

# Author's Accepted Manuscript

The Effects of Motivational Reward on the Pathological Attentional Blink following Right Hemisphere Stroke

Korina Li, Charlotte Russell, Nikita Balaji, Youssuf Saleh, David Soto, Paresh A. Malhotra



PII: S0028-3932(16)30108-7  
DOI: <http://dx.doi.org/10.1016/j.neuropsychologia.2016.03.037>  
Reference: NSY5947

To appear in: *Neuropsychologia*

Received date: 27 November 2015  
Revised date: 11 March 2016  
Accepted date: 29 March 2016

Cite this article as: Korina Li, Charlotte Russell, Nikita Balaji, Youssuf Saleh David Soto and Paresh A. Malhotra, The Effects of Motivational Reward on the Pathological Attentional Blink following Right Hemisphere Stroke *Neuropsychologia*, <http://dx.doi.org/10.1016/j.neuropsychologia.2016.03.037>

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting galley proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

## **The Effects of Motivational Reward on the Pathological Attentional Blink following Right Hemisphere Stroke**

**Korina Li<sup>1</sup>, Charlotte Russell<sup>2</sup>, Nikita Balaji<sup>1</sup>, Youssuf Saleh<sup>1</sup>, David Soto<sup>3,4</sup> and Paresh A. Malhotra<sup>1</sup>**

### **Author affiliations:**

- 1. Division of Brain Sciences, Imperial College London, Charing Cross Hospital, Fulham Palace Road, London, W6 8RF, UK.**
- 2. Department of Psychology, Institute of Psychiatry, Psychology and Neuroscience, Guy's Campus, Addison House, London SE1 1UL, UK.**
- 3. Basque Center on Cognition, Brain and Language, San Sebastian, Spain**
- 4. Ikerbasque, Basque Foundation for Science, Bilbao, Spain**

**Corresponding author: [p.malhotra@imperial.ac.uk](mailto:p.malhotra@imperial.ac.uk)**

### **Abstract**

Recent work has shown that attentional deficits following stroke can be modulated by motivational stimulation, particularly anticipated monetary reward. Here we examined the effects of anticipated reward on the pathological attentional blink (AB), an index of temporal selective attention, which is prolonged in patients with right hemisphere damage and a history of left neglect. We specifically compared the effects of reward versus feedback-without-reward on the AB in 17 patients. We found that the patients all manifested impaired performance compared to healthy controls and that reward modulated the pathological blink in the patient group, but only in the second experimental session. When the performance of patients whose neglect had recovered was compared with that of patients who had ongoing or persistent neglect, reward appeared to only influence the AB in the former. These results have implications

for our understanding of motivation-attention interactions following right hemisphere stroke, and how they may impact upon recovery from spatial neglect.

**Keywords:** Stroke; Attention; Neglect; Reward; Attentional Blink; Motivation

## 1. Introduction

Spatial neglect, which most commonly occurs following right hemisphere stroke, is the archetypal acquired disorder of attention in adults (Bartolomeo; Corbetta & Shulman, 2011). A great deal of research into neglect has been carried out to increase understanding of attentional processes, and also to develop effective treatments, as neglect has a profound impact on rehabilitation outcome. Neglect has been described as a 'weak syndrome', with a number of constituent components that frequently co-occur, but it is universally agreed that the primary cognitive processes that are disrupted in neglect relate to attention, and the syndrome results from a combination of spatially-lateralised and non-lateralised components (Corbetta & Shulman, 2011; Husain & Rorden, 2003; Vallar & Bolognini, 2014).

Attention in both healthy individuals and in patient groups has been shown to be modifiable by a number of behavioural influences, and one area that has been particularly closely studied over the last decade is the influence of reward on attentional processes (Anderson, Laurent, & Yantis, 2011; Bagurdes, Mesulam, Gitelman, Weintraub, & Small, 2008; Della Libera & Chelazzi, 2006; Hickey, Chelazzi, & Theeuwes, 2010). Numerous studies have demonstrated that anticipated reward, in the form of food or money, can modulate attention at the behavioural level, with associated neural correlates that can be observed using electrophysiology and functional imaging (Kiss, Driver, & Eimer, 2009; Mohanty, Gitelman, Small, & Mesulam, 2008; Small, et al., 2005). Interestingly,

approximately thirty years ago Marsel Mesulam noted that reward can also affect pathological impairment of attention and described the transient improvement of neglect on a standard clinical task when a patient was offered money for each target found (Mesulam, 1985). Following the more recent work with healthy volunteers described above, we systematically explored this in a group of stroke patients and showed that anticipated monetary reward can directly modulate the severity of neglect, and other investigators have also found that reward-based learning can improve spatial exploration in patients with fronto-parietal dysfunction (Lucas, et al., 2013; Malhotra, Soto, Li, & Russell, 2013).

Although these studies demonstrate that reward can reduce deficits of spatial attention in stroke patients, a number of questions regarding reward's modulatory effects remain unanswered. The first of these relates to the underlying mechanism. In a number of studies with healthy individuals, anticipated reward has been shown to affect attentional performance in specific tasks by modulating the salience of individual stimuli, and performance can in fact be worsened if distractors rather than targets are associated with reward (Anderson, et al., 2011; Della Libera & Chelazzi, 2006). However, reward has also been shown to have more general effects, acting as incentive motivation for the strategic control of attention (Chelazzi, Perlato, Santandrea, & Della Libera, 2012; Hubner & Schlosser, 2010). As our previous study employed stimuli that were explicitly associated with monetary value, either or both of these mechanisms might have been responsible for reward's effects on attention. Thus, in that study, it was not possible to determine which of these mechanisms was responsible for the effects of reward on spatial neglect.

As stated above, neglect is a clinical syndrome rather than a unitary disorder, and it is thought to arise from the combination of spatially lateralized and non-lateralized component deficits (Husain & Rorden, 2003). As previous studies looking at reward in neglect have examined spatial search behaviour, it has not been possible to ascertain whether any of the non-lateralised deficits of attention that have previously identified as part of the neglect syndrome are also affected. These non-spatially lateralized attentional deficits may persist after neglect has recovered, with the potential to impact upon everyday activities (Farne, et al., 2004).

One particularly intriguing aspect of the interaction between motivation and attention following brain damage is how it might relate to recovery (Robertson, 2013; Russell, Li, & Malhotra, 2013). Previous work showed that reward-based learning can subsequently lead to reduced bias on a standard cancellation task (without any reward involved) and that spared subcortical networks are likely to be responsible for this effect (Lucas, et al., 2013). We previously found that a lack of response to reward was associated with damage to the striatum, which is a key region in reward processing (O'Doherty, 2004). In animal models of neglect, striatal damage has been shown to worsen and prolong neglect, suggesting that the combination of subcortical and cortical damage may limit recovery (Christakou, Robbins, & Everitt, 2005). These findings support the notion that lack of response to motivational stimulation, which has been linked to clinical apathy in other populations of stroke patients (Adam, et al., 2013; Rochat, et al., 2013), may directly impact scope for recovery in patients with spatial neglect.

