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# The effects of motivational reward on the pathological attentional blink following right hemisphere stroke

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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.



## 1. Introduction

Spatial neglect, which most commonly occurs following right hemisphere stroke, is the archetypal acquired disorder of attention in adults (Bartolomeo, n.d.; Corbetta and 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 and Shulman, 2011; Husain and Rorden, 2003; Vallar and 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 et al., 2011; Bagurdes et al., 2008; Della Libera and Chelazzi, 2006; Hickey et al., 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 et al., 2009; Mohanty et al., 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 et al. 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

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can in fact be worsened if distractors rather than targets are associated with reward (Anderson et al., 2011; Della Libera and Chelazzi, 2006). However, reward has also been shown to have more general effects, acting as incentive motivation for the strategic control of attention (Chelazzi et al., 2012; Hubner and 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 and 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 et al., 2013a). 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 et al., 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 et al., 1997; Shapiro et al., 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 200–500 ms previously in a rapid serial visual presentation (RSVP) paradigm (Broadbent and Broadbent, 1987; Raymond et al., 1992; Weichselgartner and 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 and 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 (Kranczioch et al., 2005; Marois et al., 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 1260 ms compared to 360 ms 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 and 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 and Humphreys, 2011; Rizzo et al., 2001; Russell et al., 2013b; Shapiro et al., 2002).

There is evidence that the AB can be subject to modulation in healthy individuals, including by the emotional (Anderson and Phelps, 2001; de Oca et al., 2012; Kanske et al., 2013; Tibboel et al., 2011) or motivational salience of the target stimuli (Brevers et al., 2011; Liu et al., 2008; Tibboel et al., 2010; Waters et al., 2007). Monetary rewards have been reported to facilitate performance, but with variable results. Participants in a study by Raymond and O'Brien (2009) learned to associate facial stimuli with monetary gains, losses, or neither, which were subsequently used to represent T2 in an AB task. 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 and 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 et al., 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 et al., 2006; Tham and 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).