COGNITION AND EMOTION
2006, 20 (7), 1027–1045

Psychology Press
Taylor & Francis Group

Memory and the brain: A retrospective

Heather Bortfeld, Steven M. Smith, and Louis G. Tassinary
Texas A&M University, College Station, TX, USA

Memory and the Brain was Magda Arnold's final book, the capstone to an influential career that spanned half a century. Many of the proposals and insights put forth in this work foreshadowed significant theoretical developments in both psychology and the neurosciences. With few exceptions, however, modern researchers, theorists and historians have overlooked this unique contribution.

> It is a noble employment to rescue from oblivion those who deserve to be remembered.
>
> (Pliny, the Younger, ad c. 62–113, in a letter to Titinius Capito)

> . . . delayed recognition is an integral, perhaps necessary part of the scientific enterprise.
>
> (Schacter, 2001, p. 212)

Between the years 1957 and 1960, Magda Arnold completed and published two volumes entitled *Emotion and Personality* (1960). In these volumes she proposed a comprehensive theory of the relation between psychological phenomena and brain function. Between the years 1975 and 1981 she "picked up where she had left off" (Shields & Fields, 2003; see also Shields, this issue) and completed *Memory and the Brain* (1984). At the time of its publication, this final volume was described as:

> An extraordinarily ambitious attempt to develop a comprehensive neurophysiological theory of brain function, which seeks to account not only for learning and memory, as the book's title promises, but for related perceptual, cognitive, motivational, and affective processes as well . . . . It has [a] breadth unrivalled in contemporary accounts. (Grossman, 1985, p. 89)

Correspondence should be addressed to: Louis G. Tassinary, Office of the Dean, Department of Architecture, Texas A&M University, College Station, TX 77843–3137, USA. E-mail: lou@archone.tamu.edu

© 2006 Psychology Press, an imprint of the Taylor & Francis Group, an informa business
www.psypress.com/cogemotion DOI: 10.1080/02699930600616353

This capstone volume was also lauded for having provided "solid grounds for dismissing as irrelevant all abstract theoretical models which are not directly and explicitly concerned with actual brain processes and their subjectively experienced correlates" (Morrison, 1987, p. 369).

Philosophically, Arnold was credited with having characterised the mind–body problem in more tractable terms by framing it as essentially correlations between the activation of specific neural systems and conscious experiences, replacing "the human body conceived as a Cartesian three-dimensional object . . . [with] the human body conceived in terms of physiological systems and neurophysiological circuits" (Morrison, 1987, p. 370). In this sense her work can be seen as an extension of earlier attempts to provide a comprehensive framework, such as that by Leonard Troland (1929–1932). Troland's magnum opus, *The Principles of Psychophysiology: A Survey of Modern Scientific Psychology*, was extolled as "comparable with the like works of Wundt, of Ebbinghaus" and as having provided the entire field of psychology with a source "adequate for the commencement of actual research, . . . yet clear enough to be mastered without any special training". (Beebe-Center, 1932, pp. 819–820). Like Arnold, Troland focused his work around the central issue of the functional relationship between the mind and the brain, hypothesising the existence of functional networks of neurons subserving perception (neurograms) and co-ordinated action (incitograms), as well as the existence of task-specific coalitions of neural circuits (excitation centroids) (Troland, Vol. 3, pp. 77–82). All of these bear a remarkable resemblance to the cell-assembly hypothesis proposed by Hebb (1949) two decades later, as well as to the modern concept of task-specific coalitions of neural circuits (neural generators) believed to underlie the arresting images produced by fMRI (see Bandettini, Birn, & Donahue, 2000). Troland also argued forcibly and convincingly for the causal role of feelings in behaviour, a view at the time that was considered outdated (Devonis, 2000; Tolman, 1932/1951, pp. 261–263). In retrospect, it also appears that both Arnold and Troland anticipated the importance of the interaction of cognition and emotion in the regulation of behaviour. However, as with Troland's earlier attempt, reviewers were impressed but not necessarily convinced by Arnold's theory. Troland was criticised for the fact that his explanations and hypotheses went far beyond the then available data and technologies (see "Review of", 1930) and a reviewer of Arnold's final work concluded that "the careful and constrained thinking associated with good science is never demonstrated" (Hirst, 1985, p. 782; but see Arnold, 1986, for a haughty rejoinder). Yet even Hirst was impressed by her intuitions and expressed a willingness to "bet" on something like what she outlined (p. 783).

CURRENT INFLUENCE

It has now been more than two decades since *Memory and the Brain* was published. The reviews at its publication were mixed, but clearly positive. The fields of psychophysiology and neuroscience have greatly expanded over the past two decades, brought on by significant advances in technology, theory and sophisticated experimental paradigms, and the broad synthesis attempted by Arnold is now more common (e.g., Lewis, 2005). All of this would suggest that Arnold's book would be seen as increasingly relevant to modern researchers in traditional areas of psychology (e.g., cognition and emotion) as well as the burgeoning integrative disciplines spawned in the neurosciences (e.g., psychoneuroendocrinology). Yet, if citation rate may be taken as a rough index of influence, this volume has been either dismissed or ignored since its publication.

Figure 1 shows the citation rate for the two-volume *Emotion and Personality* and for the single volume *Memory and the Brain*. The arrows mark the date of publication for these respective works and the data are derived from the Web of Science database, which includes the Science Citation Index Expanded™, the Social Citation Index® and the Arts and Humanities Citation Index®. While not exhaustive, this combined database indexes over 9000 journals covering more than 200 disciplines. It is clear that while *Emotion and Personality* continues to be cited in the scholarly literature, *Memory and the Brain* does not. *Emotion and Personality* was cited at least 23 times during the 10 years following its publication in 1960 (the database begins in 1966) and has been cited 50 times in the past 5 years. In stark contrast, *Memory and the Brain* was cited only 9 times during the 10 years following its publication and was not cited even once in the past 5 years! In fact, *Memory and the Brain* is not even mentioned in a review of Arnold's work published in the decade following its publication (Mooren & van Krogten, 1993)

Why has this book been so thoroughly ignored? One possible reason is that its title was inopportune. That is, in the mid-1980s, cognitive psychologists were by and large not interested in the brain, neuroscientists were by and large not interested in memory, and emotion researchers were typically interested in neither. It would not be surprising, therefore, if a book so titled would have gone unnoticed. In 1987, however, a book by the same title was published by Larry Squire, a neuropsychologist with interests in the organisation and neurological foundations of memory. We can thus compare the citation rates for the two books, and these data are displayed in Figure 2. It is clear that the title was not the problem. In the 10 years following its publication, Squire's *Memory and the Brain* (1987) was cited over 900 times and has been cited over 200 times in the past 5 years. The author index in Squire's volume contains no reference to Arnold's *Memory and the Brain*.

