Unconscious Memory Representations in Perception

Edited by

István Czigler and István Winkler

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Processes and mechanisms in the brain

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Preface

The study of processes underlying conscious experience is a traditional topic of philosophy, psychology, and neuroscience. In contrast, until recently, the role of implicit (non-conscious) memory systems needed to establish veridical perception received much less discussion. With many new results and novel theoretical models emerging in recent years, it is time to take a look at the state of art in psychology and neuroscience about the role non-conscious processes and memory representations play in perception.

Although behavioral studies (e.g. priming) in cognitive psychology yielded indirect evidence about many of the characteristics of implicit memory representations, cognitive neuroscience and computational modeling can provide more direct insights into the structure and contents of these representations and the into various processes related to them. This book presents several different approaches of the study of implicit memory representations, using both psychological, neuroscience and computational modeling methods, assessing these representations in relatively simple situations, such as perceiving discrete auditory and visual stimulus events, as well as in high-level cognitive functions, such as speech and music perception and aesthetic experience.

Each chapter reviews a different topic, its theoretical and major empirical issues. A large part of the results reviewed in this book were obtained through recording event-related brain potentials (ERP). This is because ERPs offer high temporal resolution, and as a consequence, they are sensitive indicators of the dynamics of human information processing. Non-expert readers are offered with an appendix to help to understand and assess the ERP data reviewed in the various chapters. However, ERPs provide less precise information regarding the sources of the observed neural activity in the brain. Therefore, an increasing amount of research utilizes more recent brain imaging methods, such as functional magnetic resonance imaging (fMRI), whose spatial resolution exceed that of the ERPs. Although the experimental paradigms used in brain imaging are often not yet as highly specific as those worked out through the years in behavioral or ERP research, some of these studies already brought significant new insights into the working of implicit memories. Common to all chapters is the approach that empirical evidence is evaluated in terms of its importance to models of the processes underlying conscious perception.

In the first chapter, *Gilchrist and Cowan* review the role of working memory in conscious as well as in non-conscious cognitive processing. *Verleger's* chapter discusses ERP components related to subjective experience and non-conscious processes. *Winkler* suggests that predictive representations of acoustic regularities form the core of auditory perceptual objects, while *Denham, Dura-Berna, Coath and Balaguer-Ballester* describe a neurocompuational approach to model the processes underlying perceptual objects. The role of sensory memory in automatic visual change detection and perception is discussed in *Czigler's* chapter. *Huotilainen and Teinonen* focus on the role of learning and implicit memory in perceptual development. *Shtyrov and Pulvermüller's* chapter describes a novel paradigm for studying the memory representations involved in speech perception. They evaluate the relevant theories in light of their results and provide new insights into the non-conscious processes underlying speech perception. *Koelsch* presents an advanced theory of the perception of musical structure, emphasizing the role of non-conscious processes and implicit memory representations. Finally, the role of non-conscious and conscious processes in aesthetic appreciation is explored in *Jacobsen's* chapter. In the Appendix, *Bendixen* provides a concise description of the ERP method.

In summary, this book provides a theoretical and empirical overview of the various topics of and approaches to the question: What is the role of non-conscious memory representations in perception?

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István Czigler and István Winkler
Budapest, November 2009

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CHAPTER 1

Conscious and unconscious aspects of working memory

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1.1 Working-memory models and consciousness

A simple (and, alas, oversimplified) history of working memory models helps to lend perspective to the present endeavor. George Miller (1956) is generally credited with kicking off a renaissance in the study of temporary memory related to the conscious mind, in his published speech on the limit of temporary memory to "the magical number seven plus or minus two" (though many researchers failed to understand his humorous intent in describing a magical number surrounded by confidence intervals). Shortly afterward, Miller et al. (1960) coined the term *working memory* to describe the memory for current goals and a small amount of information that allows one's immediate plans to be carried out. Several models using something like this working memory concept will now be described.

1.1.1 Information-flow models

Broadbent (1958) proposed a very simple model of memory that took into account the latest evidence; in that model, a large amount of sensory information was encoded in a temporary buffer (like what is now called working memory). However, only a small proportion of it ever made its way into the limited-capacity part of memory, where it was analyzed and categorized with the benefit of the vast amount of information saved in long-term memory, and eventually added to that long-term bank of knowledge. Atkinson and Shiffrin (1968) then developed that sort of memory framework into a more explicit model in which mathematical simulations were made of the transfer of information from one store to another through encoding, retrieval, and rehearsal processes.

