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Neural correlates of dual task interference in rapid visual streams: An fMRI study

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Abstract

In rapid streams of visual stimuli, identification of a first target interferes with identification of a second target presented within the next half second (the attentional blink or AB). It has been suggested that rapid perceptual decisions under masking interference involve interactions between frontal and posterior cortex. We investigated the neural correlates of the AB using functional magnetic resonance imaging (fMRI). Twelve subjects viewed rapid streams of black letters in which were embedded two white target letters (T1 and T2) separated by either 300 or 700 ms. As expected, fewer correct T2 identifications were observed in the short-delay condition. Corresponding fMRI statistical images showed increased activation in inferotemporal and posterior parietal cortex, but also in lateral frontal cortex and cerebellum in the short-delay condition suggesting that these brain regions are associated with perceptual decisions under masking interference.

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1. Introduction

One of the most important functions of the brain is to regulate the constant influx of stimuli competing for a share of information processing mechanisms. This ability is generally thought to involve attentional mechanisms which help resolve this competition by biasing processing in favor of stimuli currently relevant for behavior, at the expense of non-relevant stimuli (Kastner & Ungerleider, 2000). However, attentional modulation is limited, such that when attention must be allocated to two concurrent events (dual task processing) there is often a cost in processing which can be measured as an increase in response time or in error rate.

The attentional blink (AB) is an example of dual task interference that affects accuracy in difficult perceptual decisions. The AB is often produced using a rapid serial visual presentation (RSVP) procedure in which streams of alphanumeric stimuli are presented in rapid succession (10/s) in one location. For example, subjects are required to identify a pair of target stimuli (T1 and T2) that are partially masked by distractors following them in the stream. When T1 and T2 are presented in close contiguity (less than 500 ms), identification of the first target often impairs that of the second target (Shapiro, Arnell, & Raymond, 1997) The AB occurs because attentional processing of masked targets overlaps at short inter-target delays. As a result, both targets compete for perceptual consolidation. This competition is biased in favor of T1 and impairs consolidation of T2 for approximately 500 ms.

Although numerous studies have looked at the cognitive components of the attentional blink, the neural events associated with the AB remain poorly understood. Human lesion data have implicated frontal cortex in dual task processing (Richer, Bédard, Lepage, & Chouinard, 1998) as have functional brain imaging studies (Adcock, Constable, Gore, & Goldman-Rakic, 2000; D'Esposito et al., 1995). However, few studies specifically investigated the effect of the temporal overlap between similar tasks. Clinical studies have shown the AB effect is exacerbated in patients with frontal cortex (Richer & Lepage, 1996) and parietal cortex lesions (Husain, Shapiro, Martin, & Kennard, 1997). Functional brain imaging studies have shown that interference between targets and post-target masks, a triggering condition for the AB, is linked to activity in inferior parietal and middle frontal cortex (Marois,

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Chun, & Gore, 2000; Wojciulik & Kanwisher, 1999). The frontal activity is in agreement with recordings of frontal neural activity during perceptual decisions on masked targets (Thompson & Schall, 1999).

The goal of the present study was to investigate the neural correlates of dual-task interference observed in the AB using functional magnetic resonance imaging. Based on previous studies of dual task processing we hypothesized that increases in regional cerebral blood flow within the frontal cortex should accompany the occurrence of dual task interference in the AB when two targets are in close temporal proximity. Since visual consolidation appears to be affected by the AB, we also hypothesized that temporal regions involved in visual short-term memory (Fuster, Bauer, & Jervey, 1985; Ishai, Ungerleider, & Haxby, 2000) should index the dual task load in the AB. On the other hand, if brain regions associated with managing dual task interference in the AB are similar to those associated with resolving local perceptual interference then we should observe increases in both prefrontal and posterior parietal cortex activity. We examined the regional cerebral blood flow activation in a task requiring identification of two target letters in a rapid stream (RSVP) in two conditions: (1) when the inter-target delay was 300 ms, an interval known to produce the AB; (2) an inter-target delay of 700 ms which produces no AB.

2. Method

Twelve right-handed normal adults (3 males, 9 females, mean age: 33 years) with no history of neurological disorders participated in the study. Informed consent was obtained prior to scanning.

