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The memory of what we do not recall: Dissociations and theoretical debates in the study of implicit memory

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Implicit memory reflects itself on situations in which previously acquired information is expressed, without awareness or intention. The study of implicit memory has had a profound impact on how researchers have investigated the human memory. In this paper, we review the main studies which have revealed dissociations between direct and indirect tests of memory, and address the two main theoretical approaches used to explain these dissociations: the processing view and the multiple systems view. We then describe recent neuroscience studies and discuss its contributions to help clarify the debate about the mechanisms involved in explicit and implicit memory. Finally, we critically analyze some questions and controversies surrounding this literature, such as (a) the transparency assumption and the contamination issue; and (b) the theoretical utility of the dissociations. We emphasize that the biggest challenge for future research is to develop comprehensive theories that integrate behavioral and neuroscience findings.

The memory of a past event can influence our subsequent behavior, even on the absence of explicit recall of that episode. This type of memory is called "implicit memory". The emergence of the study on implicit memory definitely impacted the literature about human memory. Some

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authors go as far as to say that this research has constituted a true scientific revolution – a paradigm shift – due to the innovative way researchers started measuring and interpreting the influence past events have on present experience (Richardson-Klavehn & Bjork, 1988; Schacter, Chiu, & Oschsner, 1993). Human memory stopped being studied as equivalent to explicit recall ability, instead encompassing every past influence on present performance.

The implicit memory construct overlaps with various concepts employed by previous generations of psychologists, namely by psychoanalysts (for a historical approach, see Schacter, 1987). The notion that there are mental contents which, even if not consciously accessed, influence our behavior, has long been a topic of debate amongst philosophers, neurologists, and psychologists. Nevertheless, the research on cognition initiated in the 80s (Jacoby, 1983; Jacoby & Dallas, 1981) has brought along methodologies which have made possible an experimental approach to the problem. It is understandable, therefore, the outburst of studies which have since addressed the issue. This approach allowed researchers to study the unconscious aspects of memory, under controlled laboratory conditions.

In the present paper our goal is to review the studies that revealed dissociations between direct and indirect memory tests and to analyze how subsequent developments in this literature have helped to clarify the nature of the processes underlying explicit and implicit memory, both at the psychological and at the physiological levels. We will begin by describing the seminal studies showing the aforementioned dissociations. Next, we will contrast the two main theoretical approaches used to explain those dissociations: the processing view and the multiple systems view, and address the ability of both theories to explain the extant data. Then, we will review recent neuroscience findings and discuss the possibility of an integrative approach. Lastly, we will address some fundamental questions and controversies which remain unsettled in the literature.

What is Implicit Memory?

The implicit memory literature is based upon the distinction between two forms of memory retrieval from long-term memory, on the one hand the explicit memory and, on the other hand, the implicit memory (Graf & Schacter, 1985, 1987). *Explicit memory* refers to the conscious and intentional retrieval of previously experienced information. This form of memory is typically studied through free recall, recognition, and cued recall traditional tests. Psychologists interested in memory phenomena have long used this type of memory tests almost exclusively so as to develop their theories.

Implicit memory, on the other hand, manifests itself in situations in which past experiences influence present task performance, although participants are not instructed in any way to recall those experiences (see Lewandowsky, Dunn, & Kirsner, 1989; Reder, 2014). In this case, participants are normally asked to complete a given task, without any reference to the previous episode. As a way of studying this type of memory, indirect or implicit tests have been utilized, such as: word-fragment completion (in which participants have to complete word fragments with the first word which comes to mind, e.g., PE_C_L for Pencil); word stem completion (in which participants are shown the first three letters of a word and they have to, similarly to the previous test, complete the fragments in order to form a word, e.g., PEN_ _ _); and perceptual identification (in which words are briefly presented and participants are asked to try to identify them). It is said that implicit memory effects occur when there is a greater likelihood of participants completing the word fragments with words presented previously, or of identifying with greater acuteness and swiftness previously studied words, when compared to words which were not shown before. Often, the terms implicit memory and priming are used interchangeably (Tulving & Schacter, 1990) as a way of referring to the transfer, or priming, from previously presented stimuli on subsequent tests which do not involve conscious recollection.

Dissociations between direct and indirect tests

The resurgence of attention to the implicit aspects of memory had, as an initial driving force, an influx of studies which revealed dissociations between the results obtained with direct and indirect memory tests[1]. A lot of these dissociations were reported in neuropsychological studies with amnesiac patients (for a review, see Shimamura, 1986). Amnesiac patients are typically described as people who, as a result of a brain deficit, become incapable of storing new verbal information in long-term memory, although

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[1] In this paper, we opted for employing the terms direct and indirect for these two types of tests. As several authors point out (Richardson-Klavehn & Bjork, 1988; Richardson-Klavehn, Gardiner, & Java, 1996), employing the terms "explicit test" and "implicit tests" to refer to them erroneously suggests an equivalence between tasks and processes (Jacoby, 1991).

their other cognitive functions remain relatively intact, such as language or intelligence (Cohen & Squire, 1980).

