# Processing approaches to cognition: The impetus from the levels-of-processing framework

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Processing approaches to cognition have a long history, from act psychology to the present, but perhaps their greatest boost was given by the success and dominance of the levels-of-processing framework. We review the history of processing approaches, and explore the influence of the levels-of-processing approach, the procedural approach advocated by Paul Kolers, and the transfer-appropriate processing framework. Processing approaches emphasise the procedures of mind and the idea that memory storage can be usefully conceptualised as residing in the same neural units that originally processed information at the time of encoding. Processing approaches emphasise the unity and interrelatedness of cognitive processes and maintain that they can be dissected into separate faculties only by neglecting the richness of mental life. We end by pointing to future directions for processing approaches.

The levels-of-processing framework has guided research in cognitive psychology and related fields since publication of the seminal paper by Craik and Lockhart (1972) that proposed the theory and the multi-experiment paper by Craik and Tulving (1975) that developed the methods of study. Both papers built on earlier work (e.g., Treisman, 1964, for levels in the cognitive system and Hyde & Jenkins, 1969, for methods), but they stand out as unique contributions, as evidenced by their overwhelming impact on the field. According to the *Web of Science* citation counts, by May, 2002 (30 years after the original "levels" paper) the 1972 paper had been cited approximately 2700 times and the 1975 paper had been cited approximately 1300 times. We can find no other paper (or chapter or book) published in cognitive psychology during this era that is as highly cited as Craik and Lockhart's 1972 paper. Its impact has been enormous.

The levels-of-processing account generally proposed that the level at which an event is coded in the cognitive system determines later recall and recognition for that event. Although the framework and method gained immediate popularity, the framework also attracted numerous critics (e.g., many chapters in the Cermak and Craik, 1979, edited volume are devoted to this endeavour). Many of these criticisms were directed at the ideas that (1) there are strict "levels" of the cognitive system through which information flows, and (2) information processing can be arrested at a particular level. Roediger and Gallo (2002) recently reviewed several theoretical and empirical challenges to the levels-of-processing explanation of how orienting tasks influence retention. They pointed out that Craik and Tulving's (1975) original experiments, and subsequent experiments by Craik (1977) and others, raised several fundamental questions that remain unanswered. Roediger and Gallo (2002) concluded that, 30 years later, the levels-of-processing theory, in its original form, cannot explain what has come to be called the levels-of-processing effect—the powerful effect of orienting tasks on recall and recognition. They argued that we still have no satisfactory theory of the effect of orienting tasks on retention, despite the wide popularity of the method over the past 30 years.

In this paper we do not want to deal with the mixed success of the concept of "levels of the cognitive system" and how orienting tasks determine retention. Rather, we focus on the other half of the title of the original paper—processing. More precisely, we consider processing approaches to cognition, and argue that Craik and Lockhart's (1972) paper propelled processing approaches to cognition to the forefront of the field. We consider the history of processing approaches to cognition, and suggest that the levels-of-processing approach helped to change the zeitgeist in the 1970s and succeeding decades. We then point to the need for further development of the processing approach.

## PRECURSORS TO MODERN PROCESSING APPROACHES TO COGNITION

The history of psychology is replete with examples of the tension between structural and more action-oriented approaches to the study of the mind (Boring, 1950). For instance, phrenologists and faculty psychologists proposed that the mind is composed of separate and distinct faculties. Although their specific endeavour did not succeed, their spirit lives on in the work of those who seek the specific function of brain structures to provide localisationist accounts of the mind. Using different methods, Wundt, Titchener, and others of their school also attempted to discern the structure of mental life. However, they approached structure through analytic introspective techniques that eventually foundered due to unreliability of results across laboratories. Whereas these structuralists were interested in determining the structure of perceptual experience, other early researchers were interested in determining the neural structures that support memory. The first half of the 20th century was devoted to the search for the engram, or memory trace, using ablation experiments in animals, but Lashley (1950) famously pronounced the search a failure. Later cognitive models followed in the structural tradition and proposed that mental life could be captured by information flow charts using box-and-arrow diagrams. Support for the structural account also came from neuropsychological studies of patients such as H.M. whose damage to the hippocampus and surrounding areas provided fresh insight into neural structures responsible for memory functioning. All these approaches examined, in one way or the other, the structure of the mind/brain system.

