COGNITIVE SCIENCE Vol 23 (1) 1999, pp. 83–116 ISSN 0364-0213

Attention Metaphors: How Metaphors Guide the Cognitive Psychology of Attention

DIEGO FERNANDEZ-DUQUE
MARK L. JOHNSON
University of Oregon

The concept of *attention* is defined by multiple inconsistent metaphors that scientists use to identify relevant phenomena, frame hypotheses, construct experiments, and interpret data. (1) The Filter metaphor shapes debates about partial vs. complete filtering, early vs. late selection, and information filtering vs. enhancement. (2) The Spotlight metaphor raises the issue of space- vs. object-based selection, and it guides research on the size, shape, and movement of the attentional focus. (3) The Spotlight-in-the-Brain metaphor is frequently used to interpret imaging studies of attention. (4) The debate between supramodal and pre-motor theories of attention replays the dichotomy between the Spotlight and the Vision metaphors of attention. Our analysis reveals the central role of metaphor in scientific theory and research on attention, exposes hidden assumptions behind various research strategies, and shows the need for flexibility in the use of current metaphors.

I. INTRODUCTION

The ways we identity, define, and study the phenomena of attention depend largely upon metaphor. Our thesis is that the impressive body of empirical theorizing and research that has been done on attention over the past four decades is guided by a small set of fundamental metaphors for attention. We will present evidence that these metaphors are essential to the cognitive psychology of attention. They define entire research programs, circumscribing which attentional phenomena are studied, how they are studied, and what counts as evidence. We show that the formation of research hypotheses and the subsequent direction taken by that research is dependent on these underlying metaphors. When theories of attention run into problems, both the problems and their proposed solutions are consequences of the logic of the metaphors that are at work. If our analysis is correct, then these metaphors

Direct all correspondence to: Diego Fernandez-Duque, Department of Psychology, University of Oregon, Eugene, OR 97403-1227<duque@uoneuro.uoregon.edu or markj@oregon.uoregon.edu>.

are anything but optional. They are the very means by which we understand and study attention. To discard them would be to destroy the entire field of attention research. To discover how the metaphors work within various theories is to understand what makes those theories hang together, what gives each the explanatory power it has, and how the specific metaphors constrain our reasoning and knowledge.

Over the last 40 years the major themes of attention research have been defined by a small set of metaphors. In this paper we will consider four of those themes and some of the research questions they give rise to: (1) **Attentional Filter**: What are the properties of the attentional filter? What is the locus of the filter? How much is filtered? Does attention act by inhibiting unwanted information or by enhancing wanted information? (2) **Attention Spotlight:** What are the properties of the focus of attention? Can it change its size and shape? Can the focus of attention be split? What controls the attentional spotlight (an executive system)? (3) **Attention in the Brain**: Should results from imaging techniques (PET, fMRI) that show increased brain activation in attended areas be interpreted in relation to pre-existent Information-Processing models? (4) **Premotor Theory of Attention:** Is attention a general supramodal system or is it a property of the visual system (pre-motor theory)? A fifth theme, which we do not discuss here, is whether the concept of attention is best captured by structural models, such as filter models, or by capacity models, such as limited resource models. Elsewhere, we examine the role of metaphors in defining this structural vs. capacity debate (Fernandez-Duque & Johnson, in preparation).

Our present aim is to show that a highly constrained set of conceptual metaphors is constitutive and definitive of the theoretical perspectives taken toward attention and toward the research programs based on these theories. The metaphors are not merely linguistic vehicles for communicating supposedly literal concepts and propositions about attention. Rather, the metaphors provide the conceptual substance and logic of the theories. We will also look briefly at the way scientific practice leads to metaphor change, that is, how data influences the evolution of metaphor and how technical advances, such as fMRI and PET have reframed attention metaphors. We conclude by pointing out some of the theoretical and practical implications of our study of attention metaphors for people engaged in attention research, metaphor theory, and the study of scientific discovery and problem solving.

II. CONCEPTUAL METAPHOR

Extensive studies and analyses have been done on a broad range of our most basic concepts, such as time, cause, event, mind, thought, memory, self, knowledge, morality, etc. These studies reveal that virtually all of our abstract conceptualization and reasoning is structured by metaphor (Gibbs, 1994; Kovecses, 1990; Lakoff, 1987; Lakoff & Johnson, 1980, 1999; Sweetser, 1990; Turner, 1991; Winter, 1989, 1999).

These metaphors are *conceptual* in nature, and not merely linguistic (Lakoff, 1993). Technically, a conceptual metaphor consists of a conceptual mapping of entities, properties, relations, and structures from a domain of one kind (the source domain) onto a domain of a different kind (the target domain). To illustrate what such mappings are and how they work, let us consider one of our most commonplace conventionalized metaphors by which we understand mind, namely, the Mind As Machine metaphor.

The Mind As Machine Metaphor

Source Domain (Machine)		*Target Domain (Mental Operations)*
Machine	———>	Mind
Functions within machine	———>	Mental capacities
Products of the machine	———>	Ideas
Automated machine functioning	———>	Thinking
Normal machine function	———>	Normal thought
Breakdown of machine	———>	Inability to think

The mapping is conceptual in nature, and it gives rise to a systematic use of ordinary, conventional linguistic expressions in much of our talk about mental operations. Thus we say such things as, "I'm a little *rusty* today," "Boy, the *wheels are turning* now," "He suffered a mental *breakdown*," "We're *cranking out* ideas." Such expressions in everyday talk about our mental functioning make sense precisely because they are based on the underlying cross-domain conceptual mapping of the Mind As Machine.

Each individual submapping (e.g., machine products ——> ideas) takes some entity or structure in the source domain and constructs a counterpart to it in the target domain. It is critical to notice that each submapping is directional, going from source to target. We understand aspects of the target domain via source domain structures, and not the reverse. Such unidirectionality shows itself clearly in the reasoning we do based on conceptual metaphors. We utilize our knowledge of the source domain plus inference patterns drawn from the source domain to reason about the target domain (Gibbs, 1994; Johnson, 1987). In the Mind As Machine metaphor, for example, we know that machines operate in a series of sequential automated subroutines (source domain knowledge). This source domain knowledge is the basis upon which we construct corresponding knowledge for the target domain: mental operations involves series of sequential automated subroutines (target domain knowledge).

Besides the directionality of the mapping, another important constraint on conceptual metaphor is the nature of the source domains. The evidence to date suggests that the range of potential source domains for conceptual metaphors is highly constrained by the nature of our bodies, our brain capacities, and the environments we inhabit (Johnson, 1987; C. Johnson, 1997; Regier, 1996; Sweetser, 1990; Turner, 1991). Typically, the source domains come from our bodily experience and action; that is, they are based on perception, bodily movements, object manipulation, and patterns of forces acting upon us and exerted by us.

Conventional conceptual metaphors are not merely crude "folk models" used only by ordinary people in their uncritical thinking. They are just as central to our best scientific theorizing as they are to our shared cultural models. The idea that metaphors structure most of our abstract concepts, both in ordinary thought and in scientific theories alike, runs directly counter to a centuries-old literalist view of language. According to the literalist view, all meaning and truth claims are ultimately reducible to literal concepts and propositions that are capable of corresponding directly to states of affairs in the world (Johnson, 1987). If all meaning is literal, then metaphor must be nothing more than a derivative function based on literal meanings and so is not itself essential to conceptualization and reasoning (Searle, 1979). When applied to science, such literalism cashes out as the view that metaphors are merely linguistic expressions useful in communicating ideas, but ultimately to be transcended as science becomes more formalized, precise, and rigorous. One version of literalism argues that, although metaphors may operate at certain early stages in the development of a theory, they are later to be replaced by formal models that use literal, metaphor-free descriptions. According to this view, metaphors are nothing but optional tools, useful in the process of scientific discovery, but lacking a significant role in any mature science.

This literalist, dismissive view of metaphor has been demolished recently by a rapidly growing number of studies of the crucial role of metaphor in science (Black, 1962; Gould, 1987; Hesse, 1966). Empirical studies done to date indicate that conceptual metaphor is basic to human conceptualization and reasoning at all levels and stages of thought (an extensive summary of this evidence can be found in Lakoff and Johnson, 1999, and in Gibbs, 1994). This applies, not just to our folk models, but equally to our most sophisticated scientific, mathematical, and philosophical theories. Therefore, the dream of a metaphor-free science appears to be an illusion that keeps us from understanding how scientific theories actually work. In this paper we want to show what the evidence for the constitutive nature of metaphor looks like in the important field of attention research.

To see how ordinary conventionalized metaphors often have sophisticated versions in even our best scientific theories, consider the following specific technical version of the Mind As Machine metaphor that controls a vast range of our scientific and philosophical thinking about mind, namely, the Mind As Information Processing Device.

The Mind As Information Processing Device Metaphor

Source Domain (Communication System)		*Target Domain (Mind)*
Transmitter	————>	Information Source
Input Modules (Buffers)	————>	Iconic Memory
Parallel Processing Channels	————>	Sensory Systems
Filter	————>	Attention
Input	————>	Stimulus
Signal	————>	Target Signal
Noise	————>	Distractors

This mapping for the Mind As Information Processing Device metaphor is oversimplified in two important ways: (1) versions of the metaphor that are actually used by scientists will be based on more technical definitions of the source domain, and (2) there is more than one way to map entities in the source domain onto entities in the target domain. Let us consider each of these variations in turn.

First, a particular scientific use of the metaphor will define the source domain entities, such as *filter, buffer, noise, signal*, and *information* in more precise, technically correct terms (Shannon, 1948). Each item in the source domain will therefore have its specific technical interpretation that will be appropriated by scientists into their understanding of the mind, and they will thus reason based on this technical knowledge that is imported from the source domain. Broadbent (1958), for example, states that:

> *capacity* in communication theory is a term representing the limiting quantity of information which can be transmitted through a given channel in a given time: if we send a Morse code with a buzzer we cannot send a dot and a dash at the same time but must send them successively (Broadbent, 1958, p. 5).

Given this specific technical conception of capacity (source domain knowledge), Broadbent then reasons appropriately to the correlative conception of capacity in mental operations (target domain):

> Any hypothetical account of brain function must in the future consider on the one hand the size of the brain (how many buzzers there are) and on the other hand the rate at which that brain will make reactions to a given set of incoming stimuli (the number of dots and dashes per second) (Broadbent, 1958, p. 5).

The second way in which the above mapping is oversimplified is that there are different ways to map the source domain onto the target domain. Even if scientists should happen to agree on their interpretation of the source domain, they might disagree about *what* in the source domain gets mapped onto *what* in the target domain. Take, for example, the notion of the *nervous system* in the target domain. Some researchers conceptualize the nervous system as a *receiver*, others regard it as a *communication channel*, and still others as a sequence of multiple *transmitter-channel-receiver modules*. Thus, the same entity in the target domain (e.g., nervous system), is mapped by different items from the source domain. This produces different specific versions of the general metaphor mapping given above. For example, Weaver (1949) sees the nervous system as the "receiver" of information: "When I talk to you, my brain is the information source, yours the destination; my vocal system is the transmitter, and your ear and the associated eight nerve is the receiver" (p. 17). Broadbent (1958), on the other hand, sees the nervous system as a "channel for communication": "Information transmitted through the man...will be limited by the size of his nervous system" (p. 41), and "a nervous system acts to some extent as a single communication channel" (p. 297).

Researchers who have utilized the Information Processing model might protest that the mapping given above is too vague and inaccurate to capture their working conception. However, there is nothing at all vague about the mapping, once it has been interpreted in a particular way, depending on specific technical knowledge of information-processing devices and on a particular version of the mapping. It is precisely such specifications of the metaphor that defines a particular theoretical and experimental viewpoint.