On a series of studies which has since become classic, Warrington and Weiskrantz (1968, 1970, 1974) observed that amnesiacs, after studying a set of words, exhibited similar priming effects as the non-clinical group in indirect tests of partial information (i.e., picture completion, word-fragment completion and word-stem completion), although they revealed a severely weakened performance in direct memory tests (recall and recognition tests). These studies clearly showed that memory can manifest itself in the absence of awareness. Patients reported not recalling the previously presented words, but their performance reflected memory ability. These results led to two important consequences. First, they revealed that, contrary to what was typically assumed, amnesiac patients are able to retain new verbal information, and that can be detected, as long as indirect memory measures are used. Second, a hypothesis started to form that indirect and direct memory tests recruit different mental systems or processes which act in a relatively independent way.

Other studies have shown that similar dissociations could be obtained in populations without brain lesions (Jacoby & Dallas, 1981; Jacoby, 1983). For instance, Jacoby and Dallas (1981, Study 1) manipulated the processing levels (semantic vs perceptual), and obtained the typical effect in a recognition test (Craik & Lockhart, 1972). In other words, a better recognition of words presented after a semantic encoding than after a perceptual encoding. Nevertheless, the performance on the perceptual identification test was similar, irrespective of the processing level according to which the words were initially coded. Subsequent studies have demonstrated that the level of processing does not interfere with the priming effects of other indirect tests, such as fragment completion tests (Srinivas & Roediger, 1990), and word-stem completion tests (Graf & Mandler, 1984, Graf, Mandler, & Haden, 1982).

In a different study, Jacoby (1983) created three conditions in which the participants: (1) read a word without any context (e.g., xxx – cold); (2) read the same word in a relevant context (e.g., hot – cold); or (3) generated that word from the context (e.g., hot - ???). Results demonstrated that generated words are better recognized than words read in a relevant context and that these, in turn, are better recognized than words read without any context. This pattern reflects a robust effect in the literature – *the generation effect* (Slamecka & Graf, 1978), according to which words that are generated are better recalled than words which are simply read. However, the opposite pattern was observed in the perceptual identification test. In this case, participants identified words which had been previously read without any context more easily than words which had been read within a context or generated, respectively. Therefore, although the generation effect is considered a classic effect in the memory literature, its occurrence is contingent upon the memory test used, and the opposite pattern can be obtained, as long as an indirect memory test is employed. The fact that the same variable has opposite effects on the two types of tests, direct and indirect, suggests once again that the processes involved in the performance on one of the tasks are probably not involved in the performance pertaining to the other task.

A different type of a commonly found dissociation involves the manipulation of the modality of word presentation. It was shown that altering such modality from the study phase (e.g., auditory) to the test phase (e.g., visual) drastically mitigated the priming effects in various indirect memory tests: perceptual identification (Jacoby & Dallas, 1981; Jacoby & Witherspoon, 1982), word-stem completion (Blaxton, 1989; Graf, Shimamura, & Squire, 1985), lexical decision (Kirsner, Milech, & Standen, 1983; Kirsner & Smith, 1974), and anagram solution (McAndrews & Moscovitch, 1990). Nevertheless, the performance in direct tests of free recall and recognition doesn't tend to be affected by the change in modality. On balance, the described dissociations lend support to the notion that explicit and implicit memory operate according to different principles. Some variables affect only the direct tests, whereas others affect only the indirect tests.

In theoretical terms, the explanation of the dissociations found between different types of memory tests is something which has aroused interest among researchers. An initial explanation was that indirect tests were less dependent upon the strength of memory trait activation. The same traits would not be strong enough to influence the performance on direct tests. Nonetheless, this explanation was soon discarded as it was incompatible with the existence of manipulations which affected direct tests without affecting the performance on indirect tests (e.g., Jacoby & Dallas, 1981). Since then, two main theoretical views have competed for an explanation of the obtained dissociations: on the one hand, the views which explain the dissociations by postulating the existence of different memory systems and, on the other hand, the views which attempt to explain the dissociations based on the functioning of different processes.

The Systems versus Processes debate

The debate (Kelley & Lindsay, 1996; Roediger, Buckner, & McDermott, 1999; Toth & Hunt, 1999) between the system approaches and the process approaches reflects a long-standing controversy between two meta-theoretical assumptions regarding the study of the human mind: structuralism and functionalism. The tension between these approaches has always been present in psychology and philosophy of the mind alike, and it is possible to trace its origins back to the beginning of psychology as a science (regarding this debate, see Roediger, Gallo, & Geraci, 2002; Toth & Hunt, 1999). Within these conceptions of the mind, structuralism argues that psychological processes, such as perception or memory, should be seen as separate phenomena. The main goal is thus to analyze the modular structure, or basic units (Fodor, 1983) of the human mind. On the other hand, functionalism rejects such mental morphology, arguing that the various processes operate in an integrative manner. Hence, instead of analyzing the structure, functionalists stress that an adequate approach to mental life should focus on trying to understand how the mind works. In other words, instead of emphasizing what the mental processes are and where they are located, functionalists emphasize what they do, and how they do it. In current research, structuralism tends to be associated with the neuroscience approach. Neuroimaging and neuropsychological methods are typically used within this approach in order to locate specific mental functions in the brain. Functionalists, on the other hand, tend to embrace a cognitive approach which makes use of data from behavioral studies in order to derive mentalistic information processing theories (Tulving, 1999). In the context of memory theories, structuralism is closer to the multiple systems approach, whereas functionalism reflects itself upon the processing memory theories.