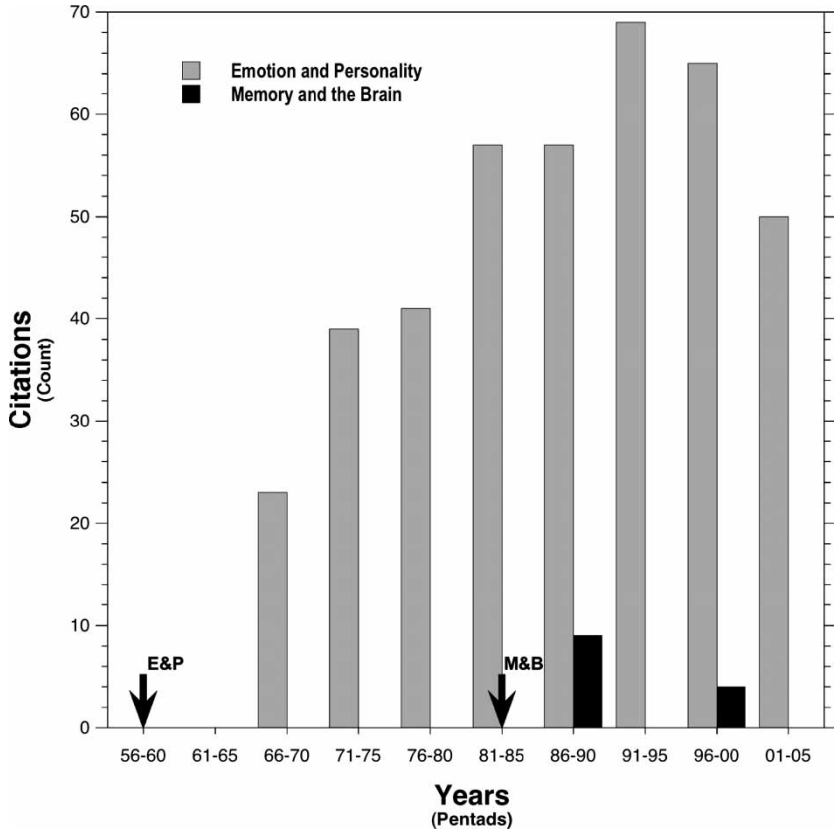

Figure 1. Citation rates for Arnold's two major works. Based on data from the Web of Science Citation Index from 1966 to 2005.

A hint as to why Arnold's book was then and continues to be ignored may be gleaned by comparing the respective tables of contents of the two books. As can be seen in Table 1, the psychological and physiological levels of description are integrated throughout Squire's presentation. There are discussions of synapses, engrams, memory models, and brain regions, as well as case studies of brain-damaged patients, all examined exclusively through the lens of memory processes. Arnold's presentation, on the other hand, is more expansive, as well as more traditional. She first describes her broad psychological theory of cognition and memory, and then proceeds to articulate how such a theory might be implemented in the known circuitry of the brain. As may be seen by the inclusion of sections titled "The Sense of Identity" and "The Problem of the Agent", Arnold was committed, as was Troland before her, to developing a language of experience that would allow

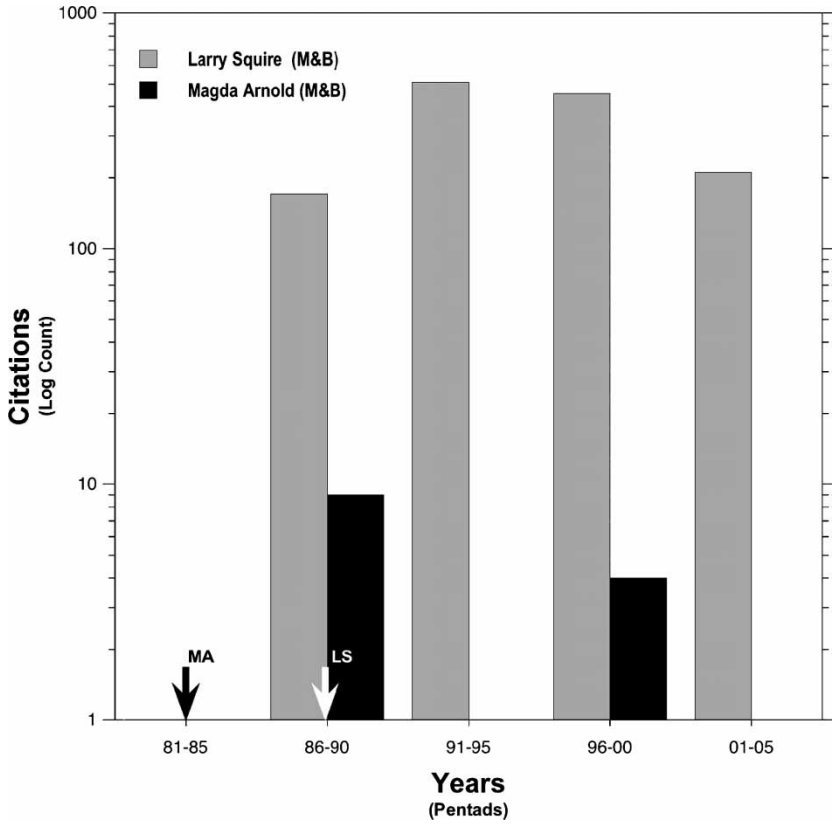

Figure 2. Citation rates for the two different volumes titled *Memory and the Brain*. Based on data from the Web of Science Citation Index from 1981 to 2005.

autochthonous psychological elements, many accessible through introspection, to be functionally related to neural systems. When compared to Squire's more mechanistic and reductionistic approach, however, this commitment appears at first glance to embrace a kind of dualism and this may be one reason why her contribution was overlooked.