In the current study, we examined all these issues by assessing the effects of reward on the attentional blink (AB), an index of temporal selective attention, which has been shown to be affected in patients with and without spatial neglect secondary to right hemisphere stroke (Husain, Shapiro, Martin, & Kennard, 1997; Shapiro, Hillstrom, & Husain, 2002). The AB specifically refers to healthy individuals' inability to detect a second visual target (T2) in a stream of distractors if another target (T1) has been presented and correctly identified 200-500ms previously in a rapid serial visual presentation (RSVP) paradigm (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Weichselgartner & Sperling, 1987). A great deal of research has gone into examining the underpinnings of the AB, and this has shown that it is a relatively robust phenomenon, which, although multifactorial, appears to relate to attentional capacity rather than being a perceptual limitation (Dux & Marois, 2009). Several functional imaging studies have attempted to identify the neural correlates of the AB and these have implicated a network distributed across multiple cortical regions (Kranzioch, Debener, Schwarzbach, Goebel, & Engel, 2005; Marois, Chun, & Gore, 2000). However damage to the inferior parietal lobe and superior temporal gyrus appears to be particularly important in the pathological AB observed following stroke (Shapiro, et al., 2002).

In one of the first studies demonstrating a non-lateralised deficit in neglect, Husain and colleagues reported a pathological prolongation of the AB in patients with the neglect syndrome (Husain, et al., 1997). Compared to healthy subjects and right-hemisphere stroke patients without neglect, the AB of those with

neglect was extended beyond 1260ms compared to 360ms in the control groups. Critically, there was a significant correlation between the degree of neglect, as measured by performance on a standard cancellation task, and the magnitude of the AB. The authors proposed that, in addition to a spatial bias, neglect has a non-lateralised, temporal component which when present, may exacerbate spatial neglect (Husain & Rorden, 2003). Further work has shown that, although there is evidently a link between poor temporal selection and biases in spatial attention, the presence of neglect is not a necessary prerequisite for a pathological AB (Correani & Humphreys, 2011; Rizzo, Akutsu, & Dawson, 2001; Russell, Malhotra, Deidda, & Husain, 2012; Shapiro, et al., 2002).

There is evidence that the AB can be subject to modulation in healthy individuals, including by the emotional (Anderson & Phelps, 2001; de Oca, Villa, Cervantes, & Welbourne, 2012; Kanske, Schonfelder, & Wessa, 2013; Tibboel, Van Bockstaele, & De Houwer, 2011) or motivational salience of the target stimuli (Brevers, et al., 2011; Liu, Li, Sun, & Ma, 2008; Tibboel, De Houwer, & Field, 2010; Waters, Heishman, Lerman, & Pickworth, 2007). Monetary rewards have been reported to facilitate performance, but with variable results. Participants in a study by Raymond and O'Brien learned to associate facial stimuli with monetary gains, losses, or neither, which were subsequently used to represent T2 in an AB task (Raymond & O'Brien, 2009). A typical AB effect was seen when T2 was of faces previously associated with loss or neutral outcomes. In stark contrast, T2 recognition for win-associated faces rendered the AB effect absent. In another study accurate T1/T2 performance was rewarded with earnings but incorrect identifications were punished with monetary losses (Olivers & Nieuwenhuis,



2005). Although no statistically significant effect of reward on the AB was found when performance was compared to another group of subjects who performed the task in the absence of anticipated monetary reward, there was a trend towards better performance at the longest T2 lag, suggesting that the duration of the AB may be reduced under conditions of higher motivation. Similarly, Bijleveld and colleagues reported no beneficial effect on the AB when monetary reward was made explicit, yet when participants were subliminally exposed to it, high value rewards improved performance (Bijleveld, Custers, & Aarts, 2011).

In the current study we examined the effects of reward on the pathologically prolonged AB in patients with a history of right hemisphere stroke and spatial neglect. In addition to examining the effects of reward on this non-lateralised attentional deficit we attempted to directly address some of the unresolved issues discussed above. By using stimuli that were not explicitly associated with monetary value, we were able to assess whether a reward would affect performance without any association between monetary value and target identity. In addition, we incorporated a control condition where feedback alone was given without any associated reward, enabling us to dissociate any effects of feedback from those of anticipated monetary reward. None of the previous studies examining the effects of reward in neglect have attempted to separate the motivational effects of anticipated reward from effects due to task feedback. It is known that task feedback can improve attentional performance in healthy individuals and evidence also exists to suggest that performance feedback per se can influence task performance in stroke patients, even in the absence of anticipated reward (Szalma, Hancock, Dember, & Warm, 2006; Tham & Tegner,

1997). Finally, although all the patients we recruited had suffered from neglect soon after their stroke, a number had recovered, such that we were able to explore any possible relationship between the reward-attention interaction and recovery from neglect.

## 2 Methods

### 2.1 Patients

Seventeen right-hemisphere stroke patients (twelve male) were recruited via the stroke unit at Imperial College Healthcare NHS Trust (See Table 1 for further details).

Table 1: Participants demographic data and neglect scores at the time of presentation and participation in the current experiment

Neglect was considered to be present if there was a difference more than two target omissions between the contralesional and the ipsilesional half of the array on the Mesulam shape cancellation task or the BIT Star cancellation task.

\* Indicates where patient was unable to perform cancellation task or where data unavailable.