On the other hand, for nearly every one of these structural approaches there was a counter "activity-based" or processing approach. For example, the act psychologists of the Würzburg school in Germany, following the lead of the philosopher Brentano, argued that the appropriate approach to mental life should focus on activity, or mental acts. According to these psychologists, all mental phenomena are inherently composed of acts and intentions—the stimulus cannot be considered in the absence of the goal or the processing of the stimulus. They contrasted their approach to the static content-based approach of Wundt's structuralists and argued that the mind/brain system cannot be usefully explained by static structures in the mind. However, the act psychologists never provided an experimental programme to study activities of mind and so the act school never developed very fully.

At various points in his writings, William James (1890) argued for a more action-oriented approach. Rather than believing that consciousness could be broken down into static structures, as the introspectionists' methods assumed, he argued in a famous quote for a "stream of consciousness" that was ever changing and flowing. In remembering, too, he noted that activity was critical. For instance, James (1890, p. 686) anticipated both the generation effect (Jacoby, 1978; Slamecka & Graf, 1978) and the testing effect (e.g., Wheeler & Roediger, 1992), when he noted that:

> A curious peculiarity of our memory is that things are impressed better by active than by passive repetition. I mean that in learning by heart (for example), when we almost know the piece, it pays better to wait and recollect by an effort from within, than to look at the book again. If we recover the words in the former way, we shall probably know them the next time; if in the latter way, shall very likely need the book once more.

An activity-based approach to cognition was also developed in Russia by Zinchenko, Vygotsky, and Leont'ev (see Wertsch, 1979). This approach was different in that it pervaded all of Russian psychology, not just the study of cognition or memory. However, in his introduction to his book, Wertsch notes parallels to the levels-of-processing tradition of memory research. For example, he describes Zinchenko's work on what he called

"involuntary memory", which was essentially about the effect of various activities performed under incidental learning conditions on later retention. As in the levels-of-processing framework, the activities performed in engaging material in the environment were said to determine retention, not intent to learn the material *per se*. According to Leont'ev (1959, 1975, as cited in Wertsch, 1979) this activity can be examined at both a global level regarding the goals of an activity and a local level regarding the particular operations carried out in the service of the overarching goal. For example, if one is trying to remember a list of words and, in doing so, forms images of the words, the goal can be described as better retention of the words and the local operation as forming images in service of this goal (Wertsch, 1979, p. 19). The Russian approach to cognition can be seen as more encompassing than most western approaches in that goals and motives were an integral part of the account (and are often neglected or assumed in memory theories in the West). The work of Zinchenko (1962; translated in Wertsch, 1979) is most relevant to issues of memory and the brief summary here does not do it justice. Suffice it to say, Zinchenko's work (following on the work of Leont'ev and Vygotsky) provides another example of an action-oriented cognitive approach to explaining human memory.

Craik and Lockhart's (1972) contribution again placed emphasis on processing, or the activities of mind. They saw their approach as running counter to the "boxes in the head" information-processing approaches of the 1960s (although to be fair, the Atkinson and Shiffrin, 1968, theory, at least, emphasised processing operations as well as structures). Nonetheless, Craik and Lockhart's heavy emphasis on processing activities as important determinants of retention played a central role in the approach, and provided a new perspective in cognitive psychology. In discussing the powerful role that encoding tasks had on retention across some ten experiments, Craik and Tulving (1975, p. 290) concluded that:

> It is abundantly clear that what determines the level of recall or recognition of a word event is not intention to learn, the amount of effort involved, the difficulty of the orienting task, the amount of time spent making judgments about the items, or even the amount of rehearsal the items receive …: rather it is the qualitative nature of the task, the kind of operations carried out on the items, that determines retention".

Further, "subjects remember not what was 'out there' but what they *did* during encoding" (p.292). Craik and Tulving argued that "The problem now is to develop an adequate theoretical formulation which can take us beyond such vague statements as 'meaningful things are well remembered'" (p. 290).

The levels-of-processing account was an attempt to bring focus on the processes, or the procedures used in perception and comprehension of the world and how they affected memory. Retention was seen as a relatively automatic byproduct of the activities of mind during perception and comprehension, and "encoding" as a special process had no distinct status (but see Tulving, 2002). Crowder (1993) argued that "Modern memory theory has more or less embraced proceduralism during the last 20 years", and that "One measure of this has been the wide acceptance of the levels-of-processing framework for memory" (p. 139). While heartened by Crowder's conclusion, we think it may be somewhat premature. Although some developments in the field are coloured by processing approaches, we suggest that the field in general has not yet been able to develop an adequate characterisation of procedures that account for memory phenomena despite efforts in this direction (e.g., Kolers & Roediger, 1984).