Squire's theory (e.g., Squire, 1987; Squire, 1992) is a representative framework of the view which postulates the existence of different memory systems. According to Squire, systems *"can be distinguished in terms of the kinds of information they process, the principles by which they operate, and the brain structures and connections that support them*" (Squire, 2007, p. 343; see also Schacter & Tulving, 1994). Squire distinguished between a declarative memory system (described as "knowing that") and a non-declarative system (described as "knowing how"). In broader terms, it is assumed that the declarative system is responsible for the performance on explicit tests, while the non-declarative memory system underlies various phenomena, including classical conditioning, the learning of motor skills, and priming effects. According to this view, amnesiac patients would have an impaired declarative system, and a relatively intact non-declarative system. With regard to the normal population, the case would be that several variables would affect a system, while other variables would affect the other, which would explain the previously described dissociations. In fact, since it is assumed that the systems are highly independent, the dissociations are not only explicable, but expected.

The alternative account, instead of assuming that implicit and explicit tests rely upon different memory systems, is based on the assumption that different tests require the operation of different mental processes, and thus require different types of information. Since in the literature dissociations between different explicit tests (e.g., between recall and recognition, see MacLeod & Kampe, 1996) are also known, the notion here is that explanatory principles, similar to the ones employed to understand those dissociations, can also explain the dissociations between indirect and direct tests. One of the fundamental ideas of this framework is that the differences between memory tests can only be comprehended by explaining the relationship between the processes which occur during encoding and the processes which occur during retrieval. This idea is particularly developed in the *transfer-appropriate procedures approach* (TAP; Weldon, Roediger, & Challis, 1989; Roediger et al., 1999; Roediger et al., 2002). The main tenet of the TAP is that memory performance is benefitted when the cognitive operations which take place during the test recapitulate the ones which occurred during learning.

According to the TAP approach, implicit and explicit tests require different operations and access to different forms of information, therefore benefitting from different types of processing during learning. More specifically, the majority of direct tests are *conceptually-driven* tests, that is, they rely on the conceptual and semantic processing of the items. Such is in accordance with several studies which have demonstrated that direct tests are sensitive to processing level manipulations, but highly insensitive to changes on superficial aspects of processing (i.e., modality) (e.g., Jacoby & Dallas, 1981). On the other hand, most indirect tests, on which perceptual information tends to be impaired, are *data-driven* tests, meaning that they strongly rely upon the perceptual and superficial processing of the stimuli. This converges with results showing that performance on indirect tests is sensitive to manipulations which affect the superficial aspects of information, but insensitive to changes on the conceptual processing level.

What is the most suitable approach?

Blaxton (1989) highlighted that an appropriate comparison between the two approaches has not been possible since the manipulations tended to confound the type of system being used with the type of processing. In other words, direct tests are always guided conceptually (e.g., recognition and recall), whereas indirect tests are always data-driven (e.g., word completion and perceptual identification). Apart from these types of tests, Blaxton (1989) included a conceptually guided indirect test (general knowledge questions) and a data-driven direct test (graphemic cued recall). The results revealed a dissociation between the conceptually guided tests and the data-driven tests, irrespective of whether they were direct or indirect. It is thus possible to find dissociations, either between two indirect tests or between two direct tests, as long as one of them relies upon a more perceptual type of processing and the other upon a more conceptual type of processing. This pattern is difficult to explain within the systems approach, as it predicts that all indirect tests, and all direct tests as well, rely upon a single memory system (Squire, 1987).

The systems approach could simply increase the number of postulated systems in order to accommodate the newly obtained dissociations. In fact, that has been done (see Schacter, 1990; Schacter et al., 1993; 1994; Squire, 1994). For example, Schacter and Tulving (1994) proposed a taxonomy of five major memory systems: episodic memory, semantic memory, primary or working memory, procedural memory, and perceptual representation memory. Some of these systems have subsystems (see Figure 1). For example, according to this account, the perceptual representation system (PRS), responsible for data-driven priming effects, is composed by three different subsystems: visual word form, structural description, and auditory word form. These three subsystems, in turn, can be further subdivided into a number of other subsystems (e.g., left-hemisphere and right-hemisphere subsystems, abstract and form-specific subsystems, see Schacter,1994)[2]. However, as several authors have pointed out, such segmentation seems contradictory with the very definition of memory system (Hintzman, 1990; Roediger, 1990; Roediger, 2003; Roediger et al., 1999). Increasing the number of systems in an *ad hoc* fashion as a function of new discoveries is not appealing as it may render the theory irrefutable.