Subject	Sex	Age (years)	Time since Stroke (months)	Stroke Type	Hemianopia (at time of study)	Initial BIT Star		Initial Mesulam		BIT Star		Mesulam		Neglect Status
						L	R	L	R	L	R	L	R	
1	F	70	3	Haemorrhage	No	0	14	0	6	20	27	*	*	Ongoing
2	M	47	68	Infarct	Yes	*	*	*	*	10	26	*	*	Ongoing
3	M	80	2	Infarct	No	18	26	2	5	26	25	22	26	Ongoing
4	F	50	4	Infarct	Yes	0	8	0	5	7	25	19	25	Ongoing
5	M	63	51	Infarct	Yes	5	27	*	*	22	27	*	*	Ongoing
6	F	68	4	Infarct	No	20	26	20	29	*	*	28	29	Recovered
7	M	63	3	Infarct	No	0	22	0	13	27	27	30	30	Recovered
8	M	73	2	Infarct	No	18	21	9	29	27	27	29	30	Recovered
9	M	49	0.25	Infarct	Yes	1	2	15	2	0	1	0	1	Ongoing

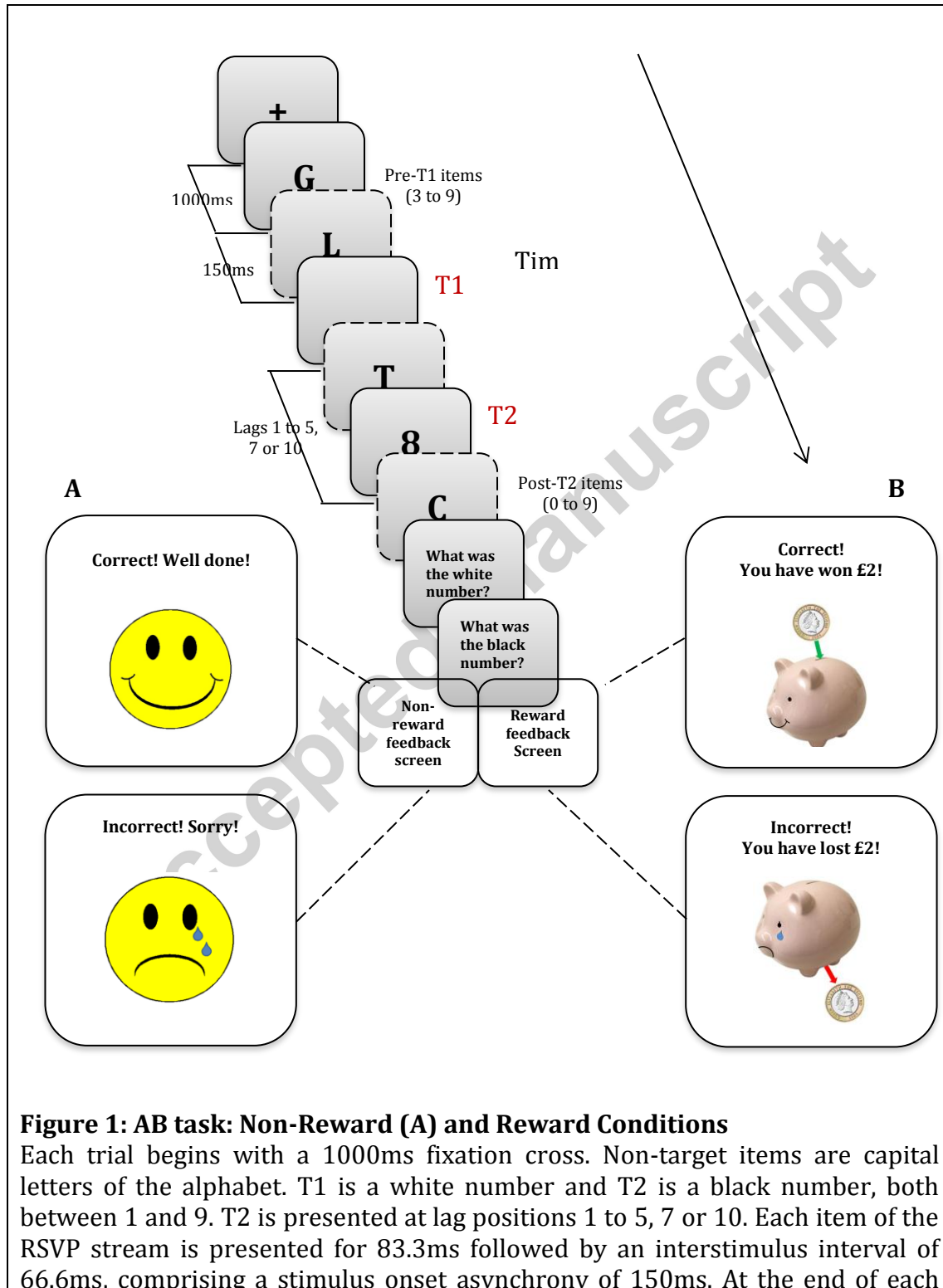
						0	0		1		7		8	ng
10	F	46	38	Infarct	No	0	1	0	8	2	2	29	2	Recov ered
11	F	61	5	Infarct	No	1	2	0	1	2	2	13	2	Ongoi ng
12	M	79	9	Infarct	Yes	0	5	0	0	0	7	0	1	Ongoi ng
13	M	74	5	Infarct	No	0	1	0	0	2	2	8	1	Ongoi ng
14	M	76	8	Infarct	No	0	2	0	0	2	2	27	2	Recov ered
15	M	63	6	Infarct	No	4	2	0	8	2	2	25	2	Recov ered
16	M	84	11	Infarct	No	2	2	4	2	2	2	29	2	Recov ered
17	M	73	4	Infarct	No	0	1	0	7	2	2	20	3	Ongoi ng

Their mean age was 65.8 yrs with a mean duration of 13.1 months since their stroke. All had evidence of left-sided visuospatial neglect when tested in the acute stage, and seven had recovered by the time of testing. For the purposes of the current study, neglect was defined by the presence of a lateralised spatial deficit on the Mesulam shape cancellation task (Mesulam, 1985) and/or the BIT star task (Wilson, Cockburn, & Halligan, 1987), as evidenced by a difference of more than two target omissions between the contralesional and the ipsilesional half of the array. Age-appropriate healthy control subjects were also recruited. All participants provided written informed consent before entering into the study, and the study was approved by the local Ethics Committee.

## 2.2 Behavioural Task and Experimental Procedure

The AB task was adapted from that used by Husain et al. (Husain, et al., 1997), and developed using E-Prime software (Psychology Tools Inc.). From a distance of approximately 50cm, subjects viewed an alphanumeric rapid serial visual presentation (RSVP) stream in bold Arial type, font size 36, presented at the centre of a Hewlett Packard EliteBook 2470p Tablet PC (See Figure 1). Subjects initiated a block of trials by depressing the spacebar key. Each stimulus was presented for 83.3ms for stimulus duration with a 66.7ms interstimulus interval (ISI). All stimuli were presented on a uniform grey background, and each trial began with a black fixation cross, presented centrally for 1000ms. Distractor

stimuli were black capital letters, the first target (T1) was a white number between 1 and 9 inclusive, and the second target (T2) was a different black number between 1 and 9. The number of letters presented before T1 varied randomly between 3 to 9 items.



trial, subjects are asked to report the identities of T1 and T2. Correct and incorrect responses are visually fed back to subjects in non-reward (A) and reward (B) conditions.

Participants had to detect and then correctly report both T1 and T2. Letters that could be mistaken for digits (I, S and Z) were removed from the distractor streams.