In the remainder of this paper, we attempt to develop more fully the proceduralist account by reviewing the memory research of Paul Kolers and by using examples from research contrasting explicit and implicit memory processes. In doing so, we illustrate the tension between the procedural and structural approaches that occur even in current memory theorising. We are optimistic, though, that researchers are increasingly coming to realise that these approaches are not mutually exclusive, but rather are complementary (e.g., Roediger, Buckner, & McDermott, 1999; Schacter, 1990; Tulving, 1999).

## KOLERS' PROCEDURAL APPROACH

Paul Kolers was perhaps the foremost champion of a procedural approach to the mind during the 1970s and early 1980s, before his untimely death in 1986. Kolers (1973, 1975a,b, 1976, 1979; Kolers & Ostry, 1974) provided a programme of research that embodied a more action-oriented approach to cognitive processing. He was originally inter-

ested in the study of reading, which is quite skilled in adults. In an effort to understand this skill and study how it developed, he took adult readers (college students) and challenged them by providing text for them to read that was misoriented in various ways. He discovered that, with many days of practice, students could come to read text presented (for example) upside down nearly as fast as they could read text presented in its normal orientation. In some experiments Kolers had people reread passages of text at various delays after the original reading (e.g., Kolers & Ostry, 1974) and measured the savings in reading speed. This savings measure, like Ebbinghaus's (1885/1964) original savings method, provided an indirect measure of retention. In Kolers' work the savings reflected savings of the pattern-analysing operations used in rereading the passage. In some studies, the savings in rereading were uncorrelated with subjects' conscious recognition of the content of the passages (Kolers, 1976), representing a dissociation between two measures of retention. This finding can be seen as one of the first experimental demonstrations of a dissociation between a conscious (or direct or explicit) measure of retention and an unconscious (or indirect or implicit) measure of knowledge (for related work see Masson, 1984). Other examples of such dissociations came from work conducted in both neuropsychological and experimental traditions.

In neuropsychology, Warrington and Weiskrantz (1968, 1970) compared performance of brain-damaged subjects to healthy controls on a variety of memory tests. They showed powerful dissociations between measures of conscious recollection (free recall, recognition) and measures of priming on tasks such as naming fragmented words and pictures (tasks that would later be classified as implicit memory tests; Graf & Schacter, 1985). Although Warrington and Weiskrantz did not originally conceptualise their results in this way, this interpretation is now accepted from later work in which the early findings were confirmed and extended using a variety of patient groups and measurement operations (e.g., Graf, Shimamura, & Squire, 1985; for a review see Moscovitch, Vriezen, & Goshen-Gottstein, 1993). Within experimental psychology, the search for dissociations between measures of retention also became a holy grail of sorts, with many researchers in the 1980s reporting such findings (Jacoby, 1983; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987a; Tulving, Schacter, &

Stark, 1982, Weldon & Roediger, 1987, to mention just a few). Dissociations both in neuropsychological research and experiments with college student populations were the primary evidence for the postulation of multiple memory systems in the 1980s (e.g., Squire, 1987; Tulving, 1983). In virtually all of the relevant experiments of that era, two measures of memory were contrasted. One measure (usually recognition or free recall) was thought to tap a conscious, recollective form of memory and the other measure assessed priming or savings on some transfer test that did not depend on conscious recollection. The two classes of test were variously called direct and indirect (e.g., Richardson-Klavehn & Bjork, 1988) or explicit and implicit (Graf & Schacter, 1985) and different memory systems were invoked to explain these tests differences (episodic and semantic, Tulving, 1983; declarative and procedural, Squire, 1987).

As long as the experimental comparison was between two tests as a function of independent and subject variables, much evidence could be obtained to support the notion of a relatively small number of memory systems as proposed, for example, by Tulving (1983). Roediger (1984) argued that, at a minimum, studies claiming dissociations between memory systems should employ at least two separate measures of the construct of interest, not just one. So, for example, one should employ two or more measures of episodic memory and two or more measures of priming on a semantic memory task, to be sure that dissociations did not occur between tests that allegedly measured the same system. Few researchers have employed this strategy, but the work done by Kolers in his rather different tradition in the 1970s had already shown that dissociations could be quite commonplace even between highly similar measures of retention.

A good example comes from Kolers and Perkins (1975). They had seven groups of students read 24 pages in one of seven types of transformed text. The transformations are shown here in Table 1 by providing a sample sentence. After this extensive practice in reading one transformation, the students next read two pages of text in each of the seven transformations, in an appropriately counterbalanced order. Of interest was how the practice at reading one transformation would transfer to the other six. The answer is provided in Table 2, where the measure is percentage of transfer. The measure of reading the trained transformation during the test was set to equal

TABLE 1
Examples of transformed texts used in Kolers and Perkins (1975). Asterisks show where to begin reading each example.

