A Brief and Selective History of Attention

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1. Roots

Attention: from the Latin attenti, from attentus, the past participle of attendere, meaning "to heed."

Although the word existed in Roman times, there is little reference to any scientific basis for the human capacity for attention until Descartes (1649), who related attention to movements of the pineal body acting on the animal spirit:

Thus when one wishes to arrest one's attention so as to consider one object for a certain length of time, this volition keeps the gland tilted towards one side during that time.

In contrast, Hobbes (1655) believed:

While the sense organs are occupied with one object, they cannot simultaneously be moved by another so that an image of both arises. There cannot therefore be two images of two objects but one put together from the action of both.

The first extended treatment of attention may be due to Malebranche (1674) who claimed that:

Attention is necessary for conserving evidence in our knowledge.

He believed that the seeker of truth must avoid strong sensations and passions that may lead to distraction. Malebranche recommended detailed procedures for cultivating attention, the study of geometry being a prime element. Leibnitz (1765) and Wolff (1734) then introduced the idea of *apperception*, the process that admits perceptions into consciousness:

In order for the mind to become conscious of perceived objects, and therefore for the act of apperception, attention is required.

This made a connection between consciousness and attention for the first time. Hebart (1824) believed, like Leibnitz, that ideas can exist in the mind without being conscious, but he attributed this to inhibition from competing ideas. He developed an elaborate algebraic model of attention using differential calculus:

He is said to be attentive, whose mind is so disposed that it can receive an addition to its ideas: those who do not perceive obvious things are, on the other hand, lacking in attention.

2. Phenomenonology and Early Psychological Accounts

Helmholtz (1860) believed that nervous stimulations are perceived directly, never the objects themselves, and there are mental activities (judgment theory) that enable us to form an idea as to the possible causes of the observed actions on the senses. He wrote:

We are not in the habit of observing our sensations accurately except as they are useful in enabling us to recognize external objects. On the contrary, we are wont to disregard all those parts of the sensations that are of no importance so far as external objects are concerned.

These activities are instantaneous, unconscious, and cannot be corrected by the perceiver by better knowledge. He disagreed with Panum (1858) who believed that attention is an activity entirely subservient to the conscious will of the observer. Attention becomes difficult to hold once interest in an object fades. The greater, the disparities between the intensities of two impressions, the harder it is to keep the attention on the weaker one. Panum studied this in the specific context of binocular rivalry; but more generally, he observed that we are able to "see" only a certain number of objects simultaneously. He therefore concluded that it makes sense that the field of view is first filled with the strongest objects. In studying an object, first attention, and then the eye, is directed to those contours that are seen by indirect vision.

Hamilton (1859) first raised the question of the span of attention:

The doctrine that the mind can attend to, or be conscious of, only a single object at a time would in fact involve the conclusion that all comparison and discrimination are impossible? [. . .]. Suppose that the mind is not limited to the simultaneous consideration of a single object, a question arises, How many objects can it embrace at once?

Brentano (1874) developed a competing theory known as *act psychology*. In this view, an act is a mental activity that affects percepts and images rather than objects. Examples of acts include attending, picking out, laying stress on something, and similar actions. This was the first discussion of the possibility that a subject's actions play a dominant role in perception. Metzger (1974) summarizes aspects of action that contribute to perception: bringing stimuli to receptors, enlarging the "accessible area," foveation (the act of centering the central, highest-resolution part of the retina onto an object), optimization of the state of receptors, slowing down of fading and local adaptation, exploratory movement, and finally the search for principles of organization within visual stimuli.

A further connection between attention and consciousness was drawn by Wundt (1874), who described attention as an inner activity causing ideas to be present in consciousness to differing degrees. The focus of attention can narrow or widen, reflecting these degrees of consciousness. G. E. Müller's (1904, 1923) *Komplextheorie*, or theory of collective attention, was based explicitly on acts of the subject, obviously following the lead of Brentano. For Titchener (1908), attention was an intensive attribute of a conscious experience equated with "sensible clearness." He compared attention to a wave, but with only one peak (focus). He further argued that the fundamental effect of attention is to increase clarity, while Kulpe (1902) suggested that attention enhanced not clarity but discriminability. Petermann (1929) argued against the subject being a passive battlefield of stimuli. He proposed an attention-direction theory, based on actions (like Brentano), as the mechanism for an active attentive process. Both Petermann and Müller needed to introduce criteria for the action of attention but were subsequently criticized for using attention as a magical principle that can do everything and explain nothing.

