available at www.sciencedirect.com
ScienceDirect
www.elsevier.com/locate/brainres
BRAIN RESEARCH

Research Report

The role of parietal cortex during sustained visual spatial attention

Preston P. Thakral, Scott D. Slotnick*

Department of Psychology, Boston College, McGuinn Hall, Chestnut Hill, MA 02467, USA

ARTICLE INFO

Article history:
Accepted 6 September 2009
Available online 16 September 2009

Keywords:
Attentional control
fMRI
MT+
Prefrontal cortex

ABSTRACT

The control of spatial attention–shifting attention between visual field locations or sustaining attention to one location–involves the prefrontal cortex and parietal cortex. Within the parietal cortex, shifting attention has been linked to the superior parietal lobule; however, the neural substrates associated with sustained attention are still unknown. In the present fMRI study, we aimed to identify generalized control regions associated with sustained attention using two different protocols. The motion protocol alternated between periods of moving or stationary dots, and the flicker protocol alternated between periods of flickering or stationary checkerboards (each period lasted 14 s). During moving and flickering periods, the behavioral task alternated between sustained attention and perception. A region-of-interest analysis confirmed that the motion but not flicker protocol produced attention effects–greater activity associated with sustained attention than perception–in motion processing region MT+. A whole brain conjunction analysis identified regions commonly associated with sustained attention for both protocols, which included the right intraparietal sulcus (BA 7/40), the right middle frontal gyrus (BA 9/46), the right superior temporal gyrus (BA 22), the right insula (BA 13), and the left cerebellum. Coupled with previous results, the present findings suggest a functional–anatomic organization of parietal cortex where shifts in attention are mediated by superior regions and sustained attention is mediated by more lateral regions.

1. Introduction

Selective attention can enhance processing within a specific region of the visual field and produce increased activity within contralateral striate and extrastriate cortex (Mangun and Hillyard, 1988; Heinze et al., 1994; Clark and Hillyard, 1996; Tootell et al., 1998; Martinez et al., 1999; Hopfinger et al., 2000; Yantis et al., 2002; Slotnick et al., 2003a). These *effects* of attention within occipital cortex are thought to reflect attention related amplification of visual sensory processing. Attentional *control*, by comparison, can refer to either a shift of attention from one spatial location to another or sustained attention to a single location. A large body of neuroimaging evidence has shown that attentional control involves the parietal cortex (including the intraparietal sulcus and superior parietal lobule) and the dorsolateral prefrontal cortex (Pardo et al., 1991; Corbetta et al., 1993, 2000, 2002; Nobre et al., 1997; Coull and Nobre, 1998; Gitelman et al., 1999; Rosen et al., 1999; Wojciulik and Kanwisher, 1999; Hopfinger et al., 2000; Beauchamp et al., 2001; Ikkai and Curtis, 2007; for a review, see Corbetta and Shulman, 2002). Previous studies, however, have not dissociated neural activity associated with shifts in attention versus sustained attention, due to methodological limitations (such as the poor temporal resolution of positron

* *Corresponding author*. Fax: +1 617 552 0523.
E-mail address: thakralp@bc.edu (P.P. Thakral).

0006-8993/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2009.09.031

emission tomography) or the use of experimental protocols in which these cognitive operations occurred in close temporal proximity (as in standard attentional orienting paradigms).

Using event-related functional magnetic resonance imaging (fMRI), there has been some work on isolating the neural regions associated with different aspects of attentional control. In two studies (Vandenberghe et al., 2001; Yantis et al., 2002), during central fixation, participants were cued to either shift attention from one peripheral location to another peripheral location or to maintain attention to the same spatial location. Shifting attention, to a greater degree than sustained attention, was associated with activity in the superior parietal lobule (see also, Le et al., 1998; Yantis and Serences, 2003; Liu et al., 2003).

Given that the superior parietal lobule and intraparietal sulcus have been associated with attentional control and the superior parietal lobule has been associated with shifting attention, subtractive logic would suggest that the intraparietal sulcus may be associated with sustained attention. There is some evidence in support of this, as sustained attention has been associated with activity in more lateral parietal regions (Vandenberghe et al., 2001; Serences and Yantis, 2007; Kelley et al., 2007). In Vandenberghe et al. (2001), during central fixation, participants either sustained attention to a white square presented in the left or right visual field (pressing a button when it dimmed) or passively fixated while no peripheral stimuli were presented. Regions associated with sustained attention were identified by contrasting sustained attention > passive fixation. This contrast, however, was confounded by perceptual processing (see also, Le et al., 1998). Serences and Yantis (2007) and Kelley et al. (2007) used paradigms involving rapid serial visual presentation of letters where, depending on target letter identity, participants either shifted attention to a new location (following a 'shift' target) or maintained attention at the current location (following a 'hold' target). Regions associated with hold targets were assumed to reflect sustained attention. One critical aspect of these paradigms is that distractor letters were presented adjacent to target letters (to motivate focused attention). As such, it is not possible to disentangle activity associated with sustained attention from voluntary suppression of distractors (Serences et al., 2004). Furthermore, the cognitive operations involved in these studies are not well defined. While it could be the case that a hold target corresponds to sustained attention to a particular spatial location, a hold target may also trigger participants to disengage or shift attention from that location and then reallocate attention to the same location (see Sperling and Weichselgartner, 1995). The current study was designed to avoid such perceptual or cognitive confounds.