The visual stimuli consisted of streams of 16 uppercase letters (25 ms duration, 10/s) presented centrally on a visual display projected into the scanner via a pair of hood-mounted goggles (Resonance Technology, St. Northridge, CA, USA). Each letter subtended a visual angle of approximately 1.5 °. In the two RSVP conditions, all letters appeared black with the exception of the two white target letters (T1 and T2). T1 was always preceded by 7 letters and followed by 8 letters. T2 followed T1 in one of two fixed positions in which a delay of 300 ms (2 letters) or 700 ms (6 letters) separated T1 and T2. All streams were constructed from random letter sequences with no repetitions. The control condition was identical to the RSVP conditions except that the entire stream of letters consisted of black Xs. The inter-trial interval for all conditions was 500 ms. The task was controlled by a computer running Neuroscan software (Neurosoft, Sterling, VA, USA).

Two experimental runs were constructed for each RSVP condition. In each run, four 30-s RSVP blocks alternated with four 30-s control blocks. Prior to each block, a message appeared on the screen to inform subjects on the condition that followed (RSVP or control). All blocks contained 12 trials, thus yielding 96 trials per run (48 RSVP trials and 48 control trials). The order of runs was counterbalanced across subjects.

In the RSVP conditions, subjects were instructed to identify a pair of white letters embedded in a series of black distractor-letters. Instructions emphasized the precision of target identification. In the control condition, subjects were told to passively view the string of black Xs. We chose this control condition instead of a stream of letters to prevent subjects from paying attention to letters which would have biased the control condition. Also, the critical contrast was that between the two delay conditions. In the scanner sub-vocal responses were required of the subjects because vocal responses increased the risk of movement artifacts in the MRI signal. Subjects' performance was assessed immediately prior to entering the scanner on the same task (72 trials/condition) and in that pre-testing phase subjects identified the targets (T1 and T2) vocally at the end of each letter stream. Images were acquired using a Siemens Magnetom Vision 1.5T MRI scanner with echoplanar imaging. One hundred contiguous multislice T_{2^*}-weighted fMRI images were obtained for each run using an axial slice orientation ($TE = 39$ ms, $TR = 2.5$ s, $64 \times 64 \times 19$ matrix size, $3.36 \times 3.36 \times 7\,mm^3$ voxels). The first four volumes of each run were discarded because of spin saturation effects.

The data were processed and analyzed with SPM99 software (Wellcome Dept. of Cognitive Neurology, London, UK) implemented in Matlab. Prior to statistical analysis, T_{2^*} volumes were realigned to the first image in their respective run, normalized into a standard space, and spatially smoothed with a 12 mm (FWHM) isotropic Gaussian kernel. Global effects were proportionally scaled and low frequency drifts were removed via a discrete cosine basis set high pass filter with a 120-s cutoff. Areas of significant brain activation, as specified by appropriately weighted linear contrasts, were determined using paired t tests. The resulting set of t values constituted the statistical parametric map of the t statistic (SPM[t]), which was subsequently transformed to z values. The statistical parametric maps were made using thresholds of $z = 3.09$ ($p = .001$ uncorrected for multiple comparisons). Statistical analyses were aimed at identifying brain areas that were sensitive to inter-target delay. These regions were isolated via an interaction contrast which compared the signal recorded in the 300 ms delay condition minus its control condition to that recorded in the 700 ms delay condition minus its control condition [(300 ms – control)–(700 ms – control)].

3. Results

Subjects showed no difficulty identifying T1 in both conditions, averaging 96 and 93% correct in the long

Table 1
Foci of activation obtained when comparing the 300 ms delay condition with the 700 ms delay condition* [(300 ms – control)–(700 ms – control)]

Foci of activation	BA	Left	Talairach coordinates			BA	Right	Talairach coordinates		
		z value	*X*	*Y*	*Z*		*z* value	*X*	*Y*	*Z*
Lateral frontal cortex	11	5.55	−42	46	−15	11	4.70	42	48	−9
	6	4.21	−45	−3	50					
Posterior parietal cortex	7	3.51	−27	−64	56					
Occipital cortex	18	4.40	−36	−88	−6	18	5.24	42	−85	−6
Inferotemporal cortex	19/37	3.64	−33	−93	10	19/37	4.07	54	−72	−6
Cerebellum		4.86	−45	−54	−25		3.59	48	−48	−25

* The threshold for significance was set at $z > 3.09$ ($p < .001$ uncorrected for multiple comparisons). BA, Brodmann's areas.