Given the cross-domain mapping, we build our knowledge of the target domain (mental operations) based on our knowledge of the source domain (information-processing device). To cite just one instance, we know the following about information-processing devices, such as telecommunications machines:

> (1) Only signals that pass through the filter can be further decoded; (2) only signals that are further decoded can be stored; thus, (3) if the signal does not pass the filter, it cannot be stored.

This argument and its conclusion are part of the body of knowledge we have about the source domain (information-processing device). When that knowledge is transferred to the target domain (mind), via the Mind As Information-Processing Device metaphor, we get:

> (1′) Only a stimulus to which attention is devoted can be recognized; (2′) only stimulus that is recognized can be "stored" in memory; thus, (3′) an unattended stimulus cannot be "stored" in declarative memory.

The guidance that the Mind As Information-Processing Device metaphor exercises is evident in the following representative examples from the scientific literature on attention:

> The process...in which one of a set of possible signals enters a system and one of another set emerges at the far end, is analogous to that of telephone or radio communication. The "number of possible states" or the "vocabulary"...is usually called the ensemble of signals by communications engineers. They speak of the "information" conveyed by a signal as increasing with the size of the ensemble from which it is drawn (Broadbent, 1958, p. 39).

> It is natural to think of attention as the *gateway* to memory, as we typically remember only those things we attend to. Correspondingly, ignored stimuli are *filtered*....Information cannot be remembered if it has been *removed* from the visual system [italics added] (Desimone, Miller, Chelazzi, 1994, p. 90).

> The *machinery* that carries out these analysis can be overloaded: if too many stimuli are admitted, accuracy suffers. In one sense then, stimuli that *pass through* the *filtering* mechanism could be said to compete for perceptual "capacity," while those blocked do not [italics added] (Pashler, 1995, pp. 94–95).

In each of these cases, specific interpretations of entities in the source domain make it possible to construct a corresponding structure in the target domain. The way scientists reason about various mental operations, such as attention, is directly dependent on their knowledge of the source domain and the inferences appropriate to it. Let us turn, then, to our analysis of the principal metaphors underlying contemporary research on attention, in order to see how they are constitutive of our understanding of the phenomena and how they influence research programs.

III. THE FILTER METAPHOR

The Mind As Information-Processing Device metaphor is representative of the way in which scientific theory appropriates a specific version of a commonplace conceptual metaphor, such as the Mind Is A Machine metaphor, that is widely accepted within a culture. The Mind As Information-Processing Device metaphor has had a major influence on the development of past and current structural models of attention. It was most eloquently

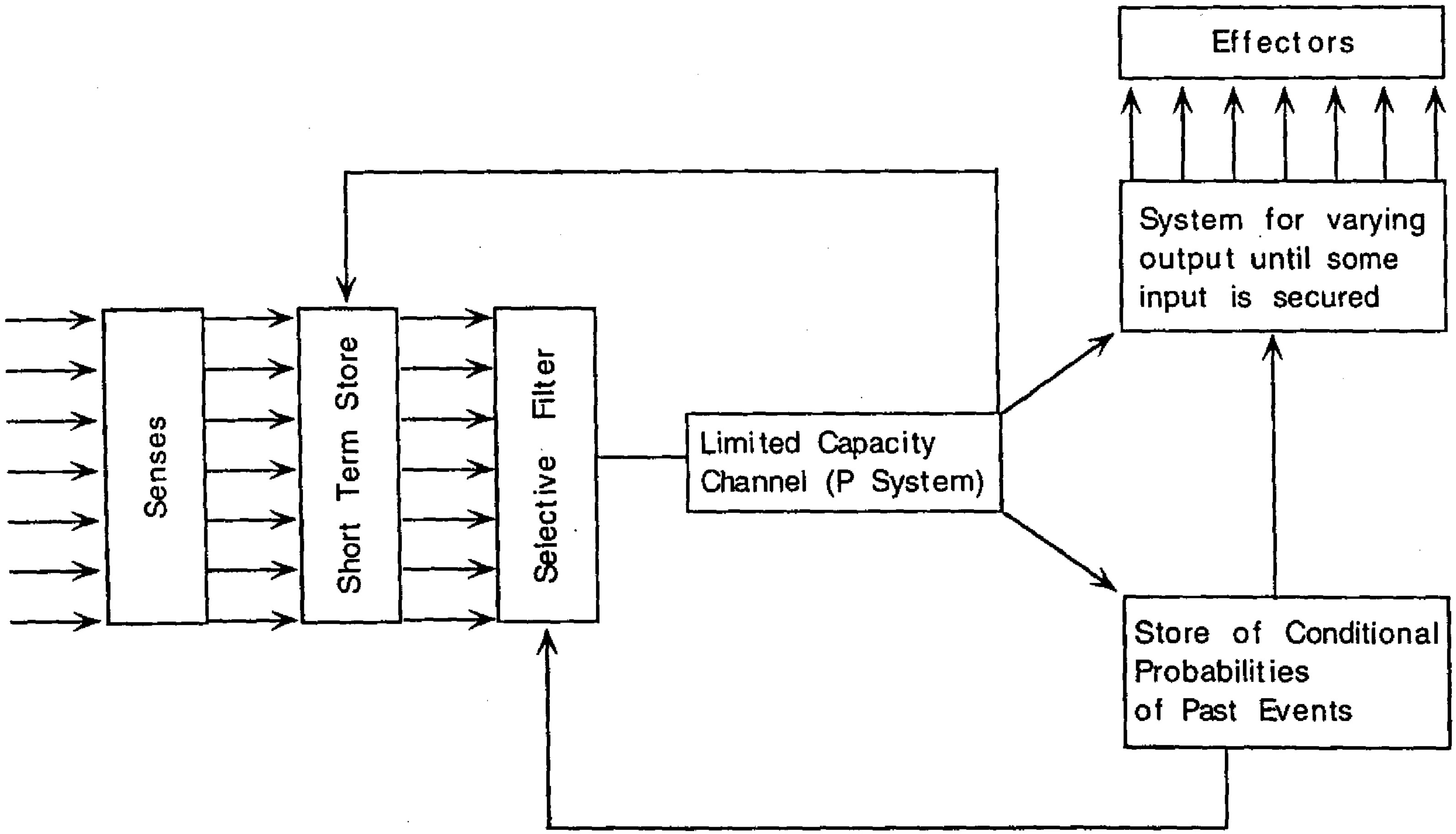

Figure 1. The structural model of attention, as depicted in Broadbent's drawings. Several correspondences between Filter and Attention can be observed: Attention is a physical system (as opposed to being an emergent by-product of the sensory or motor system); there exist discrete stages in the information-processing; the size of information is larger previous to the attention filter than after it. There is a single channel (P system) after attention, implying that the filter cannot be divided [From *Perception and Communication* (p. 299), by D. Broadbent, 1958, New York: Pergamon. Reprinted with permission].

described in Broadbent's influential book *Perception and Communication* (1958), as an attempt to apply communication theory (Shannon, 1948; Shannon & Weaver, 1949) to psychological problems. The analogy between human performance and communication theory was explicit—the essay is an "attempt to set out the consequences of describing behavior in the terms originally developed for telephone engineering" (p. 36).

The Mind as Information-Processing Device metaphor has many subsidiary metaphors, such as the Attention as a Filter metaphor (Broadbent, 1958). In these metaphors, the structure and inference patterns from the source domain determine our reasoning in the target domain. For instance, information processing devices are spatially extended and signals are processed in serial, with there being more information prior to its entering the filter than after passing through it. This source-domain fact about filters is carried over directly into the target domain. Thus, Broadbent's model has a short-term store located *before* the filter and a limited capacity channel located *after* the filter: "Incoming information may be held in a temporary store at a stage *previous* to the limited capacity channel: it will then *pass through* the channel when the class of events to which it belongs is next selected" [italics added] (Broadbent, 1958 p. 298), and "a selective filter *blocks* irrelevant messages *before* they reach the bottleneck" [italics added] (Treisman, 1969, p. 282) (Figure 1 and Note 1).

The source domain not only determines the reasoning in the target domain, but also the nature of the items in that domain. In the Information-Processing metaphor, attention is not a resource, nor an emergent process of sensory systems, but rather a physical device: attention is a *structure* (i.e., filter) that acts upon the information flow. The Filter in itself is a mechanism of information processing: "filtering would itself occupy some of the mechanisms which would otherwise be available for information processing" (Broadbent, 1958, p. 78).

The filter model of attention, and the predictions implied by its metaphorical structure, guided much of the research in the years after Broadbent explicitly introduced it. For example, according to the structure of the source domain, the attention filter cannot be split. As Kahneman (1973) puts it: "Filter theory implies that attention cannot be divided, because the P-system—i.e., limited capacity system—performs no parallel processing of discrete stimuli...the apparent division of attention in the performance of concurrent activities is mediated by alternation between channels or between acts, and the rate of alternation is slow" (p. 121). This reasoning follows directly from the constraints of the Filter metaphor, based on our knowledge of the source domain. In the source domain, the P-system is a single channel that has no mechanism for splitting information. Therefore, the Attention As Filter metaphor has no conception of divided attention after the filter.

Researchers have studied whether attention acts like a filter in this and other respects, measuring delays in attention switch and testing the system's ability to perform concurrent operations (Moray, 1959; Treisman 1960, 1964a). For example, according to the structure of the source domain, it is more difficult to filter out two spatially separate channels than to filter out one single channel. The logic of the metaphor, then, suggests that it should be more difficult to ignore two spatially distinct distractor messages than to ignore the same information delivered via a single channel. This led to the prediction that rehearsing a speech delivered to one ear (e.g., the right ear) should be more difficult when distractor speeches are displayed via two spatially separate channels (e.g., center and left ear) than when the distractor speeches are delivered on a single channel (e.g., in the center). This was confirmed by Treisman (1964b).

As a consequence of the research that studied the extent to which attention resembled a filter, two major controversies arose: (a) the locus and extent of the filter, and (b) whether attention can only filter out distracting information or whether it can also enhance attended information.

Extent (Complete/Partial) and Locus (Early/Late) of the Attention Filter

According to Broadbent's filter model, an unattended message is *completely* filtered out at an *early* stage, based on the physical features of the message, such as source, pitch, intensity, etc.: "Associated with each sensory modality is a set of filtering mechanisms that shut out unwanted stimuli...This filtering process operates "early," that is prior to object recognition but probably after some initial feature analysis." (Pashler, 1995, p. 94). An unattended stimulus is not processed beyond those physical features. Such a model predicts, for instance, that semantic content of the unattended stimulus will not capture attention, nor will it be processed further, since it is dependent on features that have already been filtered out. However, subsequent research showed that focusing attention on one message does not completely prevent the processing of information in the unattended channels (Moray, 1959). In a dichotic listening experiment, when the unattended message is made semantically relevant to the attended message (for example, by switching messages coming to the right and left ears) subjects tend to "shift" ears to keep a coherent discourse (Treisman 1960, 1964). Such experiments reveal that semantic information is processed in the unattended channel. The experimental data were inconsistent with Broadbent's model of an early and complete filter. However, researchers did not discard the Filter metaphor. Instead they explored possible modifications that would accommodate the empirical data while allowing them to retain the research programs generated by the initial metaphor. This left two alternative models. Either the filter could be early, but partial (i.e., attenuated), or else it could be complete but late in the information process (Treisman, 1960, 1964; Moray, 1959; Deutsch & Deutsch, 1963).