1.1.2 Multi-component models

Baddeley and Hitch (1974) soon found that this simple treatment of working memory would not do. In addition to information temporarily held in a form likely to be related to consciousness (James 1890), they argued in favor of other storage faculties that operated automatically, outside of voluntary control. Broadbent (1958) already had conceived of sensory memory that way, but sensory memory was not enough. There was said to be a phonologically-based temporary memory store that was vulnerable to interference from additional verbal items, no matter whether their source was visual or auditory. Similarly, there was a visuo-spatial temporary memory store responsive to the spatial layout and visual qualities of items; in theory, this store would be vulnerable to interference from spatial information even if its source were auditory. Baddeley (1986) later thought he could do without the central store or primary memory entirely; whereas Baddeley (2000) essentially restored it in the form of an episodic buffer.

1.1.3 Activation-based models

A form of model that will become the centerpiece of this chapter is the activation-based model. In that sort of model (Anderson 1983; Cowan 1988; Hebb 1949; Norman 1968; Treisman 1964) a temporary form of storage such as working memory is viewed not as a separate location in the mind or brain, but rather as a state of activation of some of the information in the long-term memory system. Hebb (1949) envisioned this activated memory as a cell assembly that consisted of a neural firing pattern occurring repeatedly so long as the idea it represented was active. Treisman (1964) and Norman (1968) distinguished between subliminal amounts of activation, which might influence behavior but not consciously, and supraliminal amounts, which attracted attention to the activated item, especially if it was pertinent to the person's current goals and concerns. Anderson (1983) used the process of activation as a way to bring long-term knowledge into working memory.

The instance of the activation-based models that we will discuss in most detail is the one that Cowan (1988, 1999) designed as a way to express what he believed to be known at the time. There were awkward aspects of the box-based models of the time, such as the well-known ones of Atkinson and Shiffrin (1968) and Baddeley (1986). These models did not readily express the assumption that information co-exists in several forms at once. Sensory information can be accompanied by more categorical information that is drawn from long-term memory into working memory. For example, the acoustic properties of a speech sound elicit the appropriate sound category that is stored in long-term memory. Other sensory information persists without invoking long-term memory information. Cowan (1988, 1999) represented this state of affairs with embedded processes. Temporarily-activated features of memory can include both sensory and abstract features. Some of these features become active enough, or active in the right way, to become part of the individual's current focus of attention, which is of limited capacity. The focus of attention is controlled in part voluntarily, and in part involuntarily through the brain's reactions to abrupt physical changes in the environment (such as a sudden change in lighting or a loud noise).

In the original model of Broadbent (1958), unattended sensory information was filtered out so that it faded away without ever reaching the capacity-limited store. This model became untenable when it was found that aspects of unattended sounds can attract attention (as when one's own name is presented; see Moray 1959) so Treisman (1964) proposed that the filter only attenuated, rather than completely blocking out, sensory input that was unattended. Potentially pertinent input could still result in attention being attracted to that input. Cowan (1988) solved this problem in another way, by indicating that all sensory input made contact with long-term memory, but with extra activation for the deliberately-attended input or the abruptly-changing input that attracts attention involuntarily. This is the converse of the filtering concept.

Cowan (2001) suggested that the focus of attention in the embedded process model of Cowan (1988, 1999) is limited to about 4 separate items in normal adults. This leaves open the basis of individual differences in capacity limits. Cowan and colleages have suggested that there is a basic difference between individuals and age groups in the size of the focus of attention (Chen and Cowan 2009a; Cowan 2001; Cowan et al. 2005, 2009; Gilchrist et al. 2008, 2009). An alternative basis of individual differences and age differences, still in keeping with the model, is that individuals appear to differ in the ability to control or allocate attention or executive function (Engle et al. 1999; Miyake et al. 2001) or, more specifically, to inhibit irrelevant items and prevent them from cluttering up the limited-capacity store (Lustig et al. 2007). These possibilities are not mutually exclusive and both of them are compatible with the basic embedded processes model. (Indeed, for a structural equation model similar to Engle et al. or Miyake et al., see Cowan et al. 2005.)

Cowan's embedded process model assumes that storage and processing both use attention, and that certain processing challenges must be kept in check using attentional capacity that otherwise could be devoted to the temporary storage of information. These challenges include stimuli that elicit strong habitual responses, and irrelevant distracters. Indeed, recent research has suggested that processing, such as tone identification, can interfere with very different storage, such as that of visual arrays of objects (Stevanovski and Jolicoeur 2007); and that, conversely, storage, such as that of verbal list items, can interfere with very different processing, such as that in a speeded, nonverbal, choice reaction time task (Chen and Cowan 2009b). It remains to be seen whether attention holds multiple items at once directly or, alternatively, is used to refresh items one at a time before their activation is lost (Barrouillet et al. 2007).