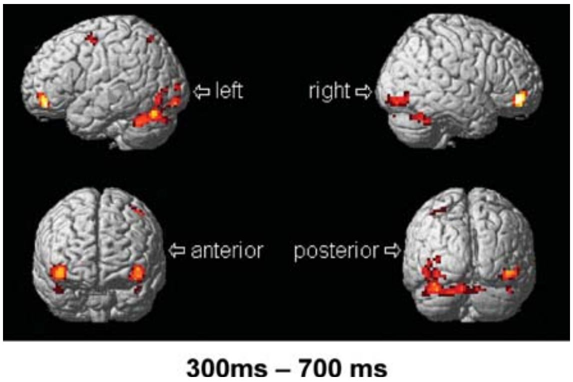

Fig. 1. Statistical parametric maps showing increased activity ($p < .001$ uncorrected for multiple comparisons) during the 300 ms delay condition minus control relative to the 700 ms delay condition minus control [(300 ms – control)–(700 ms – control)]. Foci of activation have been superimposed on lateral views of surface-rendered images of the brain.

and short delay conditions respectively [$t(11) = 1,91$, $p > .05$]. As expected, the percentage of correct responses to T2, contingent on T1 being correctly identified, decreased from 86% ($SE = 1.6$) to 69% ($SE = 4.1$), as the inter-target delay was reduced from 700 to 300 ms [$t(11) = 5.15$, $p < .001$].

No significant differences in activation were observed between the two control conditions, which insures that the interaction contrasts are not biased by differences in the control conditions. Table 1 lists the regions showing enhanced activation during the 300 ms delay condition minus control condition relative to the 700 ms delay condition minus control condition. Significant activation was obtained bilaterally in inferotemporal and lateral frontal cortices, and the cerebellum. Additional activity was observed in the posterior parietal cortex (Fig. 1). The complementary contrast examining activation enhancements at the long delay [(700 ms – control)–(300 ms – control)] revealed no significant activations.

4. Discussion

Decreasing the delay between two targets in rapid visual streams produced a bilateral increase in activity in inferior frontal and temporal cortex as well as enhanced activity in left parietal cortex and posterior cerebellum. The number of correct responses was relatively high in the two conditions, and thus the difference in error rates between the conditions cannot account for the results. These increases in activation appear to be associated with the presence of dual-task interference at the short delay.

Several imaging studies have reported increases in frontal cortex activation in dual-task conditions (Adcock et al., 2000; D'Esposito et al., 1995). Our data suggest that temporal overlap also increases the use of frontal systems, a result that agrees with the effects of frontal lesions on performance in overlapping tasks (Richer & Lepage, 1996; Richer et al., 1998).

The inferotemporal cortex activation is compatible with the role of this region in conscious identification and short-term maintenance of visual information (Fuster et al., 1985; Ishai et al., 2000). Previous studies have reported that attention increases neural activity in posterior regions involved in processing selected stimuli as well as engaging prefrontal regions (Kastner & Ungerleider, 2000). Attention can enhance neuronal activity in the inferotemporal cortex linked to relevant stimuli and suppress activity linked to other stimuli (Desimone, 1998). As a result, neural activity within this region primarily reflects the features of attended stimuli. These attention related modulations of neural activity are larger when multiple stimuli are present compared to when a single stimulus is present.

Inferotemporal cortex activation may be linked to competitive interactions between the two targets at short delays. Attending to T1 would bias neuronal activity in inferotemporal regions involved in conscious identification. The presentation of a second target while the inferotemporal cortex is busy processing T1, would result in increased inter-target competition and thus increased neuronal activity. The observed change in inferotemporal cortex activation may thus reflect part of the brain mechanisms that can lead to impaired T2 processing in the AB.

The increased activity in extrastriate association areas could be prompted by many different processes, some of which are intrinsic to the visual cortex (bottom up), and some of which depend on feedback to visual cortex from other structures such as frontal cortex (top down) (Kastner & Ungerleider, 2000). Inferior frontal areas have been shown to be associated with working memory for objects (Courtney, Ungerleider, Keil, & Haxby, 1997). The neural connections linking prefrontal cortex with inferotemporal cortex (Fuster, 1997) may be used for reciprocal fronto-temporal influences involved in perceptual consolidation under interference.

Left posterior parietal activity was also enhanced at the short delay. The posterior parietal cortex has been linked to attentional systems responsible for orienting to stimuli (Corbetta et al., 1998) and selecting stimuli (Hopfinger, Buonocore, & Mangun, 2000). Previous studies also observed activation in posterior parietal and frontal cortex in rapid visual streams linked to attending to brief partially masked targets (Marcantoni et al., 2001; Marois et al., 2000). Parietal activity may influence activity in inferotemporal cortex when masking interference is present. The links between these regions will have to be examined in more detail in future studies.

Finally, increased cerebellar activity was also observed in the short-delay condition relative to the long-delay condition. The posterior cerebellum has previously been associated with attentional processing (Allen, Buxton, Wong, & Courchesne, 1997). Taken together, these results suggest that resolving dual-task interference in the AB is associated with activity in a ventral fronto-temporal network in addition to parietal and cerebellar activity.

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