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Introduction to the special issue on 'Brain & Attention'

J.G. Taylor[a,*], A.C. Nobre[b], K. Shapiro[c]

[a] *Department of Mathematics, King's College Strand, London WC2R 2LS, UK*
[b] *Department of Experimental Psychology, South Parks Road, Oxford OX1 3UD, UK*
[c] *School of Psychology, Brigantia Building, University of Bangor, Bangor, Gwynned LL57 2AS, Wales, UK*

1. Introduction

"Everyone knows what attention is: it is the taking over of the mind (by a particular stimulus)" to paraphrase the words of the inimitable psychologist William James near the beginning of the previous century. While he was correct in general, there are still a great many questions about attention in the brain to which we do not yet have answers. For example we do not know how attention functions at a local, synaptic level. Nor do we understand enough about attention globally in the brain to be able to characterize its powers as a control system in many psychological paradigms, such as in attentive search, in rehearsal or substitution in working memory tasks or in how attention interacts with emotion. Indeed the latter question raises the further one: are attention and emotions separate control systems in the brain or is one superior to the other? Some attempt to attack this question was made in the Neural Networks Special Issue on 'Brain & Emotion' (Taylor, Scherer, & Cowie, 2005). However there is still considerable work to be done to obtain a more complete picture of this important interaction which is the basis of so much of human behavior. Beyond that higher level questions about brain and attention loom large over us with considerable applications power, such as how does attention enter into thinking and reasoning? Whilst it is the case that cognitive processes are incapacitated without strong attention control there also needs to be a relaxation of that control at certain points, especially when creativity is needed in rational thought. Thus the balance between attended and unattended thought processes needs also to be explored in order to begin to tackle these high level questions.

All of the above questions and many more indicate the problems still facing researchers in attention and brain. How can we best proceed? We find it difficult to conceive of real progress in approaching and solving these problems without the conjunction of experiment and theory. That is why the title of this special issue involves both the faculty of attention and the manner in which the brain functions so as to support this faculty. Moreover both of these – the faculty of attention and the nature of the involvement of the brain – can be considered from either an experimental point of view or alternatively from one of theory and modeling. Here we wish to consider a fusion of these two extremes of experiment and theory, a fusion which we consider essential for good future progress in the subject.

The experimental approach to attention goes back to the time of the ancient Greeks, with Aristotle and later Descartes and many other important scientists being involved. We have already mentioned William James, who brought a cohesion to the subject which has stood it in good stead ever since. The nature of attention has been probed further by generations of psychologists (Pashler, 1998), with appreciation being gained of the focusing and selective powers of attention gaining deeper clarity over the last few decades. A sudden impetus has arisen to this study by the growth of functional brain imaging, with its ability to descry active sites in the brains of subjects whilst they perform various psychological tasks. Both "where" and "when" questions have been answered with increasing precision, with the networks of brain areas involved in the paradigms now becoming increasingly clearer to answer the "where" questions, and flows of neural activity round the observed networks uncovered to help answer the "when" questions. Thus the informational as well as functional answers to the various questions raised earlier about attention are beginning to be answered.

At the same time there is increasing understanding of attention at a local, synaptic level. This has become available by the use of single and more recently multi-electrode recordings in monkeys and other animals, including use of inter-cranial electrodes in human patients in need of,

* Corresponding author.
E-mail address: john.g.taylor@kcl.ac.uk (J.G. Taylor).

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or undergoing, brain operations. Alongside this has been the increased understanding of the involvement of neuro-modulators, especially acetylcholine, but also dopamine, norepinephrin and serotonin are known to be involved in some aspects of attention and its biasing. These various neuro-modulators have important roles to play in attention, both as activating and alerting agents (especially for norepinephrine: see Posner, Sheese, Abdullaev, and Tang (2006), this issue) as well as for increasing the focusing powers of the attention system (acetylcholine) and for involving stimulus value in redirecting attention (dopamine).

Before we turn to consider in more detail the contributions to this Special Issue that attack some of these question, we will consider very briefly in the next section the general nature of attention, in the following one how best to achieve a fusion of modeling/theory and experiment. In the final section we turn to a brief description of the contents of the papers in this section, with some further comments about outstanding questions.