1.1.4 Conscious and unconscious processing in different models

Although these models were constructed with the aim of explaining behavior, they also seem relevant to the issue of consciousness. Figure 1 shows three of the models with our interpretation of what, within each model, is likely to correspond to conscious and unconscious processes. Figure 1A depicts the original model of Broadbent (1958). In that model, incoming stimulation from the environment was said to be held in a temporary store, or buffer, and to go nowhere except for the small amount that is encoded into the limited-capacity buffer. Given that sensory memory is much richer than what individuals can report (which was shown for auditory stimuli by Broadbent himself, among others, and for visual stimuli by Sperling 1960), the model must consider the contents of the sensory buffer to be unconscious. Likewise, the vast information in long-term memory could not all be in consciousness at the same time. It is the limited-capacity buffer that would hold the contents of conscious awareness.

Figure 1B shows the model of Baddeley (2000). Baddeley's models, ever since Baddeley and Hitch (1974), implicitly have assumed more automatic processing than was made clear by Broadbent (1958). In particular, the entry of information into the phonological and visuo-spatial buffers is said to occur automatically, resulting in ready-to-use codes. These, however, need not be in consciousness. For example, Baddeley (1986) summarized research indicating that unattended speech could interfere with working memory for printed words, given that phonological codes are in memory for both types of stimulus at once, leading to corruption of the material to be remembered. In contrast, the episodic buffer, which was added to the model by Baddeley (2000) in order to account for temporary knowledge of abstract features, seems more likely to be linked to conscious awareness. Although to our knowledge Baddeley has not stated as much, abstract information has the advantage that it could refer to any stimulus. Consciousness seems to have the quality of unity in that our subjective experiences are such that there is only one pool of consciousness; for example, if we are looking at a work of art and listening to a tour guide's description of it, we feel conscious of the work of art, the verbal description, and perhaps the tour guide all at once. In the Baddeley (2000) model, the only buffer capable of representing and inter-relating all of this information is the episodic buffer.

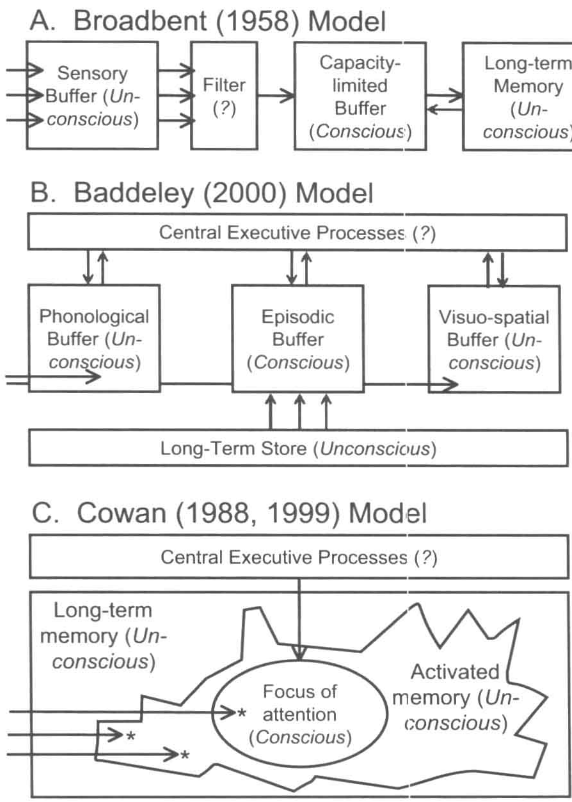

Figure 1. A depiction of three models of working memory and information processing, and the status we presume for each component of each model with respect to its inclusion in conscious awareness (*conscious*) or exclusion from it (*unconscious*). Where we did not have a presumption one way or the other, we added a question mark. The arrows coming from the left-hand side of each figure represent the entry of sensory information into components of the system as shown. A. Broadbent's early-filter model. B. Baddeley's multicomponent model. C. Cowan's embedded-processes model.