Alternatively, perhaps Squire's book has been given more credence because of his intimate and extensive involvement with the experimentation supporting his exposition. Although, as we argue below, it now appears that the fields of cognition and neuroscience have evolved into the kind of framework Arnold both envisioned and articulated, very little of Arnold's own research is actually presented in her book. What is clear is that the factors that determine whether a scientific work is accepted quickly, or initially ignored but detected and brought back to life subsequently, are both nuanced and polysemous (Lange, 2005; Van Raan, 2004). For example, the

TABLE 1
Table of contents from Squire's and Arnold's books, both titled *Memory and the Brain*, both published in the mid-1980s

Squire	*Arnold*
Definitions: From Synapses to Behavior	PART I: PSYCHOLOGICAL ASPECTS
Memory as Synaptic Change	Perception
Connections versus Molecular Codes	*Perceptual Integration*
Neurons versus Synapses	*Perceptual Space*
The Nature of Synaptic Change	*Consciousness, Memory and Perception*
Memory and the Developing Nervous System	*The Sense of Identity*
Competition	Attention
Remembering and Forgetting	Reinforcement, Reward: Appraisal and Affective Memory
Modulation of Memory	*Reinforcement Theories*
Modulatory Systems	*Appraisal*
Acetylcholine	*Affective Memory*
Hormones	Types of Memory
Modulation of Memory: One or Many Effects?	*Modality Specific*
Localized and Distributed Memory Storage	*Conceptual*
History of the Problem	Memory Registration, Retention, Recall
The Nonlocalizing Brain Lesion	*Registration*
Nonlocalizing Signs from Neurophysiology	*Retention*
Memory as a Hologram	*Recall*
Distributed Models of Memory in Cognitive Psychology	*Immediate versus Long-term Memory*
Localizationalist and Distributed Accounts of Memory Reconciled	*Decay, Displacement and Interference Theories*
Searching for Functionally Equivalent Neural Units	*Consolidation Theory*
The Penfield Studies	*Access Theory of Recall*
The Observations	*Forgetting: Lost Access or Lost Memory*
Interpretation of the Penfield Studies	Imagination and Recall
Recent Findings	*Images and Imagination*
Searching for Engrams: Simple Learning	*Recall and Imagination*
Habituation: The Acoustic Startle Reflex	*Visual Imagery and Verbal Memory*
Habituation: The Vestibulo-Ocular Reflex	*Sensory Equipment of Animals*
Classical Conditioning	Recognition
Heart-rate Conditioning	*Theories of Recognition*
Conditioning of the Nictitating	*The Problem of Recognition*
Membrane/Eyeblink Response	*Two Process Theories*
Imprinting	Memory Models
Searching for Engrams: Complex Learning	*Current Memory Models*
Brightness Discrimination	*The Problem of the Agent*
Arguments for Cortical Memory Storage	A Psychological Theory of Cognition and Memory

Table 1 (*Continued*)

Squire	*Arnold*
Split-brain Studies	*An Integral Theory of Psychological*
Plasticity of Cortical Neurons	
Inferotemporal Cortex: Visual Processing and Visual Memory Storage	*Functions*
Where is Memory Stored?	*Cognitive Functions*
Memory is Determined by Information Processing	*Appetitive Functions: Action Impulses and Actions*
The Link between Processing and Storage: Which Cells are Plastic?	PART II: NEUROPHYSIOLOGICAL CORRELATES
The Link between Processing and Storage: Considerations from Cognitive Science	A Psychological Theory of Cognition and Memory
Extraordinary Processing and Extraordinary Memory	Localization of Psychological Functions
Short-term and Long-term Memory Processes	Cortical Areas Mediating Sense Experience
Primary Memory	*Sensory Areas and Appraisal Areas*
Working Memory	Cortical Memory Registrations
Multiple Working Memories	*Sensory Memory and Affective Memory*
The Neuropsychological Perspective	Cortical Areas Mediating Movement
Neuropsychology and Neurobiology Reconciled	*Motor Areas and the Initiation of Action*
Divisions of Long-term Memory	*Motor Memory Registration*
Declarative and Procedural Memory	*Motor Memory Deficit After Frontal Lesions*
Episodic and Semantic Memory	Memory Retrieval
A Neural System with Memory Functions	The Neural Substrate of Attention and the Medial Appraisal System
Case N. A.	Damage to the Appraisal System and the Affective Memory Circuit
Amnesia: Damage to a Specialized Neural System	Hemisphere Function and Memory Impairment
Diencephalic Amnesia	The Hippocampus
Medial Temporal Lobe Amnesia	*Relay Station of Memory and Action Circuits*
From Brain Lesions to Neural Systems Aging and Memory	*Hippocampal Damage and Memory*
Amnesia and the Functional Organization of Memory	*The Hippocampal Projection*
The Formation and Consolidation of Long-term Memory	The Amygdala: Relay Station in the Imagination Circuit
The Contribution of the Diencephalon	Neurotransmitters in the Brain
The Contribution of Damage in Other Neural Systems	Neurotransmitters, the Reward System and Psychiatric Illness
The Selective Role of the Neural System Damages in Amnesia	The Action Circuit
Prefrontal Cortex	*Ascending and Descending Links; Activation-Depression*
The Sulcus Principalis and Dorsolateral Convexity	*Through the Hypothalamus*
The Inferior Convexity	The Action Circuit and Motor Memory Circuit: From Midline to Frontal Lobe
The Peri-arcuate Region	
Clinical Neuropsychological Studies of Frontal Lesions	
The Prefrontal Cortex and Memory Functions	
Specific Events versus Cumulative Experience	
Memory and the Brain: A Beginning	

topics of such "Sleeping Beauty" works may have been outside the focus of science at the time of their initial publication or may have had no explicit theoretical relevance. The authors of such publications may also have been unaffiliated with the then current psychological "disciplines" or, alternatively, the authors may simply have worked in relative social isolation. Regardless of the actual reasons for its neglect, we believe that it is time to revisit Arnold's theory and evaluate it anew, in light of what is known after two decades of research, and thus see if Hirst's "bet" has paid off.