In early-selection filter-attenuating models, stimuli are stored for a brief period of time during which the elementary characteristics of the stimuli are analyzed. This pre-attentive analysis is used by the attention filter to select the relevant stimuli based on their physical properties. The filter increases the threshold for unattended stimuli to be perceived. However, this filtering process can be overcome by an unattended stimulus, provided that the unattended stimulus is intense enough, or has a low enough detection threshold. For example, according to Treisman's theory, one's own name has such a low detection threshold that it will be consciously perceived even when it is delivered via an unattended (attenuated) channel.

Late-selection models, by contrast, propose that the stimuli are fully processed up to the stage where they are identified and a response is needed. According to this view, attention is response selection. In other words, attention selects *what* is responded to and what the response will be. The response may include either physical actions or cognitive operations on the selected item(s) (Allport, 1987, 1993).

Treisman (1988), and others (Lavie, 1995) have proposed a model that combines aspects of both the early and late selection models, depending on the nature and amount of information being processed. Simply put, if there is relatively little information to process, selection will occur later, whereas conditions of information overload are likely to require an early selection on the perceptual processes (Lavie, 1995) . Hybrid models of this sort are possible, because both early and late stage models share the same metaphorical structure, namely, an Information-Processing model in which a filter (located at some stage) acts to select information (see Yantis, 1990).

Information Inhibition vs. Information Enhancement Debate

Broadbent's filter model, which described "behavior in terms of telephone engineering" (Broadbent, 1958, p. 36), seemed perfectly adapted to studies of auditory attention, which were popular in the '50s and '60s, when dichotic listening was the chief paradigm for studying attention. In dichotic listening experiments, there is an overload of stimuli and subjects have to select a subset of the displayed stimuli for further processing.

The Attention As Filter metaphor makes good sense of our ability to filter out information overload by attenuating perceptual processes in the unattended channels. Ordinarily, we think of filters as devices that select part of what passes through them and inhibit everything else. Thus, research guided by the Filter metaphor focused primarily on inhibition and attenuation, and it tended not to pay attention to enhancement.

The idea of attention as an enhancement phenomenon entered the debate mostly in the 1970s, when the interest of the scientific community shifted from auditory attention to visual attention, and the covert orienting task replaced the dichotic listening task as the chief experimental paradigm (Kahneman & Treisman, 1984). In the covert orienting task, spatial attention is cued to a location by an arrow that informs the subject where the target will occur. The subject has good reasons to attend at the cued location, because most of the time the target occurs at the predicted location. When the target occurs at the unexpected location the response time is slower. This reaction time difference between cued and uncued locations reveals the modulatory effect of attention on performance.

In the covert orienting task, the target occurs on a screen without distractors: there is nothing to "filter out". The filter metaphor which has captured so well the role of attention in the inhibiting of unwanted information was unable to capture this new role of attention, since in the visual attention experiments there was basically no information overload that could require any filtering. It should be no surprise that, with the emergence of visual attention research and its superseding of auditory research, a visual metaphor—the Attention As Spotlight metaphor—became the dominant theoretical concept. The Spotlight metaphor proved to be ideal for conceptualizing attention in the visual domain, just as the Filter metaphor had worked well for auditory attention. Moreover, the Spotlight metaphor naturally highlighted the notion of attention as an enhancement phenomenon.

IV. THE SPOTLIGHT METAPHOR

The technical metaphor of Attention As Spotlight is part of an extensive metaphor system in which we understand all mental activity and all forms of thinking as acts of seeing. The Understanding Is Seeing metaphor (Johnson, 1987; Sweetser, 1990), which appears to be pervasive across cultures and throughout history, uses aspects of vision for conceptualizing mental operations. In the conceptual mapping, Ideas *are* Objects Seen, Conditions of Understanding *are* Light Sources, Understanding *is* Seeing, Impediments to Understanding *are* Objects Obstructing Vision, etc. We thus speak of "*seeing* what a person means," "having *insightful* thoughts," "speaking *clearly*," "*shedding light* on a topic," "having *obscure* thoughts," etc. (Fernandez-Duque, & Johnson, submitted).

According to the Understanding Is Seeing metaphor, when adequate "light" shines on an idea-object we can "see" it clearly, that is, we can understand the idea. Within this metaphor, Attention Is A Spotlight (see Note 2). When the attention-spotlight is directed on some area, we are said to be attending to whatever falls within that "illuminated" area. The mapping for the Spotlight metaphor is as follows:

The Attention As a Spotlight Metaphor

Source Domain (Spotlight)		*Target Domain (Attention)*
Spotlight	——>	Mechanism of Attention (Attentional System)
Agent who controls the spotlight	——>	Executive System
Agent who sees	——>	Awareness System
Potential field of vision	——>	Representational Space
Area illuminated by the spotlight	——>	Attended area

According to this mapping, attention is separate from the executive system by which it is controlled and is also separate from the awareness system that consciously perceives representations. This conception follows directly from the structure of the source domain. In the source domain the spotlight is neither part of the agent who controls it, nor is it part of the visual system of the person who sees what the spotlight illuminates.

Just as with the Filter metaphor, the Attention As Spotlight metaphor led researchers to a number of important inferences about attention that guided their questions and their experiments. They reasoned about the target domain (attention) based on their knowledge of the source domain (spotlight phenomena). In the source domain:

> (a) there is a field with (b) objects in it. (c) The spotlight sheds (d) light over the field and this facilitates objects in that part of the field (e) so that they can be seen. When the spotlight sheds light over the target object, (f) the target object is seen by the subject, who immediately realizes that she has found the object she was looking for.

When this knowledge about the source domain is transported to the target domain, we reason as follows:

> (a′) there is a mental field with (b′) unconscious ideas in it. (c′) The attentional system directs (d′) attention over the brain areas (or mental field) and this facilitates the ideas

(or mental representations) in that part of the mental field so that (e') they are accessible by our awareness system. When the attentional system expresses attention over the target idea, (f') the target idea is acquired by the awareness system—it becomes conscious.

The Spotlight metaphor, like the Filter metaphor before it, redefined the concept of attention and guided research toward the investigation of shared features between a spotlight and attention. It highlighted the enhancement aspects of attention. The ensuing debates about the properties of the attentional focus have thus included issues such as: (1) the number of attentional spotlights, and the split of attention (object- vs. space-based attention); (2) the control of the spotlight (executive system); (3) the movement, size, and homogeneity of the focus of attention.

Object- vs. Space-Based Attention Debate

Castiello and Umiltà (1992) claim that there is nothing in the Spotlight metaphor that requires a single, unified spotlight:

> the notion of a unitary attentional focus does not seem to be demanded by the features of the [spotlight and zoom lens] models. There is no theoretical reason for maintaining that there is only one single spotlight or one single zoom lens instead of two (Or maybe more than two). Similarly, focal attention might be directed to two perceptual objects instead of just one (Castiello & Umiltà, 1992, p. 846).

The existence of multiple attention foci implies an attention system that enhances discontinuous areas. If we tried to understand the Spotlight metaphor as permitting multiple foci of attention, we would have to postulate a splitting of the attention beam. This is clearly inconsistent with our ordinary conception of the Spotlight metaphor, in which the spotlight illuminates only one location at a time. Research in the early '80s tested this entailment of the Spotlight metaphor and concluded that splitting the focus of attention was not possible (Eriksen & Yeh, 1985; Posner, 1980). However, in the late 1980's and early 1990's a new set of experimental designs suggested that splitting of attention was, indeed, possible (Driver & Baylis, 1989; Kramer & Hahn, 1995; Castiello & Umiltà, 1992). Scientists concluded from such experiments that the Spotlight metaphor was misleading and should not be applied to such cases.

Another possible way to achieve multiple foci of attention would be to postulate multiple attention systems, each of them with its own single beam. In the source domain, such an idea is counterintuitive, because it requires the existence of multiple spotlights controlled by a single person. Nevertheless, some researchers have actually proposed multiple foci of attention models.

The debate on the ability to split spatial attention is closely linked to debate on the ability to select objects that are spatially disparate. Object-based theories, first postulated in the '60s, argue that objects are constructed pre-attentively by perceptual primitives. According to this view, attention acts upon objects, independent of their spatial location (Kahneman & Treisman, 1984; Kanwisher & Driver, 1992; Neisser, 1967). In contrast, space-based theories of attention postulate that spatial attention is necessary for integrating features into objects (Treisman & Gelade, 1980). In this view there are no objects without spatial attention (for a review, see Johnston & Dark, 1986).

Although the debate is far from being resolved, research with clinical and normal populations provides support for an object-based model (but see Yantis, 1990). In patients with neglect (i.e., spatial attention deficit) certain perceptual abilities are spared (e.g., figure-ground segregation) suggesting a pre-attentive construct of perceptual primitives. When neglect patients are presented two objects within the same category, one in each hemifield, the object in the neglected hemifield fails to reach awareness. However, this deficit is reduced by showing objects of different categories, suggesting that object properties other than spatial location are influencing the allocation of attention (Rafal, 1994). Moreover, neglect patients show object-based neglect, the inability to attend to two objects that occur simultaneously in the same location. Finally, normal subjects have more difficulty ignoring irrelevant information when that information is part of the relevant object (Kahneman & Henik, 1981), and they find it easier to shift attention within objects than across objects (Egly, Driver, & Rafal, 1994) (see Note 3). This experimental support for object-based theories led some researchers to reject the Spotlight metaphor.

Intuitively, the Spotlight metaphor seems to be more compatible with space-based theories, since we think of the spotlight as illuminating a space in which objects can appear.

The spotlight is spatial and does not distinguish among objects. It illuminates whatever falls in its field. Space-based theories emphasize the spatially continuous aspect of attention (Treisman & Gelade, 1980). Therefore, results in favor of an object-based attention have been taken as conclusive evidence against the Spotlight model of attention (Driver & Baylis, 1989; Kramer & Hahn, 1995; Castiello & Umiltà, 1992). Are object-based models of attention irreconcilable with the Spotlight metaphor? We will argue that a variant of the Spotlight metaphor, in which the attentional Spotlight sheds light *in the brain*, not only is consistent with object-based theories, but it is *the* metaphor these theories rely on (see Section V).

The Control of the Spotlight Debate (Executive System)

According to the Spotlight metaphor, a spotlight is a device separate from the field upon which it sheds light, and separate from the agent that controls it. This structure entails that the attention shift, which is controlled by the agent, is independent of the intensity of the attention beam. Therefore, adding a secondary non-visual task to a primary visual task should delay the onset of the attention shift, without altering the intensity of the attentional beam (Posner, Inhoff, & Friedrich, 1987). In the Attention Spotlight metaphor the spotlight is controlled by an executive system, which is also in charge of detecting verbal targets, initiating volitional acts, etc. The positing of an all powerful executive system gains its appeal from the structure of the source domain of the Spotlight metaphor, in which there is an agent who is in control of the spotlight.

Consequently, the logic of the Spotlight metaphor raises the crucial question of who or what is controlling the attention-spotlight:

> Directing attention from one object to another involves choosing a specific object to move to....The choice process requires information, like proximity, direction, or relative position, that is not directly available in the perceptual representation and cannot be produced simply by spatially indexing different items. Further computation with different computational machinery (i.e., spatial reference frame) is necessary before the choice can be made...someone should have explained this important step (Logan, 1995, pp. 108–109).

If this is such an important issue, as Logan correctly points out, why has nobody addressed it? Rephrasing the problem in the source domain offers a possible answer. In the source domain the question reads: how does the spotlight choose its next location? how does the spotlight choose its new target? The obvious answer is that it does not. The choice is made by the human controlling the spotlight. She is the one with the spatial reference frame to complete the task. Asking about the reasons for choosing the next object equates to asking about the reasons the controller of the spotlight might have for moving it to a new object. This already takes the emphasis away from the attention mechanisms and puts it onto the executive control mechanisms. Moreover, we usually do not ask for mechanistic explanations of free actions, like choosing where to move the spotlight. Transferred to the target domain, scientists did not ask for mechanistic explanations of voluntarily choosing a new object of attention.