Based on pilot work, between 3 and 9 non-target items appeared before T1 to optimise T1 detection. The position of T1 was not fixed to prevent subjects from predicting its location within the distractor stream, and thereby potentially bypassing processing limitations through the establishment of temporal expectations (Tang, Badcock, & Visser, 2014). T2 was presented at lag positions (composed of multiples of 150ms) 1,2,3,4,5, 7 or 10. Thus this target could be presented between 150ms and 1500ms following the presentation of T1. Both identification and detection tasks have been used to study the AB but it has been argued that identification tasks are more complex than those of detection, and therefore more challenging for participants (Kawahara, Di Lollo, & Enns, 2001). An SOA of 150ms (83.3ms for stimulus duration with a 66.7 ms ISI) was chosen on the assumption that an AB would be evident before lag 10, when T2 would occur 1500ms after T1, based on the results of Husain and colleagues (Husain, et al., 1997), who demonstrated that right hemisphere stroke patients with neglect recovered from the AB effect by 1440ms. It should be noted that in an earlier

pilot task that induced an AB in healthy individuals, patients' T2 performance was at floor. Given that the aim of the current experiment was to examine the effects of reward on the AB in patients, the task parameters were adjusted so that patients were more likely to manifest a blink.

All patients carried out reward (R) and No reward (NR) versions of the task and each of these consisted of eight blocks of 21 trials. Short breaks were provided between each block. At the start of the R session, subjects were informed that they would earn 10% of their total winnings on the task, but all subjects were rewarded with £20 in vouchers regardless of performance (the Ethics committee requested that all subjects were awarded an identical amount for participating in any particular experiment). However, participants were unaware of this and believed that they were remunerated based on their performance on the task. In the R version of the task, correct responses for both T1 and T2 were fed back to subjects in pictorial representations in the form of a £2 coin and an incorrect response for T1 or T2 was fed back by a an image depicting the loss of £2 (see Figure 1). In the NR condition a correct response was fed back by a smiling face and an incorrect response led to a crying face.

Participants carried out the two experimental conditions in two sessions, on separate days within one week of each other. Subjects received 14 practice trials in each condition prior to data collection. The order of the task conditions (R and NR) was counterbalanced across subjects to minimise the possibility that any observed effect of reward could be related to practice.

## 2.4 Lesion Anatomy

All patients included in the study underwent imaging during their acute admission as part of their clinical work-up. Six patients had CT imaging only, whereas eleven patients had MR imaging. Diffusion-weighted images were used for those patients with MR scans acquired within 48 hours of stroke presentation, otherwise T2-weighted FLAIR sequences were utilised instead.

Lesions were drawn directly onto patients' native CT or MR scans using MRICron software ([www.mccauslandcenter.sc.edu/mricro/mricron](http://www.mccauslandcenter.sc.edu/mricro/mricron)) by a trained neurologist (KL) who was not aware of individual patients' performance at the time of lesion mapping. The anatomical scan and lesions were subsequently mapped onto stereotaxic space using Clinical Toolbox ([www.mccauslandcenter.sc.edu/CRNL/clinical-toolbox](http://www.mccauslandcenter.sc.edu/CRNL/clinical-toolbox)) for spatial normalisation, implemented via the SPM8 software package ([www.fil.ion.ucl.ac.uk/spm/software/spm8](http://www.fil.ion.ucl.ac.uk/spm/software/spm8)) (Rorden, Bonilha, Fridriksson, Bender, & Karnath, 2012).

## 3. Results

### 3.1 Healthy Control Group

Age-appropriate healthy control subjects were recruited (mean age 63.8 yrs) to ensure that any AB effect obtained in the patient group was pathological relative to controls. The presence of an AB deficit was determined based on the method described by McLaughlin and colleagues (McLaughlin et al., 2001). Combined mean T1 performance across all lags was calculated and considered to equate to that subject's asymptotic performance. Lags at which T2 performance was 30%

or more below the asymptote were considered to be part of the blink. This value of 30% is based on the results from multiple studies in both healthy subjects (Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994) and brain injured patients (di Pellegrino, Basso, & Frassinetti, 1998; Georgiou-Karistianis, et al., 2012; Hillstrom, Husain, Shapiro, & Rorden, 2004; Husain, et al., 1997; Kavcic & Scheid, 2011; Rizzo, et al., 2001), where lags that were typically incorporated into the AB included those where T2 performance was more than 30% below the asymptote. Recruitment was discontinued after the first four subjects (two male) as it became evident that by the criteria of McLaughlin et al. (McLaughlin, Shore, & Klein, 2001), healthy individuals did not appear to exhibit an AB on this specific paradigm. Thus, any observed deficit in the patient group was considered to be pathological.