A NEW LOOK

Current discussions of memory generally are divided in terms of time and content. Along the dimension of time, a distinction is made between short-term memory (e.g., working memory) and long-term memory. Generally, short-term memory is characterised as lasting from seconds to minutes while long-term memory refers to anything of longer duration. With respect to content, there are a variety of approaches to dividing up memory systems. A few researchers see the system as unitary (e.g., Rajah & McIntosh, 2005). Most see it as composed of several subsystems (e.g., declarative and non-declarative; episodic and semantic). For example, Tulving and his colleagues (2000) currently view memory as consisting of five such subsystems, each with its own dedicated anatomical network. The most complex of these constitutes what can be described as autobiographical or episodic memory, which requires self-conscious reflection and is situated in both place and time. This subsystem is most likely affect based. In contrast to this very localised and detailed form of memory, semantic memory is context-free, "fact" memory. Implicit processes constitute perceptual memory, procedural memory, and priming. This characterisation of memory as consisting of systems with underlying neural substrates is substantiated by both patient data and data from normal subjects using functional imaging methods and is quite consistent with the general portrayal of memory as foreseen by Arnold (1984). Importantly, however, Arnold also anticipated the relevance of emotion and its connection to the formation of so many of these "types" of memory. The overview she provides of the recursive perception–decision–action cycle (see p. 92) in *Memory and the Brain* attests to the breadth and depth of her thinking.

THE NATURE OF MEMORY

What Arnold wrote about memory included her ideas about the state of memory theory in general, as well as her own memory theory, which was largely based on her notions about appraisal. Her critique of the state of

memory theories in *Memory and the Brain* reflected her career-long work on memory. *Memory and the Brain* touched on many standard issues, such as the distinctions between recall and recognition, primary and secondary memory, and the availability versus the accessibility of memories. Although she was critical in one way or another of all of the theories that she reviewed, Arnold reserved her mordant comments for "computer models" of memory (e.g., p. 75), now commonly referred to as "computational models". Arnold rejected the idea that human memory can be reduced to information states, as suggested by all computational models since the earliest works of Alan Newell and Herb Simon (e.g., 1963). For example, referring to Norman and Rumelhart's (1970) information processing model of cognitive systems, Arnold wrote:

> Norman and Rumelhart's model assumes that recall consists essentially of a search through a passive memory store but is not quite clear who does the searching. There are various active systems (perceptual system, naming system, memory system, etc.); but it is really an anthropomorphic notion to suggest that the naming system uses a dictionary, or that the decision system decides between response alternatives. (p. 83)

Indeed, since Arnold's critique, we have recognised some of the critical shortcomings of computational models of human cognition, particularly their lack of ability to generate clear new theoretical predictions. The simple algorithms and numerous parameters of computational models, such as SAM (Raaijmakers & Shiffrin, 1981), MINERVA-II (Hintzman, 1984), and connectionist models (e.g., McClelland & Rumelhart, 1985), gave them the algorithmic power to model (and thereby "postdict") memory phenomena such as output interference (e.g., Rundus, 1973), misinformation effects (e.g., Loftus & Palmer, 1974), or false memories (e.g., Roediger & McDermott, 1995). The number of unconstrained independent parameters characteristic of these models, however, makes it nigh impossible to predict these same phenomena.

The computer metaphor of memory has largely given way to a brain metaphor that characterises memory as the product of neuropsychological states, as Arnold and others foreshadowed in their writing. The disembodied computational models of the past have more recently evolved into a sort of shared language in which to express the workings of neural mechanisms (e.g., information transfer; redundancy), rather than acting as scientific models that make clear predictions in highly specified domains irrespective of their neural substrates (e.g., McClelland & Rumelhart, 1985).

Arnold also rejected the storage metaphor, claiming, "memories cannot be stored like bales, or even filed away on filing cards" (1984, p. 40). Again foreshadowing our current views of the mind, she stated that memories are patterns of activation, as opposed to passive repositories of representations of knowledge and past experiences. For example, Arnold (1984, p. 95)

claimed that memories are "potential dispositions to be actualized. There are traces in the brain, but they are not images that only need to be lit up to be recalled".

Another of Arnold's notions about memory that became well accepted was the importance of motor memory, which she also referred to as kinaesthetic memory. Since her writing, the field of motor memory and cognition has flourished, including the establishment of scientific journals devoted to the subject. Currently, the topic of motor memory strongly complements and interrelates to research and theory that concerns other aspects of memory (e.g., Carlson, 1997), although the very topic of motor control has a long history of being the "Cinderella" of psychology (see Rosenbaum, 2005).

Undoubtedly, one of Arnold's most important ideas about memory concerns her belief that the interrelation of emotion and memory is essential to our understanding of the mind. Her theory of emotion (see Figure 9.1, p. 92, 1984) is predicated upon the brain initially appraising an object as either good or bad for oneself. This initial appraisal triggers recall and imagination of similar things, thereby affecting further attention to the object, triggering affective memories of past experiences, and eventually resulting in overt actions that are seen as occurring in the service of motivational goals. Although her appraisal theory, which integrated emotion and memory, remains largely unknown to cognitive and neuroscientists today, it is nonetheless broadly accepted that the relationship of emotion and cognition must be considered to understand the workings of the human mind.