However, it does not suffice to demonstrate that the systems approach has difficulties in making sense of certain patterns of data, it is also necessary to demonstrate that the processing approach is more capable of explaining them. In fact, the TAP approach predicts dissociations among different indirect tests (Blaxton, 1989), as long as one of them is data-driven and the other is conceptually guided. Moreover, the approach is able to explain dissociations between two implicit perceptual tests (Weldon & Roediger, 1987), assuming that the operations between the study and test phases can be similar to some extent, and depending on the test being employed. Therefore, the dissociations between different memory tests, even if those tests are quite alike, can be seen as natural within a processing approach.

System	Other terms	Subsystems	Retrieval
Procedural	Nondeclarative	Motor skills Cognitive skills Simple conditioning Simple associative learning	Implicit
Perceptual representation (PRS)	Nondeclarative	Visual word form Auditory word form Structural description	Implicit
Semantic	Generic Factual Knowledge	Spatial Relational	Implicit
Primary	Working	Visual Auditory	Explicit
Episodic	Personal Autobiographical Event memory		Explicit

Figure 1. Taxonomy of memory systems proposed by Schacter and Tulving (from Schacter & Tulving, 1994).

Nevertheless, this approach has also been the target of some criticism (Kelley & Lindsay, 1996). The main problem is that numerous dissociations have been reported between tests which supposedly rely upon the same type of processing. Dissociations have been observed either between different implicit conceptual tests (Cabeza, 1994), or between different implicit perceptual tests (McDermott & Roediger, 1996; Weldon, 1991; Weldon & Coyote, 1996; Witherspoon & Moscovitch, 1989). Weldon (1991), for instance, showed that encoding in terms of meaning affects performance on the fragment completion test, but not on the perceptual identification task, two tests supposedly reliant upon a perceptual processing. Other studies (Toth & Hunt, 1990) have demonstrated that a perceptual variable (word spelling manipulation) affects performance on an explicit conceptual test, which is also not predicted by the TAP approach. Finally, there are tasks which seem to be based on both perceptual and conceptual information, as is the case, for example, with the picture naming task (e.g., Cave & Squire, 1992; Mitchell & Brown, 1988). Taken together, these results suggest that the conceptual-perceptual distinction is too broad to account for the differences in performance among the different memory tests.

The difficulties above could possibly be overcome if the various types of processing, which influence our memory, are specified. The distinction between conceptual processing and perceptual processing is considered by some authors (Roediger et al., 1999) as an initial attempt at specifying the processes which are inherent to the functioning of memory. While that distinction has been able to accommodate several results in the literature, the theory could be improved. One avenue for such improvement focuses on the distinction among different types of conceptual and perceptive processing.

On balance, an explanation of the different dissociations found in the literature has been done in terms of different systems or of different processes. Both approaches experience, however, some difficulty in understanding every extant data pattern. The processing alternative, though not devoid of problems, resorts to a smaller number of mechanisms in order to make sense of the data.

In the last decades we have witnessed a decrease in the number of studies that directly address the debate between systems and processes. Recent studies have been marked, however, by the expansion of the neuroscience approach. The recent developments in neuroimaging techniques have led to a proliferation of studies which investigate the neural mechanisms of explicit and implicit memory. We will now briefly summarize this research and discuss its implications for the debate about the underlying mechanisms of explicit and implicit memory.

Neuropsychology and neuroimaging findings

To a great extent, the debate about the nature of implicit and explicit memory was stimulated by neuroscience findings, in particular by studies of amnesiac patients. These patients provide unique opportunities for exploring the relation between damages in specific brain regions and the loss of certain memory functions. The most important case study in the neuroscience of memory literature is probably the one of the patient H.M., who had most of the bilateral medial temporal lobe (MTL) removed as part of a surgery to treat epilepsy. However, despite severely amnesic, H. M. was still able to acquire new motor skills (Milner, Corkin, & Teuber, 1968; Scoville & Milner, 1957). This case was revolutionary in the field because it seemed contrary to the prevailing view that mental functions, such as memory, were too complex to be localized in the brain.

Since this initial study, several other cases of amnesiac patients, with lesions in the MTL, and related explicit memory deficits, have been reported (Insausti, Annese, Amaral, & Squire, 2013; Rempel-Clower, Zola, Squire, & Amaral, 1996; Smith, Urgolites, Hopkins, & Squire, 2013). These studies led to the dominant idea that regions in the MTL, and, in particular, the hippocampus, are specifically involved in explicit or declarative memory. Recent experiments that have made use of brain imaging techniques lend support to this notion (Davachi, Mitchell, & Wagner, 2003; Nyberg, McIntosh, Houle, Nilsson, & Tulving, 1996; Schacter & Wagner 1999; cf. Shallice et al., 1994). In addition, the hippocampus was found to be critical to the recollection component of memory, but not to familiarity (Eichenbaum, Yonelinas, & Ranganath, 2007; Eldridge, Knowlton, Furmanski, Brookheimer, & Engel, 2000; cf. Eichenbaum et al., 2007; Manns, Hopkins, Reed, Kitchener, & Squire, 2003).

