Defining Awareness by the Triangular Circuit Of Attention

David LaBerge
Department of Cognitive Sciences
University of California, Irvine
Irvine, CA 92717
USA

dlaberge@simons-rock.edu

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1. Introduction

This paper proposes that the experience of attending to an object becomes an experience of being aware of that object when it is conjoined with attending to a representation of the self. In other words, awareness occurs when "an experience" becomes "my experience". Attention is assumed here to be an event in the brain consisting of simultaneous neuroactivity in three areas, which are interconnected by a triangular circuit (LaBerge, 1995). The three activity sites correspond to three aspects of attention: expression, enhancement mechanism, and control. The brain sites corresponding to each of these aspects are: (a) for the expression, clusters of neurons in the posterior and anterior cortex that serve cognitive functions, such as perceptions of objects and attributes, and the organizing and executing of action plans, (b) for the enhancement mechanism, the thalamic nuclei, whose excitatory neurons activate neurons in corresponding cortical columns (see Figure 1 <1>), and (c) for the control, clusters of neurons in the frontal cortex. When the three sites are simultaneously active, it is said that an attentional event occurs.

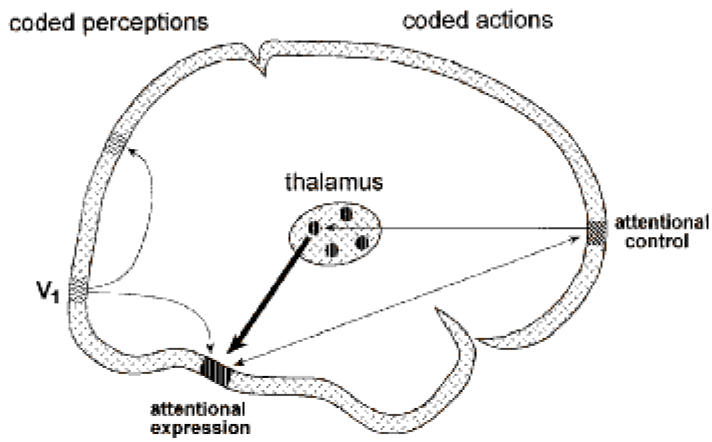

Figure 1

Schematic diagram of the three major (human) brain sites connected in an attentional triangular circuit that results in attentional intensification of activity in a cortical column cluster. The presumed control site in prefrontal cortex directly selects the site of attentional expression in the occipitotemporal cortex, and this control site also regulates the intensity of the cortical expression in the occipitotemporal cortex by means of the indirect connection through a thalamic nucleus. The posterior cortical areas serve mainly perceptions, while the anterior cortical areas serve mainly actions, and sites of attention expression may exist in both areas.

The triad of sites connected by the triangular circuit is initially activated by sources inside and outside the system. Internal sources normally activate the triangular circuit at the frontal control node of the circuit. These endogenous sources are connected with motivational areas of the brain (e.g., the basal ganglia), and may operate through momentary considerations of the person's interests or may operate relatively automatically by habitual interests. External sources are sensory stimuli (e.g., abrupt onsets that involve the orienting system) that activate the cortical column site where attention is eventually expressed. However, it is assumed here that the activations of these cortical sites of attentional expression from sources exogenous to the system are not sufficient to produce an attentional expression, owing to their short durations and rapidly decaying intensities. In order to achieve a sufficiently intense and long lasting activation in a column cluster (to qualify as an expression of attention), the appropriate frontal area must be signaled to return activation to that column.

2. The Triangular Circuit

Since most of the knowledge we have of cortical and thalamic circuitry has been obtained from studies of the primary visual cortex and its adjacent areas, the description given here of the triangular circuit is based on a schematic diagram of the triangular circuit involving areas V1 and V2. In Figure 2 the direct (forward) connecting fibers between a V1 column and V2 column arise from Layer 5 of the V1 column, and terminate on a thalamic relay neuron, which in turn projects to the middle layers of a V2 column. Thus, at the thalamic relay neuron, a Layer 5 neuron of a V1 column has the same anatomical relation to a V2 column that an optic nerve cell has to a V1 column.