Arnold claimed that spontaneous memory, or what she termed "implicit recall", is the most common form of memory, and is far more common than the deliberate type of remembering that was accepted by psychologists in earlier decades. Currently, the term used for such memories is "involuntary" recall, with the term "implicit memory" reserved for all types of memory that are not accompanied by conscious states or deliberate intentions. Indeed, her claim that cognitive psychologists must focus more on issues of consciousness is now widely accepted, thanks largely to the work of Tulving, Schacter, and others. Arnold insisted that the language of cognitive psychologists needs to emphasise phenomenological states over information states, an idea now at the core of much of the current research in memory and metacognition (e.g., Mazzoni & Nelson, 1998; Metcalfe & Shimamura, 1994; Nelson, 1992; Perfect & Schwartz, 2002).

THE CONCEPT OF EVALUATION

Magda Arnold was one of the first theorists to frame our understanding of emotional response in cognitive terms (see also Kappas, this issue;

Reisenzein, this issue). In *Emotion and Personality* she both reviewed and critiqued well over a century of theories on emotion, including those of James and Darwin. Though heavily influenced by both, she ultimately expressed dissatisfaction with how these theorists accounted for the sequence of events that elicit an emotional response. In *Emotion and Personality* Arnold argued that emotions stem from situations first being evaluated as good or bad. She made the important point that the bodily change one experiences directly following the perception of something was not enough to explain why humans experience emotion. She instead accounted for this experience in terms of appraisal, defined as the potential mental value assigned to the cost or benefit of any situation. She argued that this emotional sense motivated people to pursue things evaluated positively and avoid things evaluated negatively; as she put it, "emotion becomes a felt tendency toward anything appraised as good, and away from anything appraised as bad" (Arnold, 1960, Vol. 1, p. 182).

Although Arnold characterised the process of evaluation as an unconscious one, she argued that the effects of this evaluation were manifest consciously as an emotional response. The key difference between her view and those put forth earlier is that, for Arnold, information processing precedes emotion. This was a substantial departure from theoretical approaches to understanding emotion at the time, in that Arnold invoked "affective memory". This notion became part of her bigger "Theory of Brain Function" (Arnold, 1984, p. 115), which included several circuits underlying the processing of specific senses. These circuits serve to integrate and guide experience based on inputs from the senses, and include the "memory circuit" (mediating modality-specific memory), the "imagination circuit" (meditating the relay of impulses that followed appraisal via the amygdala and thalamic association nuclei, and back to the cortical association areas), and the "affective memory circuit" (reviving prior appraisals for an event via the hippocampus, postcommissural fornix, mammillary bodies, and midbrain, and returning via the anterior thalamic nuclei to the cingulate gyrus and other limbic structures). Arnold envisioned these circuits and the processing they allow as the underpinnings for all subsequent appraisals. Lastly, she hypothesised that an "action circuit" mediated impulses to action, and was housed in the limbic system, but also included the prefrontal and frontal cortical areas. As she put it, "every intention to remember, recall, imagine, or act necessarily starts from an appraisal that this is good to do" (Arnold, 1984, p. 115). In earlier work (e.g., Arnold, 1970) Arnold had pursued the view that affective memories (and the appraisals they lead to) could moderate concurrent perception-based appraisals. Her theory of how this takes place neurologically, as laid out *Memory and the Brain,* was the follow-up to that hypothesising.

LOCALISATION OF FUNCTION

Arnold's analysis of memory and the brain was in the tradition of her earlier writings on emotion, both in terms of being couched in the tradition of psychological theorising and by reflecting its position in that history. In particular, and as if in anticipation of the next twenty years of progress in mapping the brain, the section of *Memory and the Brain* devoted to neurophysiological correlates begins with a section devoted entirely to her views on the localisation of psychological functions. On the one hand this opening is prescient, given that there remained then a clear division between neuroscientists and cognitive psychologists about the relevance of such localisation. On the other hand, her review of a wealth of data from both fields was limited by the thinking of the time, as reflected by her conclusion that "[today] only the localization of sensory and motor areas is generally accepted" (Arnold, 1984, p. 113). Her conclusion was based on a thorough review of competing views held both contemporaneously and historically on the issue of localisation of psychological functions, as she was well aware that "expert opinion on the localization of sensory and motor functions has made several pendulum swings" (Arnold, 1984, p .110). Arnold's insight lies in her synthesis of data and theory from numerous fields, rather than in any specific proposal regarding localisation. Through this synthesis, she also demonstrates why the pendulum would (and undoubtedly will) continue to swing between views supporting local or global processing; that is, both views are necessary and neither is sufficient.

While there is still some debate about whether and to what extent the past twenty plus years of functional imaging research have generated a new form of phrenology (e.g., neophrenology; see Uttal, 2003), anyone paying attention to even their daily newspaper would now have grounds to argue against Arnold's seemingly superficial conclusion about the limitations of localisation. But her discussion actually anticipated the bigger issue of mediating structures and mediated sensory experience. In fact, Arnold's theory in many ways anticipates the current thinking on physiological function in the brain, even as she acknowledged only the most basic reality of localisation, e.g., "[the five senses] are "localized" in the cortex in . . . that these sensory areas are the endstations of their sensory systems" (Arnold, 1984, p. 108). While by the second half of the 20th century, most researchers were willing to agree that some localisation of function existed in the cerebral cortex, the real issue was about whether higher cortical functions like thinking and memory were likewise localised.

Arnold identifies the work of both John Hughlings Jackson and Karl Lashley as the sources of the antilocalisation viewpoint that held sway throughout most of the first half of the 20th century, particularly among psychologists. Since lesion data were the basis of much neurological

theorising, Hughlings Jackson (Taylor, 1932) had already provided the insight that localisation of symptoms and localisation of function needed to be distinguished. His view that behaviours were constellations or collections of independent activities rather than of a single unit (e.g., area) continues to influence how brain imaging data are analysed today. This view was further supported by Karl Lashley (1950, 1958), whose methodological rigour and abundant data particularly influenced psychologists. In his research, Lashley observed that lesions in various sites throughout the brain did not necessarily lead to deficits in rats' ability to learn tasks for later performance. Arnold (1984, p. 111) points out that Lashley's findings bolstered antilocalisation arguments among psychologists, though his conclusions have since been re-evaluated. For example, if a lesion knocks out a particular sensory modality for a rat running a maze, the animal can often use another modality to learn the task. In other words, one modality can make up for the loss of another as reflected in the rats' learning.

