

# Resource sharing in the attentional blink

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Humans have difficulty processing more than one event at a time, as is evidenced by the attentional blink ('blink') phenomenon: the second of two targets in a visual stream of events cannot be reported accurately if it appears between 100 and 500 ms after the first. By using whole-head magnetoencephalography, we show that the probability of behaviourally failing to correctly identify the second target can be predicted from the amount of attentional

resources devoted to processing the first target, as indexed by T1 activation. This important finding supports resource sharing accounts of divided attention tasks such as the 'blink'; that is, such tasks may reflect an individual processing strategy rather than an immutable structural processing bottleneck. *NeuroReport* 17:163–166 © 2006 Lippincott Williams & Wilkins.

**Keywords:** attention, magnetoencephalography, resource model

## Introduction

Humans find it difficult to process and respond to more than one event at a time. A particularly impressive demonstration of this attentional limitation is provided by the attentional blink ('blink') phenomenon: when humans are required to detect two targets (T1 and T2) in a rapid stream of events, they often cannot correctly report T2 if it occurs within 500 ms after T1 [1]. The available accounts differ in detail but most share the assumption that processing T1 leads to the occupation of some attentional mechanism that is unavailable for processing T2 until T1 processing is completed [2,3].

The attentional blink has been observed in numerous studies using various stimuli and response modalities, suggesting a structural bottleneck of human information processing. Recent models of dual-task performance including the 'blink', however, have raised the possibility that what appears as a structural bottleneck may actually be the result of particular processing strategies (which need not be intentional or conscious). For instance, people may allocate all available resources to one task, thereby rendering the actually parallel processing system effectively serial [4,5]. Applied to the attentional blink this may mean that people are unable to process T2 only because they either intentionally or unintentionally allocate all available resources (or devote the relevant attentional mechanism exclusively) to the processing of T1. If this were not the case, they may be able to process both targets, at least in a larger number of trials.

Evidence supports such a strategic interpretation. For instance, if T2 appears immediately after T1 (i.e. at lag 1) performance on both targets is often very good [6], which

suggests that more than one event can be processed at the same time in principle. [It should be noted that in the lag 1 condition T2 occurs immediately after T1. Given research showing that the presence of the next item in the stimulus stream is a prerequisite for the 'blink' to occur (i.e. T1 is masked), T2's occurrence in this particular condition is different from when it occurs at any later lag. At all other lags, T1 is masked independently of T2's occurrence.] Even for longer lags, the attentional blink has been observed to get smaller or even disappear if measures are taken to make the study participants more relaxed and to distract them from the task [7]. In addition, a reduced 'attentional blink' effect has been reported when participants are explicitly informed about the lag between the targets in the upcoming trial [8]. This evidence is consistent with informal observations in our and other labs that not all participants show a reliable attentional blink (S. Martens, J. Munneke, H. Smid, A. Johnson, in preparation), which is surprising if the attentional blink represents a general, immutable bottleneck of human information processing. In the present study, we exploited the natural variability in attentional processing within and between healthy humans to investigate whether the successful report of T2 can be predicted from the amount of resources allocated to T1 processing.

With respect to interindividual variability, we predicted that participants may differ in the amount of resources they allocate to T1 processing. If so, those who allocate more resources to T1 should produce a larger attentional blink than those who allocate fewer resources to T1. In other words, we expected a positive correlation between measures of the strength of T1 processing and the sizes of the individual 'blinks'.

With respect to intraindividual variability, we considered that participants may vary from trial to trial with respect to the amount of resources they allocate to T1 processing. If so, the trials in which more resources are allocated to T1 should be more likely to yield an attentional blink than trials in which fewer resources are allocated to T1. Given that our method did not allow for computing correlations on a trial to trial basis, we reversed the logic and tested whether trials in which T2 could not be reported ('blink') show evidence of stronger T1 processing than trials in which T2 could be reported.