## 3.2 Patient Group

### 3.2.1 T1 Performance

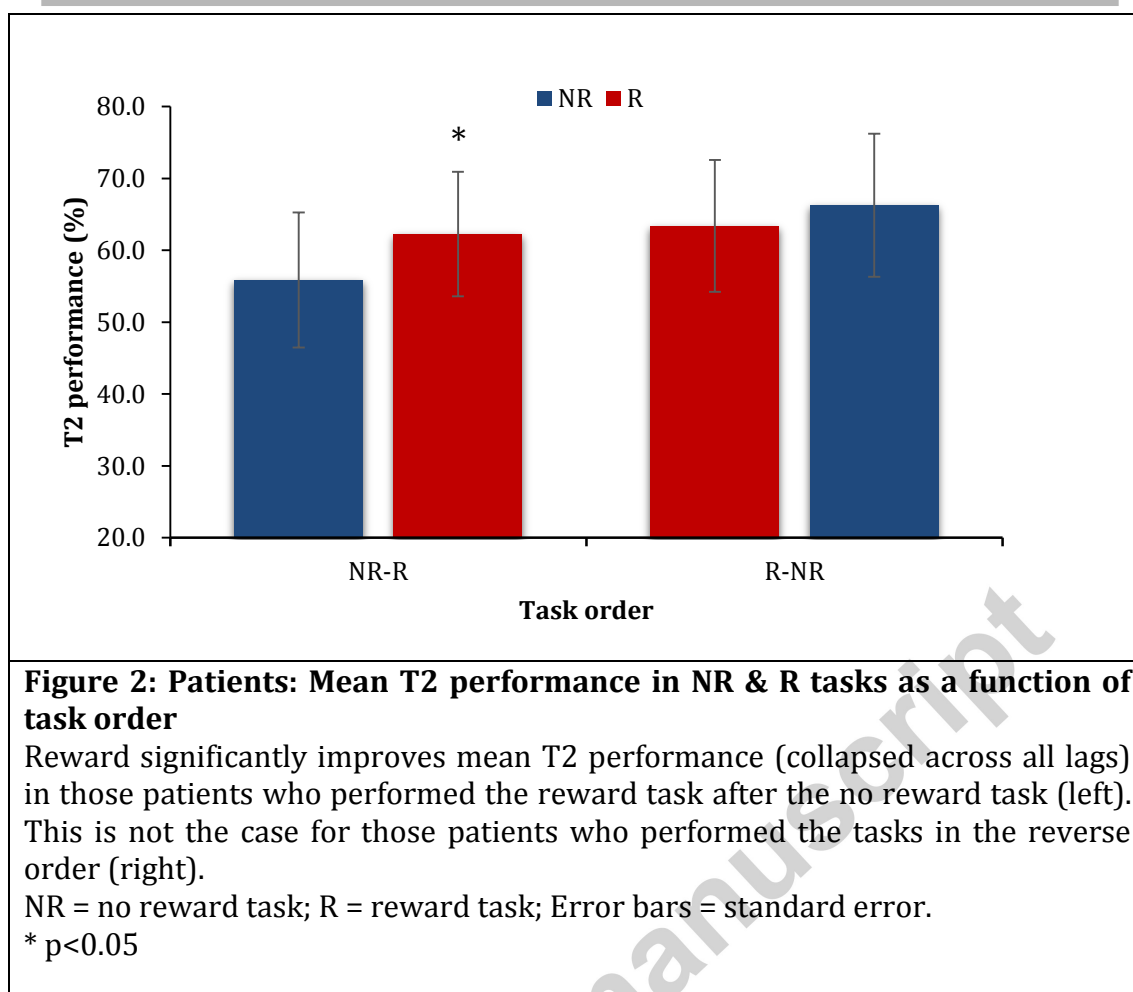
A repeated measures ANOVA for T1 performance (condition by lag with task order as a between-subjects factor) revealed a main effect of lag ( $F(3.2, 48.3)=6.24, p<0.005$ ) where T1 accuracy was poorer when T2 occurred at lag 1. There was no main effect of condition for mean T1 performance collapsed across lags (90.4% and 89.8% for NR and R conditions respectively). There was no main effect of task order ( $F(1, 15)=0.31, p=ns$ ) but there was a condition x task order interaction ( $F(1, 15)=8.35, p<0.05$ ). Post hoc t-tests to explore this further (Fig. 1A) found no significant difference between NR and R performances in those who performed the task in the order of NR-R ( $t(8)=-1.74, p>0.05$ ), nor in those



who performed the task in the reverse order ( $t(7)=2.32, p>0.05$ ). It should be noted that T1 performance was not at ceiling for either condition.

### 3.2.2 T2 Performance

Correct T2 performance was determined by both accurate T1 performance and correct identification of T2 on the same trial. A repeated measures ANOVA (condition (Reward V Non-Reward) by lag with task order as a between-subjects factor for T2 accuracy also revealed a main effect of lag ( $F(6,90)=6.83, p<0.005$ ), with a characteristic U-shaped function of the AB effect, where performance was worst at lags 2, 3 and 4 in comparison to lag 10. There was also a significant condition x task order interaction ( $F(1,15)=7.22, p<0.05$ ). In contrast to the results for T1 performance, post hoc t-tests demonstrated that when the second session was the R condition, there was a significant improvement in overall T2 performance compared to the NR condition ( $t(8)=-3.45, p<0.01$ ), but not vice versa ( $t(7)=0.97, p>0.05$ ) (Fig. 2) However, there was no significant difference between NR and R when patients carried out the R task in the first session. This shows that the improvement observed when the R task was second was not due to a practice effect and also suggests that when patients performed the R condition first, reward affected performance in Session 1 and this carried over to Session 2.



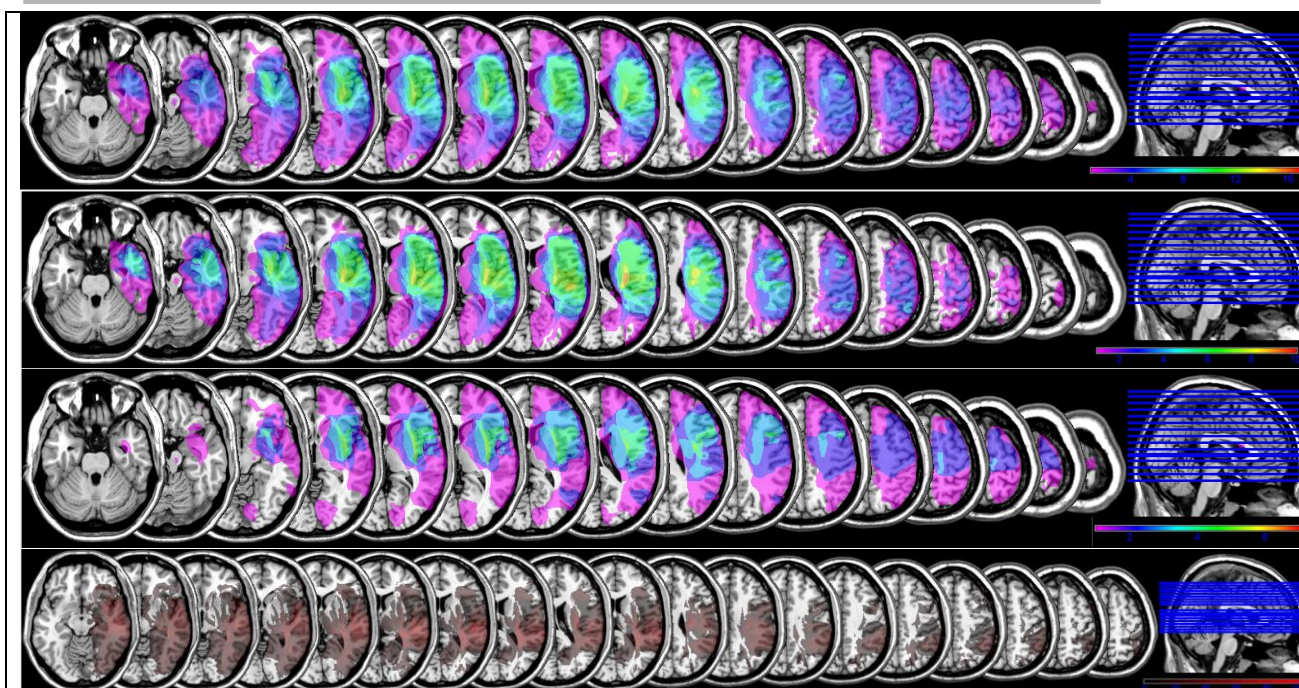
### 3.2.3 Ongoing Neglect versus Recovered Neglect