Of course, the difficulties with the Spotlight model of attention have become evident to many researchers, and alternative models without a central executive system have been proposed (Allport, 1993; Johnston & Hawley, 1994; Dennet & Kinsbourne, 1992; Desimone & Duncan, 1995). Such models, in which perceptual inputs compete for resources, solve the infinite regression problem of having a volitional executive system, but they create a similar problem by postulating perceptual inputs that have agent-like properties. Moreover, competition models usually beg the difficult question of top-down, volitional selection, that is central to the idea of agency. Finally, it is important to remember that competition theories of attention are metaphorical in structure too (for a more detailed analysis, see Fernandez-Duque & Johnson, in preparation).

In short, one of the central problems of the Attention As Spotlight metaphor remains unsolved, namely, what is the nature of the control system for the attention-spotlight. Although the Spotlight metaphor has been remarkably robust in generating attention research, one of its core concepts remains highly problematic.

Movement, Size, and Homogeneity of the Focus of Attention

According to the Spotlight metaphor, a spotlight of attention should have homogeneous intensity, fixed size, and move in analog fashion. Psychologists have studied each of these properties about the focus of attention (Shulman, Remington, & McLean, 1979; Tsal, 1983; Egly & Homa, 1991; Sperling, 1995) as well as other movement properties such as speed (Remington & Pierce, 1984) and invariance of velocity (Shulman et al., 1979; Remington & Pierce, 1984).

Ordinarily, we think of the focus of a spotlight as having an invariant size. When we transport this knowledge to the target domain, we expect the focus of attention to be invariable. However, research evidence that attention can have a variable size, created an apparent inconsistency between the source and the target domains (Ericksen & St. James, 1986). This tension was resolved by the emergence of a Zoom Lens metaphor, in which the attention-spotlight has a variable focus, similar to the optical structure created by the use of a zoom lens. The focal area could then be varied, although the larger the focal area, the less fine-grained the discrimination would be. This new metaphoric model accommodated data that show an inverse correlation between attentional benefit and size of attention (Ericksen & St. James, 1986). Another contribution of the zoom lens metaphor was to bring the concept of limited resources into structural models of attention. In the Zoom Lens metaphor:

> visual attention is a limited-resource system and...these resources can be directed to bound regions of space that vary in size. Increasing the size of the attended region spreads available resources over a greater area and thus reduces the *"resolving power"* at any particular location within the attended region [italics added] (Henderson, 1991, p. 91).

The Zoom Lens metaphor makes its own predictions about the properties of attention. For example, according to the zoom lens metaphor (and the spotlight metaphor before it) the focus of attention must be homogeneous. When this epistemic correspondence was tested, data argued against it: attentional fields are heterogeneous (Shulman, Wilson, & Sheehy, 1985; Downing & Pinker, 1985). Researchers confronted with this tension proposed the Attention As Gradient metaphor, in which there is a peak of attention at the center of the focal area, with a continuous decrease in attention as the field extends outward (Downing & Pinker, 1985; LaBerge & Brown, 1989; Shulman et al., 1985) :

> One way to conceptualize preparatory attention to a spatial location is to imagine a local distribution of activity in a spatial map....in the shape of a flat-topped mountain: the plateau portion of these shapes represents peak activity at the attended area, and the amount of activity decreases with distance from the attended area (LaBerge, 1995, pp. 66–67).

In the Gradient model of attention, as in the Zoom Lens before it, there is an appeal to limited resources, which are integrated into a structural model: "the *resources allocated* to a given location depend on the *distance* of that location from the *peak* of attention. There is a center of attention (peak of the gradient) and attentional resources fall off continuously from the center, as a function of the spatial distance" [italics added] (Henderson, 1991, p. 91).

In the Gradient metaphor, the amount of resources in a certain part of the attention field is a function of its distance from the attention peak and the slope of the gradient. The gradient model predicts that, as the separation between the target location and a distractor increases, the amount of attention allocated to the distractor will decrease. Therefore, the Gradient model predicts that the interference between target and distractor will decrease as a function of the distance between them (LaBerge, 1995; Johnston & Dark, 1986). Recently, the gradient metaphor has been challenged by the results showing that informational load, not spatial distance, is the critical factor in decline of attention (Lavie, 1995).

We can see in our brief survey of the Spotlight metaphor a pattern of reasoning that is highly characteristic of scientists' use of metaphorical models. Various entailments of the metaphor determine the research hypotheses that are put forward and the types of experiments that are done to test them. In cases where experimental data are incompatible with the founding metaphor, one might simply give up on the current metaphorical model and search for another one. However, the most typical strategy is to seek a different or transformed version of the original metaphor, one that is more broadly compatible with the available data. This latter strategy requires the least amount of change to the model and it permits the continuation of research programs generated by the initial metaphors. The relation between metaphor and experiment is typically a delicate balance. Scientists tend not simply to run out the entailments of the metaphor, regardless of counterevidence; but neither do they usually take counterevidence as absolutely compelling, and thus requiring them to discard the metaphor altogether. More often, they seek some modest transformation of the underlying metaphor system that can be accomplished while preserving much or all of the experimental data.

V. THE SPOTLIGHT-IN-THE-BRAIN METAPHOR

Attention is not allocated to objects at location in space, but rather to internal representations of locations in space

—Farah, 1994, p. 44

In the last few years a major transformation in the study of attention has begun, and, with it, the dominant interpretation of the Spotlight metaphor has undergone substantial change. Until fifteen years ago, cognitive psychologists, most of them entrenched in the information-processing tradition, were agnostic about the physical instantiation of mental processes. Concepts of attention, memory, imagery, and others, were regarded as functional descriptions of mental activities. A few researchers became aware of the fact that attention was allocated to the brain and not to the visual field, but the climate was not yet amenable to this substantial opening up of new directions for research. For example, Posner (1978) in his influential book *Chronometric Explorations of Mind* (1978), comments on the difference between attention to the visual field and attention to the representations.

> Subjects may shift their attention to a position corresponding to the likely input...This mechanism could in principle be differentiated from...[another] mechanism...mediated by a shift in attention to a *location in the brain* that would be contacted by the external stimulus [italics added] (p. 191).

In a footnote, Posner suggests the possible experiment:

> If we assume that visual and tactile input arising from the same position in physical space have their primary input to different primary projection areas [in the brain], then it is possible to discriminate set [i.e., attention] directed toward a position in the external world from set [i.e., attention] toward a modality-specific sensory area (p. 191).

To our knowledge, those experiments were never carried out, perhaps because the scientific community failed to realize the important implications those experiments would have for attentional theories. Moreover, Posner's proposal for future research does not tell the whole story, since attention to physical location of the target has to occur in the brain, too!

In the last decade, this picture has changed radically. Imaging techniques such as PET and fMRI have revealed the physical substrate of many mental processes. This change has facilitated a major shift in the conception of the Attention As Spotlight metaphor—it has been moved from an attention-spotlight shining on "objects" in a visual or auditory field, to an inner neural spotlight shining on brain areas and neural connections. Cognitive neuroscientists now conceptualize mental processes as having a physical aspect. LaBerge and Baron's (1989) argument for a role of the pulvinar as the zoom lens of attention, and the title of Posner and Raichle's book (1994), "Images of Mind", are just two examples of this trend.

Transporting the Spotlight metaphor from the outside (i.e., visual field) to the inside (i.e., brain areas) may be the single most important contribution of imaging techniques to our concept of attention. Instead of attentional effects being allocated quite mysteriously to the external visual field, attentional effects are said to be allocated to brain areas, where they modulate signal-to-noise ratio of neuronal activity (LaBerge, 1995). Some brain areas have a topographic map of the visual field. For those areas there is a correspondence between "shedding light" on certain part of the visual field and "shedding light" on certain parts of the brain area.

Other brain areas are not organized topographically with respect to the visual field. For those areas, there is no correspondence between the visual field location at which the stimulus occur and the cortical map location at which neurons representing that stimulus are activated. In cases like these, attention "sheds light" over certain parts of the representational map which have no corresponding location in the visual field. Based in this property, we can argue that splitting attention in the visual field does not entail splitting attention in the brain. Also, we can reconcile object-based and space-based theories of attention, because, as realized in the brain, both are space-based models. Finally, we can reconcile modality-dependent effects of attention (Woodruff, Benson, Bandettini, Kwong, Howard, Talavage, Belliveau, & Rosen, 1996). Shedding light on the visual cortex should enhance visual perception, while shedding light on the auditory cortex should benefit auditory perception.

Let us consider some of the more important ways in which this new conception of the Spotlight-In-The-Brain has opened new directions in research.

Shedding Light over Area MT: Attention to Common Motion

If we accept the existence of feature maps spatially organized in the brain, "spatial attention" acting on the brain can select items that share the same feature. Red items will all activate the same part of the color map, even if red items are in disparate parts of the visual field. Area MT provides a good example. Area MT has a topographic map, with neurons being organized according to direction of movement and velocity of movement (Salzman, Murasugi, Britten, & Newsome, 1992). Thus, attention may select moving objects by activating those neurons in MT that respond to motion of a given velocity and direction. Presumably, those neurons are spatially close to each other in the motion perception map in MT, although what they represent in the visual field need not be spatially close in the visual field. Thus an attentional spotlight can shed light onto a unitary area of the brain that corresponds to non-contiguous regions of the visual field.

To better understand this example, let's recall the reasoning in the source domain, as described at the beginning of the attentional spotlight section. In the source domain:

> (a) there is a field with (b) objects in it. (c) The spotlight sheds (d) light over part of the field and this facilitates objects in that part of the field (e) so that they can be seen by the subject.

When this knowledge about the source domain is transported to the target domain, we reason as follows:

> (a′) there is a brain area MT, with (b′) neuronal representations of velocities in it. (c′) The attentional system directs (d′) attention over part of area MT and this facilitates the neuronal representation of such velocities (e′) so that they are accessible by our awareness system—they become conscious.

Accordingly, attention should enhance the activity of the neurons in area MT that code the velocity the subject is attending to (Treue & Maunsell, 1996). More generally, attention to common movement should highlight area MT (which codes motion perception), attention to color should enhance activation in area V4 (which codes for color), and attention to object recognition should activate the ventral pathway, (which codes for shape). Research to date has confirmed those expectations (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997).

Regardless of whether the expression of attention is spatially distributed in the brain, the important message that emerges from our analysis is that scientists have attempted to apply to the brain the same metaphor they had already applied to the external world (or to some mental model of it). Instead of a visual field onto which attention sheds light, there is a brain area (which sometimes, but not always, has a map of the visual field) onto which attention sheds light (i.e., modulates, increases signal-to-noise ratio). This variation of the metaphor provides an account of object-based models of visual attention, in which perceptual grouping is based on common movement or common features (Baylis & Driver, 1993; Kahneman, Treisman, & Gibbs, 1992; Kramer & Jacobson, 1991).

The spotlight can highlight many types of maps that exist in the cortex. When the spotlight acts upon sensory areas, such as those in the auditory or visual cortex, it will enhance sensory perceptions (Woodruff et al., 1996). When the spotlight acts upon semantic maps, such as those underlying semantic categories, it will highlight the category selected (e.g., furniture, animal), making it more likely that we will be aware of that category or will utilize that category in our conceptualization and reasoning (Spitzer, Kwong, Kennedy, & Rosen, 1995).