## Method

Ten volunteers (mean age 32.6 years;  $SD=6.1$ ) monitored streams of rapidly presented white capital letters (7/s; visual angle= $3.72^\circ$  at 1.2 m) for two targets, the letters X or O in one group and the letters L or T in another. Non-target letters were chosen randomly from the entire alphabet, with the exception of the target letters. Twenty-seven to 30 blocks containing 72 trials were run, plus one block for practice. On any given trial, no target (24 trials/block), only one target (24 trials/block), or both targets (either one followed by the other; 24 trials/block) could appear. When both targets appeared (dual-target condition), they were separated by either a short lag (lag 2=292 ms; 12 trials/block) or a long lag (lag 6=876 ms; 12 trials/block). On the basis of previous research, the short lag was chosen to place the second target at an interval at which the attentional blink is maximal, whereas the long lag placed the second target at an interval outside the temporal boundary when the attentional blink occurs [1]. Single targets were presented at positions 4–6 (T1 positions), 6–8 (short-lag T2 positions) and 10–12 (long-lag T2 positions), making their presentation exactly comparable to their occurrence when followed by a second target. Participants responded to the occurrence of the targets at the end of a trial, in a two-part sequence, indicating first how many targets had been observed and second, the identity of those targets. While performing the task, brain activity was recorded continuously with a 122-channel whole-head neuromagnetometer [9], using a band-pass filter of 0.03–170 Hz, and digitized at 514 Hz. Horizontal and vertical electro-oculograms were recorded simultaneously for offline rejection of epochs contaminated by eye movements. Parts of the behavioural data and localization-related coherence findings from the present study were reported in [10].

## Analytical procedures

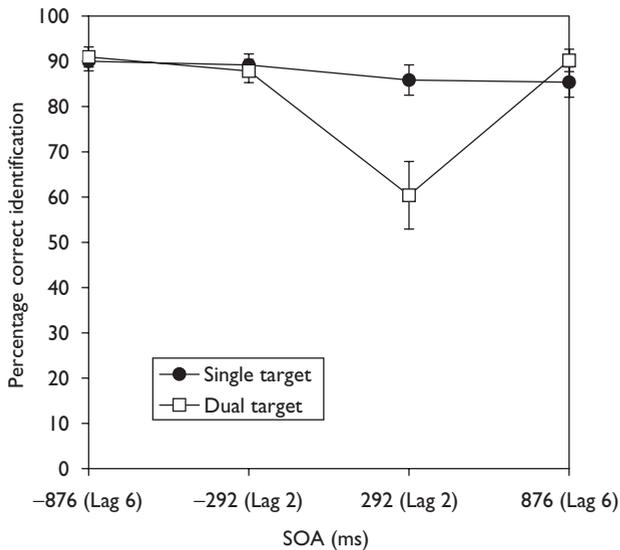
Magnetoencephalography signals were averaged offline from  $-300$  to  $+1500$  ms with respect to T1 onset. We used a boundary element method enveloping the brain surface to create a realistic head model (cf. [11]). All participants' data were analysed individually. Active cortical areas were modelled as current dipoles [12]. The dipole's location, orientation, and amplitude represent the centre of gravity of the active cortical area and the direction and mean strength of current flow therein. The process of source modelling consists of continuous interplay between visual inspection of coherent local signal variations in the original responses, search for clear dipolar field patterns in the analysis program, and evaluation of how well the source model accounts for the measured signals (goodness-of-fit). The current dipoles were identified one by one, at time points at which each specific field pattern was clearest. The sources

were then brought into a multi-dipole model in which the source locations and orientations were kept fixed while their amplitudes were allowed to vary as a function of time to best account for the signals measured by all 122 sensors. The resulting source waveforms represent the timecourse of activation in the cortical source areas. The complete model of the single-target condition with correctly identified targets included 6–10 sources in each individual. For all conditions, these sources were introduced into a multi-dipole model to extract the respective activations as a function of time.

The location of the sources is defined in head coordinates, set by clearly identifiable points in front of the ear canals ( $x$ -axis, from left to right) and by the nasion (positive  $y$ -axis); the  $z$ -axis is oriented towards the vertex. The position of the head within the magnetometer was found by attaching three small coils on the participant's head, measuring their location in the head coordinate system with the help of a three-dimensional digitizer, and energizing them briefly to obtain their locations in the magnetometer coordinate system. The magnetoencephalography sources were combined with the individual anatomy by marking the preauricular points and also the nasion in the magnetic resonance images.

To identify sources showing clear target-related activation, source waveforms of trials with no appearances of targets were subtracted from waveforms obtained from the single-target condition (correct responses). This subtraction method was used for all other experimental conditions as well. We did not delete any of the sources from our multi-dipole models but selected the 'strongest' source for each participant and target letter (X, O, L, T) for peak amplitude measurements. These measurements were taken from this selected dipole within the entire multi-dipole model. Moreover, we did not find sources that reacted differentially to T1 and T2 presentations. We found only two types of response: early, occipital activation related to the presentation of letters of all kinds; and late, extrastriatal activation related to the presentation of target letters. A computer-based procedure scanned within a time range from 200 to 500 ms for the largest absolute deflection in each source waveform. As all extrastriatal sources showed a similar pattern of activation, the source with the largest deflection was chosen to provide the best signal-to-noise ratio. The target-induced activation related to this source was taken to represent the strength of target processing.