A common thesis concerning the specific mechanisms involved in declarative episodic encoding is that MTL regions surrounding the hippocampus (namely the parahippocampal and entorhinal cortex) receive sensorial information from different areas of the cortex. This information converges in the hippocampus, which has an essential role in binding and relating the different components together (Eichenbaum, 2001; Cohen, Ryan, Hunt, Romine, Wszalek, & Nash, 1999). At retrieval, the hippocampus is assumed to enable episodic holistic retrieval through pattern completion (Horner, Bisby, Bush, Lin, & Burgess, 2015; Preston & Eichenbaum, 2013).

While it is consensual that MTL is involved in explicit memory, other areas of the brain (namely, the ones which are not damaged in amnesiacs) would subserve implicit memory. At this level, studies have suggested that different neural structures are particularly central to different forms of implicit memory. For example, the neostriatum and basal ganglia for habit learning (Knowlton, Mangels, & Squire, 1996; Yin & Knowlton, 2006), prefrontal regions for conceptual priming (Dobbins, Schnyer, Verfaellie, & Schacter, 2004; Maccota & Buckner, 2004; Wig, Grafton, Demos, & Kelley, 2005), the occipital lobe for perceptual priming (Gong et al., 2016; Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995), and the amygdala for fear and emotional learning (Bechara et al., 1995; Johansen et al., 2010; Orsini & Maren, 2012).

Recent research suggests, however, that the dichotomy explicit memory-MTL versus implicit memory-non MTL is probably too simplistic.

For example, some studies have reported cases of amnesiacs who showed impairments in implicit memory tasks (Addante, 2015; Butters, Heindel, & Salmon, 1990; Chun & Phelps, 1999; Duss et. al., 2014). In addition, neuroimaging studies have provided evidence that the hippocampus is recruited during implicit relational tasks (Reber, Luechinger, Boesiger, & Henke, 2012; Ryals, Wang, Polnaszek, & Voss, 2015; for reviews see Hannula & Greene, 2012; Henke, 2010). These results indicate that the hippocampus is important for both direct and indirect relational memory tasks, which contradicts the notion that the hippocampus is exclusively involved in explicit memory.

Additionally, despite the prevailing view that the MTL underlies explicit memory, studies have been reported which show that some forms of declarative memory are independent of the activation of the hippocampus. For example, semantic memory can be preserved in patients with damage to the hippocampus (Vargha-Khadem et al., 1997). Indeed, there is now good evidence that other areas, besides the hippocampus, are also important for declarative memory, such as the diencephalic midline (Squire & Wixted, 2011) and, in particular, the prefrontal cortex (Simons & Spiers, 2003). The important role of the prefrontal cortex on reducing interference (Shimamura, Jurica, Mangels, Gershberg, & Knight, 1995) suggests that the communication between the hippocampus and the prefrontal cortex has a critical role in the retrieval of specific memories. The mechanisms through which these two systems interact during the encoding and retrieval of episodic memories are still not fully understood and have thus been a subject of current research (Preston & Eichenbaum, 2013; Schlichting & Preston, 2015).

Neuroscience studies have made valuable contributions to the understanding of the neural structure of memory. However, it has now become apparent that memory functions involve complex interactions between different cortical areas. Thus, instead of associating self-contained areas with certain functions, the current focus of neuroscience research has been on exploring the neural networks involved in different memory functions. It should be noted that the interpretation of the data with amnesiac patients may be fallacious. Of course, the fact that a lesion in a brain area X leads to the loss of a function, does not imply that X is the only area involved in that function, and not even that X is central to that function (Andrewes, 2003).

Another important aspect concerning neuropsychological data is related to the great plasticity of the brain. Patients may function in a qualitatively different manner than they used to before sustaining the lesions. For example, some studies have found that patients with brain injuries may perform *better* on certain indirect tasks than normal control subjects (see Kapur, 1996) – the so-called paradoxical facilitation effect. In addition, Vargha-Khadem et al. (1997) reported cases of patients with hippocampus lesions, and with loss of episodic memory, but unimpaired semantic memory. Since it is usually assumed that semantic knowledge is acquired through the accumulation of episodic memories, the authors put forward the possibility that other neuronal routes are being used to store semantic memories. These results suggest that patients and controls may use different processes to perform the same tasks. Thus, a convergence of methods is desirable.

But what do the neuroscience data tell us about the debate regarding the processes involved in explicit and implicit memory? The most important aspect is that the results counter a unitary view of memory. The traditional idea that two broad memory systems (declarative and non-declarative) underlie explicit and implicit memory doesn't seem to be supported by the data. For example, implicit memory not only involves different neuronal areas, depending on the type of indirect task, but may also depend on areas typically associated with conscious uses of memory, such as the hippocampus (Addante, 2015). This supports the notion that there needs to be a specification of the mental processes involved, and that dissociations can occur between processes, and not necessarily between levels of consciousness.

Most of the neuroscience studies are restricted at a structural and physiological level of analysis, and few of them have used the data as a way of contrasting alternative psychological theories. This is unfortunate. In fact, despite the skepticism regarding the utility of neuroscience to explain the mind (Henson, 2006), it is at present unquestionable that the data from neuropsychology and functional neuroimaging can constitute important tools to inform cognitive theories (Cooper & Shallice, 2011; Hutzler, 2014). For example, if one assumes that a specific brain region is important to a certain function, one can test to what extent that area is activated in different types of memory tests. At the same time, that would allow one to predict that patients who have sustained lesions in those regions will probably lose that type of processing capacity.