William James (1890) is credited for perhaps the best-known plain language description of attention:

Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought.

James specified two domains in which these objects occur, sensory and intellectual. He listed three physiological processes which he believed played a role in the implementation of attention: the accommodation or adjustment of the sensory organs, the anticipatory preparation from within of the ideational centers concerned with the object to which the attention is paid, and an afflux of blood to the ideational center.

3. Early Behavioral Findings

Early experimentalists played an important role in shaping views on how to address questions related to attention. Jevons (1871), following Hamilton's suggestion, investigated the span of attention by throwing sets of black beans into a round box and examining his ability to estimate the number by a single mental act (subitizing). This was later studied in a controlled manner using the tachistoscope. Cattell (1885) first manipulated the tachistoscope to control temporal span and thus prevent fixation changes. Attention not only had a span in space, as was studied by Hamilton and Jevons, but also in time. Binocular rivalry was thought to be a result of attention fluctuating over time but with a constant stimulus by Breese (1899) and Helmholtz (1860).

Attention was also studied beyond the visual modality. The "complication" experiment (which grew out of the difficulties astronomers faced in recording transit times of stars) was introduced by von Tschisch (1885). Subjects were required to watch a moving pointer and specify its location when a sound or some other non-visual stimulus occurred. Even though the two events differed in modality (the visual pointer and the sound, for example) and were presented simultaneously, one was registered in consciousness before the other. James (1890) believed this may be due to concentration of attention on each in turn. Angell and Pierce (1892) corroborated this experimentally. The effects of attention on behavioral measures of perception and action were further investigated by many others, including Exner (1882) and Cattell (1885).

Around this time, Helmholtz (1896/Mackeben and Nakayama 1989) introduced the idea that attention could be deployed in a covert fashion, independent of eye movements:

The electrical discharge illuminated the printed page for a brief moment during which the image of the sheet became visible and persisted as a positive after-image for a short while. Hence, perception of the image was limited to the *duration of the after-image. Eye movements of measurable size could not be performed during the duration of the flash and even those performed during the short persistence of the after-image could not shift its location on the retina. Nonetheless, I found myself able to choose in advance which part of the dark field off to the side of the constantly fixated pinhole I wanted to perceive by indirect vision. Consequently, during the electrical illumination, I in fact perceived several groups of letters in that region of the field [. . .]. The letters in most of the remaining part of the field, however, had not reached perception, not even those that were close to the point of fixation.*

Such a demonstration is simple and compelling and so represents powerful evidence for the existence of covert attention without independent eye movements. The similarities and differences between movements of the eye and those of spatial attention have been a focus of research ever since.

After the exuberant early behavioral experiments at the end of the 19th century, Ribot (1889), Watson (1919), Holt (1915), Dashiell (1928), Mowrer (1938), and others attempted to describe mental phenomena solely in behaviorist terms. To them, attention was a by-product of behavior, and identified with the postural or motor processes that facilitate reception of stimuli. Mowrer (1939) studied the effects of expectancy on reaction time and response amplitude, and connected these effects with what he called the "preparatory set," later called attention. He believed that this mechanism is central rather than peripheral.

The Gestalt school did not believe in attention. Köhler's 1947 book, for example, only barely mentions attention. Gestaltists could have been expected to take attention seriously. However, they believed that the patterns of electrochemical activity in the brain are able to sort things out by themselves, and to achieve an organization that best represents the visual world, reconciling any conflicts along the way. The resulting internal organization includes portions that seem more prominent than others. Thus attention became an emergent property and not a process in its own right. Figure-ground concerns loomed larger for them and the figure would dominate perceptions within a scene, thus emerging as the focus of attention rather than being explicitly computed as such. Berlyne (1974) tells us that Edgar Rubin, well known for his vase/profile illusion of figure-ground perception, actually read a paper at a meeting in Jena in 1926 titled "On the nonexistence of attention." Healthy skepticism continues to this day.