Shedding Light over the Auditory Cortex: Attention to Pitch

If attention is a spotlight that sheds light over brain areas, then attention should also behave as a spotlight in modalities other than vision. The only requirement would be the existence of stimulus representations in a cortical area so that "light" can be shed over them. This reasoning is apparent in auditory attentional research.

The auditory cortex is tonotopically organized. It is a one-dimensional map in which neurons that respond best to high frequencies are located most medially and neurons that respond best to low frequencies are located most laterally. Frequency is spatially coded on the surface of the auditory cortex so that tone frequency maps systematically onto space in the auditory cortex. The term "tonotopic representation" captures this idea: tonos means "tone" and *topos* means "place."

The epistemic entailments for the Spotlight metaphor predict that when the spotlight sheds light over a specific region of the auditory cortex (e.g., a lateral area), it will enhance perceptual accuracy for a particular frequency (e.g., low frequencies)(see Note 4). Accordingly, researchers have tried to determine whether "attention may be allocated to a specific frequency region" (Mondor and Bregman, 1994, p. 272).

Once attention is conceptualized as shedding light over the auditory cortex, the same issues previously raised for visual attention can be raised for auditory attention. For example, it takes time to move physical devices, such as a spotlight, from one location to another. Similarly "the rate with which attention can be shifted between two frequencies is ...limited" (Mondor & Bregman, 1994, p. 275). Spotlights move in analog fashion, shedding light at intermediate locations. We expect that in the near future scientists will test this entailment of the metaphor in the pitch perception domain.

Similar to the reasoning about attention to visual areas, one can ask whether the allocation of attention to the auditory cortex is best captured by the Spotlight metaphor or by the Gradient metaphor. Is there a homogeneous distribution of resources within the attended region and a sharp demarcation between attended and unattended regions (i.e., Spotlight metaphor), or, on the contrary, is there is a peak of resources allocated to the focused frequency with these resources gradually declining relative to their separation from the focused frequency (i.e., Gradient metaphor)? Mondor and Bregman asked this question and concluded that attention to frequencies resembled the Gradient metaphor: "the focus of attention conforms to a gradient with the density of attentional resources declining with increasing frequency separation from the focal point of attention" (p. 274).

Shedding Light as a way to Increase Contrast: Intensive and Modulatory Aspects of Attention

According to the source domain of the Spotlight metaphor, brightness increment is coupled with contrast increment: (1) when a spotlight sheds light, (2) the brightness of the field increases, and thus (3) the contrast of objects within the beam increases, too. When transferred to the target domain of the Spotlight-In-The-Brain metaphor, this piece of knowledge predicts that (1′) when attention is expressed in a brain area, (2′) the neuronal activity of that area will increase (brightness), and thus (3′) the signal-to-noise ratio (contrast) will increase too. Therefore, we are enticed to assume that a "light up" area in the fMRI (brightness increase) is evidence for attentional modulation (contrast increase) (see Note 5). However, electrophysiological data from animal research suggests otherwise. Most likely, attentional modulation (contrast) is independent of the overall level of neuronal activity (brightness) (Foote, Berridge, Adams, & Pineda, 1991). The relation between brightness and contrast in the source domain might also have influenced the conceptual rélation between alertness and attention. The accepted view is that attention (i.e., modulation of signal-to-noise ratio) and alertness (i.e., increase of overall level of activity) are coupled. The force of this argument relies on the source domain, where brightness increment is coupled with contrast increment. Recent studies have tested this prediction and found independence between attention and alertness (Fernandez-Duque & Posner, 1997). The relation between signal-to-noise modulation and overall neuronal activity might be captured best by a TV metaphor. In a TV screen, contrast (signal-to-noise ratio) and brightness (overall neuronal activity) can be modified independently (for a recent use of this metaphor, see Spitzer, 1997)

What we see with the Spotlight-In-The-Brain metaphor is exactly parallel to the development of the earlier (external) version of the Spotlight metaphor. The metaphor is enormously powerful in suggesting research strategies and experiments. Many of those experiments appear to argue for the validity of some version of the Spotlight metaphor. However, not all of the evidence produced by the experiments is compatible with the metaphor as it is currently understood. As we will see below, this pattern is characteristic of the way metaphor structures our concepts. No one conceptual metaphor is adequate to the phenomena as a whole. Multiple metaphors, with the various research programs and experimental designs that each sanctions, are necessary.

A second point illustrated by the Spotlight-in-the-Brain metaphor is that metaphors do not act in isolation but are instead immersed within an ecology of scientific and social practices. These other factors, including technical advances, mathematical elaborations, cultural influences, and empirical data, constrain how the metaphor is used and shape its evolution. Technological advances, such as the emergence of imaging techniques, have reframed the Spotlight metaphor. Mathematical elaborations and computational simulations, in their quest for internal consistency, have imposed their own constraints on how metaphors are interpreted and on which ones are regarded as being plausible. Social transformations, such as the emergence of telecommunications, have favored the rise of new metaphors and have introduced pragmatic constraints on metaphor-based models (see, e.g., Gigerenzer, 1991; Gigerenzer & Goldstein, 1996).

Empirical data also influence the evolution of scientific metaphors, in some cases confirming, and in others challenging the predictions entailed by the metaphor. The most frequent strategy to solve the tension between data and theory is to co-opt the conflicting data by making slight changes to the source domain. Such alterations of the metaphorical framing allow the incorporation of the data that was conflicting when the frame was narrowly conceived. Much less frequently, an entire metaphor is discarded and is replaced by a new one, but this requires such a drastic restructuring of the theoretical framework that this strategy is used only in exceedingly rare cases of radical theory change.

VI. THE ATTENTION AS VISION METAPHOR: PRE-MOTOR THEORY OF ATTENTION

Considered the 'eyeball behind the eyeball,' attentional orienting is viewed as a covert analog of overt eye movements, and therefore movements of attention can be regarded as sharing characteristics with the movements of the eyes

—LaBerge, 1995, p. 35.

There is no question whatever that attention augments the clearness of all that we perceive

—James, 1890, p. 426

A different metaphor, less often recognized but equally influential, is the Attention As Vision metaphor. According to it, we "look" out of the corner of our eyes, and orienting is "the mind's eye's movement" (Jonides, 1981). In the Attention As Vision metaphor, the fovea (area of the eye that has maximal sensitivity) maps onto focus of attention, and saccades (rapid eye movements) map onto shifts of attention. This mapping leads us to conceptualize attention as an emergent property of the visual system. The Vision metaphor has a long tradition in psychology, having been used by William James (1890, p. 437) Wündt (1912, p. 20) and Von Helmholtz (1924, p. 455), and having been rediscovered by cognitive psychology in the '50s, during the rise of the Information-Processing approach to perception (van der Heijden, 1986). The appeal of this metaphor is based also on the close physiological connections between items in the source domain (foveation, saccades) and items in the target domain (focus of attention, shift of attention). For example, foveation and focus of attention usually coincide, perception can be enhanced by focusing attention as well as by foveating, and neither attention nor foveation can be split (but see Driver & Baylis, 1989; Castiello & Umiltà, 1992). There are also many similarities between saccades (in the source domain) and "shifts of attention" (in the target domain): both can be triggered automatically by an exogenous attentional cue, both can be initiated voluntarily, both are ballistic (they cannot be stopped once initiated), and they usually coincide (i.e., covert shifts of attention are very infrequent). The epistemic entailments of the Attention As Vision metaphor have prompted many research questions. According to the Vision metaphor, attention must be unitary, and splitting attention should not be possible, because humans have only one fovea (i.e., foveation cannot be split). Of course, the unity of attention is also implied by other metaphors, such as the Spotlight metaphor. However, the Vision metaphor (and only the Vision metaphor) also predicts that animals with two foveae, such as pigeons, should be more capable of splitting attention than animals with only one fovea, such as humans. That pigeons would be more capable of splitting attention than humans has, in fact, been hypothesized by Frost (personal communication, 1995). As such, it is not only a good example of the guiding role of the Vision metaphor, but also a good illustration of the role of metaphorical reasoning in the creative scientific process. In the Vision metaphor, attention is conceptualized as an emergent property of the visual system. As such, the Vision metaphor is the basis for the pre-motor theory of attention, which says that "the mechanisms responsible for spatial attention and the mechanisms involved in programming ocular saccades are basically the same" (p. 507) (Sheliga, Riggio, & Rizzolati, 1995). Part of the debate between the pre-motor and the supramodal theories of attention arises from the failure to recognize that these theories appeal to different metaphors. Although their names are misleadingly similar, Attention As Vision and Attention As A Spotlight [For Vision] have very different epistemological entailments and create different ontologies in the target domains. The Attention As Vision metaphor supports the pre-motor theory of attention, whereas the Attention As Spotlight metaphor supports the supramodal theory, which posits a separate executive system.

The intuition of "looking" out of the corner of one's eyes without eye movements is used by scientists and lay persons alike, not only to talk about attention but also to reason about attention. Posner (1978), in an intriguing variation of the classical covert orienting task, showed that subjects believe (incorrectly) that attention is a constitutive property of the fovea. When a target is as likely to occur in the periphery as it is to occur in the fixation point, subjects tend to orient to the peripheral location, as if they believed that the fovea will not suffer from that shift (as if they believe that foveation guarantees attention). In fact, there is neither benefit nor detriment in orienting to the periphery, because the attention effect in the fovea is as large as in the periphery. Subjects may believe that attention is a constitutive feature of the fovea because the fovea provides the largest acuity. Presumably, subjects equate the concept of attention to the subjective experience of "clarity." If so, they will conclude that attention is a constitutive property of the fovea because foveating allows them to see "clearly."

VII. IS ATTENTION METAPHORICAL?

In this paper we have examined some of the more important and influential metaphors that structure our theories of attention and guide the research that is based on those theories. We have argued that our concepts of attention are defined via metaphor and that often there are multiple, conflicting metaphors at work in these theories. Scientific literalists and objectivists, who think that our core concepts, the concepts that allow us to state basic truths about the world, must be literal if they are to map directly onto states of affairs in the world, will want to deny that our most basic concepts of attention are metaphorical. "Surely," they will argue, "attention just *is* what it *is in itself*, independent of our theories of it. There must be a set of phenomena that constitute attention, and the job of the cognitive psychologist and neuroscientist is to find out what attention really is. If our current theories happen to be full of metaphors, so much the worse for them. It may be," they will insist, " that we currently understand attention by using such metaphors as you have described, but that is merely an unfortunate limitation of the current state of cognitive psychology. A fully mature cognitive psychology and neuropsychology of attention will be able to say what attention really is and how it works without any reliance on metaphorical concepts. Moreover, our use of metaphor in our theories is primarily about how we understand and think about various mental phenomena, but it does not give the essence of those phenomena in themselves." The analyses that we have given in this paper reveal what is wrong with any literalist and objectivist view of the sort just summarized. Conceptual metaphors are not merely heuristic devices, useful in our current theorizing, but in no way defining the nature of attention. Rather, such metaphors play a central role in our understanding and reasoning about attention. *Attention* is a human category, a category we form in order to circumscribe and understand a range of cognitive phenomena that seem important to us in our successful functioning. Each of those many cognitive phenomena is itself understood by us in terms of some theory or conception of mind and mental activity, and there is no way of identifying or describing those phenomena independent of some such theory or model. Those theories of mind will involve metaphorical concepts. Therefore, even something as basic as our ability to identify a certain range of phenomena as being about attention requires our use of metaphorical concepts and reasoning. In order to see more clearly the ways in which attention is constructed metaphorically by us, let us first recall from our earlier analysis that what we take attention to be will depend very directly on the overarching metaphor for mental operations that we are assuming. The Attention As Spotlight metaphor leads to a certain way of identifying attention, whereas the Attention As Vision metaphor gives us a different ontology. In the former case, attention appears as a supramodal phenomenon, whereas in the latter case, it is a pre-motor phenomenon. These different metaphorical conceptions define attention as being two different kinds of entities (one supramodal and the other tied to specific sensory modes). These are two different ontologies of attention, and they are not mutually consistent. What we take attention to be will depend on how it is understood relative to one or another of these views of mind.