A number of reasons may be given for choosing the 200–500 ms time range. First, studies using evoked response potentials suggest a role of two 'late', cognitive components in the attentional blink. One is the P300, occurring within a range of 200–400 ms after target presentation. The production of the P300 to T1 may prevent or at least attenuate the (presumably necessary) P300 to T2, reflecting attenuated cognitive processing when T2 occurs with a short lag relative to T1 ([13,14,]; S. Martens, A. Johnson, K. Elmallah, R. London, in preparation). Indeed, we will see a comparable attenuation of the neural response to T2 at the short lag in our data (Fig. 2). Apart from the role of P300, the 200–500 ms time range also reflects the interval during which clear field distributions emerged (see Fig. 2). T2-related activation in correctly reported dual-target trials at lag 6 was determined by scanning for a target-evoked peak in a range between 1076 and 1376 ms ( $200-500 + \text{lag } 6$ ) after T1 onset. T2-related activation at lag 2 was determined by scanning



**Fig. 1** Single-target and dual-target responses of 10 participants. In dual-target conditions, negative and positive lags refer to performance for T1 and T2, respectively. In the single-target conditions, negative and positive lags refer to the lag of the single target as a function of where the other target would have occurred had it been presented. Overall single-target accuracy was 87.6% and was independent of the position of the target in the stream. A repeated-measures analysis of variance on T2 accuracy in T1 correct trials with main factors attention (single vs. dual target) and lag (lag 2 vs. lag 6) confirmed significant effects of attention [ $F(1,9)=21.8, P<0.001$ ] and lag [ $F(1,9)=24.7, P<0.001$ ], and a significant interaction [ $F(1,9)=19.0, P<0.01$ ], reflecting the occurrence of a standard ‘blink’.

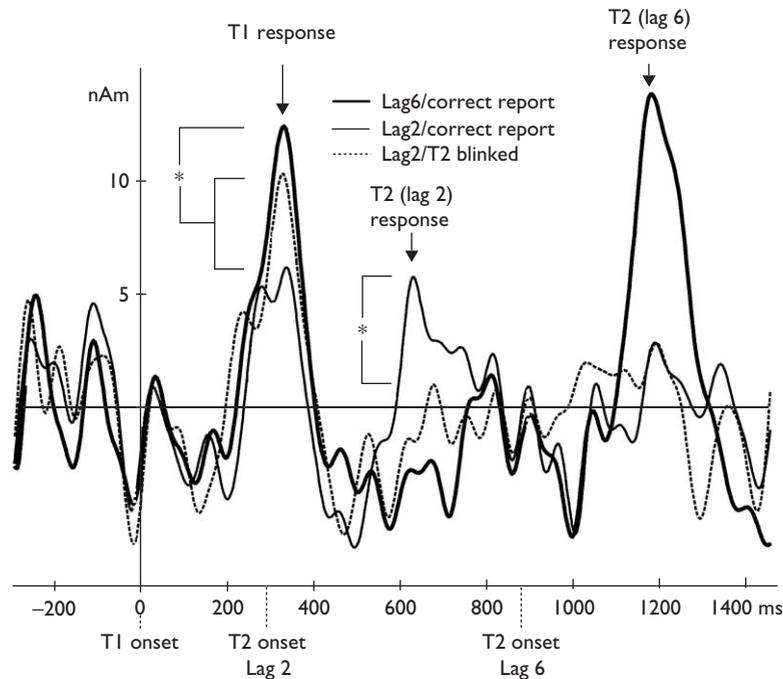
for a T1 activation peak between 200 and 500 ms and picking up the amplitude 292 ms after the T1 peak latency.