A more difficult, thorny issue is whether we are conscious of central executive functions. These are functions driven by motivations and intentions, as one can tell by testing individuals under different sets of instructions or reward contingencies. The central executive is, by definition, the set of mechanisms responsible for planning, scheduling, and executing information processing that transforms codes in buffers and memory stores, affects what information is attended, and affects what actions are performed. Although we are at least typically aware of the items to which attention has been directed and the items that are being transformed from one code to another or, in the parlance of the model, shuttled from one buffer to another, we may not be aware of the process by which the transformations are accomplished. Because of the theoretical difficulty of this question, we leave a question mark in the central executive. Basically, it is not clear to us whether it is feasible to consider processes to be in consciousness, or whether it is only information in stores that is held open to conscious reflection. One resolution of this question is that processes may give rise to stored representations that are held in consciousness, whereas other processes operate without attention and consciousness directed to them. Indeed, when one becomes too aware of the central executive processes governing a complex behavior, it can lead to poor performance or "choking" (Beilock and Carr 2005); as Fyodor Dostoevsky's character complained in the short novel, *Notes From Underground*, in such cases consciousness is a disease.

Finally, Figure 1C shows the activation-based, embedded processes model of Cowan (1988, 1999). For our purposes, this model has the advantage that the access to consciousness is a key aspect of the model. This access to consciousness is synonymous with the focus of attention. Elements of memory outside of the focus of attention, whether active or not, are outside of conscious awareness. If the line between the focus of attention and the rest of activated memory is seen as a blurry or gradual one, then the focus of attention might be viewed as being the same as primary memory as described by James (1890). One reason to demarcate conscious versus unconscious processing in the model is that the information in conscious awareness is assumed to gain access to much deeper and extensive perceptual and conceptual analysis using long-term memory information than information that is outside of conscious awareness. Therefore, directing conscious awareness is an important skill for harnessing information processing to succeed at a task.

One of the strong suits of Baddeley's models is that they have been well-grounded in research on patients with brain injury. One can find instances in which patients appear to be deficient in temporary phonological storage or rehearsal (e.g., Baddeley et al. 1988), attention-related working memory (e.g., Jefferies et al. 2004), or long-term episodic storage (e.g., Baddeley and Warrington 1970). None of these cases are especially problematic for the Cowan model, either. It is acknowledged in the model that phonological activation is one type of activated memory and that rehearsal of it can take place without much attention. Attention-related working memory and automatic activation are both intrinsic to the Cowan model, as is long-term storage. There is no reason why specific lesions could not selectively impair these aspects of memory. Although patients with long-term episodic storage impairments obviously would be unable to activate information that was not stored in the first place, information in semantic memory can become temporarily activated by new stimuli and, in that way, used in short-term storage tasks.

An important issue that was addressed in enough detail by Cowan (1988, 1999) is where information about the individual's goals is held. When the goals keep shifting or when there is information that undermines the goal, the goal presumably must be kept in the focus of attention, using up some of the limited capacity of that store. An example of this is the Stroop effect, in which the goal is to name the color of ink but the word spells out a different color. Kane and Engle (2003) showed that individuals with high working memory span carry out this task more successfully than low spans if a conflict only occurs on a small proportion of the trials. In contrast, if the goal becomes routine and it is not undermined by conflicting stimuli, that goal need not use up some of the limited capacity of the focus of attention and may be held instead in a portion of long-term memory (or in the central executive itself if it can be considered to have a memory, which was sometimes assumed by Baddeley, but not by Cowan).

1.1.5 More detail on the embedded-processes model

Thus, the embedded-processes model, rather than being composed of separable structures, includes within the *long-term memory* system a currently *activated* subset of memory and, within that in turn, a subset that is the current *focus of attention*. The activated portion of memory was said to include unlimited information at once but it was assumed to lose its activation through time-based decay within 10 to 20 seconds, provided that activated items are not attended or rehearsed. The focus of attention comprises a limited number of items that are not only highly activated, but are also most rapidly accessible and are in one's awareness ('in mind'). In contrast to the time-limited decay of activated long-term memory, the focus of attention was assumed not to decay but was limited to only several separate, meaningful items at once.

The focus of attention functions as a zoom lens with respect to its comprising information (see also LaBerge and Brown 1989). It can 'zoom in' on a particular item, leading to more focused and precise allocation of attention to a single item, with remaining items in the focus receiving considerably less attention and detail; this suggests that attentional resources can be allocated on the basis of prioritization if necessary. In contrast, if multiple items need to be processed simultaneously, the focus of attention can 'zoom out', leading to a greater breadth of processing, but with less precision overall.

How information enters into awareness depends upon several different factors that are accounted for in the model. The first factor involves the origin of