Let us ask whether we can discover a nonmetaphorical concept of attention that might tell us what attention is "in itself." The following list gives some of the features that psychologists have tended to attribute to attention:

- Attention improves performance of a wide range of tasks, such as perception, various motor activities, and many kinds of cognitive operations.
- Correspondingly, attention minimizes distraction.
- Attention enhances processes in the area that one is attending to.
- Attention involves some form of stimulus selection.
- Attention facilitates access to awareness, that is, attention is necessary for focused awareness.

These and other features have been widely recognized by researchers as salient aspects of attention. They circumscribe a broad range of cognitive and performative phenomena as being instances of attention. We might say that they define a basic "skeletal" concept of attention. That is, they set certain minimal conditions or constraints on an adequate understanding of what attention is and how it works. However, even when taken together, this list is far too minimal to define attention in a way that adequately accounts for all of the relevant phenomena and that connects up in an appropriate fashion with our general theories of mind and cognitive operations. In other words, although the above list helps to circumscribe what we count as attention, it lacks sufficient conceptual structure to provide adequate explanations of what attention is and of how it works. We have given evidence above showing that the actual theorizing, experimental research, and analysis of data depends additionally on one or more of the kinds of metaphors we have been examining. The metaphors are not optional modes of expression; rather, they define the structure of the phenomena that constitute attention. They tell us *what will count as attention* and they give us the only way we have of seriously thinking about attention in a precise and rigorous way. When scientists use such metaphors, therefore, they are not simply reverting to vague notions or sloppy reasoning. They are using the only means available for understanding and reasoning about cognition. Scientists reason, not just on the basis of the skeletal literal conception, but specifically via the types of metaphors given above. What we have found via our analysis is that we cannot even understand the above list of features without reference to some conception of mind and mental activity that is defined by metaphors. For instance, consider what we mean by "stimulus selection" Granted, there does exist a literal concept of selection, such as when we pick out (select) one apple from a basket of them or press one key on a keyboard rather than another. But notice that this so-called "literal" concept of selection is *not* the same concept that is used in any fully-developed scientific theory of attention. What we mean by "selection" (attention as selection) will depend specifically on which metaphorically defined view of mental processing we are assuming. Each different theory of mental operation has its own specific concept of attention as selection. *Selection* is a concept that has one interpretation within an Information-processing metaphor for mind, while it has another interpretation within what we have elsewhere (Fernandez-Duque & Johnson, 1997) called the Limited Resource metaphor of mind. And it has still another interpretation relative to "attention for action" theories (Neisser, 1967; Allport, 1987, 1993). "Selection" as a process of attention does not mean anything "in itself," independent of a host of other conceptions about mental operations. Another key problem with the idea that we have a univocal, literal concept of attention that is theory-independent is that we cannot simply point to some set of bodily performances, such as foveation or auditory memory, and equate those operations with attention *simpliciter*. To see why, consider foveation. For the most part, foveation (capacity to have a small field of maximal clarity and discrimination in our visual field) is identical with focal awareness. Therefore, it is tempting to assert simply that foveation = focal awareness = visual attention. However, this is not always the case. There can be awareness in the parafoveal area, so that we can attend to things not in the fovea. The dependence of the concept of attention on a theory of attention is clearly expressed by Jones and Yee (1993):

> Attention itself is an inferred construct. Any meaningful definition of it quickly becomes "theory bound," virtually compelling a commitment to "what" attention is. Ultimately, definitions of attention become theories of attention (Jones & Yee, p. 70).

Saying that attention is a "construct" can be a bit misleading insofar as it suggests that there is no such thing as attention and that we merely make up a fictional concept of it. Attention is a real phenomenon (or rather a complex category of related phenomena). To say that we "infer" or "construct" our notion of attention means only that we have no coherent concept of attention apart from the minimal skeletal core and its elaboration via a host of other metaphorically defined concepts of various aspects of cognition and mind. To say that attention is a construct is to say that which phenomena get defined as phenomena of attention depends on our skeletal concepts and also on which set of metaphorically defined concepts of mind we are using.

Certain philosophers of science have acknowledged the existence of metaphors and analogies in much scientific reasoning, but they resist the idea that those metaphors are ultimately constitutive of science (Nersessian, 1984, 1992). After studying the process that led Maxwell to discovering the laws of electromagnetism, Nersessian (1992) concludes that "Analogical reasoning process often creates an abstraction or "schema" common to both domains that can be used for future problem solving" (Nersessian, p. 20). Such a schema, or set of general relations, could be "applied to the target domain directly, without the need for any specific analogy" (Nersessian, p. 23).

According to Nersessian, Maxwell (1) first retrieved a crude source domain ("continuum mechanics") then (2) used constraints from the target domain ("electromagnetism") to modify the source domain. (3) He reiterated this process of modifying and enhancing the analogy to fit the constraints of the target domain, until (4) he "put together a system, which in its entirety even he maintained did not exist—possibly could not exist—in nature…drawing inferences from this abstracted model" (p. 23).

In further research, Nersessian and collaborators (Nersessian & Greeno, 1990) have proposed that abstraction from the source domain of an analogy involves the following sequence of events. First, the scientist grasps the relational structure underlying the phenomenon. After that, she abstracts that relational structure and expresses it in mathematical formulae. Finally, she applies the formalism back to a wider class of phenomena.

We find no evidence of such an abstractive procedure in attention research. Our findings agree with Nersessian's about the existence of constraints from the target domain (e.g., the "literal skeleton of the concept"), but we have found no evidence for the existence of impossible "schemas." No attention researcher violates his metaphor, and in trying to explain attention, a scientist does *not* "put together a system, which in its entirety even he maintained did not exist—possibly could not exist—in nature." Possibly, the difference between our finding and Nersessian's lies in her different understanding of "source domain." Continuum mechanics, which is the source domain proposed by Nersessian to explain Maxwell's reasoning, is a rather complex and abstract domain. There might exist other, more basic, domains that served Maxwell for his conceptualization of "continuum mechanics," before he used "continuum mechanics" as the source domain for "electromagnetism."

There is also evidence against the idea that an abstracted metaphor-free mathematical formalism can be derived as a structure shared by both source and target domains. Lakoff and Nuñez (1996) have shown that even our most basic mathematical ideas are defined by numerous metaphors. Moreover, the abstractionist hypothesis requires that there is just as much relational structure in the target domain as in the source domain. However, as we have seen, this is not the case in conceptual metaphors for attention extensive evidence against abstractionist theories of metaphor and analogy is summarized in Lakoff and Johnson, 1980.

In short, our analysis suggests that there is a literal skeletal conception of attention shared by all researchers, but that their actual reasoning and research are generated by specific conceptual metaphors that define how they identify the relevant phenomena and how they reason about them.

VIII. METAPHORICAL PLURALISM

Attention is a complex concept defined by multiple metaphors, some of which are inconsistent with each other. Two different metaphors often will generate two different sets of inferences about what attention *is* and will lead to different expectations about what is likely to be observed in an experimental setting. For example, the existence of a specialized supramodal system of attention is posited in the Spotlight metaphor (where attention is directed to various sensory modalities), but not in the Vision metaphor (where attention is a pre-motor capacity).

Metaphorical pluralism is evident in the two different understandings of the relation between attention and awareness that come from two different metaphors. In the Spotlight metaphor, for example, there is a link between attention and awareness, with attention being necessary but not sufficient for awareness. This link is motivated by the Spotlight metaphor because in the source domain light is necessary for seeing. Correspondingly, in the target domain, attention is necessary for awareness. Therefore, one of the epistemological entailments of the Spotlight metaphor is that attention usually leads to awareness (Iwasaki, 1993).

In the Attention Is Vision metaphor, by contrast, there is an even closer link between the focus of attention and awareness, with attention being both necessary *and* sufficient for awareness. In Attention Is Vision, the fovea maps onto attention. According to our folk theory of vision, we are aware of what we see (an Awareness Is Vision metaphor). Therefore, awareness and attention are one and the same, as they are correlated (via the fovea) in the source domain. This mode of awareness is sometimes called focused awareness, to differentiate it from a global mode, in which awareness occurs without attention (Iwasaki, 1993). This distinction between focused awareness and global awareness comes from the source domain distinction between foveal vision and parafoveal vision. Global awareness and parafoveal vision are thought to be crude and less detailed than focused awareness and foveal vision (Iwasaki, 1993).

The scientific study of attention depends upon the inferential structure of such metaphors. Research hypotheses are framed and evidence is evaluated relative to the conceptual mapping that defines these metaphors. The multiple metaphorical character of our understanding of attention is precisely what allows us to make sense of a complex range of phenomena and to design experiments that can reveal some of the marvelous workings of the attentional system. In these respects, attention appears to be entirely characteristic of the vast majority of our abstract concepts for mind and mental operations, virtually all of which are metaphorical in character.

The existence of multiple, incompatible, metaphors would be merely a curiosity, if metaphors were just an optional rhetorical device. However, our analysis of the role of metaphor in attention research suggests strongly that the metaphors are anything but optional. Just the opposite seems to be true—the metaphors provide the means by which scientists identify phenomena, frame hypotheses, pursue research strategies, interpret data, and expand their knowledge.

One might think that the pervasive use of conceptual metaphor in attention research is merely a contingent artifact of the immature nature of the field. One might hold out hope that eventually a single, unified, internally consistent model of attention (either a literal or a metaphorical one) will be forthcoming. While this must always remain a theoretical possibility, the evidence weighs rather heavily against it. Metaphorical pluralism appears to be characteristic, not just of ordinary folk models, but of mature scientific thinking in general. Roediger, (1980) and Koriat and Goldsmith (1996) showed this for memory research. Metaphorical pluralism is clearly documented in physics, for example in optic phenomena, where light is understood metaphorically both as photons and waves. Gould (1987) analyzes the irreducible metaphors used to understand deep geological time, including "time's arrow" (unidirectional movement) and "time's cycle."

The same pluralism holds in genetics. Most theories in genetics and developmental biology use a metaphor in which genes are active agents. Genes are attributed autonomy and causal primacy in the construction of the organism: genes "make" proteins , using RNA as intermediary. Genes are carriers of information, in the colloquial sense of the term: "once 'information' has passed into protein it cannot get out again" (Crick, 1958, p. 153, quoted in Keller, 1995, p. 93). Genes provide instructions for protein synthesis. The only function of the soma (i.e., the part of the cell without genes) is to serve as the material from which the agent (the genes) construct the organism. There is a strong unidirectionality from the genes to the soma. The environment (either intracellular or extracellular) cannot give feedback information to the genes. It can only activate or de-activate certain genes, but it cannot change the information those genes code.

However influential this metaphor is in current theorizing, other competing inconsistent metaphors exist. For example, the agency role is sometimes located outside the genes. According to this view genes "are passive sources of materials upon which a cell can draw" (Nijhout, 1990, p.144, quoted in Keller, 1995, p.29). Another metaphor regards genes as "data to a parallel computing network embedded in the global geometrical and biochemical structure of the cell" (Atlan & Koppel, 1990, p. 333, quoted in Keller, 1995, p. 28).

