A Computational Model of Attentional Networks

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***Abstract* - Attention is a complex system subserved by at least three interacting attentional networks in the brain. This paper describes a computational model of attentional networks, developed in the framework of *leabra* [1]. We evaluated the model using Attentional Networks Test [2] and the simulation results fitted the behavioral data well. The model provides a computational explanation of how the three attentional networks work together to achieve the function of attention.**

***Keywords* - Computational modeling, Attention, Alerting, Orienting, Executive Control**

I. INTRODUCTION

Although “everyone knows what attention is” [3], the nature of attention remains one of the central puzzles in science. Recent findings in psychology and brain imaging have increasingly suggested that it is better to view attention not as a unitary faculty of the mind but as a complex organ system subserved by multiple interacting neuronal networks in the brain [4]. At least three such attentional networks, for alerting (achieving and maintaining an alert state in preparation for coming stimuli), orienting (selectively focusing on one or a few items out of many candidate ones), and executive control (monitoring and resolving conflicts in planning, decision-making, error detection, and overcoming habitual actions), have been identified (Fig. 1). Considerable functional neuroimaging evidence has shown activities of these areas highly correlate with the essential functions of attention [2, 5].

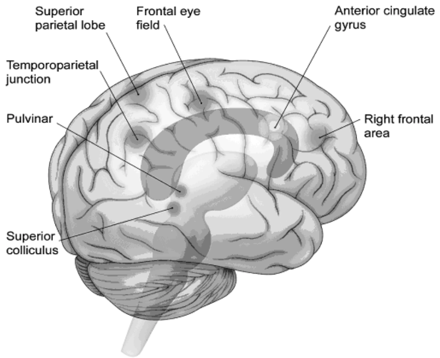

Fig. 1. A sketch of the three attentional networks. The alerting network consists of the frontal and parietal cortical regions particularly of the right hemisphere. The orienting network consists of parts of the superior and inferior parietal lobe, frontal eye fields and such subcortical areas as the superior colliculus of the midbrain and the pulvinar and reticular nucleus of the thalamus. The executive control network includes the midline frontal areas (especially the anterior cingulate cortex, or ACC), lateral prefrontal cortex, and the basal ganglia.

How the distinct attentional networks interact and work together to achieve the functions of attention is not clear. Computational modeling has the potential to provide important computational links that lead from neuroimaging evidence to behavioral data. Seeking such principled computational links is also a challenge that is facing the field of cognitive neuroscience in general. Here we describe a computational model of attentional networks. The model is developed in PDP++ (an object-oriented connectionist modeling environment) and adopts the *leabra* algorithm (***l**ocal, **e**rror-driven and **a**ssociative, **b**iologically **r**ealistic **a**lgorithm*) [1]. We evaluate the model in the paradigm of the Attentional Networks Test (ANT), a behavioral task that was designed to evaluate the efficiency of the three attentional networks [2]. The results have shown that the model is capable of reproducing the behavioral data and helps explain the computational mechanisms underlying human attention.

II. ANT

The ANT paradigm is based on a combination of spatial cueing and a flanker task and simultaneously involves all three attentional networks. The subject is presented a row of 5 horizontal arrows and is required to report as quickly as possible the direction (left or right) of the center arrow (the target) by pressing a corresponding key. As a result, the target is flanked by four side arrows, which can be either in the same direction as that of the target (congruent condition), or in the opposite direction (incongruent condition). To introduce an orienting factor, the stimulus row can be presented at two different locations, either above a fixation point or below it. To introduce an alerting factor, the row may be preceded by a cue (cue condition) or not (no-cue condition). In addition, when there is a cue, it may be presented at the center fixation location (center-cue condition) or at the locations where the stimulus row is to appear (orienting-cue condition). If the subject’s reaction time (RT) is recorded, then the *efficiencies* of the three attentional networks can be measured as follows:

Alerting efficiency = RT(no-cue) – RT(center-cue)
Orienting efficiency = RT(center-cue) – RT(orienting-cue)
Conflict efficiency = RT(incongruent) – RT(congruent)

III. MODEL

The structure of the model is shown in Fig. 2. This model contains modules for all the three attentional networks. In addition, it contains modules for perception (visual input and primary visual cortex), object recognition (object pathway), and response (output). The networks are connected in such a way that they conform to the known functional an anatomical constraints described above as much as possible.