Note also that, as the systems and processing theoretical approaches develop in order to explain the extant data, it is natural that they will become less and less incompatible and that the distinction between them will fade. An adequate system theory, that is, a sufficiently explanatory one, will have to specify the computational characteristics of each system. On the other hand, it is plausible to assume that the same processes are consistently based on specific neural networks. This is in line with Tulving's argument that the opposition between "processes" and "systems" is false (Tulving, 1999). Such considerations open the possibility of an integrative approach (Cabeza & Moscovitch, 2013; Schacter, 1992).

Still, some authors question whether complex mental processes can ever be adequately mapped onto the brain (Coltheart, 2006; Uttal, 2001). The possibility of a neural mapping of the memory processes will probably be contingent upon how sophisticated the imaging techniques become, and how precise those techniques are at the cellular level. The advancements in the imaging techniques over the last few years have been remarkable, and their potential application for treating degenerative memory diseased is certainly desirable (see Lisman, 2015; Chang, 2015), but this is an area which is still in its infancy.

Questions, controversies, and debates

To conclude, we will now consider two critical debates in the literature: the contamination problem, and the discussion about the use of dissociations as a tool to reveal the architecture of the mind and brain.

The assumption of transparency and the issue of contamination.

Research on implicit memory has faced some critical methodological problems, one of which being the contamination problem. The majority of the research on unconscious influences on memory has assumed the existence of a direct correspondence between processes and tasks. More specifically, implicit processes are typically equated with performance on indirect tests, whereas explicit processes are paired with performance on direct tests. However, this approach is susceptible to contamination problems. It is not appropriate to equate processes with tasks. Conscious processes can contaminate performance on indirect tests. If participants realize that the stimuli used in the indirect test are part of a previous learning stage, they may employ conscious and deliberate recollection strategies, which would turn a test, meant to be implicit, into an explicit one. Conversely, unconscious processes can also contribute to performance on direct tests (Jacoby, 1991; Sheldon & Moscovitch, 2010). It has been shown, for instance, that the performance on the recognition test depends on an implicit memory component (Yonelinas, 2002). Understandably, calling a memory test "implicit" does not assure that the participant relies only on unconscious memory processes to complete it, and such a designation could be misleading in scientific communication.

Having become aware of this problem, researchers have developed different ways of trying to avoid it, such as presenting the indirect test as one of several distractor tasks, testing only a small number of previously studied stimuli, or encouraging rapid responses (see MacLeod, 2008). All these procedures aim to prevent participants from noticing the connection between the study and test stages, and to decrease the likelihood of their using explicit recall strategies. Nonetheless, even if such methods succeed in making the study/test relationship more inconspicuous, they are not a guarantee that the participants will not become aware of the relationship. An alternative consists of simply asking participants at the end of the experiment if they became aware of the relationship between the study and the test phases, and if they employed conscious recollection strategies during the completion of the indirect test (Bowers & Schacter, 1990). Such an alternative is, however, susceptible to the typical problems of self-report measures. Some participants may say that they were not aware of any relationship, even if they truly were, while others may report awareness in its absence, simply to confirm, or disconfirm, the experimenters' expectations. What is more, self-report measures, being employed at the end of the experiment, do not allow one to study the level of awareness pertaining to each studied stimulus.

Jacoby (1991) developed a method, the process dissociation procedure (PDP), which aims to deal with the contamination issue. The PDP (Jacoby, 1991; Jacoby & Kelley, 1992; Jacoby, Toth, & Yonelinas, 1993) stems from the notion that most memory operations reflect a joint contribution of conscious and unconscious processes. Therefore, more important than developing pure tests is finding ways to separate the contribution of both types of processes in a given task.

By applying the PDP, the contribution of conscious and unconscious processes can be measured by comparing the results pertaining to two conditions named Inclusion and Exclusion. In the Inclusion condition, the conscious and unconscious influences act in the same direction, leading to the same response. In the Exclusion condition, the conscious and unconscious influences act in opposite ways, thus leading to contrary responses. It follows from this that the difference between the Inclusion and the Exclusion conditions provides researchers with a measure of the contribution of the conscious processes. Through elementary algebra, and assuming independence between the two processes, a mathematical estimate of the contribution of conscious and unconscious processes for the task can be obtained.

The main criticism of the PDP has to do with the independence assumption. It has been shown that this assumption can be violated under different circumstances (Curran & Hintzman, 1995), which places some limits on the applicability of the PDP approach. These criticisms have led to an intense debate (Hintzman & Curran, 1997; Jacoby, 1998; Jacoby & Shrout, 1997; Yonelinas & Jacoby, 2012). At the same time, several adaptations and extensions of the PDP have been formulated in order to deal with the potential violations of its assumptions (Buchner, Erdfelder, & Vaterrodt-Plünnecke, 1995; Klauer, Dittrich, Scholtes, & Voss, 2015; Vaterrodt-Plünnecke, Krüger, & Bredenkamp, 2002). Despite its potential limitations, the fact that the PDP is a simple, yet powerful, tool might explain why it continues to be so widely applied across a number of different domains (Conway & Gawronski, 2013; Ferreira, Garcia-Marques, Sherman, & Sherman, 2006; Shimizu, Lee, & Uleman, 2017).