4. Early Neuroanatomy and Neurophysiology

Early findings from neuroanatomy and neurophysiology contributed to knowledge about basic brain function that would form the foundation of contemporary understanding of the neural mechanisms of attention. Helmholtz (1866) demonstrated that the rate of nerve conduction was not infinitely fast, but only a relatively slow 100 meters/second. Thus, every mental operation requires a period of time for its accomplishment. Sechenov (1863/1965) argued that the highest levels of the nervous system exercise inhibitory control over lower levels, and thus one might expect inhibition to be associated with central attention.

Hebb (1949) extended Cajal's (1909) single neuron doctrine by considering assemblies of neurons, functional entities that formed the basis of a neural theory for perception and learning. He emphasized that the perceiver's attention or expectations must form an integral part of the perceptual process. Pavlov (1927) described two basic internal aspects of behavior: facilitation and inhibition. An unexpected stimulus is likely to induce the orientation reflex, and at the same time there is an interruption of response to other stimuli that may be present. This "negative induction" was the tendency for a strong focus of excitation in one region of the cerebral cortex to generate inhibition in neighboring regions and consequently to weaken responses controlled by those regions. Sokolov (1963) studied the orienting reflex and elaborated it into a general view about the alignment of the central nervous system with sources of stimulation. This reflex combined outward signs and inward systems designed to improve processing of selected signals.

5. Information Processing and the First Articulated Models of Attention

Selective hearing is the domain where early research motivated the development of the first information processing models of attention. Cherry (1953) and Poulton (1953) first exposed subjects to two or more verbal messages simultaneously by presentation to different ears. The messages were distinguished by gender of speaker, by content, and by language or acoustical characteristics. Subjects were instructed to attend to one particular characteristic or were given no instructions at all, and then were asked questions about the messages. Some experiments involved "shadowing," repeating verbal stimuli as they were received. Subjects showed surprisingly little awareness for the content or even characteristics of unattended stimuli, suggesting that unattended stimuli were rejected from further processing. In an intellectual landmark, Broadbent summarized this empirical data and presented a theoretical synthesis in 1958. Broadbent proposed that humans can be viewed as limited-capacity information processing systems. He suggested a model of processing that included a short-term store to act to extend the duration of a stimulus; that stimuli could be partitioned into channels (modalities); then a selective filter selects among channels, and a limited capacity channel then processes the selected channel. This is the prototypical *early selection* model of attention and represents the first theoretical account to relate psychological phenomena to information processing concepts from computer science. Broadbent's clear empirical and theoretical synthesis stimulated the development of alternative accounts. Deutsch & Deutsch (1963), Norman (1968), Moray (1969), and MacKay (1973) proposed *late selection* models. In their view, limited awareness of unattended stimuli has little to do with perceptual processing but instead represents a failure of perception to subsequently access memory or control action, a view later developed by Duncan (1980). Late selection theories propose that all information is completely processed and recognized before it receives the attention of a limited capacity processor. Recognition can occur in parallel, and stimulus relevance determines what is attended. These models typically included some form of memory within the process. How attention may interact with perceptual memory was first investigated by Sperling (1960), who observed that cues that follow a visual display by a short fraction of a second can be used to select information from a brief sensory memory system that seems to hold much more than the subject was able to report (the partial report task).

Treisman (1964) was not completely convinced by the stark dichotomy between early and late selection models, and suggested a hybrid view. Her model included a filter that attenuates (in a graded fashion) unattended signals, leaving them incompletely analyzed. Importantly, this filter can operate at different stages of information processing. Treisman thus introduced the notion that the effects of attention may be hierarchically described. But these levels need not be all based on perception, as Neisser (1967) noted. He claimed that we can attend to our own thoughts as well as to external stimuli, and that attention worked by matching stimulus sequences to internal processes. Moray (1969) added that attention, although restricted to one channel at a time, is allowed to switch over to a different channel when the importance of channels changes. This switching required time, and in this way he hoped to explain some of the temporal characteristics of attention.