Such a finding speaks to the multimodal nature of experience, dependent both on the localisation of processing of any particular sense, as well as the integration of modalities into a coherent representation of the experience itself. Such a process involves so much of the brain that one lesion will often not produce learning deficits. Lashley's work led to strong support in the psychology community, particularly among cognitivists, of a holistic argument over a strict localisation one. Arnold was among the few who divined the duality inherent—if not recognised at the time—in Lashley's conclusion. Such duality, rather than being of the Descartes (e.g., Cartesian) variety, dictates that localisation and holistic (e.g., mediated) processing both underlie our conscious experiences. According to this view, localisation is a matter of a fact, but the totality of conscious experience depends on those localised functions being bound via a holistic neurological system.

In *Memory and the Brain*, Arnold was interested in the question of how psychological activities (e.g., holistic experiences) can themselves be created via structures in the brain to guide action. Other researchers were asking similar questions around this time as well (e.g., how does the brain enable the mind?), in particular those who were part of the emerging field of cognitive neuroscience. But since the cognitive neuroscience of emotion, as well as affective neuroscience (e.g., Panksepp, 1998), emerged as legitimate areas of study only later, Arnold's interest in how emotion and cognition are integrated to produce one's experience of the world was quite beyond where most were focusing at the time. What was her characterisation of the issue of such integration? Simply, Arnold's insight about mediating areas is illustrated by her summary of two main problems that a theory of brain function would need to address. First, she argued that such a theory would need to identify what areas in the brain mediate the registration of sensory experience so that it can be recalled, and, second, it would need to delineate

how those areas are connected with, for example, the motor cortex so that sensory experience ultimately produces a desired motor reaction. Ultimately, Arnold's focus in *Memory and the Brain* is on the latter question, given that at that point there was much less data addressing the connection between sensory and motor cortex. Arnold had identified the principle challenge to the advancement of her theory. Her solution was to propose that the mediating factor in how we react to sensory stimulation was the appraisal of the stimulation as "good or bad for me here and now" (Arnold, 1984, p. 115). The key to her theory was the addition of emotion as a basic part of the processing circuit, rather than something layered on top of initial processing. Her view was that such an appraisal could only take place in the limbic cortex, which in turn could only do such appraising by means of recall of dispositions and the actions called for given such dispositions. In this way, she comes full circle, back to the overarching issue of the nature of memory and how emotion is part and parcel of it.

Given that the most compelling early account of emotional circuitry in the brain was proposed by Papez in 1937 and that Arnold had been deeply involved in mapping psychological activities to their neurological correlates, her insight at this later point in her career makes sense. Papez was a neuroanatomist who argued that rather than being based in a specific brain "centre", emotion was created by the interaction of four basic structures (i.e., the hypothalamic and mammillary bodies, the anterior thalamic nucleus, the cingulate gyrus, and the hippocampus) with connected circuitry. This circuit, the limbic system, in conjunction with frontal cortical regions is generally identified as being at least partially responsible for the various forms of affect (the central function of emotion), as well as for their symptoms (e.g., peripheral expressions). Additional structures that have since been added to the circuit since Papez's time include the amygdala, the medial thalamic nucleus, the prefrontal area, and the parahippocampal gyrus. But even Papez's rudimentary characterisation of this circuit allowed a clearer picture of the link between emotion and memory (see also MacLean, 1990). This link guided Arnold's theorising. Current views among emotion researchers on the organisation of emotions are complex. Some researchers (e.g., Dolan & Morris, 2000; Ekman, 1994; Le Doux, 1996) argue that there are separate circuits for each distinctly identifiable emotion, a more complex version of the single circuit approach initiated by the work of Papez. Others (e.g., Bradley & Lang, 2000) focus on valence dimensions and the resulting arousal, a view consistent with Arnold's characterisation of appraisal. Ultimately, much of the debate lies in lack of agreement about how to characterise emotion itself.

From a neurological standpoint, the question of interest is how incoming sensory information leads to the behavioural and physiological responses associated with various emotions. As noted by Damasio (1994), within

certain limits, affective participation reinforces cognition, giving more colour and nuance to daily experience and ultimately facilitating adaptive behaviour. Importantly, in refuting the notion that the human mind is separate from the body and its processes, Damasio (1994) drew on neurobiology and neurochemistry to support the claim that emotions play a central role in human reasoning. Arnold's theorising about emotional influences on memory anticipated such arguments. While her characterisation of mediating areas ultimately serves her view that appraisal drives the system, the fact that appraisal led her to a careful and thorough analysis of how the amygdala and other neural structures underlie the processing of emotion is noteworthy. Moreover, whether one agrees that the limbic system should be referred to as a system or not (see Kotter & Meyer, 1992, for an argument against such a view), the orbitofrontal cortex and the amygdala are currently acknowledged to be two brain regions in particular whose main function is in processing emotion. Finally, Arnold's proposal that the amygdala lies at the centre of an imagination circuit (Arnold, 1984, pp. 340–58) may turn out to be particularly prescient given recent results that suggest that this brain structure is critical to the control of attention and exploration, rather than simply to the visual recognition of fear (Adolphs, Gosselin, Buchanan, Tranel, Schyns, & Damasio, 2005).

One can quibble about the details, but Arnold's big-picture vision of memory as something not reducible to computer analogies certainly was bucking trends among many of her contemporaries. And her framing of mounds of physiological data in cognitive terms was likewise bucking the compartmentalisation approach taken by many animal researchers who were not interested in having their data incorporated in the emerging cognitive science framework. Ultimately, Arnold's theorising anticipated the subsequent years of detailed data collection from humans on the neurophysiological correlates of memory, much of which was simply undoable prior to the introduction of the wide variety of brain-mapping techniques currently available to researchers. While localisation is still a legitimate goal in brain research, its more nuanced form recognises the importance of mapping connections between areas (e.g., circuits or systems). In fact, mapping connections has emerged as the driving force behind many cognitive and neuroscience research programs, regardless of the subject in question. Arnold anticipated the need to understand how specific brain areas operate to deliver their functions rather than localising where those functions live.