2. The nature of attention

Attention is the ability to focus on a particular sensory input (or group of them) and be able to inhibit consideration of all distracters elsewhere in the external world. This ability occurs in each modality, and develops in a regular manner from birth. Attention can also be moved independently of the eyes, when it is called covert attention. Only covert attention will be discussed from now on. Attention can be guided in an internal or endogenous manner, as when one is searching for a particular person in the crowd of people getting off a railway train. One holds an image of the person in one's mind, and in this way can scan relatively quickly across the hordes of hurrying people so that the required person is not missed. One can make a mistake, but attention allows one not to spend too long looking at those whose faces are very different from the person for whom one is waiting. On the other hand if there were to be a sudden flash of light in the station or just outside, then your attention would be drawn exogenously to the flash so that you would attend to it temporarily, until you were convinced it presented no danger to yourself. In this manner attention can either be controlled endogenously (from internally to oneself) or exogenously (by events outside oneself).

These two forms of attention have different temporal characteristics. This can be measured by the benefit attending to a stimulus gives to response to it. If someone is attending to a stimulus then they can respond with a faster reaction time to the presence of the stimulus compared to if they are attending to another place: the reduction in response time is called the Posner benefit (Posner, 1980). The Posner benefit may be measured by cueing the subject to attend to a certain place and then presenting a target to that position (valid cueing) or to another place (invalid cueing): the Posner benefit is the difference of the reaction times between the invalidly cued target and the validly cued one. If the cueing of attention uses a signal, it could be such as a central arrow pointing to left or right, in the exogenous case attention can be caught by the sudden brightening of a box round a possible target site. Then endogenous attention benefit gradually increases with increasing time between cue and target onsets; exogenous benefit increases up to about 200 ms between cue and target, and then falls off to zero. An important distinction between the two forms of attention is that inhibition of return (IOR) occurs for peripheral but not for endogenous attention. IOR consists of the increase of reaction time if a target reappears at a site just visited by attention (in the previous 500 ms or so).

Attention is used in visual search. Here a target may be contained in a visual input also consisting of a number of distracters. If there is little overlap between target and distracters then there may be "pop-out", in which the target can be detected in a time that is independent of the number of distracters. This is termed "pre-attentive" processing and has been observed by brain imaging to occur in early visual cortex. Search time per distracter item is slow (from 20 to 100 ms per distracter) when a number of features on the objects being searched have to be conjoined correctly to define a target. Such attentive search is thought to involve an event-related potential negative peak termed the N200 for each item searched, as well as one for the final target item.

There has been considerable controversy over the temporal nature of attention processing: is it early (and expected to be at a low level in the hierarchy of brain sites) or late (arising from a top-down control signal from higher-order cortical sites)? The question was thus reduced to: is attention early or late in its action in the brain? At least in temporally demanding tasks, such as the attentional blink, this question has been answered as being late. The attentional blink (AB) (Shapiro, Raymond, & Arnell, 1994) arises when a subject is presented with a fast stream of stimuli, at a rate of about 10 per s. The task is to detect a given target, say a black X on a white background (termed target T1), and then shortly thereafter to detect another target, such as a black T (the second target, T2). The subject is then required to respond a second or so after the cessation of the stimulus stream to report if they have detected both or either of the targets T1, T2. In cases when T1 was detected it has been found universally that there is a lower detection level for T2 when the time between the onsets of T1 and T2 is about 250–300 ms. This critical delay period is termed the 'attentional blink', in that attention seems to have 'blinked' its detection system closed especially strongly during that period, and is struggling most strongly to succeed in processing It is this delayed processing of T1 which is evidence for attention processing to be late rather than early.

Brain imaging techniques have exposed the networks of sites in the brain involved in various attention paradigms. As expected, fMRI and PET have given spatially accurate sites involved throughout the brain (including sub-cortical sites), whilst EEG and increasingly MEG have added to this the temporal dynamics of the flow of activity between these sites. In the AB paradigm described above it was found by EEG (Vogel, Luck, & Shapiro, 1998) that the N200 and P300 of T2 are much reduced when there is no awareness of T2, so fitting well with the late interpretation of the behavioral data on the AB.

Use of fMRI and PET has displayed the brain networks employed in attention movement control. These involve