The influence of computer technology and information processing can be seen perhaps most strongly in the theory of Kahneman (1973), who argued that attention is a general-purpose limited resource. Some activities are more demanding and therefore require more mental effort than others. The total available processing capacity may be increased or decreased by other factors such as arousal. Several activities can be carried out at the same time, provided that their total effort does not exceed the available capacity. Rules or strategies exist that determine allocation of resources to various activities and to various stages of processing. Attentional capacity will therefore reflect the demands made at the perceptual level, the level at which the input is interpreted or committed to memory, and the response selection stage. Kahneman thus believed in the existence of a Central Processor that operates a Central Allocation Policy, constantly evaluating the demands made by each task and adjusting attention accordingly. It is clear that Kahneman's inspiration came from consideration of the operating systems of computers; but beyond the metaphoric use, the connection is a weak one, if not irrelevant.

Milner (1974) considered the role that attention plays in visual recognition. He claimed that the unity of a figure at the neuronal level is defined by synchronized firing activity and that attention acts in two ways: to select relevant figure from among others and to activate the feedback pathways from the cell assembly to the early visual cortex for precise localization. Milner suggested that feedback pathways communicate attentional instructions.

Perhaps the first mathematically articulated theory relevant to attentional processing was Grossberg's Adaptive Resonance Theory (1975, 1976). ART algorithms are clustering algorithms that obey the following governing principles: bottom-up activation can drive a cell if strong enough; top-down priming can modulate a cell; a cell becomes active if it receives large enough top-down and bottom-up activation; top-down activation, even small, can negate bottom-up activation; and, feedback leads to resonance and convergence. He believed that top-down attentional mechanisms should occur in every cortical area where learning can occur and suggested specific circuitry for interactions.

An important aspect of attentional processing missing from these models, and not well understood to this day, is the temporal nature of the process. C. Eriksen and colleagues (Eriksen and Collins 1969, Colegate, Hoffman and Eriksen 1973) performed the first experiments attempting to illuminate the subject. They used spatial cueing in selection tasks where the display was made up of arrays of characters and subjects were asked to respond to the cued characters. They investigated primarily cue-stimulus onset timings (SOA) and the resulting response times (RT) and accuracy. Accuracy improved as the cues were presented earlier than the stimulus up to around 100 msec. with the benefit peaking at about 200 msec.

and plateauing afterwards, showing that it takes time for the cue to take effect.

6. Neurophysiology

Modern techniques in neurophysiology have led to major advances in the understanding of brain mechanisms of attention through experiments in awake behaving animals and in humans. With the invention of human electroencephalography (Berger 1929) many stimuli were found to generally increase "arousal" or attentiveness in subjects. In particular, activation of the reticular formation can produce these effects. Increased arousal was found to accompany an increased capacity to take in and process information. Detailed electrophysiological investigation of the brain mechanisms of attention began with event-related potential (ERP) studies in animals (Hernandez-Peon et al. 1956, Horn 1965) and humans (Spong et al. 1965, Groves and Eason 1969, Harter and Salmon 1972, Hillyard et al. 1973, Naatanen 1975, Simson et al. 1977), followed closely by single unit recordings in monkeys (Goldberg and Wurtz 1972, Goldberg and Bushnell 1981, Bushnell et al. 1981, Mountcastle et al. 1981, Moran and Desimone 1985). These experiments revealed that sensory responses to auditory or visual stimuli were modulated by the animal's attentional state. For example, Hernandez-Peon, Scherrer and Jouvet (1956) measured activity evoked by the ticking of a metronome in neurons in the cochlea nucleus of a cat. When the cat was shown a mouse, the neural activity evoked by the metronome disappeared. They concluded that top-down signals exist that alter sensory processing to prevent distraction. Initially, such top-down effects of attention appeared relatively modest, or restricted to brain areas traditionally associated with spatial attention (e.g., the parietal lobe; Wurtz et al. 1982). However, as the scope of the research proceeded and experimental paradigms became more sophisticated, it became clear that attentional modulation of sensory responses could be found throughout the hierarchy of sensory processing areas and indeed in virtually every cortical area. Such empirical findings challenged early theoretical accounts of attention as a unitary sensory filter and began to stimulate the development of more sophisticated theoretical models.