**N**

*Expectations can also mislead us; the unexpected is always hard to
perceive clearly.  Sometimes we fail to recognize an object because we

**R**

*Emerson once said that every man is as lazy as he dares to be.  It was the
kind of mistake a New England Puritan might be expected to make.  It is

**I**

*These are but a few of the reasons for believing that a person cannot
be conscious of all his mental processes.  Many other reasons can be

**M**

*Several years ago a professor who teaches psychology at a large
university had to ask his assistant, a young man of great intelligence

**r N**

*On his first day in topsy-turvy land he was thoroughly disoriented.
His feet were above his head; he had to reason for them when his

**r R**

*A very young child of scarcely more than a year was merely a
visual image that arrest and leaves the sense that each eyes away

**r I**

*Psychology began during the nineteenth century, at a time when thought
by detained was thought during the scinecg during the emaceb psychology

**r M**

*Imagine two different pictures. One shows a bright red circle on a pale
yellow background, the other a bright green circle on a gray background.

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**TABLE 2**
Percentage transfer from training to test

| Training | M | R | rR | rN | rl | I | rM | Average |
|---|---|---|---|---|---|---|---|---|
| I | 95 | 118 | 97 | 80 | 84 | 100 | 52 | 89 |
| rl | 92 | 112 | 90 | 82 | 100 | 78 | 72 | 89 |
| rR | 81 | 84 | 100 | 68 | 56 | 79 | 56 | 74 |
| rM | 88 | 67 | 70 | 57 | 37 | 44 | 100 | 66 |
| R | 87 | 100 | 70 | 37 | 58 | 44 | 41 | 62 |
| M | 100 | 69 | 71 | 72 | 38 | 28 | 52 | 61 |
| rN | 82 | 3 | 57 | 100 | 36 | 34 | 20 | 47 |
| Average | 89 | 79 | 79 | 71 | 58 | 58 | 56 | 70 |

100%—how well reading one type of text transferred to reading those last two pages of text in that transformation. Reading the other transformations usually (but not always) produced less transfer, so that most of the values in Table 2 are less than 100. However, in some interesting cases, reading one transformation (e.g., reading Inverted text, or I) transferred better to reading another transformation (e.g., Rotated, or R) than did reading the original transformation itself (118% transfer in this case). On the other hand, reading transformation rN hardly transferred at all to reading rotated text (3%).

Reading the final two pages of text can be considered an indirect measure of retention or transfer. Starting at Table 2, and examining many possible $2 \times 2$ combinations of study and test conditions, leads inexorably to the conclusion that even the highly similar tasks of reading various orientations of text can lead to numerous dissociations among memory measures. Dissociations among memory measures, even relatively similar ones, can be seen as a perfectly natural state of affairs from a procedural approach (Kolers & Roediger, 1984). The difficulty is in specifying the procedural approach and distinguishing various types of procedures.

## TRANSFER-APPROPRIATE PROCESSING

During the same period that Kolers was developing his ideas about procedures of mind, Morris, Bransford, and Franks (1977) and Bransford, Franks, Morris, and Stein (1979) provided a useful parallel development by proposing the notion of transfer-appropriate processing. Briefly, they endorsed the idea that a proper account of mind and memory should emphasise mental procedures, but they criticised the levels-of-processing approach as focusing only on processing during encoding of events as determining later retention. Rather, they pointed out that retention was determined by how well the processing requirements of the test matched those used originally to encode information.

In the Morris et al. (1977) experiments, subjects encoded words phonemically or semantically. On a standard recognition test, semantic encoding led to greater recognition than phonemic encoding, the standard finding in the levels-of-processing paradigm (Craik & Tulving, 1975). However, on a novel rhyme recognition test—does this word rhyme with a word seen during encoding?—the standard levels-of-processing effect was eliminated or, in some conditions, even reversed, such that phonemic processing during encoding led to greater recognition than did semantic processing. Other researchers reported similar results from slightly different paradigms (Fisher & Craik, 1977; Hunt & Elliott, 1980; Jacoby, 1975; McDaniel, Friedman, & Bourne, 1978). Types of processing during encoding therefore cannot be said to be inherently deep or shallow (or good or bad) for later retention; rather, it depends on the demands of the situation in which knowledge is assessed (see Kolers & Roediger, 1984, for further discussion).