Another argument that is sometimes leveled against the view that metaphors are actually constitutive of our most basic abstract concepts concerns the fact that there are always multiple inconsistent metaphors for any single concept. It is argued that this would make our theorizing incoherent unless there exists some higher level nonmetaphoric model or concept that is internally consistent. Thus, for example, Naomi Quinn (1987) has found several basic metaphors by which Americans conceptualize marriage. She argues that there must be a nonmetaphoric cultural model of marriage to which the various metaphors are then applied.

The question of whether metaphorical pluralism is a fact or whether there do, indeed, exist non metaphorical abstract models for basic phenomena is an empirical question. As such, it can only be answered case by case through thorough analysis of the conceptual structure and logic of the proposed models. This is basically the same question as to whether there exists a literal skeletal concept that is adequate to the actual ways we conceptualize and reason about the phenomenon in question. The evidence cited above for attention suggests that it is indeed the metaphors that give the crucial structure necessary for inference and reasoning. Where a literal skeleton exists, it is too impoverished to generate the appropriate inferences we make.

We have analyzed the role played by some of the dominant conceptual metaphors of attention as a representative example of the constitutive nature of metaphor in scientific theories generally. We have certainly not shown the metaphorical bases of *every* theory of attention. The list of models we have explored is not exhaustive, but we have considered some of the most influential theories in cognitive psychology (Note 6).

Metaphorical pluralism has far-reaching implications for cognitive science. It means that there will probably not exist a single, univocal, literal conception for any particular kind of cognitive phenomenon. It means that no one metaphorical structuring is likely to capture all important dimensions of a concept. It means that our theorizing and our experimental research is typically guided by multiple, perhaps inconsistent, conceptual metaphors. This is disturbing for anyone who still cherishes a literalist, objectivist view of experience, conceptualization, and knowledge. But for anyone not held in the laws of such a reductivist program, the fact of metaphorical pluralism is simply a reminder of the remarkable complexity and variety of the vast range of phenomena that we group together, conceptualize as part of an allegedly single concept, and call by the same name (such as "attention").

IX. CAN WE EVER GET BEYOND METAPHOR IN SCIENCE?

Is metaphor in scientific thinking only a feature of immature science, science too closely tied to our mundane folk models of mind? In other words, when a science grows up, comes of age, will it eventually transcend the supposedly murky, imprecise workings of metaphor? Will mature science replace metaphors with a monolithic, literal, univocal conceptual system for the phenomena being studied? Many people still want to believe that it will. They want to believe that fields like the cognitive psychology of attention only use metaphor because they are in their infancy. They envision a future in which attention would be studied and understood in highly formalized, precise, literal terms.

The business of cognitive science is to give empirically grounded explanations of the phenomena of mind, in the broadest sense of that term. Therefore, studies of the role of metaphor in scientific theorizing and research are about science as we know it, about how it works now. *A priori* speculations about what future, not-yet-existing, sciences might be like are not good research. It will, of course, always be an option for skeptics to say that the metaphorical character of science today is merely an early step on the road to a future pristine, metaphor-free science.

However, *all* of the evidence available to date goes against this literalist dream. Do we have any mature sciences today? If so, then let us look at them to see what role, if any, metaphor plays. So far, studies (see citations in Section VIII above) have revealed the constitutive role of metaphor in several parts of cognitive psychology, physics, biology, neuroscience, computer science, economics, and other fields. This work is not exhaustive and leaves a vast number of projects to be carried out within various fields of science. What researchers observe, over and over again, is the same general situation as we have found in attention research. The metaphors circumscribe the phenomena, define the basic concepts, guide the research program, and determine the inferences drawn about the phenomena.

It is often said that mature theories will use only mathematics and formal logic, thereby supposedly transcending metaphor. But both logic and mathematics are based on large numbers of conceptual metaphors that define their most fundamental concepts and operations (Johnson, 1987; Lakoff & Nuñez, 1996). Mathematizing science doesn't eliminate metaphor.

What we have seen to be true about the role of conceptual metaphor in determining the nature and direction of attention research appears to be a general cognitive phenomenon. That is, conceptual metaphor is basic to human conceptualization and reasoning. The central role of conceptual metaphor (and other imaginative modes of reasoning) is now being argued on several grounds, including philosophy (Flanagan, 1992; Lakoff & Johnson, 1999), linguistics (Lakoff, 1987), cognitive psychology (Gibbs, 1994; Varela, Thompson, & Rosch, 1991), artificial intelligence (Winograd & Flores, 1986), neuropsychology (Bisiach, 1992), and neuroscience (Thompson, Palacios, & Varela, 1992). The findings of this paper lead to the same conclusion. We showed evidence that metaphors are central to scientific knowledge, very much in the same way that they are central to ordinary knowledge.

Psychological terms are conceptualized metaphorically. Hence, conceptual metaphor and other dimensions of our imaginative rationality cannot be neglected in our attempts to build a theory of the mind. Moreover, worries that reasoning based on conceptual metaphor cannot be objective enough are unwarranted. Metaphorical reasoning is, in an important sense, both rigorous and subject to public scrutiny. It is a primary basis for our shared knowledge in science. It gives rise to, and guides, our research programs. It is not objective in the mistaken sense that logical positivists envisioned for science. It is not objective in that narrow sense because nothing is objective in ***that*** sense, as has been acknowledged for a long time now by philosophers of science (Quine, 1951; Hempel, 1965; Kuhn, 1962). Reasoning based on metaphor is intrinsically bound to our condition as human beings. It gives us a more humble sense of objectivity that is tied to an inter-subjectivity based on shared patterns of metaphorical reasoning.

The literalist hope of one and only one true literal description will never die. But what the evidence from cognitive science suggests is that our best science, like all our thinking with abstract concepts, is irreducibly metaphoric. Without metaphor, no science.

X. IMPLICATIONS FOR RESEARCH

We have argued that conceptual metaphors play a central role in the science of attention. They cannot be eliminated, because they are the basis for the concepts and inferences that lie at the heart of the theories and practices of scientific research about attention. Although such knowledge is obviously important for philosophers and psychologist who want to understand the nature of scientific thinking, one might wonder whether any of this should matter for people who are actually doing the research, not just on attention but in any area of science. How would any of such knowledge affect the way researchers ought to study cognitive phenomena?

The answer is that good science is self-critical. We need to know what our deepest assumptions are, how they affect what we can think and know, and whether they need to be revised in various ways. Otherwise, we are blind to the implications of our models, including both what they highlight and what they hide from us. Science is a special kind of problem solving (Langley, Simon, Bradshaw, & Zytkow, 1987; Nersessian, 1992; Giere, 1992;

Dunbar, 1993; Gopnik, 1996). As with any form of problem solving, we do it better when we know the nature and limitations of our models, methods, conceptual systems, and practices.

Our theories are irreducibly metaphoric. If what we have concluded about metaphorical pluralism is correct, then different metaphorical conceptions may circumscribe the basic phenomena of attention in different ways. No single metaphorical conception will be adequate to account for the phenomena. Understanding the metaphorical structure of one's model and theories—how the metaphors define phenomena, how they structure concepts, and how they generate inferences—is thus essential to any self-reflective scientist's method.

Metaphor is not a *problem* for science. On the contrary, it is one of our most basic and indispensable tools for doing good science

Acknowledgment: Special thanks to Mike Posner for his encouragement and support. We are grateful to Gilles Fauconnier, Ray Gibbs, Chuck Goodwin, and James Greeno for contributing with helpful criticisms to the development of this article. Thanks also to Jodie Baird, Jennifer Freyd, Morris Goldsmith, Asher Koriat, and an anonymous reviewer for their comments on earlier drafts. During the preparation of this paper Diego Fernandez-Duque was supported in part by the James S. McDonnell Foundation, Pew Memorial Trust through the support of the Center for Cognitive Neuroscience of Attention. A preliminary report on this project appears in the 17th Proceedings of the Cognitive Science Society.

NOTES

1. The relation between technical concepts of filter and more mundane ones is certainly a question of interest that deserves further exploration, but we cannot address it here.
2. The following analysis of Attention As A Spotlight metaphor is taken from Fernandez-Duque & Johnson (in preparation).
3. An exhaustive review of strengths and weaknesses of each camp in the space- vs. object-based debate is beyond the scope of this article. We illustrate some of the major points of this debate, as they relate to our claim for the central role of the spotlight metaphors in attention research.
4. It is possible that attentional effects occur not only at the auditory cortex but also at more peripheral stations. Because the cochlea is also tonotopically organized, our analysis is not affected by the debate regarding early vs. late selection.
5. The further assumption is made that brightness increase in the fMRI picture means increase of neuronal activity in that area.
6. Although not discussed in this paper, the metaphors' influence on attention research extends beyond the limit of cognitive psychology, toward computational and neurobiological models.

REFERENCES

Allport, D. A. (1987). Selection-for-action: some behavioral and neurophysiological consideration of attention and action. In H. Heuer, & Sanders, A. F. (Eds.), *Perspectives on perception and action*. Hillsdale, NJ: Erlbaum.

Allport, D. A. (1993). Attention and control: Have we been asking the wrong questions? A critical review of 25 years. In D. E. Meyer, & Kornblum, S. (Eds.), *Attention and performance XIV*. Cambridge, MA: MIT Press.

Atlan, H., & Koppel, M. (1990). The cellular computer DNA: Program or data. *Bulletin of Mathematical Biology, 52*(3), 335–348.

Baylis, G., Rafal, R., & Driver, J. (1993). Attentional set determines extinction following parietal lesions. *Journal of Cognitive Neuroscience, 5*, 453–466.

Baylis, G., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 451–470.

Bisiach, E. (1992). Understanding consciousness: clues from unilateral neglect and related disorders. In A. D. Milner & M. D. Rugg (Eds.), *The neuropsychology of consciousness*. London: Academic Press.

Black, M. (1962). *Models and metaphors*. Ithaca, NY: Cornell University Press.

Broadbent, D. (1958). *Perception and communication*. New York: Pergamon.

Castiello, U., & Umiltà, V. (1992). Splitting focal attention. *Journal of Experimental Psychology: Human Perception and Performance, 18*(3), 837–848.

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991). Selective and divided attention during visual discriminations of shape, color, and speed: Functional anatomy by positron emission tomography. *Journal of Neuroscience, 11*, 2383–2402.

Crick, F. (1958). On protein synthesis. *Symposium of the Society of Experimental Biology.*

Dennet, D. C., & Kinsbourne, M. (1992). Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences, 15*(2), 183–247.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222.

Desimone, R., Miller, E. K., & Chelazzi, L. (1994). The interaction of neural systems for attention and memory. In C. Koch & J. L. Davis (Eds.), *Large-scale neuronal theories of the brain. Computational neuroscience.* Cambridge, MA: MIT Press.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80–90.

Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI*. Hillsdale, NJ: Erlbaum.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology, 15*(3), 448–456.

Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17*, 397–434.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*(2), 161–177.

Egly, R., &. Homa, D. (1991). Reallocation of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 17*(1), 142–159.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception and Psychophysics, 40*, 225–240.

Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11*(5), 583–597.

Farah, M. (1994). Neuropsychological inference with an interactive brain: A critique of the "locality" assumption. *Behavioral and Brain Sciences, 17*(1), 43–104.

Fernandez-Duque, D., & Johnson, M. L. (in preparation). On the role of metaphors in science: Metaphors of attention in psychology.

Fernandez-Duque, D., & Posner, M. I. (1997). Relating the mechanisms of orienting and alerting. *Neuropsychologia, 35*(4), 477–486.

Flanagan, O. (1992). *Consciousness Reconsidered*. Cambridge: MIT Press.

Foote, S. L., Berridge, C. W., Adams, L. M., & Pineda, J .A. (1991). Electrophysiological evidence for the involvement of the locus coeruleus in alerting, orienting, and attending. In C. D. Barnes, & O. Pompeiano (Eds.), Neurobiology of the locus coeruleus. New York, NY: Elsevier.

