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On the Neurodynamics of the Attentive Brain

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Abstract: An autonomous neurobiological mechanism is proposed for attention and its drift and switch without recourse to any metaphysical agency. This mechanism makes use of widely available empirical findings on the functions of the neuronal units of the brain such as the thalamus, hippocampus, basal ganglia and thalamocortical pathways. This formulation has been prompted by *Abhidhamma* and *Vipassana Meditation* and stands as an alternative to Francis Crick's *'Searchlight Hypothesis'*.
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Introduction

Of course, our ability to recognize and recall is so ordinary and common that we take it as an absolute given in our daily life. However, on closer observation, we have an interesting result that could be of use in understanding the neuronal mechanism of recall in cognition.

> *The functions of consciousness should be understood as tenfold by stage. Namely: Emergence, Pulsation, Adverting, {Seeing or Hearing or Smelling or Tasting or Touching}, Attention, Association, Discerning, Reverberation, Registration, Extinction.*

It may be of surprise to note that the above is not a quotation from some modern journal of brain science, but one from a 2,500-year-old treatise, The Abhidhamma Pitaka, that was taught by the Gothama Buddha. [Ref 1; Ch 3 Section 8, pp 122 with some of the Pali words have been rendered into English by the present author]

> *Therefore, if a visual stimulus, having lasted more than one moment, enters the avenue of the eye, pulsation occurs for two moments and is arrested. Then adverting arises and ceases in one moment. Immediately after that seeing, attention, association and discernment arise and cease in four consecutive moments. Following this any one of the twenty-nine sense sphere reverberations that has gained the right conditions runs its course, generally for seven moments. At the end of the reverberations, two registration resultants arise accordingly. Then comes the subsidence into quiescent pulsation.* [Ref 1; Ch 4 Section 6, pp 154]

In the Buddhist tradition of Sri Lanka, through the process of introspective meditation, called Vipassana Bhavana, which is still actively practiced by many around the world, the Dhammists had arrived at such penetrating observations in the distant past.

One of the main results of such meditative 'first-person' observation is to realize the conditional nature of 'consciousness' or 'the flow of thought' as arising from sensory forms in incidence with conditions of the body including the nervous system, which is referred to as the 'thinking apparatus' [Ref: 1; Ch 1 Section 2, pp 25] in the ancient treatise.

The relative consonance between the Vipassana insight observations and the elegant synthetic model put forward by Edward de Bono in 1969 [Ref 2] are also very striking. We can use some of the observations of Vipassana to create a conceptual foundation for the attentive brain.

Why this hypothesis?

First person empirical observation, now further justified in the light of modern neurobiology, leads us to question whether we can postulate the flow of thought and its concomitant drift and switch of attention as a dynamic neuronal process in the brain that could be explained by an autonomous mechanism without recourse to any metaphysical agency.

This paper answers the question with the proposal of such a mechanism, identified as the “neurodynamic hypothesis of attention”, in terms of well-known neuro-anatomical features of the brain. Though the present author has formulated his hypothesis independently, it is of relevance to note that the proposed mechanism competes directly with the "Searchlight Hypothesis" put forward by Francis Crick in 1984.

> *In 1984, long before consciousness studies had become fashionable, Francis Crick suggested that an "internal attentional searchlight ... controlled by the reticular complex of the thalamus" could serve to combine the activities of local networks in visual cortex. This searchlight could activate "transient cell assemblies" representing conjunctions of features of the attended object.- James Newman.* [Ref: 3]

Also the new neurodynamic mechanism proposed provide a consistent empirical basis of a neuronal mechanism upon which we may review and unify other hypotheses. Of note are the Crick and Koch "40 Hz" Binding, Llinas' et al's "40 Hz" Scanning, Taylor's Reticular Nucleus Global Guidance and Bernard Baars' ERTAS Global Workspace Model etc. discussed in an E-seminar by James Newman. [Ref: 3]

Neurodynamic Hypothesis of Attention

Neuronal pathways originating in the sensory receptors pass through the thalamus, diverge on to the cortical regions and then project back to the thalamus through the hippocampus or the basal ganglia. The reticular complex that surrounds the surface of the thalamus interconnects these pathways in such a way that the intensity of activity in every such pathway suppresses directly in proportion the ongoing activity in every other pathway. The hippocampus and the basal ganglia function as the unit of reverberation in which lasting pathway reverberation is set off on adequate activation of any pathway passing through it.

Trains of impulses originating in the intra-laminar nuclei of the thalamus feed into every pathway passing through the thalamus in the wakeful state. This brings up into

threshold of attention one of the pathways that emerges prominently by virtue of its greater impulse generation activity and also its concomitant suppression of all other pathways into quiescence by virtue of the arrangement of pathways. Then, after some time, the prominent pathway regresses into fatigue by virtue of synaptic fatigue of neurons in prolonged activity. This leads to one of the quiescent pathways emerging into attention by the same mechanism as before, thus manifesting as drift of attention.

Upon any specific sensory stimulus, the corresponding pathway gains prominence by virtue of its overriding impulse generation activity within the above mechanism, holding prominence in the duration of the stimulus, thus manifesting as a switch of attention. Also every adequately activated pathway retains its reverberation in the hippocampus or the basal ganglia for some time. And this provides the basis for the continuing higher quiescent activity of pathways that have been recently activated.

