A Cognitive Model of Modulation between Attentional Networks

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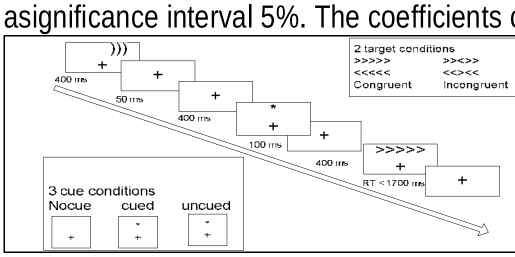
Introduction: Recent neuroscientific studies of human visual attention have given us a much clearer understanding of the role and interplay of top-down and bottom-up processes involved in visual search, and visual stimulus response processes [5,9,14]. A clear model has emerged involving three distinct brain area 'networks' underlying three separate processes governing visual attention: 'alertness', 'orienting' and 'executive control' [11,12,13]. Alerting means becoming ready for incoming task related event, orienting corresponds to visual selective attention, and executive control relates to conflict monitoring and resolution among thoughts, responses and emotions. Functional anatomy of these networks proves their existence both at cognitive and neuroanatomical levels[14]. Neuroimaging data shows support for this [6].

A very popular and widely applied experimental paradigm to study these networks in a single task is the Attentional Network Test (ANT) [5]: a combination of cueing experiments [9] and a flanker task [4]. ANT has also been successfully used to study human attentional development [14], attention deficits [2], and patients with schizophrenia and Alzheimer's disease [7]. Computational implementations of this model have confirmed its validity [16,17]. However, despite the confirmed independence of the networks, recent studies indicate a subtle interplay between them [3]. ANT mainly relies on correlation analysis to report the effect of one network on the other but using an adapted version of ANT (see Figure 1A) to find the correlation and interactions of the alerting, orienting and executive control networks, these new studies suggest that, although the three attentional networks may have functional independence and may be measured independently, they can modulate each other. It is well understood that neurological deficit appears to target more than one aspect of attentional processes, resulting in common malfunctions of attention. For example, in Alzheimer's disease patients, conflict resolution is thought to be impaired [7]. Hence, to better understand the interrelationship between the three networks, and potentially deficit of this kind, a computational model has been implemented and its performance tested against experimental results [3].The model and its performance on the modified ANT are reported below.

Model: The original ANT studies used spatial cueing to measure orienting effects whereas temporal cueing is used to measure alerting effects. Callejas et al [3] separated these by using an audible tone for temporal cueing (rather than the onset of the spatial cue), giving rise to 2 alerting conditions (present, absent) X 3 cue conditions (no-cue, cued, un-cued) X 2 congruency conditions (congruent, incongruent). The ACT-R [1] model simulates the performance of the attentional networks under these experimental conditions. The symbolic component of the architecture implements each condition using rules such as *detect-sound,* notice-stimulus-at-cued-top-location etc. The sub-symbolic component of ACT-R implements the attentional networks by using utility values and noise to help the model resolve conflict and also make human-like errors. For example in the no-alert cued, congruent condition the model produces reaction time of 527 ms compared to the human average response of 533 ms. The model's performance is compared against the human study data in Figure 1B, Pearson correlation coefficient was used to measure the degree of linear correlation between two results. P-values used were 0.0001 at asignificance interval 5%. The coefficients came out to be 0.89 giving a good fit to the data.



Mean Reation Times in ms for each condition for the experiment and (the model simulation)							
	No Alerting tone				Alerting tone		
	No cue	Cued	Uncued		No cue	Cued	Uncued
Congruent	573 (577)	533 (527)	561(595)		530 (545)	519 (475)	547 (545)
Incongruent	644 (690)	617 (597)	648 (710)		625 (680)	603 (543)	659 (680)

Figure 1: (A) Sketch of the design of the adapted version of ANT based on Callejas study[3]. (B) Comparison of the results from the original experiment [3] and simulation of the ACT-R model.

Results: The model demonstrates similar interactions to those seen in the original experiment, whereby the alerting network has an inhibitory influence on the congruency effect (in line with Posner's [12] view of 'clearing of consciousness' phenomenon). The influence of the orienting network on executive control is also captured in the model. That is, when the location of the target was cued, the congruency effect was smaller, compared to the condition when the location of the target was cued in the opposite location. Also the model successfully demonstrates the affect of alerting upon the orienting of attention. The alerting system helps prepare for a task and prevents the control network from further processing the stimulus. The orienting network can take advantage of this preparatory state that the system is in to speed up the orienting process, as further demonstrated by the model. Hence this clearly shows that though these networks may be anatomically and functionally independent, they function under the influence of each other in order to produce effective behavior. The modulation effects are depicted in figure 2(A&B).