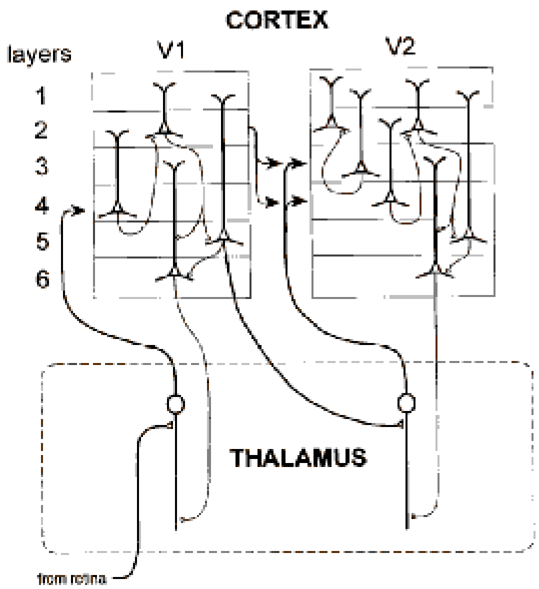

Figure 2

Schematic diagrams of excitatory neurons within a pair of cortical columns and within a thalamic nucleus, along with their main interconnections. The forward connection from the first column (e.g., in area V1) to the second column (e.g., in area V2) occurs both directly and indirectly by means of a synapse in a thalamic nucleus, forming a triangular circuit.

Evidence from neural tracing studies (e.g., Ungerleider, Galkin, & Mishkin, 1983) indicate that V1 fibers synapse on the pulvinar nucleus of the thalamus (which projects directly to V2) and indicate that these fibers arise from Layer 5 of V1 (Conley and Razkowski, 1990). Relay neurons in the pulvinar project directly to area V2 (Jones, 1985), as well as to the other visual areas in the posterior cortex (including V1). Thus, the triangular circuit depicted in Figure 2 begins with neurons in a V1 column that connect with a V2 column by a direct connection and by an indirect connection by way of the thalamus.

The indirect connection between V1 and V2 that enlists thalamic neurons, shown in Figure 2 appears to have characteristics that enhance firing rates. Layer 5 neurons fire in bursts of a few spikes at rates at least as high as 250 Hz, with intraburst firing rates on the order of 15 Hz (Connors & Gutnick, 1990; Gray & McCormick, 1996), and therefore these neurons have the ability to drive their target neurons to high rates of firing. The intrinsically spiking Layer 5 neurons synapse near the cell bodies of thalamic relay neurons and are therefore in a privileged position to drive the spike outputs of the cell body. Layer 6 neurons, whose fibers have smaller diameters and thus can be distinguished from those of Layer 5, synapse well away from the cell body, mostly at remote locations on the dendrite (Sherman, 1990). A major function of Layer 6 axons is to lower the threshold of the thalamic neuron, so that signals arriving at synapses near the cell body will have a greater probability of inducing the cell body to fire (McCormick &

Von Krosigk, 1992). Thus, the feedback loop involving Layer 6 neurons and the thalamic relay neuron appears to facilitate synaptic transmission of Layer 5 neurons contacting that relay neuron. This reduction of threshold at the synapse would potentiate the already strong effects of the bursting Layer 5 neurons on the receiving relay neuron.

It is therefore conjectured that the thalamocortical loop, involving the ascending thalamic relay fibers together with the feedback fibers from Layer 6 neurons, has the ability to enhance firing rates of input fibers arriving from Layer 5 cells of another column. This conjecture is supported by a study in which the thalamocortical circuit was modeled as a neuron network so that simulations of its operations could be carried out for a selective attention task (LaBerge, Carter, & Brown, 1992). The neural network was based on the known interconnections of all the types of thalamic neurons, including the local inhibitory cells and the reticular nucleus inhibitory cells, which are located between the relay cells and the cortical columns to which they project. The results of the simulations in that study showed sharp increases in firing-rate trajectories in cortical cells corresponding to attended stimuli (relative to trajectories in cortical columns corresponding to neighboring unattended stimuli). In particular, small initial differences between inputs to the relay cells (from Layer 5 cells in cortical areas of attentional control) serving target and distractor columns were strongly magnified (e.g., by a factor of 25 or more) by the thalamocortical circuit. Thus, the thalamocortical circuit appears to function as an enhancement mechanism of cortical activity.