Figure 1

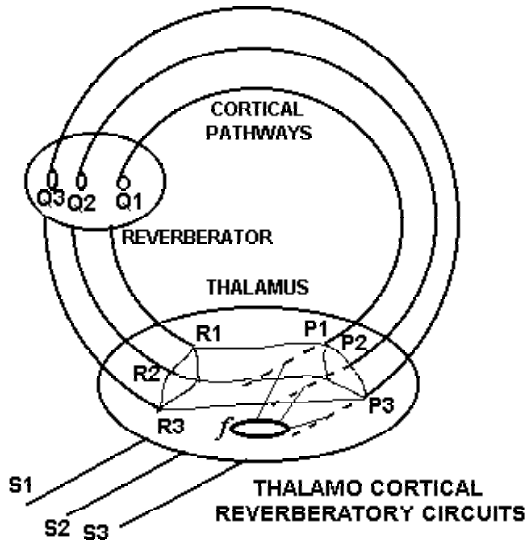

Figure 1. Illustration of the Neurodynamic Hypothesis of Attention

For the purpose of illustration, the above diagram shows three neuronal pathways $\mathbf{S_iP_iQ_iR_iP_i}$ (for i=1,2,3) from the sensory regions passing through the **thalamus** up to the **cortical regions** and then returning through the **hippocampus** or the **basal ganglia** back to the **thalamus**. All three pathways get uniform activation of common **'awake'** frequency $\mathbf{f_o}$ from within the **thalamus**, perhaps from the **intra-laminar nucleus.** The **reticular complex** on the surface of the **thalamus** interconnects P1, P2, P3 etc. and R1, R2, R3 etc. in such a way that activity in any one pathway suppresses activity in all neighboring pathways, in what is called **Lateral Suppression**.

At the beginning, let there be activation **a1**, **a2** and **a3** respectively along the three pathways, activation being measured by the average frequency of impulse generation along the pathway given a uniform equal input of impulse to every pathway. Let us also say that, for our purpose that **a1 > a2 > a3**.

The common input of waves of impulse of **'awake'** frequency $\mathbf{f_o}$ into all pathways through the **thalamus** is a continuous process in the wakeful state. This will be called the "Uniform Impulsion at Uniform Impulsion Frequency".

On such an **Uniform Impulsion**, the pathway that has the highest activation, i.e. the **Prominent Pathway**, will begin to generate greater activity than others. And by **Lateral Suppression** via the **reticular complex**, this will lead to suppression of activity in all neighboring pathways, which will, in turn, lead to still greater activity in the **Prominent Pathway**. Thus, Pathway 1 is in Attention by virtue of it reverberating at a frequency that exceeds the **Attention Threshold Frequency**.

If activity along the **Prominent Pathway** reaches a certain **Reverberation Threshold Frequency**, say **q** - then **Reverberant Activation** occurs- setting off a reverberation that lasts a duration of minutes along that specific pathway within the **Reverberation Unit**, the **hippocampus** or the **basal ganglia**. However, every pathway is subject to **Synaptic Fatigue** when such activity persists. And the **Prominent Pathway** soon reaches the condition of **Pathway Fatigue**, which leads to disruption of cyclical activity along that pathway, and as a consequence, the **Lateral Suppression** imposed by that pathway upon others declines. This makes way for another pathway, the one with the highest activation of the pathways available now, to emerge as the **Prominent Pathway**. Thus Pathway 1 becomes **quiescent** while Pathway 2 becomes **prominent**. This is the **Drift of Attention**.

While this process of alternate activation of pathways takes place, let us say that a **Sensory Stimulus S** appears on one of the pathways, say **S3**. Now, this sensory stimulus drives that specific pathway into high activity, and depending on its intensity, it overrides the **Lateral Suppression** acting upon that pathway from the currently **Prominent Pathway**. This leads to that specific sensory activated pathway gaining prominence over the rest. Thus Pathway 3 becomes prominent, pushing both Pathway 1 and Pathway 2 into quiescent condition. This is the **Switch of Attention**. But, with time, this pathway too will reach the state of **Pathway Fatigue** and another pathway will come into prominence, either as **Drift** or as **Switch** depending respectively on absence or presence of adequate sensory stimulus.

In the same fashion, multiple **Sensory Stimuli** could compete for attention at the same time. But only the stimulus that generates the strongest activation, and thereby causing strong **Lateral Suppression** of others, thereby gaining prominence into **Attention**.

When there are no sensory stimuli, the inner state of activity along respective pathways in the **Reverberation Unit**, the **hippocampus**, or the **basal ganglia**, determine the **Quiescent Activation** of recently activated pathways, and therefore their subsequent transience into and out of **Conscious Attention**. Also, this could be the basis of **Short-term Memory.**

Conclusion

Thus the proposed neurodynamic mechanism of attention, while being entirely within modern empirical neurobiology, is also seen to be an autonomous activity that does not call for any metaphysical agency. Also this prompts an overall architecture for the brain, entirely based on neurobiological foundations. It may also be possible to build such a mechanism into useful automata as well for applications that require attention-like interactive response.

In the converse, this could provide a scientific foundation for the study and practice of Vipassana insight meditation, which is of prime importance in unveiling the physical

basis of ethics. Further, this could guide future research into the claims of insight meditation, especially addressing their empirical validity or invalidity. Also here arises the unique opportunity of relating a 'first person' empirical study with 'third person' science that has matured to the threshold of being a new paradigm on consciousness.

Eventually this could pave way for a scientific theory of consciousness, which is the prime curiosity, and perhaps the lifetime goal, of many talented and enthusiastic researchers worldwide. Our search shall not be in vain, provided we nose up in the right direction.

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