Roediger and Blaxton (1987b) and Roediger, Weldon, and Challis (1989b) developed the transfer-appropriate processing framework to help account for the burgeoning literature showing dissociations between explicit and implicit memory tests. The hope was that a relatively small set of principles would account for the welter of dissociations being discovered and predict new dissociations. Roediger et al. (1989b) made four assumptions. The first assumption followed directly the principles of transfer-appropriate processing or encoding specificity (Tulving & Thomson, 1973) and stated that memory tests benefit to the extent that the operations they require overlap or recapture the operations used during encoding. The second assumption is that most (but not all) explicit and implicit memory tests rely on different types of processing. The third assumption is that most standard explicit memory tests (free recall, cued recall, recognition) depend primarily on meaningful (conceptual, semantic) information for their successful performance. The fourth assumption is that most implicit memory tests in standard use rely on perceptual information, or are data-driven. For these tests, the match in perceptual processes between study and test matters much more than the match in meaning-based processing. These last two assumptions were drawn from provocative experimental work of Jacoby (1983).

The distinction between perceptual and conceptual forms of test advanced by Roediger et al. (1989b; see also Roediger, 1990) attempted to provide some further specification to the processing approach, at least in terms of two broad types of processing. The framework was successful because it permitted the prediction of many dissociations between tests. Just as Morris et al. (1977) obtained interactions or dissociations

between two types of explicit recognition tests, so experiments done within the transfer-appropriate processing framework revealed dissociations between implicit memory tests. For example, Blaxton (1989) and Srinivas and Roediger (1990) showed dissociations in priming on implicit tests such that a variable could have one effect on a perceptual implicit test and the opposite effect on a conceptual implicit test. Weldon and Roediger (1987, Experiment 4) showed that two perceptual implicit memory tests could themselves be dissociated if the operations required between study and test matched or mismatched, as discussed in more detail later. Dissociations among memory measures—explicit or implicit—can be easily achieved, even when the memory tasks involved are thought to be undergirded by the same memory system (see Roediger, Srinivas, & Weldon, 1989a, for a review).

Although generally successful in explaining dissociations between tests, Roediger et al.'s (1989b) transfer-appropriate processing approach attracted critics due to both conceptual and empirical problems. A first problem is that a strict procedural approach does not concede a sharp contrast between perceptual levels of analysis (specific, data-driven) and a conceptual level of analysis (abstract, semantic) (Kolers, 1978). Rather, perceptual experience gives rise to meaning and even perceptual recognition depends on classifying objects into abstract categories (horse, tree). Roediger et al. (1989a) attempted to finesse this point by referring to perceptual and conceptual continua of experience such that a picture or word could be treated more as a perceptual object or more as an abstract entity; the two dimensions need not trade off against one another (see also Weldon, 1991).

In addition to this conceptual problem, problematic data also appeared, showing dissociations among perceptual and conceptual tests (e.g., Cabeza, 1994; Hunt & Toth, 1990; McDermott & Roediger, 1996; Tenpenny & Shoben, 1992; Vaidya et al., 1997; Weldon & Coyote, 1996). For example, McDermott and Roediger (1996) and Weldon and Coyote (1996) showed that pictures and words produced equivalent levels of priming on two conceptual implicit memory tests, rather than pictures producing greater priming, as predicted by Roediger et al.'s (1989a) theory. In contrast, Cabeza (1994) showed an unexpected dissociation in priming between two conceptual implicit memory tests. Thus, although the distinction between perceptual and conceptual pro-

cesses helps to capture a large-grained distinction of importance, clearly the theory must be developed much further to capture the more fine-grained aspects of retention on the many different types of memory test (see Roediger & McDermott, 1993). We note, though, that many of the dissociations among conceptual or perceptual tests can be accommodated within a proceduralist approach to memory if the exact type of conceptual or perceptual processing is considered (see Geraci & Rajaram, in press; Geraci & Rajaram, 2002). Therefore, we argue that performance on both explicit and implicit memory tests—and therefore, we would argue, on all memory tests—hinges on highly specific aspects of encoding/retrieval interactions, a point to which we turn next.

## SPECIFICITY OF PROCESSING

One central tenet of the procedural approach is that performance depends on the *specific* match of encoding and retrieval (a point emphasised in this issue by Reingold, 2002). This claim is in contrast to abstractionist theories such as those of Anderson (1990, p. 122) that claim that:

> Representations that do not preserve the exact perceptual structures of the events remembered are the mainstay of long-term memory. It is important to appreciate that these meaning representations are neither linguistic nor pictorial. Rather they encode the meaning of pictures and linguistic information.

The proceduralist programme of research has shown, to the contrary, that recapitulating specific encoding and retrieval operations enhances performance.