The model works as follows. When a cue comes on, the primary visual cortex module is activated, which in turn triggers the alerting network. This cue-induced alerting affects later stimulus processing because the alerting network will remain excited for a while which will activate the orienting network in general causing it to become ready for the incoming stimulus. In addition, when the cue is a spatial one (i.e., a cue that indicates where the target stimulus is to appear), it will further make the corresponding sub-region of the orienting network even more excited. This occurs because the orienting network adopts a retinotopy-based spatial representation of the environment. This extra excitation in the sub-region of the orienting network will facilitate the corresponding stimulus processing in the object pathway network, due to the connections between them. This accounts for the orienting effect. Finally, note that it is the object pathway network that is responsible for the arrow direction detection. When the incongruent stimulus (e.g., a left arrow flanked by four right arrows) is presented, the object pathway network may propose different responses, which compete for the final expression in the output network. The executive control network then activates making the center arrow defeating the flankers. This is where the executive control attention plays a role.

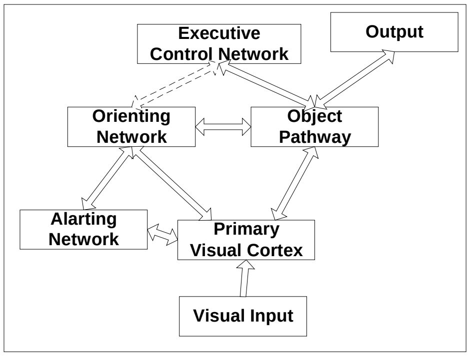

Fig. 2. A sketch of the computational model of attentional networks. The modules are connected bi-directionally (except the one from visual input to primary visual cortex). The link between the orienting network and the executive control network has not yet been implemented.

IV. RESULTS

We evaluated the performance of the model by using it to perform the ANT task. Stimuli are presented to the model in the same way as for a human. Depending on the conditions, a cue, which can be either a center cue or a spatial cue, may be presented for a fixed time period before the stimulus presentation. The number of cycles the output module takes to produce a stable response after the stimulus presentation serves as a measure of the reaction time. The simulation results are shown in Table 1, along with the empirical behavioral data.

A regression analysis showed that

$$RT(ms) = 9.7 * RT(cycle) + 97.6,$$

with a correlation of 0.94. It is clear that the model fits the behavioral data reasonably well

Table 1
Empirical (in ms) and modeling (in cycles) results. Empirical results are based on 40 human subjects (adopted from [2]).

Cue	*Target*	*RT*	
		Empirical (ms)	*Modeling (cycles)*
No-cue	Neutral	525	44
	Congruent	528	45
	Incongruent	605	54
Center	Neutral	480	41
	Congruent	485	39
	Incongruent	570	45
Spatial	Neutral	440	38
	Congruent	445	36
	Incongruent	505	41

V. CONCLUSION & DISCUSSION

Attention is subserved by multiple interacting neuronal networks in the brain. This paper described a computational model of attentional networks. It provided a detailed computational explanation of how the three attentional networks work together to achieve the function of attention. The model is biologically plausible in that it is constrained by both neuroimaging findings [2, 5] and the underlying principles of the *leabra* framework. The model is psychologically sound in that it fits the behavioral data reasonably well.

The model not only reproduces the attentional effects in the ANT task, it also makes novel predictions. For example, the model predicts that damage to the ACC causes more response errors but not longer response time in the ANT task. This prediction needs to be tested in later neuropathological studies.

ACKNOWLEDGMENT

The authors thank Dr. Michael E. Brandt for helpful suggestions and editorial assistance. This work is partially supported by a grant from Office of Naval Research (Grant No. N00014-01-1-0074) to H. Wang, a DeWitt Wallace Readers Digest Fellowship to J. Fan.

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