As an alternative to PDP, several other multinomial processing tree (MPT) models have been proposed, such as the QUAD model (Conrey, Sherman, Gawronski, Hungenberg, & Groom, 2005), the conjoint recognition model (Brainerd, Reyna, & Mojardin, 1999), or the ABC model (Stahl & Degner, 2007). MPT models employ a greater number of parameters to estimate the independent contributions of the latent psychological processes underlying a particular task. Multinomial models are represented in a tree structure, and each branch of the tree represents a process, or a sequence of processes, which can be followed when performing a given task. Each path results in a response category (i.e., the terminal nodes of the tree). MPT models allow one to test how well the model fits the data, and to mathematically estimate the contributions of the different processes towards performance on the task.

One example of an MPT model is the conjoint recognition model (Brainerd et al., 1999), which is described by the authors as a second-generation model derived from the PDP procedure. The conjoint recognition model was primarily applied to recognition tests with three types of items (targets, related lures, and unrelated lures). In addition, besides the typical inclusion and exclusion instructions, a third type of instruction is also included (i.e, recognize only related lures). One of the major merits of the model is the possibility of estimating a response bias parameter. Brainerd et al. (1999) used the model to separate verbatim memory (i.e., item-specific information, usually associated with explicit recollection) and gist memory (i.e., the general meaning, often associated with a feeling of familiarity). More recently, Stahl and Klauer (2008) suggested a simplified version of the conjoint recognition procedure.

Another MPT model which was also largely influenced by the PDP is the Quadruple (QUAD) process model. The QUAD model allows the estimation of the contribution of four processes which are assumed to influence performance on implicit tasks: two processes with controlled features (detection and overcoming bias) and two largely automatic processes (guessing and association activation). The QUAD model has often been applied to different tasks in the social domain, including the implicit association task (IAT, Conrey et al., 2005; for a review see Sherman, 2008).

The employment of MPT models (see Batchelder & Riefer, 1999; Payne & Bishara, 2009) has the advantage of requiring a psychological theory which makes explicit the underlying cognitive processes and assumptions. The application of these models has been met with success in various areas (Batchelder & Riefer, 1999). Despite the popularity of the MPT models, they are usually restricted to a particular paradigm, are necessarily mathematical simplifications of the mechanisms involved in a given task, and are not always easily integrated within more general psychological models.

In sum, the approach which matches processes to tasks, treating the latter as if they were pure, is theoretically and empirically limited. Multinomial models are an example of an approach which allows us not to restrict ourselves to studying the conscious and unconscious influences in separate tasks, but that instead permits us to explore tasks in which multiple processes contribute to performance, a situation which should be more the norm than the exception.

What reveals a dissociation?

Dissociations have been the main empirical criterion to establish the existence of different memory systems or processes. However, the role of dissociation in modelling theoretical knowledge has been highly debated. Regarding this matter, Dunn and Kirsner (2003) refer that:

> (…) since any two tasks, different enough to be called different, cannot recruit exactly the same mental functions in exactly the same way, it is inevitable that they will eventually yield a dissociation (…) such fractionations call into question the utility of dissociations as they seem to suggest that we will eventually need as many mental functions or modules or systems as there are tasks to humans to do (Dunn & Kirsner, 2003, p. 5).

In line with this view, numerous authors state that dissociations do not suffice to establish the existence of two memory systems or processes (e.g., Bedford, 2003; Chater, 2003; Karmiloff-Smith, Scerif, & Ansari, 2003; McCloskey, 2003; Reingold, 2003). For instance, in the case of a simple dissociation what happens is that task A is affected by some manipulation or brain lesion, while task B is not. It is therefore concluded that there is an underlying process to task A which is not present in task B. However, an alternative interpretation is that task B is simply easier or less reliable (Buchner & Wippich, 2000; Meier & Perrig, 2000) and that is why performance remains unaffected.

Another type of dissociation is the double dissociation. In this case, there is another variable or lesion which affects task B without exerting any effect on task A. This is a stronger kind of dissociation. Nonetheless, since a double dissociation is not more than the result of two simple dissociations, it may be explained by the same alternative account as above. Task A could be dependent upon a greater degree of a given process X, and that does not necessarily mean that said process cannot, or will not, affect task B. On the other hand, task B could require the presence of any given process Y in a greater degree than task A. Another alternative explanation is that both tasks rely upon the same processes, but in a reverse way, that is: process X facilitates a task and interferes with the other, and vice-versa for process Y (Dunn & Kirsner, 1988). In fact, it is possible to simulate double dissociations in single-system models (Juola & Plunkett, 2000; Kinder & Shanks, 2003). The essential aspect is that the presence of dissociations can be indicative, but does not constitute irrefutable evidence, that multiple processes exist.