Non-invasive ways of measuring brain processes in humans began to appear at the end of the 1980s, including magnetoencephalography (MEG), positron emission tomography (PET), and subsequently functional MRI (fMRI). Such techniques measure the activity in relatively large neuronal populations, either directly (MEG/ERP) or indirectly through measuring changes in local cerebral hemodynamics. In the decade leading up to this volume, there has been an explosion in the use of functional imaging to characterize attentional functions in humans that is beyond the scope of this history and indeed is the focus of much of this volume. In general, the principles that characterize attentional modulation of sensory processing measured using functional imaging techniques are remarkably similar to those determined by single unit electrophysiology, though important issues remain in understanding the relationship between these two measures.

7. Integrated Theories of Attention

Broadbent's (1958) synthesis, discussed above, opened up the prospect of integrated psychological theories of attention. Continuing from where late selection models left off were Shiffrin and Schneider (1977), who claimed that automatic processes, such as parallel visual analysis, do not require significant mental capacity, are resistant to suppression, and do not require deliberate intent by the observer to have effect. Their model required a final comparison stage where a target in memory may be checked against the resulting visual representations. Interestingly, they also included the practice effect in their model, that is, how responses to visual search tasks change with training. Their results led them to believe that even the final comparison stage could be made automatic with sufficient practice. In general, the changes in processing induced by practice remain poorly understood.

Feature Integration Theory was first presented in a seminal paper by Treisman & Gelade (1980). Here they introduced for the first time several ideas that have subsequently pervaded the attentional literature, and strongly influence the field to this day:

> *[. . .] the feature-integration theory suggests that we become aware of unitary objects in two different ways—through focal attention or through top-down processing. The first route to object identification depends on focal attention, directed serially to different locations, to integrate the features registered within the same spatio-temporal "spotlight" into a unitary percept [. . .]. The second way [. . .] is through top-down processing. In a familiar context, likely objects can be predicted. Their presence can then be checked by matching their disjunctive features to those in the display, without also checking how they are spatially conjoined.*

They argued that separate feature maps existed, all connected to a master map of locations over which an attentional spotlight would move, illuminating particular locations that were to be attended. The "illumination" metaphor to describe an analog selection of a contiguous portion of an image seems to have its roots in Shulman, Remington and McLean (1979). When more than one visual object is present and the visual system is overloaded, incorrect combinations of features belonging to different objects occur, known as "illusory conjunctions" (Treisman and Schmidt, 1982). These are failures of binding, as pointed out first by Rosenblatt (1961). Rosenblatt's classical view of binding is one in which one kind of visual feature, such as an object's shape or color, must be correctly associated with another feature, such as its location, to provide a unified representation of that object. Such explicit association or binding is important when more than one visual object is present, in order to avoid incorrect combinations of features belonging to different objects.

Although Feature Integration Theory, and in fact most models, concentrates on covert attention alone, it is clear that fixation changes (whether overt or covert) are tightly coupled, and a considerable amount of research has studied such a relationship. Top-down influences on overt attention were perhaps most clearly demonstrated by Yarbus (1967). He showed that eye movements changed depending on the question asked of the subject; that is, the reason for looking at an image in the first place. For a very conventional picture of a family in their living room he asked observers several different questions pertaining to different aspects of the scene (such as the nature of the clothing worn by the family, or where the family were located in the room) and recorded the ensuing eye movements. The eye movement patterns were radically different and consistent across observers, thus providing strong evidence for the role of task in how we acquire information from an image.

Noton and Stark (1971) reported a connection between the eye movement patterns observed during learning of a visual pattern and the subsequent viewing of that pattern. During learning, subjects followed a characteristic scanpath. When later presented with the pattern again, subjects usually followed a very similar scanpath for at least the first few fixations. This suggested that the internal representation of a pattern in memory is a network of features, and thus attention shifts move from feature to feature.