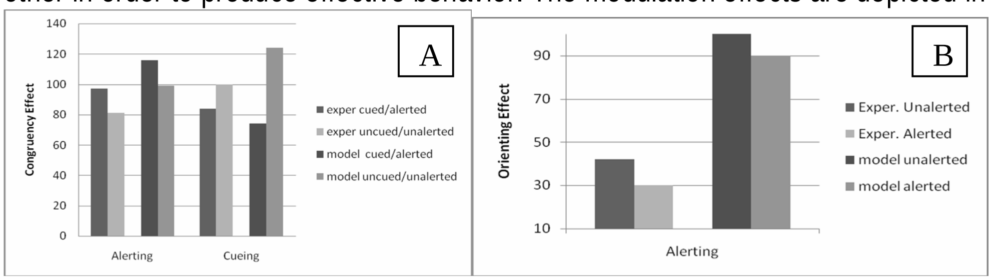


Figure 2: Interactions between the variables. (A) Congruency effect as a function of cueing and alerting. (B) Orienting effect as a function of alerting.

Discussion: The goal of this study was not only to provide a tool for measuring the functioning of the three attentional networks but also to study the interactions among them. The work presented here serves to demonstrate that this kind of model can help us understand better not only how our attention system works but also explain how it functions in a coordinated way to produce effective behavior. This cognitive model of the adapted version of ANT can be used as a potentially important assessment tool for neuropsychology. Modeling the deficit/dysfunction of attention and attention related functions using behavioral data associated with neurological disorders, we can show the effect of neglect. Simulating deficits in the attentional networks may not only facilitate understanding of these functional systems but may also help to design rehabilitative procedures. For example, it has been thought that the influence of the orienting network on the executive function may be stronger in schizophrenic patients [8]; such interactions can be closely examined using such a modeling approach.

References:

[1]. Anderson, J. R., & Lebeire, C. (1998). The atomic components of thought. Mahwah, NJ: LawrenceErlbaum.
[2]. Booth, J., Carlson, C. L., & Tucker, D. (2001). Cognitive inattention in the ADHD subtypes. ISRCAP Vancouver.
[3]. Callejas, A., Lupianez, J., Tudela, P., (2004). The three attentional networks: on their independence and interactions. Brain Cog. 54, 225– 227.
[4]. Eriksen BA, Eriksen CW, (1974). Effects of noise letters upon the identification of a target letter in a non search task. Perception and Psychophysics, 16:143-149
[5]. Fan J, McCandliss BD, Sommer T, Raz M, Posner MI. (2002). Testing the efficiency and independence of attentional networks. J. Cog Neurosci. 3(14):340–47
[6]. Fan J, McCandliss BD, Fossella J, Flombaum JI, Posner MI. (2005). The activation of attentional networks. Neuroimaging 26:471–79
[7]. Fernandez-Duque, D., Black, S.E., (2006). Attentional networks in normal aging and Alzheimer's disease. Neuropsychology . 20:2, 133-143.
[8]. Gooding, D., Braun, J, Studer, J. Attentional network task performance in patients with schizophrenia– spectrum disorders: Evidence of a specific deficit. Schizophrenia Research, Volume 88, Issue 1-3, Pages 169-178
[9]. Hopfinger, J.B., Buonocore, M.H. & Mangun, G. R. (2000) The neural mechanisms of top-down attentional control. Nat. Neurosc 3, 284-291.
[10]. Posner M.I. (1980). Orienting of Attention. Quarterly Journal of Experimental Psychology. 32, 3-25.
[11]. Posner, M.I. & Petersen, S.E. (1990). The Attention system of the Human Brain. Annual Review of Neurosci, 13: 25-42.
[12]. Posner, M.I. & Dehaene, S.(1994). Attentional Networks. Trends in Neuroscience, 17,75-59.
[13]. Posner, M.I., Rothbart, M.K., Vizueta, N., Levy, K.N., Evans, D.E., Thomas, K.M., et al., (2002). Attentional mechanisms of borderline personality disorder. Proc. Natl. Acad. Science. U. S. A. 99 (25), 16366– 16370.
[14]. Raz, A. Anatomy of Attentional Networks. (2004). Anatom. Rec, Part B, New Anatomist, 281(1), 21- 36
[15]. Rueda MR, Fan J, McCandliss BD, Halparin JD, Gruber D.B., (2004). Development of attentional networks in childhood. Neuropsychologia 42:1029–40
[16]. Wang H, Fan J, Johnson TR. (2004). A symbolic model of human attentional networks. Cog. Sys. Res. 5:119–34
[17]. Wang, H., & Fan, J. (2007). Human attentional networks: A connectionist model. J. of *Cog. Neurosc, 16*(10), 1678-1689.