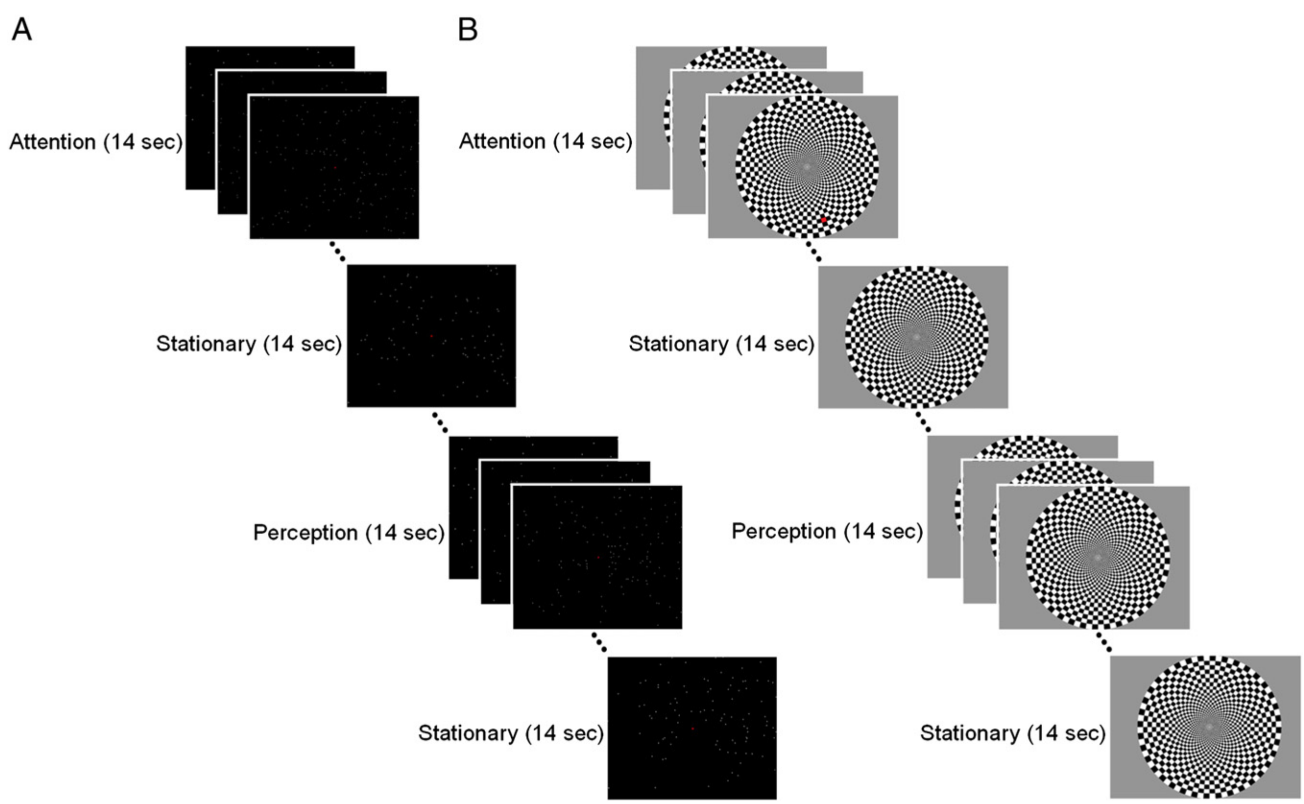

Fig. 1 – (A) The motion protocol was comprised of dots moving from the outer edge of the display toward the fixation point during alternating periods of sustained attention (followed by a stationary period with no motion) and sustained perception (also followed by a stationary period). During attention periods, cued auditorily with the word 'attend,' participants were instructed to press a button each time the moving dots briefly slowed. During perceive periods, cued auditorily by the word 'perceive,' participants were instructed to continually perceive the entire stimulus. (B) The flicker protocol was a circular checkerboard that reversed in contrast during attention and perception periods, with no flicker during stationary periods. During attention periods, participants were instructed to press a button each time a red square briefly appeared.