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Research Report

A neurodynamic model of the attentional blink

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Abstract

A brain-based neural model of attention is used to simulate results for the 'attentional blink', observed when a subject is exposed to a rapid stream of stimuli and required to monitor for two successive targets in the stream. The 'blink' occurs when the time between the first and second targets is 200–500 ms, when there is reduced accuracy for report of the second target. The model gives a qualitative explanation of the phenomenon, especially of how attention is bolstered, during the processing to report of a given stimulus, in order to defend reportable information from attack by distracters.

Theme: Neural basis of behaviour
Topic: Cognition

Keywords: Attention; Perception; Awareness; Neural network model; Prefrontal goal; Corollary discharge

1. Introduction

The attentional blink is an important phenomenon for probing the temporal dynamics of attention. The advance resulting from this is in terms of a possible understanding of consciousness as arising from specialised components of the resulting neural model of attention. In particular, we are thereby able to explore dynamical contributions from various attention control modules needed to explain the attentional blink. We suggest that a corollary discharge or efference copy module is needed to enable needed excitatory and inhibitory signals to be generated, with correct timing, to explain the blink. The corollary discharge signal has been proposed as a fundamental component of the CODAM model of consciousness, in which the experience of ownership of conscious content is generated by the corollary discharge component of the attention movement control signal [42–45]. In this way, we can begin to approach the problem of distinguishing attention involved in blindsight and that when awareness is also present [24].

Stimuli in the attentional blink are presented at so fast a rate (one every 100 ms or so) that the subject's task of detecting a specific first target, and then a further one presented several stimuli later, is made difficult by the other stimuli acting as distracters. If no distracter is present after the first target, but just a blank, then there is no attentional blink. This implies that the attentional blink is employing some aspects of the supposed scarce nature of attention.

We here analyse the attentional blink by means of a brain-based neural network model using the engineering control model of attention, the COrollary Discharge of Attention Movement model or CODAM, introduced by one of us [42–46,48]. The CODAM model was developed by analogy to motor control models in the brain [12,51,52] but is now applied to attention. Such a control approach is further supported by the motor approach to attention [39].

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The CODAM model is based in detail on numerous experiments on attention [45], especially those showing that the creation of the attention modulation signal occurs in a separate control module to those where activations are to be modulated [7,22,23]. These and many other references show that the attention control region comprises a prefrontal–parietal network, while the controlled region consists of lower level sensory and motor cortices. Furthermore, the creation of the attention movement signal is itself biased by an early goal signal created by the stimulus in prefrontal cortex [15], a feature also supported by numerous experiments [7,22]. The attention control signal, generated in the parietal component of the control network, is then sent to modulate a lower spatial or object map (in vision). In the CODAM model, there is also a sensory buffer (in parietal cortex) which must be accessed by an incoming signal (suitably amplified by attention) for there to be report of the input. Finally, there is supposed to be, in CODAM, a predictor of the attended input, together with an associated monitor which compares the expected input signal with the desired goal signal. The use of a predictor is an important technique in engineering control systems, shown to be of value in motor control models in the brain [12]. The monitor (supposedly in cingulate cortex) generates an error signal used in CODAM to support early attention amplification until the higher level goal is achieved, as well as providing simultaneous inhibition of any attention control signal generated in response to distracters. The specific provision of an early boost for attention, by use of the corollary discharge of the attention control signal, is consistent with various aspects of attention [28] and gives a neural basis for the scarce nature of attention. This refers to the limited attention capabilities possessed by subjects, as shown for example in the phenomenon of 'attentional blindness' [29] or the attentional blink itself [50].

We apply the CODAM-based approach to simulate the attentional blink paradigm. This will help to specify how various inhibitory processes can bring about the blink. We also explore the manner in which the CODAM model is able to throw more detailed light on the nature of the scarce resource of attention. We also relate the CODAM model to the earlier two-stage [6] and interference [41] models of the blink. The simulation is one of the first to explain the loss of the attentional blink when a blank occurs after the first target (see also [3,4]) and shows how attention is far more than a competition between stimuli for higher cortical sites, as in [10].

2. Methods

2.1. An introduction to the CODAM model

The architecture of the CODAM model has already been described elsewhere [42–45]. Here, we initially briefly review the components of the CODAM model as specifically applied to object detection and recognition in vision. We therefore reduce the CODAM model to be used for the simulation by leaving out spatial or feature maps (or motor maps), and further we take solely high level object representations (such as faces or shapes in the temporal lobe). These objects will be taken as represented by dedicated nodes for simplicity, representing localised ensembles of neurons.

The basic architecture of the resulting simplified CODAM model of attention control is shown in Fig. 1a.

It consists of the modules:

(1) The primary and associative cortices in a given modality, acting as the 'plant' in an engineering control approach, modulated by the attention control signal. This region is denoted as the *object map* in Fig. 1a;
(2) The attention control signal generator, as a separate site compared to the modulated region, sited in parietal cortex [7]. This is denoted as *IMC* in Fig. 1a, where IMC stands for 'inverse model controller' in the engineering control approach;
(3) The *goals* module in Fig. 1a, sited in prefrontal cortex and used to bias the attention movement control signal generated by the IMC;
(4) The sensory *working memory* module in Fig. 1a, sited in parietal cortex and functioning as an estimator of the attended stimulus or of the 'attention state' in engineering control terms. Items arriving here are available for report by the subject;
(5) The *corollary discharge* of the attention control signal in Fig. 1a, derived from a copy of the attention movement control signal and used both to produce fast error correction by comparison between the attention control signal and the goal in the monitor, as well as to give an early 'wake-up call' to the working memory site to help speed up its processing of the incoming attended stimulus. Such a signal functions as a predictor of the attended stimulus or in engineering control terms as a predictor of the 'attended state' just mentioned in (4). This corollary discharge signal in the CODAM model is assumed to be held on another working memory buffer site, separate from that for the attended sensory input, so as to be available for rapid error correction before being replaced by the more correct working memory signal of the attended object (the latter process not used in our simulation of the CODAM model).
(6) The *monitor* site in Fig. 1a, sited in cingulated cortex and used to generate an error signal computed by subtracting from the goal signal the value of the predicted attended object signal arriving from the corollary discharge buffer. We could also use the later attended state estimate from the working memory buffer when that has been amplified by the attention feedback signal, as noted above. We expect the later signal to be used in learning corrections to the