Supporting evidence for the existence of the triangular circuit in other regions of the cortex is provided by the confirmation of large Layer 5 fibers that synapse near the relay cell body and small Layer 6 fibers that synapse at the distal regions of the relay dendrites of the auditory cortex (Ojima, 1994) and for the prefrontal cortex (Schwartz, Dekker, & Goldman-Rakic, 1991). Since all regions of the cortex are connected with the thalamus (it has been said in a personal communication by a noted neurophysiologist that thalamic cells constitute the seventh layer of cortex), it seems highly probable that the triangular circuit exists wherever cortical columns in one area communicate with columns in another area. Figure 3 shows the diagram of several proposed triangular circuits crossing cortical areas (LaBerge, 1995) that would appear to have the structure to be particularly relevant to attentional processing in the brain.

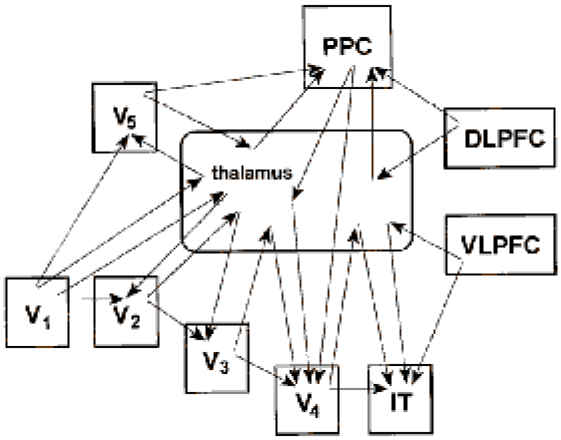

Figure 3

Schematic diagrams of some of the triangular circuits in the visual system. The triangular circuits serving visual attention are believed to originate in the dorsolateral prefrontal cortex (DLPFC) for location and in the ventrolateral prefrontal cortex (VLPFC) for shape. Effects in the posterior parietal cortex (PPC) of DLPFC activations may be relayed to V4 via an attentional triangular circuit to select the location of a part of a stimulus array.

The proposed triangular circuits of Figure 3 function to amplify corticocortical connections in both bottom-up and top-down directions. Triangular circuits confined to the posterior cortical regions presumably enhance bottom-up sources of cortical column activation. However, the set of triangular circuits of most interest in this paper are those that project activation in the top-down direction to posterior cortical columns in which attention is expressed. It is conjectured here that the enhancement operations provided by the thalamic part of the triangular circuit typically are stronger and of longer duration when the circuit involves top-down sources of activation than when it involves only bottom-up sources of activation.

Several PET experiments have shown activation of the pulvinar during visual attention. When subjects attended to the shape of many objects in a multidimensional visual display in order to detect small changes in their size, activation was found in a region containing the right pulvinar (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991). Activations were located in the right pulvinar when subjects concentrated attention (in the prolonged anticipatory mode) to a single target shape in a known location to the right or left of center fixation (LaBerge & Buchsbaum, 1990). Using the same anticipatory attention task of the LaBerge and Buchsbaum (1990) experiment, Liotti, Fox, & LaBerge (1994; submitted) compared hard and easy levels of attentional difficulty with a control condition and examined changes throughout most of the brain. The right pulvinar effect was strongly confirmed for the hard task (when the hard task condition was compared with that of the easy task as well as with that of the control task). Two other thalamic regions showed activations when the hard condition was compared with the easy and control conditions. One activated thalamic region contained the mediodorsal nucleus, which connects strongly with the prefrontal cortex and also with the posterior parietal cortex (in monkeys); this region was also activated in the Corbetta et al. (1991) study with shapes and in the Heinze et al. (1994) study in which subjects sustained focal attention on locations in the right visual field. The other region activated by the hard task in the Liotti et al. study was the ventrolateral nucleus, which connects with both frontal areas and the basal ganglia. Corbetta et al. (1991) found activations at or near this region when subjects discriminated shape sizes or changes in the velocity of shape movements, and Corbetta et al. (1993) found activations in this region when subjects shifted attention toward the right in the right visual field. Thus, three regions of the thalamus have been shown to be selectively active when humans attend to visual shapes and their locations.