In an endeavor to circumvent this issue, Dunn and Kirsner (1988) suggest the use of reverse associations. These authors call the attention to the fact that a uniprocessing explanation requires that the performance in a task be a monotonic function of the performance in another. Therefore, the only way of showing the existence of two processes is by means of reverse associations, that is: it is necessary that a variable affects two tasks in the same way, and that another variable has opposite effects on the two tasks. Such a pattern would suggest a non-monotonic relationship between the performance on both tasks, which would be incompatible with a single processing vision.

More recently, several authors have proposed the use of a “state trait” (STA) analysis as a way of determining the number of processes, or latent variables, underlying a set of data which derives from the manipulation of two or more independent variables on two or more dependent variables (Dunn, Kalish, & Newell, 2014; Newell & Dunn, 2008). STA allows one to understand in what way the set of data is mediated by a single latent process (a single curve), or by more than one latent process (more than one curve). This type of analysis has been applied in a wide variety of fields (see Prince, Brown, & Heathcote, 2012), although its ability to differentiate between single processing and multiple processing visions has also been called into question (Ashby, 2014).

Final Remarks

Implicit memory is a fascinating topic. The study of implicit memory opens the door to the understanding of the deepest origin of our behavior and it requires addressing fundamental questions about the nature of the mind, such as the issue of the correspondence between mind and brain.

The two main approaches employed to explain the dissociations between direct and indirect tests, the system approach and the processing approach, both struggle to understand all data. Yet, while a processing theory can be assessed regardless of assumptions pertaining to brain location, the reverse, that is, a systems theory in the absence of an information processing theory, is insufficient. Thus, it is essential to go beyond a topography of brain regions, and define the computational principles which govern each memory system, their level of specialization or selectivity, as well as how different systems interact with each other. We should note that it may well be the case that the concept of memory system is, above all, a tool with heuristic value to generate hypotheses about patterns of dissociations. If so, despite its empirical merit, the concept should neither replace, nor obscure, the investigation of the rules of operation that govern mental functions. A challenge for future research is to stimulate a greater interaction between the psychological and the neuroscience perspectives. While we are certainly dealing with two different levels of analysis, a thorough explanation of how memory works should cross neuropsychology, neuroimaging, and behavioral data.

Analyzing the literature reveals that the distinction between implicit and explicit memory is clearly an insufficient dichotomy. It is necessary to go beyond it and specify which processes are common or different among tasks. For example, let us consider two memory tasks: word completion and perceptual identification. Although the two are perceived as being implicit, they certainly differ in various aspects. It is likely that they share certain subprocesses, but that they diverge on others, and may therefore be affected similarly, or differently, as a function of distinct variables. It is then likely that high-level theories, which postulate general memory principles, may feel the need to encompass auxiliary "task theories" (Garcia-Marques & Ferreira, 2011).

In the present paper we highlighted some central problems in this literature, such as equating tasks with processes, and the issue of dissociations not constituting either a sufficient, or a necessary, criterion to establish the existence of multiple memory processes or systems. These questions are not always fully considered in the literature, but ignoring them prevents the development of new theoretical and methodological alternatives to study implicit and explicit memory influences. With regard to the first problem, there are techniques which allow the dissociation of the contributions of different processes on a certain task. These techniques, such as the PDP (Jacoby, 1991), have been refined and extended in recent years (Klauer et al., 2015). With regard to the second issue, given the ambiguity of the dissociations, they should be used in a convergent way with other tools – imaging data and state trait analyses, for instance – to draw conclusions about the number of the underlying processes in a specific action. The more single processing and multiple processing models are compared in their ability to generate specific predictions regarding different patterns of data, the bigger the theoretical development will be.

It should be noted that the study of implicit memory is present across several other domains. In fact, implicit memory underlies many other cognitive processes, such as learning, categorization, language, and decision making. In these cases, existing models may be adjusted to incorporate implicit memory effects. A case in point is the counter model proposed by Ratclliff and McKoon (1997) which is based on the logogen model of word identification (Morton, 1969). The authors use this model in order to explain the implicit memory effects on the perceptual identification task, as an intrinsic part of the word identification process.

The concept of implicit memory may be too broad, which could compromise its theoretical usefulness. It is likely that the majority of our behavior relies much more on implicit, rather than explicit, memory influences. Implicit memory seems to be present in almost all of our actions, in most of what we do. Children use it considerably more, constantly. As Lockhart (1989, p.6) points out: "*Why else should we be impressed by the fact that a response to a current stimulus can be influenced by a past event of which the subject is unaware? Isn't that how most organisms behave most of the time…*". It seems that the explicit recollection of past events as an end in itself is the exception, and not the other way around. So, critics may argue that the concept of implicit memory is misleading, or scientifically damaging, because it encompasses phenomena that can only be understood in a fragmented way, and as a function of the different tasks and contents. Nevertheless, if the scientific merit of a construct is measured by the number of questions and hypotheses it has generated, and by the amount of empirical discoveries it has promoted, then the relevance of the implicit memory construct becomes unquestionable. Major breakthroughs have been made which have helped us to better understand how memory works in different tasks, and under different conditions. These discoveries have intrinsic value (Garcia-Marques & Ferreira, 2011) and restrict the development of any comprehensive theory of memory.

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