The emerging view that plasticity of function is a question that reaches far beyond single methods or cortical areas is foreshadowed in Arnold's work as well. For example, she was acutely aware of research on patients with various forms of brain damage, and she acknowledged the importance of such research in answering questions of the mind much sooner than did the mainstream of cognitive psychology (e.g., aphasia, pp. 260–266). While the

work done by Penfield, Sperry, and Luria early in the second half of the 20th century served as the basis for a variety of cognitive models, these researchers were embraced by the cognitive community relatively later, though their focus on the biology underlying the mind is now a fundamental aspect of current theories of memory. But Arnold was quick to integrate their work in her theorising, doing so sooner than would many others.

Nonetheless, Arnold appears to have incorrectly interpreted the implications of these data, such as the effects of bilateral hippocampal lesions on memory, stating that such damage leaves short-term memory intact, but prevents new memories from being encoded in long-term memory. The fact that new experiences have the same effect on these patients and control participants on many implicit memory tests, such as word fragment completion (e.g., Graf & Schacter, 1985) or perceptual identification (Jacoby & Dallas, 1981), shows that the experiences are indeed encoded in some form even for hippocampal patients. Our current understanding is that such patients cannot form new explicit memories of events, but their implicit memory of events is intact (e.g., Schacter, 1987; Squire, 1992). The distinction between explicit and implicit memory, as well as discoveries about the factors that differentially affect the two is perhaps the greatest development in memory theory since the publication of Arnold's book. Furthermore, Jacoby's (e.g., Jacoby & Kelley, 1992) rejection of the "process pure" assumption, the assumption that tests such as recall or recognition measure purely one process or another, is based on a similar distinction. That is, it is based on a distinction between an automatic and rapid familiarity process and a slower, conscious, intentional memory process, now referred to as "recollection". Arnold rejected the idea that recognition is equivalent to the process of recall of context, as advocated by Anderson, Bower, and Tulving, claiming that recognition corresponds simply to familiarity, whereas recall is the formation of a visual image of a past experience. Current views of recall and recognition see them as a combination of the two types of processes, familiarity and recollection (retrieval of a memory's source), and cognitive psychologists have gone to great lengths to explicate the co-ordination and, at times, the opposition of these two different memory processes in a variety of memory tests.

Arnold's view of imagination and memory as highly similar and interactive activities, and her linking the two to shared neural mechanisms, was fundamental to her theory of memory and the brain. For example, she stated that, "The sensory and motor images that remain after every perception and action provide the raw material for memory and imagination" (p. 95), and further that, "When memory fails, imagination rounds out the picture" (p. 96). This view, which Arnold attributes originally to Bartlett's writing in the early 20th century, is now a well-accepted one, at least with regard to the subject of false memory. The past decade has seen a

great volume of research, led by Roediger, Loftus, and others, on the participation of imagination and inference in everyday remembering, including studies of such memory phenomena as "imagination inflation" (e.g., Garry, Manning, Loftus, & Sherman, 1996; Goff & Roediger, 1998). Arnold's theory is quite consistent with the underlying premises of this research, and her ideas about the neural substrates of memory and imagination could very well inspire future research on the subject. Her theory also highlights the participation of memory processes in activities that require imagination, a notion that is consistent with current research on creative cognition.

In sum, Arnold's ideas about memory, while missing out on an important distinction between implicit and explicit forms of memory, were nonetheless consistent with, and predictive of, many of the important issues of the memory research that has been conducted since the writing of her 1984 book. Although to date her writing has not directly influenced memory researchers, the degree to which her ideas have foreshadowed modern memory research signifies the value of her work, and indicates that memory researchers may do well to better familiarise themselves with Arnold's theory.

REFERENCES

Adolphs, R., Gosselin, F., Buchanan, T. W., Tranel, D., Schyns, P., & Damasio, A. R. (2005). A mechanism for impaired fear recognition after amygdala damage. *Nature*, *433*, 68–72.

Arnold, M. B. (1960). *Emotion and personality* (2 vols.). New York: Columbia University Press.

Arnold, M. B. (1970). Perennial problems in the field of emotion. In M. B. Arnold (Ed.), *Feelings and emotions* (pp. 169–186). New York: Academic Press.

Arnold, M. B. (1984). *Memory and the brain*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Arnold, M. B. (1986). Eppur si muove! *Contemporary Psychology*, *31*, 548–549.

Bandettini, P. A., Birn, R. M., & Donahue, K. M. (2000). Functional MRI: Background, methodology, limits, and implementation. In J. T. Cacioppo, L. G. Tassinary, & G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 978–1014). New York: Cambridge University Press.

Beebe-Center, J. (1932). Leonard Thompson Troland: 1889–1932. *The American Journal of Psychology*, *44*, 817–820.

Bradley, M., & Lang, P. (2000). Measuring emotion: Behavior, feeling, and physiology. In R. Lane & L. Nadel (Eds.), *Cognitive neuroscience of emotion* (pp. 242–276). New York: Oxford University Press.

Carlson, R. A. (1997). *Experienced cognition*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Damasio, A. (1994). *Descartes' error: Emotion, reason and the human brain*. London: Papermac.

Devonis, D. C. (2000). Troland, Leonard Thompson (1889–1932). In A. E. Kazdin (Ed.), *Encyclopedia of psychology* (pp. 124–125). New York: Oxford University Press.

Dolan, R. J., & Morris, J. (2000). The functional anatomy of innate and acquired fear: Perspectives from neuroimaging. In R. Lane & L. Nadel (Eds.), *Cognitive neuroscience of emotion* (pp. 225–241). New York: Oxford University Press.

Ekman, P. (1994). All emotion are basic. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 15–19). New York: Oxford University Press.