In one theoretical synthesis of research on both overt and and covert attention, Posner (1980) proposed that attention had three major functions. First, it provided the ability to process high priority signals, or *alerting*. Second, it permitted *orienting* and overt foveation of a stimulus. Finally, it allowed *search* to detect targets in cluttered scenes. Orienting improves efficiency of target processing in terms of acuity, permitting events at the foveated location to be reported more rapidly as well as at a lower threshold. Overt foveation is strongly linked to movement of covert attention. Overt orienting, whether of the eyes or the head or both, is termed *exogenous* while covert fixation shifts are called *endogenous*. Exogenous control of gaze direction is controlled reflexively by external stimulation while endogenous gaze is controlled by internally generated signals. Covert fixations are not observable and thus must be inferred from performance of some task.

The psychological "binding problem" has also motivated consideration of possible physiological mechanisms. Von der Malsburg (1981) sought to understand how active cells can express relationships among themselves and developed his Correlation Brain Theory. He suggested that synapses could be modulated, so that they switch between conducting and non-conducting states, and that the modulation is governed by correlations in the temporal structure of signals. In this way, momentarily useless connections are deactivated, and interference between different memory traces is reduced and memory capacity increased; thus synapses were dynamically modulated. He also claimed that the brain does not contain complex feature detector cells; rather, timing correlations signal objects.

When stimuli are available for just a brief period (approximately 100 ms) only limited amounts of spatial information can be extracted by the visual system, according to Bergen and Julesz (1983). Eye movements are not possible and the time during which the after-image of the stimulus is available for inspection is cut by presentation of a masking pattern. Bergen and Julesz showed that under these conditions a small pattern is easily detected against a background made up of many others, only if it differs from the background patterns in certain local features. If so, its detectability is almost independent of the number of background elements, suggesting that a parallel process is responsible for the computation. Detection of patterns that do not differ from the background in such features requires a serial focal attention process.

An early attempt to connect previous ideas and speculate on the neural correlate of attentional control was presented by Crick (1984). He suggested that the spotlight of Treisman and Gelade is controlled by the reticular complex of the thalamus, and that the searchlight is expressed by rapid bursts of firing from subsets of thalamic neurons. Feature conjunctions are mediated by rapidly modifiable synapses (Malsburg synapses) by these bursts. Activation of Malsburg synapses produces transient cell assemblies connecting neurons at different levels.

A bias against returning attention to previously attended locations was first reported by Posner and Cohen (1984). They argued that the mechanism responsible for the effect "evolved to maximize sampling of the visual environment." Posner, Rafal, Choate, and Vaughan (1985) coined the term "inhibition of return" (IOR) to refer to this inhibitory component. This terminology derives from the notion that attention is drawn reflexively to the location of a salient cue. Following the withdrawal of attention back to fixation, attention is then relatively impaired for returning to the previously cued location. Posner and colleagues (1985) thus characterized IOR as an effect of attention on attention.

Koch and Ullman (1985) presented a model of visual attention that has played a major role in the discipline, based largely on Feature Integration Theory, but providing a detailed mathematical foundation. Their model included a saliency map (Treisman and Gelade's master map of locations) that was an encoding of overall feature saliency at each location in an image. Saliency was determined by a weighted sum of all features computed at each point. A winner-take-all competition would choose the strongest and thus assumed most salient point. All features at that point would then be routed to a central representation for further processing. Due to the mathematical characteristics of a winner-take-algorithm, selected points must be inhibited or eliminated from the competition in order for the next most salient item to be selected. This kind of inhibition of return is not really the same as that of Posner and Cohen; the underlying intent of each is different. In their model, the time to move attention was proportional to logarithmic distance between stimuli. Interestingly, Sagi and Julesz (1985) documented the independence of performance in visual search on distance, suggesting fast non-inertial shifts of attention. Koch and Ullman's theory did not include single cell or synaptic modulations.

