings, the way it is described by Anderson (1995).

Transference

Patient's performance in Raven's Progressive Matrices was under the percentile 5. No statistical differences were found between the first and the second execution of this test ($F_{1/118} = 0.5395$; $p > .01$). These results show that although it was possible for our amnesic subject to learn to solve a problem, this learning did not have the potential to be transferred to another material. Nevertheless, It is noteworthy that the patient successfully solved the tower when the direction of solving was inverted, which we interpret as a kind of transference, but performed with the same material.

Discussion

Learning to Solve the TOH

Memory depends on the motivational state of the subject to be acquired and retrieved. We supposed that the motivation in this case was the visit of the researcher to the patient per se, since the inpatient lived in an asylum with a low frequency of visitors. As usual in dynamic assessment, the researcher developed qualitative and quantitative stimuli to help the subject to improve his performance: the stimuli necessarily include motivational aspects in order to prompt learning.

Outcomes from this study allow us to prove our hypothesis. Furthermore, we registered more than one strategy of problem solving in the subject's performance. Although transference of learning to another material was not proved, a phenomenon that we interpret as transference was demonstrated by solving the problem in an inverse, non-practiced direction.

Performance at pre-test was characterized by the lack of self-experience learning and feedback utilization, difficulties to posit alternatives, low level of solution seeking, diminished initiative and self-monitoring, and problems to follow the rules.

Along the treatment sessions the patient was able to learn the rules and self-monitoring strategies, to develop constancy in the pursuit of solutions, to improve initiative, to keep objectives in mind, and to posit alternatives and sub-objectives. His performance showed more than one solution to the same problem. This means that acquired learning was not an automatic procedure but a problem solving process based on working memory. The patient did not recognize that he had used more than one strategy because learning was supported on non-declarative systems given his deficit in explicit, episodic memory. Prompting served as an extrasomatic frontal lobe which helped the patient to cope with the problem and visualize valid alternatives, to learn the rules and follow them and to keep in mind and reach objectives and sub-objectives.

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To sum up, while in the pre-test the patient was not able to think about any valid option to move the discs in order to solve the tower, he progressively elucidated possible movements to approach the solution. The enhanced execution of the patient along the treatment showed the two stages proposed by Berg, Byrd, McNamara and MacDonald (2006) (see also Unterrainer, Rahm, Halsband & Kaller, 2005), where the pre-goal phase was identified with silence and immobility times in the patient's behaviour, and the goal phase showed fast ring movements that brought the performance closer to the goal. These phases were repeated consecutively along the resolution of the tower. This behaviour could be a sign of metacognition or at least a kind of self-reflection over his own execution made in order to continue the action or modify it to achieve the goal. Besides, the patient showed flexibility by using more than one strategy to solve the tower with the same level of complexity, and demonstrated to have made some kind of transference of learning by solving the tower in the inverse, not practised direction.

Our results can be compared with the results published by Bayley and Squire (2002). In their paper the authors reported the case of an amnesic patient who acquired some kind of verbal information, which was surprising because what was generally believed previously was that amnesic patients could only form procedural memories (see for example the original articles written by Corkin, 1968; Scoville & Milner, 1957 and the revision of patient HM memory made by Rosenzweig & Leiman, 1995). However, in Bayley and Squire's paper it was reported that the verbal memory acquired by the patient was more similar to non-declarative memories than declarative ones, and that it was gradually acquired, neither flexible nor transferable, and shared characteristics with perceptual priming. This memory acquisition reported by Bayley and Squire is very different from the results we report in this paper, as we explain in the next paragraph.

In our patient's behaviour we observed that sometimes he could change from one strategy to another to solve the tower with the same number of rings. Developing more than one strategy to solve the tower means that the learning was flexible. In our opinion, these results seem to indicate that this kind of learning can be only partially based on non-declarative memory, since non-declarative memory is not characterized by flexibility but by a permanent, repeatable structure which facilitates memorization by practice. Therefore, we suggest that his performance was mainly sustained by working memory in which non-declarative elements can be included but linked strategically with other components.

What We Can Learn from Studies which Combine Qualitative and Quantitative Methods

Qualitative and quantitative methods are not opposite but can be combined to obtain fruitful conclusions in the study of behaviour. Although they have been put in confrontation in past times (Bryman, 2007; Jacob, 1998; Sale, Lohfeld & Brazil, 2002), there is growing agreement among scientists that their combination can bring mutual benefits for themselves and for the research on scientific problems (Bryman, 2006; Campos, 2007; Marradi, Archenti & Piovani, 2007; Reichardt & Cook, 1986).

In fact, we conceive the researcher as an everyday problem solver (following the analogy of Tashakkori & Teddlie, 2010), which means that they focus, first and before, on the research question; only after having understood the problem, do they look for the best methods to answer it. This illustrates the pragmatic way of acting to cope with a problem. Actually, we consider mixed methods research as a third methodological movement based on pragmatic means to respond to the needs of empirically-based research and to move beyond the traditional qualitative-quantitative opposition (Truscott et al., 2010). There are controversial opinions about using mixed methods research (Fielding, 2010), for example that two very different epistemologies cannot be mixed appropriately. Yet, we understand that instead of mixing epistemologies we can follow the methodological notion that pragmatism is the best philosophy when we focus on a research problem, supporting mixed research (Johnson & Onwuegbuzie, 2004; Johnson, Onwuegbuzie & Turner, 2007).

We also hold the view that researchers are usually educated in one methodological tradition or another and continue working in the same tradition along their careers. This situation has pros and cons: although it can make research more effective thanks to growing experience and specificity in methods, it can also have a negative effect on achieving global understanding of some complex problems.

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Actually, we think that appropriate training does not need to be epistemologically mixed (qualitative and quantitative) *per se* but it should be possible to develop collaborative research with scientists from other traditions and to educate open-minded researchers who are able to use as many methods as may be in accordance with their research problem.

This kind of collaboration can bring into the scene a situation where different methods are applied in the context of one methodological perspective that can be called «quantitative dominant» or «qualitative dominant» mixed methods research, according to Johnson et al. (2007). Furthermore, Bryman, Becker and Sempik (2008), focusing on quality criteria for research, support that mixed methods research should be judged by the degree or way in which the different components are integrated. We consider that the example provided in this paper is mainly a mixed methodology study instead of being classified as «quantitative or qualitative dominant».

To conclude, we agree with Jick (1979) that qualitative and quantitative methods should be viewed as complementary rather than as rival camps. Therefore mixing methods is necessary for a variety of reasons, including interdisciplinarity and complexity of problems, and can serve to expand our understanding of research problems (Creswell, 2009). Mixed-methods approaches raise challenges in reconciling different epistemologies and ontologies, and in integrating different forms of data and knowledge (Mason, 2006).

We are convinced that the complete understanding of a problem needs flexibility and creativity to adapt methods to our research objectives. This means that methodology should not be used as a dogma but in a flexible, pragmatic way that will make it possible to make the most of methods in order to solve a problem, and eventually to do our best as researchers in social and natural sciences.

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