Gibbs, R. W. (1994). *The poetics of mind: figurative thought, language, and understanding*. New York: Cambridge University Press.

Giere, R. N. (1992). *Cognitive Models of Science*. Minneapolis: University of Minnesota Press.

Gigerenzer, G. (1991). From tools to theories: a heuristic of discovery in cognitive psychology. *Psychological Review, 98*(2), 254–267.

Gigerenzer, G., & Goldstein, D. G. (1996). Mind as computer: Birth of a metaphor. *Creativity Research Journal, 9*(2 & 3), 131–144.

Gopnik, A. (1996). The scientist as a child. *Philosophy of Science, 63*, 485–514.

Gould, S. J. (1987). *Time's arrow, time's cycle*. Cambridge, MA: Harvard University Press.

Hempel, C. (1965). *Aspects of scientific explanation*. New York: Free Press.

Henderson, J. M. (1991). Stimulus discrimination following covert attentional orienting to an exogenous cue. *Journal of Experimental Psychology: Human Perception and Performance, 17*(1), 91–106.

Hesse, M. B. (Ed.). (1966). *The explanatory function of metaphor*. Notre Dame: University of Notre Dame Press.

Iwasaki, S. (1993). Spatial attention and two modes of visual consciousness. *Cognition, 49*, 211–233.

James, W. (1890/1950). *The principles of psychology*. New York: Dover.

Johnson, C. (1997). Metaphor vs. Conflation in the acquisition of Polysemy: The case of SEE. In M. K. Hiraga, C. Sinha, & S. Wilcox (Eds.), *Cultural, typological, and psychological issues in cognitive linguistics*. Amsterdam: John Benjamins.

Johnson, M. (1987). *The body in the mind*. Chicago: University of Chicago Press.

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology, 37*, 43–75.

Johnston, W. A., & Hawley, K. J. (1994). Perceptual inhibition of expected inputs: The key that opens closed minds. *Psychonomic Bulletin and Review, 1*(1), 56–72.

Jones, M. R., & Yee, W. (1993). Attending to auditory events: The role of temporal organization. In S. B. McAdams (Ed.), *Thinking in sound: The cognitive psychology of audition* (pp. 69-112). Oxford: Oxford University Press.

Jonides, J. P. (1981). Voluntary versus automatic control over the mind's eye. In J. Long, & A. Baddeley (Eds.), *Attention and performance IX*. Hillsdale, NJ: Erlbaum.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy, & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181-211). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In D. R. Parasuraman, & R. Davies (Eds.), *Varieties of attention* London: Academic Press.

Kahneman, D., Treisman, A. M., & Gibbs, B. (1992). The reviewing of object files: object-specific integration of information. *Cognitive Psychology, 24*, 175–219.

Kanwisher, N., & Driver, J. (1992). Objects, attributes, and visual attention: Which, what, where. *Current Directions in Psychological Science, 1*(1), 26–31.

Keller, E. F. (1995). *Refiguring life: Metaphors of twentieth-century biology*. New York: Columbia University Press.

Kovecses, Z. (1990). *Emotion concepts*. New York: Springer-Verlag.

Koriat, A., & Goldsmith, M. (1996). Memory metaphors and the laboratory/real-life controversy: Correspondence versus storehouse views of memory. *Behavioral and Brain Sciences, 19*(2), 167–228.

Kuhn, T. (1962). The structure of Scientific Revolutions. Chicago: University of Chicago Press.

Kramer, A. F., & Hahn, S. (1995). Splitting the beam: Distribution of attention over noncontiguous regions of the visual field. *Psychological Science, 6*(6), 381–386.

Kramer, A. F., & Jacobson, A. (1991). Perceptual organization and focused attention: the role of objects and proximity in visual processing. *Perception & Psychophysics, 50*, 267–284.

LaBerge, D. (1995). *Attentional processing: The brain's art of mindfulness*. Cambridge, Mass: Harvard University Press.

LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96*, 101–124.

Lakoff, G., & Johnson, M. L. (1999). *Philosophy in the flesh: Cognitive science brings to philosophy the embodied mind, the cognitive unconscious, and metaphorical thought*. Chicago: University of Chicago Press.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago: University of Chicago Press.

Lakoff, G. (1993). The Contemporary Theory of Metaphor. In A. Ortony (Ed.), *Metaphor and thought* (pp. 202-228). Cambridge: Cambridge University Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Lakoff, G., & Núñez, R. E. (1996). The metaphorical structure of mathematics: Sketching out cognitive foundations for a mind-based mathematics. In L. English (Eds.), *Mathematical reasoning: Analogies, metaphors, and images* Hillsdale, NJ: Erlbaum.

Lakoff, G., & Turner, M. (1989). *More than cool reason: a field guide to poetic metaphor*. Chicago: University of Chicago Press.

Langley, P., Simon, H. A., Bradshaw, G. L., Zytkow, J. M. (1987). *Scientific Discovery: Computational explorations of the creative process*. Cambridge, MA: MIT Press.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451–468.

Logan, G. D. (1995). Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology, 28*, 103–174.

Mondor, T. A., & Bregman, A. S. (1994). Allocating attention to frequency regions. *Perception & Psychophysics, 56*(3), 268–276.

Moray, N. (1959). Attention in dichotic listening; affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 12*, 214–222.

Neisser, U. (1967). *Cognitive psychology*. Englewood Cliffs, NJ: Prentice-Hall.

Nersessian, N. J. (1984). *Faraday to Einstein: Constructing meaning in scientific theories*. Dordretch: Martinus Nijhoff.

Nersessian, N. J. (1992). How do scientist think? Capturing the dynamics of conceptual change in science. In R. N. Giere (Ed.), *Cognitive models of science*. Minneapolis: University of Minnesota Press.

Nersessian, N. J., & Greeno, J. G. (1990). Multiple abstracted representations in problems solving and discovery in physics. *Proceedings of the Cognitive Science Society, 11*, 77–84.

Nijhout, H. F. (1990). Metaphors and the role of genes in development. *Bioessays, 12*(9), 441–446.

O'Craven, K. M., Rosen, B. R., Kwong, K. K, Treisman, A., & Savoy, R. L. (1997). Voluntary attention modulates MRI activity in Human MT-MST. *Neuron, 18*, 591–598.

Pashler, H. (1995). Attention and visual perception: Analyzing divided attention. In S. M. Kosslyn, & D. N. Osherson (Eds.), *Visual cognition: An invitation to cognitive science*. Cambridge, MA: MIT Press.

Posner, M. I. (1978). *Chronometric explorations of mind*. Hillsdale, NJ: Erlbaum.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I., Inhoff, A. W., Friedrich, F. J., & Cohen, A. (1987). Isolating attentional systems: A cognitive-anatomical analysis. *Psychobiology, 15*(2), 107–121.

Posner, M. I., & Raichle, M. E. (1994). *Images of mind*. NY: Scientific American Library.

Quine, W. V. (1951). Two dogmas of empiricism. *Philosophical Review, 60*, 20–43.

Quinn, N. (1987). Convergent evidence for a cultural model of American marriage. In D. Holland, & N. Quinn (Eds.), *Cultural models in language and thought*. Cambridge University Press.

Rafal, R. D. (1994). Neglect. *Current Opinion in Neurobiology, 4*, 231–236.

Regier, T. (1996). *The human semantic potential*. Cambridge, MA: MIT Press.

Remington, R., & Pierce, L. (1984). Moving attention and evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics, 35*, 393–399.

Roediger III, H. L. (1980). Memory metaphors in cognitive psychology. *Memory and Cognition, 8*(3), 231–246.

Salzman, C. D., Murasugi, C. M., Britten, K. H., & Newsome, W. T. (1992). Microstimulation in visual area MT: Effects on direction discrimination performance. *Journal of Neuroscience, 12*(6), 2331–2355.

Searle, J. (1979). Metaphor. In A. Ortony (Eds.), *Metaphor and thought* (pp. 92-123). Cambridge: Cambridge University Press.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technological Journal, 27*, 379–423.

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. Urbana: The University of Illinois Press.

Sheliga, B. M., Riggio, L., & Rizzolati, G. (1994). Orienting of attention and eye movements. *Experimental Brain Research, 98*, 507–522.

Shulman, G. L., Remington, R, & McLean, J. P. (1979). Moving attention through visual space. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 522–526.

Shulman, G. L., Wilson, J., & Sheehy, J. B. (1985). Spatial determinants of the distribution of attention. *Perception & Psychophysics, 37*, 59–65.

Sperling, G. (1995). Episodic theory of the dynamics of spatial attention. *Psychological Review, 102*(3), 503–532.

Spitzer, M., Kwong, K. K., Kennedy, W., & Rosen, B. R. (1995). Category-specific brain activation in fMRI during picture naming. *Neuroreport, 6*(16), 2109–2112.

Spitzer, M. (1997). A cognitive neuroscience view of schizophrenic thought disorder. *Schizophrenia Bulletin, 23*(1), 29–50.

Sweetser, E. (1987). *Semantic structure and semantic change: A cognitive linguistic study of modality, perception, speech acts, and logical relations*. Cambridge: Cambridge University Press.

Sweetser, E. (1990). *From etymology to pragmatics*. Cambridge: Cambridge University Press.

Thompson, E., Palacios, A., & Varela, F. J. (1992). Ways of coloring: Comparative color vision as a case study for cognitive science. *Behavioral and Brain Sciences, 15,* 1–74.

Treisman, A., M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12,* 242–248.

Treisman, A., M. (1964a). Selective attention in man. *British Medical Bulletin, 20,* 12–16.

Treisman, A. M. (1964b) The effect of irrelevant material on the efficiency of selective listening. *American Journal of Psychology, 77,* 533–546.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review, 76*(3), 282–299.

Treisman, A. (1988). Features and objects. *Quarterly Journal of Experimental Psychology, 40A*(2), 201–237.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Treue, S., & Maunsell, J. H. (1996). Attentional modulation of visual motion processing in cortical areas MT and MST. *Nature, 382,* 539–541.

Tsal, Y. (1983). Movements of attention across the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 523–530.

Turner, M. (1991). *Reading minds: the study of English in the age of cognitive science.* Princeton, NJ: Princeton University Press.

van der Heijden, A. H. C. (1986). On selection in vision. *Psychological Research, 48,* 211–219.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind.*Cambridge, MA: M.I.T. Press.

Von Helmholtz, H. (1924). *Treatise on psychological optics.* Rochester, NY: Optical Society of America.

Wedner, W. (1949). Recent contributions to the mathematical hteory of communication. In Shannon C.E. & W. Wedner (Eds.). *The mathematical theory of communication.* Urbana: The University of Illinois Press.

Winograd, T., & Flores, F. (1986). *Understanding computers and cognition.* Addison-Wesley.

Winter, S. (1999). *A clearing in the forest.* Chicago: University of Chicago Press.

Winter, S. (1989). Transcendental nonsense, metaphoric reasoning, and the cognitive stakes for law. *University of Pennsylvania Law Review, 137,* 1105–1237.

Woodruff, P. W. R., Benson, R. R., Bandettini, P. A., Kwong, K. K., Howard, R. J., Talavage, R., Belliveau, J., & Rosen, B. R. (1996). Modulation of auditory cortex and visual cortex by selective attention is modality-dependent. *Neuroreport, 7*(12), 1909–1913.

Wündt, W. (1912). *An introduction to psychology.* London: Allen & Unwin.

Yantis, S. (1990). On the locus of visual selection: Evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception and Performance, 16*(1), 135–149.