8. *Disorders of Attention*

The identification of neuropsychological deficits of attention following brain damage has played an important role in shaping notions of attentional mechanisms in the human brain. Poppelreuter (1917) introduced the word inattention, thus conceiving of the notion of a brain disorder affecting attention. Brain (1941) and Critchley (1966) proposed that unilateral neglect following parietal damage reflected an attentional disorder. However, not until Kinsbourne (1970) and Heilman & Valenstein (1972) was the notion that an attentional impairment underlays unilateral neglect more generally accepted. Unilateral neglect is a common and disabling deficit after unilateral brain damage, particularly following strokes centred on the right inferior parietal lobe. Many of the ideas and methods developed in the study of normal attention have been applied fruitfully to the study of such patients, particularly the demonstration of residual processing for neglected information and the modulation of visual extinction (one of the components of the neglect syndrome) by grouping processes.

9. *Conclusions*

Like attention, all histories are selective and this chapter is no exception. We have chosen to cover the field until the mid-1980s. Since then, a great deal has happened to attention research that history has yet to judge, and this chapter will make no attempt to second-guess the future. The interested reader can read the comprehensive and detailed treatments by Posner (1978), Allport (1993), Desimone and Duncan (1995), Maunsell and Ferrera (1995), Rafal and Robertson (1995), Wolfe (1996) for a review of visual search; Pashler (1998), Driver & Mattingley (1998) for a review of disorders of attention; Chapter 11 of Palmer (1999), Colby and Goldberg (1999), Kastner and Ungerleider (2000) for a review of brain areas where attentional effects have been observed; Logothetis et al. (2001) and Bandettini and Ungerleider (2001) for a review of brain imaging techniques; and Itti and Koch (2001) for a review of computational models of attention. Additional material on the history of the field can be found in Pillsbury (1908), Treisman (1969), Berlyne (1974), and Metzger (1974). In any case, most if not all of the chapters in this volume provide some level of background to the work presented, thus filling in much of the events since 1985 in a manner not subject to our interpretation. This may be the best way to permit the reader to play a role in the historical judgment of research in the past 20 years.

All attention researchers recognize the diversity of possible definitions of the topic and this has sometimes led to healthy expenditure of a great deal of critical angst (Allport 1993). Indeed, Groos wrote as early as 1896 that:

"To the question, 'What is Attention'? there is not only no generally recognized answer, but the different attempts at a solution even diverge in the most disturbing manner."

Pillsbury (1908) agreed, saying that attention was "in disarray." Spearman (1937) commented on the diversity of meanings associated with the word:

"For the word attention quickly came to be associated . . . with a diversity of meanings that have the appearance of being more chaotic even than those of the term 'intelligence' ".

Even as recently as 1998, Sutherland in reviewing recent attention books claimed that:

"Over the past 50 years, the sheer ingenuity displayed by psychologists working on attention rivals if it does not exceed that of cosmologists studying black holes. Indeed, there is a similarity in their results—after many thousands of experiments, we know only marginally more about attention than about the interior of a black hole."

Of course, quite a bit is known about black holes nowadays (Hawking et al. 2004). Nevertheless, the point remains that the very diversity of the field can be seen as an impediment to understanding. We disagree. In preparing this volume, we celebrate the intellectual diversity of opinion and multiplicity of empirical findings that characterize contemporary attention research. Diversity stimulates ingenuity, interdisciplinarity, and a wide diversity of empirical work, and it may well be the case that a full explanation of attention is not possible from a single viewpoint alone. The explosion of interest in cognitive neuroscience and the development of non-invasive neuroimaging techniques in the last decade have led to an ever-increasing body of knowledge about attention and the brain on which this volume is focused. The papers in this volume represent a necessarily selective but comprehensive snapshot of the current enthusiasm, both empirical and theoretical, that characterizes attention research.

Regardless of one's methodology, discipline, and intuitions, there is only one core issue that justifies attentional processes: *information reduction*. Humans are faced with immense amounts of information, through not only their senses but also through the need to manage their memory and knowledge, and to utilize that information at appropriate moments. The search for how this occurs in support of the complex sensory-guided behaviors we humans exhibit is what motivates the research that is represented in this volume.

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