Let us consider one example of such processing specificity involving pictures and words. Weldon and Roediger (1987) had students study pictures and words and then different groups were given either an explicit free recall test or an implicit word fragment completion test. As is often found, pictures were better remembered than words in free recall (the picture superiority effect). However, words produced much more priming than did pictures on the implicit word fragment completion test. In a later experiment, the one of more interest for present purposes, Weldon and Roediger again presented pictures and words during study but now participants received an implicit test of either word fragment completion or picture

fragment naming. Now, as expected, the experience of studying pictures and words transferred differentially to tests: pictures showed more priming on picture fragment completion, whereas words showed more priming on word fragment completion.

McDermott and Roediger (1994, Experiment 4) replicated this pattern under somewhat stricter test conditions and their data are shown in Figure 1. Again, on the verbal implicit test, words produced more priming than pictures; on the pictorial test, pictures produced more priming than words. The amount of cross-form priming was quite low and not significant, showing the highly specific nature of the encoding/retrieval match necessary for priming. For example, seeing a picture of an elephant produced essentially no priming on completing a word fragment of e_e_h_n_. Interestingly, if subjects were given a picture during study and asked to imagine the written name of the concept, then a small amount of cross-form priming did occur (and conversely when words were studied with the imagine-a-picture instruction on the picture fragment naming test). So, cross-form priming was obtained when subjects had imagined words at study (when given pictures) or imagined pictures at study (when given words). McDermott and Roediger (1994) pro-

posed that instructing subjects to form relevant images engaged top-down imaginal processes that could transfer to the test situation, albeit at an attenuated level relative to actual perception (see Pilotti, Gallo, & Roediger, 2000, for relevant findings with auditory materials). These dissociations between priming tasks demonstrate similar processing specificity as shown in Table 2 from Kolers and Perkins' (1975) work. Roediger and Srinivas (1993) and Reingold (2002) review many examples of specificity in implicit memory tests, but of course the same kinds of encoding/retrieval interactions can be obtained in explicit tests, too (e.g., Balota & Neely, 1980; Morris et al., 1977). The concepts of encoding specificity and transfer-appropriate processing were, after all, first developed to explain such effects on explicit tests (cued recall and recognition).

The transfer-appropriate processing framework was originally intended as an alternative to memory systems interpretations of these data. However, accumulating evidence over the years has made it clear that the original framing of the question in terms of ''systems and processes'' was too simplified. Performance on tests designed to measure the ''same'' system can be dissociated, which poses a problem for the idea that only a few memory systems underlie all performance. For
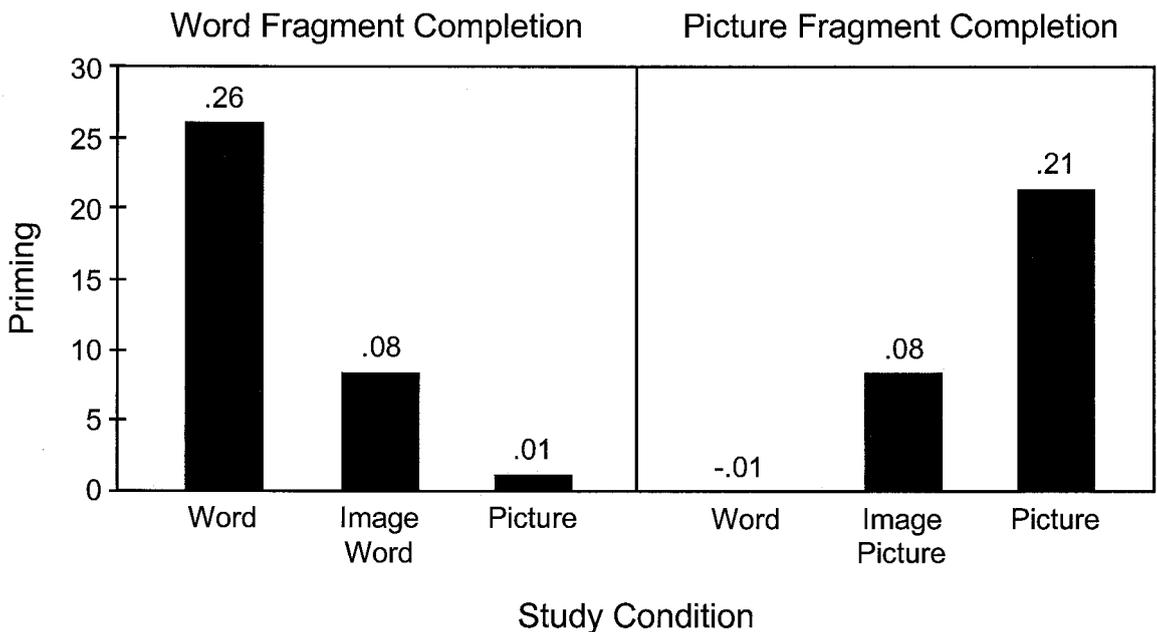