At the same time that thalamic nuclei are active in these visual attention tasks, cortical regions that are directly connected with these thalamic nuclei are also active. Occipitotemporal areas and posterior parietal areas, which are closely connected with the pulvinar nucleus, showed activations in the Corbetta et al. (1991) and Liotti et al. (submitted) studies. These areas are presumed to exhibit the expressions of attention to shapes and locations. Prefrontal areas in the dorsal areas in the dorsal (DLPFC / premotor) region and the ventral (VLPFC) region were also activated in the Liotti et al. study. These areas of the frontal cortex are strongly implicated in the voluntary control of location and shape, respectively (e.g., Wilson, O'Scalaidhe, & Goldman-Rakic, 1993; Frith, Friston, Liddle, & Frackowiak, 1991). Thus, taken together, these PET studies show activations both in thalamic nuclei and in the cortical areas of attentional expression and attentional control that are reciprocally connected with these thalamic nuclei.

3. Attention and Awareness

Traditionally, the term "awareness" has often been used synonymously with the term "consciousness", which has been called a "mongrel" concept, owing to the variety of its definitions (Block, 1995). A main goal of this paper is to forge a clear concept of "awareness" in the brain not by attempting to distinguish it from "consciousness" , but rather by defining it with concepts described in the earlier part of this paper. Specifically, an event of awareness is conjectured to involve (a) the operation of attention (b) which is directed toward a representation of the self. Thus, it is presumed that awareness requires an attentional event that is added to the simple act of attending to an external object or event. Awareness involves the agent or actor whose cortical representation is activated when attention is directed to it. Simply attending to an object or event requires action on the part of the cortical area of control, but the representation of the responsible actor need not be activated. For example, one may attend strongly to a bird which is struggling against the window without attentively processing one's own participation in the action of attending to it. Another example is given by Sartre (1957), in which I am running down the street to catch a bus and attending to "the bus having to be caught" but without attending to "myself having to catch it" (I may include myself in the attended events after I catch the bus). Thus, additional brain areas are active when attention is directed to the actor along with the external event.

The properties coded by the representation of selfhood accessed by the self-attended triangular circuit undoubtedly vary greatly across individuals, but there is a common component of the representations that provides a means of locating the object-attended event in space and time. The location marker is almost always associated with the body, and the body surface is richly represented within the cortex (Damasio, 1994). The location of the body with respect to a changing environmental scene is updated continually within the self-representation. Thus, for example, I can realize that I perceived a windy day yesterday or that I am now perceiving a windy day, where "I" is associated with my body being in a particular place relative to the windy day event.

But the self conceivably may be referenced on occasion without attending to one's bodily landscape. Verbal representations linked strongly to one's personal history are readily accessed from memory and can serve as the self-attended event. One would expect that, on many occasions, the verbal representation will automatically activate bodily landscape codes, and vice versa, so that attention to the self would typically involve both sets of representations.

Specifically, it is assumed here that the event of awareness requires that attention be directed to the regions where the self is expressed at the same time that attention is directed to the cortical regions where the object is expressed (noting that, on occasion, self and object may be the same). Simultaneous activation of the two triangular circuits is assured if they are both activated from a common brain area in the frontal cortex, that is, the two triangular circuits are joined at their common control center. The action of activating both the object-attended and the self-attended triangular circuits presumably produces more than the simultaneous (or near-simultaneous) increase in activity at the object- and self-attended cortical sites of attentional expression. Within each triangular circuit the feedback from the expression site to the frontal area of control is synchronized with the activation flowing from the common control site to the expression site. As a result of the temporal coincidences between the two triangular circuits, not only is attention being directed to the self along with attention to an object, but attention is being directed to "the self doing the control" of attention to the object.

The concept of awareness, as used here, is not necessarily synonymous with the concept of self-awareness. When attention is shared between an object and the self, the term "awareness" seems appropriate; when attention is directed entirely or almost entirely to the self, then the term "self-awareness" seems appropriate. An event of awareness may be relatively brief, as when we experience the coincident occurrences of the self and the perception of an object; and an event of awareness may be relatively prolonged, as when the sheer sensation of the object's attributes, and/or the sheer feeling of the self's bodily landscape, is allowed to intensify and be sustained for a time. Thus, according to the definition of awareness given by the present paper, an attention event is a necessary but not sufficient condition for an awareness event, so that there can be attention without awareness but no awareness without attention.

Notes

<1> Figures and captions are from the original article and have been renumbered. In this precis Figures 1, 2, and 3 refer respectively to Figures 5, 3, and 4 in the original text. These figures, along with the original article, are available in PDF format from the website of the journal *Consciousness & Cognition* <http://www.apnet.com/www/journal/cc.htm>.

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