To examine whether there was any possible relationship between motivational response and recovery from neglect, we separated the patient group into those individuals who had neglect at the time of participation and those who had recovered. Ten patients had ongoing neglect, and seven had recovered and the two groups did not differ in age ( $t(15) = 0.49$ ,  $p = 0.63$ ) or time since stroke. For the patients with ongoing neglect, a repeated measures ANOVA (condition x lag x task order) for T2 performance revealed a main effect of lag ( $F_{(6,48)} = 7.22$ ,  $p < 0.05$ ), with lags 2 to 4 being the worst performing lags compared to lag 10. There were no other main effects or interactions. For the seven patients with recovered neglect, a repeated measures ANOVA (condition x lag x task order) for

T2 performance revealed no main effects of lag, condition or task order, but a marginal trend for a condition x task order interaction ( $F_{(1,5)}=5.37$ ,  $p=0.07$ ). Additional post hoc t-tests suggested that when the second session was the R condition, there was a improvement in overall T2 performance compared to the NR condition ( $t_{(4)}=-2.83$ ,  $p<0.05$ ), but not vice versa ( $t_{(1)}=0.93$ ,  $p>0.05$ ). That is, those who performed the task in the order of NR in session 1 and then R in session 2, showed a significant improvement in overall T2 performance with reward compared to no reward. Again, as for the patient group as a whole, there was no significant difference between reward and no reward for those who performed the task in the order of R in session 1 and NR in session 2.

### 3.2.4 Lesion Anatomy

Fig 3 (Panel A) shows the overlap for all patients who took part in the experiment. This shows that the majority of patients had damage to the middle cerebral artery territory, with two patients also having damage to regions supplied by the posterior cerebral artery. Patients were split into groups of individuals with ongoing and recovered neglect (Panels B and C). When the two sets of patients are compared, as can be seen in the lesion subtraction in Panel D, patients with recovered neglect were less likely to have damage to temporal cortex and underlying white matter, extending superiorly into the superior temporal gyrus.



**Figure 3 Lesion Maps**

Sagittal image shows slice levels and colour scale indicates number of patients with damage to each region. The number of patients with damage affecting a particular region is represented by the colour bar at the right of each panel (Panels A –C). Brighter red regions in Panel D are those most likely to be damaged in Persistent neglect and least likely to be damaged in patients with Recovered neglect.

Panel A: Overlap of All 17 Patients

Panel B: Overlap of Patients with Ongoing Neglect

Panel C: Overlap of Patients with Recovered Neglect

Panel D: Lesion Subtraction (Percentage) Showing Regions Damaged in Individuals with Persistent neglect that were less likely to be damaged in those with Recovered Neglect

## 4 Discussion

### 4.1 Patient Performance on the Current Paradigm

As anticipated, patient performance in the AB paradigm was impaired relative to the healthy control group. In fact, healthy controls did not show any deficit on the current task. As the purpose of this study was to explore the effects of reward on the pathological AB, the parameters of the task were adjusted so that they would reliably demonstrate an effect in the patient group, enabling us to identify any reward-related response. Even though a number of patients had

apparently recovered from their neglect at the time of their participation, they still manifested an attentional blink, in keeping with previous observations that attentional deficits often persist after apparent recovery from neglect on standard clinical tasks (Russell, Malhotra, Deidda, & Husain, 2013). In comparison to the findings of Husain and colleagues the post-T1 target processing deficit of patients was of much shorter duration (starting to recover from 750 ms) and we note that the patients who participated in the current study manifested much less of a spatial bias on cancellation tasks than did those in the previous study, all of whom failed to locate any targets on the left side of space on standard clinical tests (Husain et al., 1997).

#### 4.2 The effects of anticipated monetary reward versus feedback

There was no overall effect of reward versus performance feedback alone on T2 performance in the patient group. However, reward did improve performance in stroke patients with right hemisphere damage when the Reward session was carried out second, with patients' T2 performance of the patients improving (from 55.9% to 62.3%) compared to the NR condition. Crucially, there was no improvement in the second session of the task when the R condition was carried out first, which would be expected if practice effects were solely responsible. Moreover, there was no significant reward-associated improvement in T1 performance when the NR condition was carried out first even though T1 performance was not at ceiling, suggesting that the any effect of reward was specific to T2 performance and the AB.

We speculate that reward effects on the AB might have also been present in the first R session and these then carried over to the second NR session, hence precluding the observation of a general difference between reward and feedback cases. Such an explanation is consistent with recent research in healthy subjects that the AB can be eliminated by prior exposure to the task under conditions in which T2 is made salient (Choi, Chang, Shibata, Sasaki, & Watanabe, 2012).

Reward may have increased the attentional capacity and hence the salience of T2 during the first session, and this training effect on the AB carried over the second session. This interpretation is also consistent with the study of Lucas and colleagues where attentional deficits were modulated by reward-based learning (Lucas, et al., 2013). In that study carried out a 'gambling' search task where patients where choices were reinforced by reward, and following this they made fewer omissions on standard cancellation tasks that involved no reward.

The results show that reward may, in addition to modulating search behaviour (Lucas, et al., 2013; Malhotra, et al., 2013), also influence non-lateralised attentional impairments following hemispheric damage such as the AB. Reward appeared to improve pathological attentional capacity, and the lack of any significant effect on T1 performance indicates that this relates to the temporal-based selective attention deficits involved in the AB rather than any increase in generalised arousal (Robertson, Mattingley, Rorden, & Driver, 1998). The lack of a difference in T2 performance between the two conditions when the R condition was carried out first is in contrast to our previous study, which showed a difference between almost identical rewarded and non-rewarded tasks even when they were carried out within minutes of each other (Malhotra, et al., 2013).

However, as noted in the introduction, that paradigm involved target stimuli that were explicitly associated with monetary value, and furthermore, there was no direct feedback for every correct and incorrect trial.

#### 4.3 Recovered versus Ongoing Neglect

The effect of reward was observed at the group level; however we were interested in how this related to degree of neglect in the patients. We carried out an exploratory analysis of its relationship to recovery, by splitting the group into those individuals who had recovered, as measured by standard clinical tests, and those who had ongoing neglect. These two groups did not differ in age or time since stroke, but there was evidence that patients who had recovered from neglect appeared to respond more strongly to reward, suggesting that response to motivational stimulation may be important in recovery from attentional biases. Reward responsiveness has been linked to clinical apathy in other populations of stroke patients, and this may be an important factor in recovery (Adam, et al., 2012; Rochat, et al., 2013).