**Figure 1.** Demonstration of processing specificty between encoding and retrieval (McDermott & Roediger, 1994, Experiment 4). Subjects studied words or pictures, and were asked either to make pleasantness ratings of the presented stimulus or to form a mental image in the opposite format (and to rate its vividness). Implicit memory was tested using either a word fragment completion test or a picture fragment naming test.

example, when Blaxton (1989) showed dissociations between tasks that should, according to Tulving's (1972, 1983) theories, reflect semantic memory, Tulving and Schacter (1990) proposed that some tasks (including the ones used by Blaxton) were underlain by a perceptual representation system. Therefore, dissociations between tasks could be explained by appeal to differences between perceptual representations (essentially data-driven or perceptual processing in Roediger et al., 1989b) and other systems.

This idea is fine as far as it goes, but within perceptual or data-driven tests it is perfectly possible to dissociate verbal from pictorial tests (McDermott & Roediger, 1994; Weldon & Roediger, 1987), auditory from visual tests (Habib & Nyberg, 1997), and visual from tactile tests (Srinivas, Greene, & Easton, 1997). In short, "the" perceptual representation system really refers to the fact that priming can occur in various modalities that transfer imperfectly from one to another. Even for visually presented words there can be different levels of priming depending on the match or mismatch in perceptual features between study and test (Graf & Ryan, 1990; Roediger & Blaxton, 1987b), and similarly for auditorily presented words (Church & Schacter, 1994; Pilotti, Bergman, Gallo, Sommers, & Roediger, 2000). Hayman and Tulving (1989) argued that perceptual systems exhibit "hyperspecific" priming effects. Kolers' work from the 1970s had demonstrated the same point (Kolers, 1975b; Kolers & Perkins, 1975). We assume no one would propose that a different memory system underlies reading of each type of transformation of text shown in Table 1 that produces the dissociations seen in Table 2. Rather, an appropriate account should appeal to the perceptual/cognitive procedures used in developing skill in reading various kinds of transformed text.

Of course, neurocognitive systems underlie all cognitive performance, so there is no gainsaying the need to refer to these systems. The point to emerge from the procedural framework is that neurocognitive systems are complex and interactive, not encapsulated. Moscovitch (1992, 1994) and Roediger et al. (1999) have championed a components-of-processing approach in which any task can be seen as a more or less complex concatenation of component processes that are underpinned by local neurocognitive systems. Changing task requirements can easily add or subtract one or more components that can produce dissociations. The upshot is that to dissociate

any two tasks one only need change one component (see also Hintzman, 1990; Tenpenney & Shoben, 1992). Roediger et al. (1999) proposed that future memory systems theories may appear more like the wiring diagrams discovered from animal work for the visual system (Van Essen, Anderson, & Felleman, 1992), with complex interactive patterns of connection. The neurocognitive systems that underlie retention will involve components from many brain regions in complex networks. As Crowder (1993, p. 145) noted, "The resolution of the systems argument is obvious from a proceduralist point of view. Of course there are different systems of memory, but systems as defined by different ensembles of information processing units—different codes—not different organizational or operational rules." For example, a principle such as transfer-appropriate processing or encoding specificity may apply to retention in all systems. To continue with Crowder's point, "In general the number of different memory systems is a count of the number of different information processing ensembles that can be recruited to do the cognitive work required for a task" (Crowder, 1993, p. 145).

## FUTURE DIRECTIONS

"Proceduralism, in memory theory, is the idea that memory storage for an experience resides in the same neural units that processed that experience when it happened in the first place" (Crowder, 1993, p. 139), as opposed to some special store or system in which information resides after it has been processed. Modern neuroimaging experiments are showing the truth of this central tenet of proceduralism that could not have been imagined when the 1972 levels-of-processing paper was originally published. This work shows that brain activation patterns at test mimic the processing from study. For example, Wheeler, Petersen, and Buckner (2000) had people study pictures and sounds that corresponded to a descriptive label (e.g., the word "dog" was accompanied either by a picture of a dog or the sound of a dog barking). At test, subjects were given the same descriptive label and asked to mentally recall the corresponding referent (i.e., the picture or the sound). Using event-related fMRI methods, Wheeler et al. (2000) showed that successful picture recall was associated more with visual cortex activation, and successful sound recall was associated more with auditory cortex activation. Importantly, these

regions were a subset of those regions that were activated during a perception task, in which subjects saw the same descriptive labels paired with their actual percept (the picture or the sound). Similar findings have been reported by Nyberg, Habib, McIntosh, and Tulving (2000), who showed that some of the same auditory regions that were active during the encoding of sounds were reactivated during the recall of those sounds. Collectively, these studies suggest that similar neural structures support perception, encoding, and retrieval, which is consistent with the proceduralist point of view.