Garry, M., Manning, C. G., Loftus, E. F., & Sherman, S. J. (1996). Imagination inflation: Imagining a childhood event inflates confidence that it occurred. *Psychonomic Bulletin & Review*, *3*, 208–214.

Goff, L. M., & Roediger, H. L. (1998). Imagination inflation for action events: Repeated imaginings lead to illusory recollections. *Memory and Cognition*, *26*, 20–33.

Graf, P., & Schacter, D. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *11*, 301–318.

Grossman, S. P. (1985). Memory and the brain. *American Scientist*, *73*, 89.

Hebb, D. O. (1949). *Organization of behavior*. New York: Wiley.

Hintzman, D. L. (1984). MINERVA 2: A simulation model of human memory. *Behavior Research Methods, Instruments and Computers*, *16*, 96–101.

Hirst, W. (1985). Mapping psychological function onto the brain: Memory as a case study. *Contemporary Psychology*, *30*, 782–783.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General*, *110*, 306–340.

Jacoby, L. L., & Kelley, C. M. (1992). A process-dissociation framework for investigating unconscious influences: Freudian slips, projective tests, subliminal perception, and signal detection theory. *Current Directions in Psychological Science*, *1*, 174–179.

Kotter, R., & Meyer, N. (1992). The limbic system: A review of its empirical foundation. *Behavioral Brain Research*, *52*, 105–127.

Lange, L. L. (2005). Sleeping beauties in psychology: Comparisons of "hits" and "missed signals" in psychology journals. *History of Psychology*, *8*, 194–207.

Lashley, K. S. (1950). In search of the engram. *Symposia of the Society for Experimental Biology*, *4*, 454–482.

Lashley, K. S. (1958). Cerebral organization and behavior. In *The brain and human behavior: Proceedings of the Association for Research in Nervous and Mental Disease* (Vol. 36, pp. 1–18). Baltimore: Williams & Wilkins.

Le Doux, J. E. (1996). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.

Lewis, M. D. (2005). Bridging emotion theory and neurobiology through dynamical systems modeling. *Behavioral and Brain Sciences*, *28*, 169–194.

Loftus, E. F., & Palmer, J. L. (1974). Reconstruction of automobile destruction: An example of the interaction between language and behavior. *Journal of Verbal Learning and Verbal Behavior*, *13*, 585–589.

Mazzoni, G., & Nelson, T. O. (1998). *Metacognition and cognitive neuropsychology: Monitoring and control processes*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Metcalfe, J., & Shimamura, A. P. (1994). *Metacognition: Knowing about knowing*. Cambridge, MA: The MIT Press.

MacLean, P. (1990). *The triune brain in evolution*. New York: Plenum Press.

McClelland, J. L., & Rumelhart, D. E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General*, *114*, 159–188.

Mooren, J. H. M., & van Krogten, I. A. M. H. (1993). Contributions to the history of psychology: CXII. Magda B. Arnold revisited: 1991. *Psychological Reports*, *72*, 67–84.

Morrison, A. (1987). Book review of Memory and the Brain. *Review of Metaphysics*, *41*, 369–370.

Nelson, T. O. (1992). *Metacognition: Core readings*. Needham Heights, MA: Allyn & Bacon.

Newell, A., & Simon, H. (1963). GPS, a program that simulates human thought. In E. Feigenbaum & J. Feldman (Eds.), *Computers and thought* (pp. 279–293). New York: McGraw-Hill.

Norman, D. A., & Rumelhart, D. F. (1970). A system for perception and memory. In D. A. Norman (Ed.), *Models of human memory*. New York: Academic Press.

Papez, J. (1937). A proposed mechanism of emotion. *Archives of Neurology and Psychiatry*, *38*, 338–353.

Panksepp, J. (1998). *Affective neuroscience: The foundations of human and animal emotions*. New York: Oxford University Press.

Perfect, T. J., & Schwartz, B. L. (2002). *Applied metacognition*. New York: Cambridge University Press.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review*, *88*, 93–134.

Rajah, M. N., & McIntosh, A. R. (2005). Overlap in the functional neural systems involved in semantic and episodic memory retrieval. *Journal of Cognitive Neuroscience*, *11*, 470–482.

Review of *The fundamentals of human motivation*. (1930). *The American Journal of Psychology*, 42, 327–331.

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not present in lists. *Journal of Experimental Psychology: Human Memory and Cognition*, *21*, 803–814.

Rosenbaum, D. A. (2005). The Cinderella of Psychology: The neglect of motor control in the science of mental life and behavior. *American Psychologist*, *60*(4), 308–317.

Rundus, D. (1973). Negative effects of using list items as recall cues. *Journal of Verbal Learning and Verbal Behavior*, *12*, 43–50.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 501–518.

Schacter, D. L. (2001). *Forgotten ideas, neglected pioneers: Richard Semon and the story of memory*. Philadelphia: Psychology Press.

Shields, S. A., & Fields, R. M. (2003). Magda B. Arnold (1903–2002). *American Psychologist*, *58*, 403–404.

Squire, L. R. (1987). *Memory and the brain*. New York: Oxford University Press.

Squire, L. R. (1992). Memory and the hippocampus: A synthesis of findings with rats, monkeys, and humans. *Psychological Review*, *99*, 195–231.

Taylor, J. (1932). *Selected writings of John Hughlings Jackson* (Vol. 2). London: Hodder & Stoughton.

Tolman, E. C. (1951). *Purposive behavior in man and animals*. Berkeley, CA: University of California Press. (Original work published 1932).

Troland, L. T. (1929–1932). *The principles of psychophysiology: A survey of scientific psychology* (Vol. 1–3). New York: Van Nostrand.

Tulving, E. (2000). Concepts of memory. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 33–43). New York: Oxford University Press.

Uttal, W. R. (2003). *The new phrenology: The limits of localizing cognitive processes in the brain*. Cambridge, MA: MIT Press.

Van Raan, A. F. J. (2004). Sleeping beauties in science. *Scientometrics*, *59*, 467–472.