In previous work, including our own study of reward and neglect, lack of response to reward has been associated with damage to the basal ganglia, and particularly the striatum. It was not the main purpose of the present study to examine the anatomical underpinnings of the reward response, but lesion subtraction revealed that the regions spared in those patients who had recovered from neglect (and responded to reward) included the superior temporal gyrus (STG). Interestingly, in a previous study, Shapiro et al. demonstrated that patients with lesions to the STG and inferior parietal lobe had

evidence of a prolonged AB effect compared to those without (Shapiro, et al., 2002). The subtraction analysis that we carried out would suggest that patients with STG damage have an attentional capacity deficit that is not modifiable by behavioural intervention, and we note that damage to this region has previously been associated with prolonged neglect (Golay, Schnider, & Ptak, 2008; Karnath, Rennig, Johannsen, & Rorden, 2011). However, we note that this anatomical subtraction analysis is based on a preliminary result from a post hoc analysis, and as such, requires further examination before any firm conclusions can be drawn.

## **5 Conclusions**

In the current study we found that motivational stimulation, in the form of anticipated monetary reward, could modulate the pathological attentional blink that has been observed in patients with right hemisphere stroke. This effect was most pronounced in those individuals who had recovered from spatial neglect, as indexed by standard clinical tests, suggesting a possible role for motivational responsiveness in recovery from attentional biases.

## **Acknowledgements**

This work was funded by a HEFCE Clinical Senior Lectureship to Dr Malhotra , and a grant from the National Institute for Health Research (NIHR) Imperial Biomedical Research Centre.



## References

- Adam, R., Leff, A., Sinha, N., Turner, C., Bays, P., Draganski, B., & Husain, M. (2012). Dopamine reverses reward insensitivity in apathy following globus pallidus lesions. *Cortex*.
- Adam, R., Leff, A., Sinha, N., Turner, C., Bays, P., Draganski, B., & Husain, M. (2013). Dopamine reverses reward insensitivity in apathy following globus pallidus lesions. *Cortex*, 49, 1292-1303.
- Anderson, A. K., & Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature*, 411, 305-309.
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proc Natl Acad Sci U S A*, 108, 10367-10371.
- Bagurdes, L. A., Mesulam, M. M., Gitelman, D. R., Weintraub, S., & Small, D. M. (2008). Modulation of the spatial attention network by incentives in healthy aging and mild cognitive impairment. *Neuropsychologia*, 46, 2943-2948.
- Bartolomeo, P. *Attention disorders after right brain damage : living in halved worlds*.
- Bijleveld, E., Custers, R., & Aarts, H. (2011). Once the money is in sight: distinctive effects of conscious and unconscious rewards on task performance. *Journal of Experimental Social Psychology*, 47, 865-869.
- Brevers, D., Cleeremans, A., Tibboel, H., Bechara, A., Kornreich, C., Verbanck, P., & Noel, X. (2011). Reduced attentional blink for gambling-related stimuli in problem gamblers. *J Behav Ther Exp Psychiatry*, 42, 265-269.
- Broadbent, D. E., & Broadbent, M. H. (1987). From detection to identification: response to multiple targets in rapid serial visual presentation. *Percept Psychophys*, 42, 105-113.
- Chelazzi, L., Perlato, A., Santandrea, E., & Della Libera, C. (2012). Rewards teach visual selective attention. *Vision Res*.
- Choi, H., Chang, L. H., Shibata, K., Sasaki, Y., & Watanabe, T. (2012). Resetting capacity limitations revealed by long-lasting elimination of attentional blink through training. *Proc Natl Acad Sci U S A*, 109, 12242-12247.
- Christakou, A., Robbins, T. W., & Everitt, B. J. (2005). Prolonged neglect following unilateral disruption of a prefrontal cortical-dorsal striatal system. *Eur J Neurosci*, 21, 782-792.
- Corbetta, M., & Shulman, G. L. (2011). Spatial neglect and attention networks. *Annu Rev Neurosci*, 34, 569-599.
- Correani, A., & Humphreys, G. W. (2011). An impaired attentional dwell time after parietal and frontal lesions related to impaired selective attention not unilateral neglect. *Cogn Neuropsychol*, 28, 363-385.

- de Oca, B. M., Villa, M., Cervantes, M., & Welbourne, T. (2012). Emotional modulation of the attentional blink by pleasant and unpleasant pictures. *J Gen Psychol*, 139, 289-314.
- Della Libera, C., & Chelazzi, L. (2006). Visual selective attention and the effects of monetary rewards. *Psychol Sci*, 17, 222-227.
- di Pellegrino, G., Basso, G., & Frassinetti, F. (1998). Visual extinction as a spatio-temporal disorder of selective attention. *Neuroreport*, 9, 835-839.
- Dux, P. E., & Marois, R. (2009). The attentional blink: a review of data and theory. *Atten Percept Psychophys*, 71, 1683-1700.
- Farne, A., Buxbaum, L. J., Ferraro, M., Frassinetti, F., Whyte, J., Veramonti, T., Angeli, V., Coslett, H. B., & Ladavas, E. (2004). Patterns of spontaneous recovery of neglect and associated disorders in acute right brain-damaged patients. *J Neurol Neurosurg Psychiatry*, 75, 1401-1410.
- Georgiou-Karistianis, N., Farrow, M., Wilson-Ching, M., Churchyard, A., Bradshaw, J. L., & Sheppard, D. M. (2012). Deficits in selective attention in symptomatic Huntington disease: assessment using an attentional blink paradigm. *Cogn Behav Neurol*, 25, 1-6.
- Golay, L., Schnider, A., & Ptak, R. (2008). Cortical and subcortical anatomy of chronic spatial neglect following vascular damage. *Behav Brain Funct*, 4, 43.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010). Reward changes salience in human vision via the anterior cingulate. *J Neurosci*, 30, 11096-11103.
- Hillstrom, A. P., Husain, M., Shapiro, K. L., & Rorden, C. (2004). Spatiotemporal dynamics of attention in visual neglect: a case study. *Cortex*, 40, 433-440.
- Hubner, R., & Schlosser, J. (2010). Monetary reward increases attentional effort in the flanker task. *Psychon Bull Rev*, 17, 821-826.
- Husain, M., & Rorden, C. (2003). Non-spatially lateralized mechanisms in hemispatial neglect. *Nat Rev Neurosci*, 4, 26-36.
- Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature*, 385, 154-156.
- Kanske, P., Schonfelder, S., & Wessa, M. (2013). Emotional modulation of the attentional blink and the relation to interpersonal reactivity. *Front Hum Neurosci*, 7, 641.
- Karnath, H. O., Rennig, J., Johannsen, L., & Rorden, C. (2011). The anatomy underlying acute versus chronic spatial neglect: a longitudinal study. *Brain*, 134, 903-912.
- Kavcic, V., & Scheid, E. (2011). Attentional blink in patients with multiple sclerosis. *Neuropsychologia*, 49, 454-460.
- Kawahara, J., Di Lollo, V., & Enns, J. T. (2001). Attentional requirements is visual detection and identification: evidence from the attentional blink. *J Exp Psychol Hum Percept Perform*, 27, 969-984.
- Kiss, M., Driver, J., & Eimer, M. (2009). Reward priority of visual target singletons modulates event-related potential signatures of attentional selection. *Psychol Sci*, 20, 245-251.
- Kranczioch, C., Debener, S., Schwarzbach, J., Goebel, R., & Engel, A. K. (2005). Neural correlates of conscious perception in the attentional blink. *Neuroimage*, 24, 704-714.