**Results**

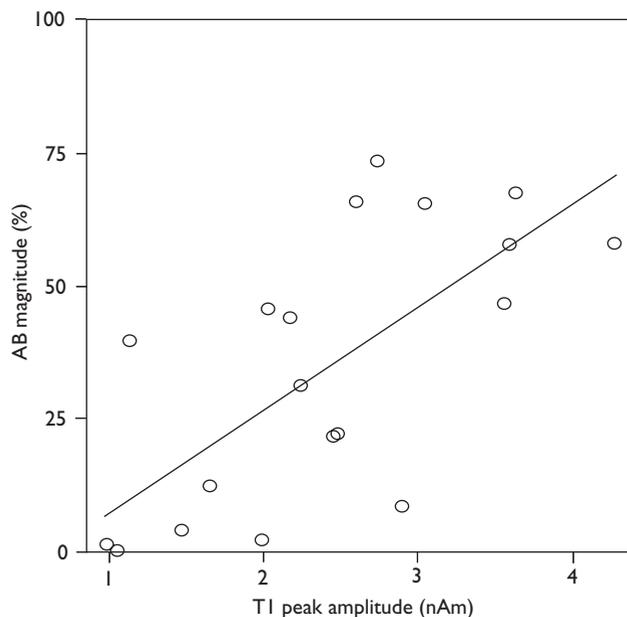
The behavioural results show a standard ‘blink’ with a considerable drop in performance on T2 if it appears soon after T1 (Fig. 1). The neurophysiological results follow the well known pattern (see [15]) with target-specific activation being restricted to postoccipital processing stages [16,17] and the T2-related P300 (or M300) being more pronounced for reported than unreported T2s ([9,14]; S. Martens, A. Johnson, K. Elmallah, R. London, in preparation). More importantly for our purposes, however, are the relationships between intraindividual and interindividual variability in T1-induced activation on the one hand and the individual sizes of the attentional blink on the other.

The results for the effect of intraindividual variability (Fig. 2) reveal that, even though the considerable numerical drop in T1 activation for lag 2 trials in which T2 could not be reported, with respect to lag 2 trials in which T2 could be reported, was not reliable (which, given the large interindividual differences of ‘blink’ sizes, is not surprising), the average T1 activation is reliably smaller for the short lag than for the long lag. Thus, the outcome provides preliminary evidence for the assumption that performance on T2 can be predicted from the strength of processing T1.

With regard to the effect of interindividual variability (Fig. 3), a reliable positive correlation confirms the expectation that interindividual differences in the amount of



**Fig. 2** Target-related activation on (1) lag 6 trials in which both targets can be reported (bold); (2) lag 2 trials in which both targets can be reported (non-bold) and (3) lag 2 trials in which T2 is not reported, that is, a ‘blink’ occurs (dashed). Waveforms represent sources with strongest target-related responses averaged across all participants and target letters. Note the ‘trade-off’ between T1- and T2-related activity in lag 2 conditions: whereas T2 activation is higher for successful T2 reports ( $Z=-1.9; P<0.05$ , one-tailed), T1 activation shows the opposite tendency. The latter did not produce a reliable difference ( $P>0.05$ ), presumably because of the large interindividual variability (i.e. the large differences in the numbers of trials falling into the T2-reported and T2-unreported categories). Comparing T1 activation at lag 2 (averaged over correct and incorrect T2 reports) and lag 6 (correct T2 report only), however, a more conservative but less noisy test, did yield a reliable difference ( $Z=-2.3; P<0.01$ , one-tailed).



**Fig. 3** Significant, positive correlation ( $r=0.71$ ;  $P<0.01$ ; one-tailed) between individual T1 peak amplitude and the individual magnitude of the 'blink' (difference between single and dual-target trials at each lag).

processing resources allocated to T1 can predict the individual size of the attentional blink. That is, people exhibiting a smaller attentional blink are not simply better in detecting the second of two events under attentionally demanding conditions but they seem to be better because they invest fewer resources into detecting the first.

### Discussion

Taken together, the present findings suggest that the attentional blink may not reflect an immutable structural processing bottleneck. Rather, people may fail to report correctly some T2s because they allocate more attentional resources to T1 than necessary, either voluntarily (i.e. strategic) or involuntarily (e.g. attentional capture by the stimulus). Whether voluntary or involuntary, such T1 resource allocation must further interact with resources available for T2 processing, in turn yielding the behavioural outcome we refer to as 'divided attention'. Importantly, flexible resource allocation argues against a structural bottleneck model as an account of dual-task performance and suggests productive lines of research to locate the determinants of resource allocation. Given that our evidence is only correlational, however, this conclusion is inevitably tentative and in need of further support.

### Conclusion

The attentional blink as both a paradigm and an outcome has been very useful in probing the limits of human ability to process information requiring divided attention. The present results suggest that this limitation may be more the result of a strategic approach to information processing rather than a structural bottleneck *per se*.

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