McDermott and Watson (2002) provided further support for the idea that retrieval relies on brain regions that were involved in encoding. Participants read lists of words related in terms of either phonology (*beep, weep, peep, sheep* …) or in terms of meaning (*bed, rest, awake, dream* …) while neural activity was assessed with fMRI. During encoding, some regions (e.g., within left anterior ventral inferior frontal cortex and left middle/superior temporal cortex) were more active for the meaningfully associated lists, whereas other regions (e.g., within left posterior dorsal inferior frontal cortex and bilateral/inferior/superior parietal cortices) demonstrated more activation for lists of rhyming words. Using a free choice recognition test, patterns of reactivation were obtained; that is, some regions showing preferential activation for semantics during encoding also showed greater activation for hits studied in the context of semantic associates (e.g., *rest*) than for hits studied in the context of rhymes (e.g., *peep*). Conversely, some regions showing preferential activation for phonology during encoding also showed greater activation for hits to words studied in the context of phonological associates than for hits studied in the context of semantic associates.

The design of McDermott and Watson's study permitted a novel comparison that was not possible in the other studies cited earlier. Their materials were designed to elicit false recollection of a nonpresented word (*sleep* for the materials just described). After reading the list of phonemically or semantically similar words, false recognition of a related word such as *sleep* occurs very frequently (Roediger & McDermott, 1995; Sommers & Lewis, 1999). Interestingly, when subjects falsely recognised the related word in McDermott and Watson's study, the patterns of activation were similar to those obtained for the studied words. That is, when falsely recognising *sleep* after the

relevant phonemic list, the phonological regions were preferentially active, whereas when falsely recognising *sleep* after the semantic list, the semantic regions were preferentially active. This pattern is even more striking, because the actual test item (e.g., *sleep*) was the same in the two cases. McDermott and Watson's experiment shows that the type of processing during test recruits the same brain regions as engaged during study even with the test item held constant.

Neuroimaging studies of memory retrieval have generally shown that retrieval processes require a complex interaction of cooperating systems. Many of the brain regions identified through neuroimaging studies are ones that had not been identified from patient or animal studies as important to learning and memory. Just as visual perception involves the complex interaction of neural systems, so recent results suggest that similar complex systems underlie language processing (Dronkers, Redfern, & Knight, 2000) and memory processing (Roediger et al., 1999; Nyberg, Forkstam, Petersson, Cabeza, & Ingvar, 2002).

The procedural approach argues that encoding is not the passive laying down of traces, but a constructive activity. Another discovery from recent neuroscientific approaches that is consistent with this aspect of the procedural approach is that of mirror neurons in premotor cortex. The majority of work in this area has involved single-unit recordings in monkeys, but a few neuroimaging studies have extended the basic findings to humans (see Rizzolatti, Fogassi, & Gallese, 2000, for a review). The basic finding is that populations of mirror neurons selectively respond to specific types of motor actions both when an action is performed (i.e., an object is grasped) and when the identical action is only observed (i.e., another monkey grasps an object). Further, more than half of these neurons are very specific, in that they will only respond when a very specific type of action is performed or observed (e.g., grasping vs placing). These findings suggest that the same neural assemblies that are active during the perception of a behaviour (which ostensibly involves identification from long-term memory and encoding into episodic memory) are also involved in the actual performance of that behavior. Further, Nilsson et al. (2000) have shown that when people perform action events during encoding and recall them later, motor cortex is reactivated during their retrieval (relevant to an appropriate control). These findings fit well with an action-

oriented approach to cognition as embodied in the procedural approach.

## CONCLUSION

The procedural approach to understanding the mind/brain system in general and human memory in particular has proven quite fruitful. The levels-of-processing framework helped to develop the approach in the 1970s, along with the developments of Kolers' procedural viewpoint and transfer-appropriate processing theory. Although there are a variety of approaches to studying memory, the processing or procedural approach surely has and will continue to have a central role in furthering our understanding.

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