- Liu, N., Li, B., Sun, N., & Ma, Y. (2008). Effects of addiction-associated and affective stimuli on the attentional blink in a sample of abstinent opiate dependent patients. *J Psychopharmacol*, 22, 64-70.
- Lucas, N., Schwartz, S., Leroy, R., Pavin, S., Diserens, K., & Vuilleumier, P. (2013). Gambling against neglect: unconscious spatial biases induced by reward reinforcement in healthy people and brain-damaged patients. *Cortex*, 49, 2616-2627.
- Malhotra, P. A., Soto, D., Li, K., & Russell, C. (2013). Reward modulates spatial neglect. *J Neurol Neurosurg Psychiatry*, 84, 366-369.
- Marois, R., Chun, M. M., & Gore, J. C. (2000). Neural correlates of the attentional blink. *Neuron*, 28, 299-308.
- McLaughlin, E. N., Shore, D. I., & Klein, R. M. (2001). The attentional blink is immune to masking-induced data limits. *Q J Exp Psychol A*, 54, 169-196.
- Mesulam, M. M. (1985). *Principles of behavioral neurology*. Philadelphia: F.A. Davis.
- Mohanty, A., Gitelman, D. R., Small, D. M., & Mesulam, M. M. (2008). The spatial attention network interacts with limbic and monoaminergic systems to modulate motivation-induced attention shifts. *Cereb Cortex*, 18, 2604-2613.
- O'Doherty, J. P. (2004). Reward representations and reward-related learning in the human brain: insights from neuroimaging. *Curr Opin Neurobiol*, 14, 769-776.
- Olivers, C. N., & Nieuwenhuis, S. (2005). The beneficial effect of concurrent task-irrelevant mental activity on temporal attention. *Psychological Science*, 16, 265-269.
- Raymond, J. E., & O'Brien, J. L. (2009). Selective visual attention and motivation: the consequences of value learning in an attentional blink task. *Psychological Science*, 20, 981-988.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *J Exp Psychol Hum Percept Perform*, 18, 849-860.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18, 849-860.
- Rizzo, M., Akutsu, H., & Dawson, J. (2001). Increased attentional blink after focal cerebral lesions. *Neurology*, 57, 795-800.
- Robertson, I. H. (2013). The neglected role of reward in rehabilitation. *J Neurol Neurosurg Psychiatry*, 84, 363.
- Robertson, I. H., Mattingley, J. B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature*, 395, 169-172.
- Rochat, L., Van der Linden, M., Renaud, O., Epiney, J. B., Michel, P., Sztajzel, R., Spierer, L., & Annoni, J. M. (2013). Poor reward sensitivity and apathy after stroke: implication of basal ganglia. *Neurology*, 81, 1674-1680.
- Rorden, C., Bonilha, L., Fridriksson, J., Bender, B., & Karnath, H. O. (2012). Age-specific CT and MRI templates for spatial normalization. *NeuroImage*, 61, 957-965.

- Russell, C., Li, K., & Malhotra, P. A. (2013). Harnessing motivation to alleviate neglect. *Front Hum Neurosci*, 7, 230.
- Russell, C., Malhotra, P., Deidda, C., & Husain, M. (2012). Dynamic attentional modulation of vision across space and time after right hemisphere stroke and in ageing. *Cortex*.
- Russell, C., Malhotra, P., Deidda, C., & Husain, M. (2013). Dynamic attentional modulation of vision across space and time after right hemisphere stroke and in ageing. *Cortex*, 49, 1874-1883.
- Shapiro, K., Hillstrom, A., & Husain, M. (2002). Control of visuotemporal attention by inferior parietal and superior temporal cortex. *Curr Biol*, 12, 1320-1325.
- Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *J Exp Psychol Hum Percept Perform*, 20, 357-371.
- Small, D. M., Gitelman, D., Simmons, K., Bloise, S. M., Parrish, T., & Mesulam, M. M. (2005). Monetary incentives enhance processing in brain regions mediating top-down control of attention. *Cereb Cortex*, 15, 1855-1865.
- Szalma, J. L., Hancock, P. A., Dember, W. N., & Warm, J. S. (2006). Training for vigilance: the effect of knowledge of results format and dispositional optimism and pessimism on performance and stress. *Br J Psychol*, 97, 115-135.
- Tang, M. F., Badcock, D. R., & Visser, T. A. (2014). Training and the attentional blink: limits overcome or expectations raised? *Psychon Bull Rev*, 21, 406-411.
- Tham, K., & Tegner, R. (1997). Video feedback in the rehabilitation of patients with unilateral neglect. *Arch Phys Med Rehabil*, 78, 410-413.
- Tibboel, H., De Houwer, J., & Field, M. (2010). Reduced attentional blink for alcohol-related stimuli in heavy social drinkers. *J Psychopharmacol*, 24, 1349-1356.
- Tibboel, H., Van Bockstaele, B., & De Houwer, J. (2011). Is the emotional modulation of the attentional blink driven by response bias? *Cogn Emot*, 25, 1176-1183.
- Vallar, G., & Bolognini, N. (2014). Unilateral spatial Neglect. In K. Nobre & S. Kastner (Eds.), *The Oxford handbook of attention* (pp. p972-1027). Oxford ; New York: Oxford University Press.
- Waters, A. J., Heishman, S. J., Lerman, C., & Pickworth, W. (2007). Enhanced identification of smoking-related words during the attentional blink in smokers. *Addict Behav*, 32, 3077-3082.
- Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, 238, 778-780.
- Wilson, B., Cockburn, J., & Halligan, P. W. (1987). Behavioural inattention test. In. Bury St. Edmunds: Thames Valley.

# **Highlights:**

- 5. Anticipated reward can modulate the pathological attentional blink in right hemisphere stroke**
- 6. Reward's effects are greater than those of performance feedback alone**
- 7. Reward response appears to be related to neglect recovery**