

Visual Attention: What Inattention Reveals about the Brain

Masud Husain

Nuffield Dept of Clinical Neurosciences, Department of Experimental Psychology and Wellcome Trust Centre for Integrative Neuroimaging, University of Oxford, Oxford OX3 9DU, UK

Correspondence: masud.husain@ndcn.ox.ac.uk

<https://doi.org/10.1016/j.cub.2019.02.026>

The precise contribution of brain regions to selective attention is disputed. New research identifies what happens to nodes in the attention network when one of them is inactivated and reveals whether they might have a causal role in directing attention.

Brains have limited capacity. They cannot process all the rich, diverse array of information that impinges upon our peripheral sense organs on a millisecond by millisecond basis. Nor would this be a very efficient strategy, because only a tiny fraction of that information is potentially useful. Hence items have to compete for selection, either by being more physically salient or because animals are biased to prioritise certain types of information. The processes that underlie such selectivity and prioritisation are referred to as selective attention. A new study by Bogadhi *et al.* [1], reported recently in *Current Biology*, uses an innovative strategy that combines four different methods to provide important insights into cortical contributions to selective attention. The results lead to a provocative conclusion that deserves careful consideration.

Technically, the study is a *tour de force*. By combining functional magnetic resonance imaging (fMRI) with electrophysiological recordings, microstimulation and local reversible inactivation of brain regions in macaque monkeys, Bogadhi *et al.* [1] have managed to pull off a startling feat. First, they mapped cortical brain regions that are active when the animals performed a *covert* visual attention task — one where they attend to a peripheral location while keeping their eyes still. This allowed the investigators to observe the network of brain regions that become active during selective spatial attention. Then, using recording electrodes and microstimulation, they localized the superior colliculus, a region which lies in the midbrain, high in the brainstem. The colliculus is directly connected to cortical

regions implicated in selective covert attention. It also plays a pivotal role in directing *overt* shifts of gaze to visual targets, and it was possible by stimulating this region to evoke rapid eye movements into the opposite — contralateral — side of space.

Next, reversible pharmacological inactivation of the colliculus on one side of the brain was conducted using muscimol, a GABA receptor agonist, while monkeys performed the covert attention task. This led to deficits in spatially selective visual inattention, with the animals becoming significantly worse in detecting salient events contralateral to the inactivated colliculus, even when no eye movements were required. The key new strategy employed here was simultaneously to use fMRI to establish what happens to the cortical attention network during this state of unilateral inattention, induced temporarily by inactivating one colliculus. The results revealed that there was significant reduction of activity across nodes of the cortical attention network. In addition to previously commonly identified brain regions in posterior parietal cortex — such as the lateral intraparietal area (LIP) — and the frontal eye fields (FEF), there was deactivation within a small area located in the floor of the superior temporal sulcus (STS). In fact, rather surprisingly, the greatest reduction of activity occurred in this region (Figure 1), leading the authors to suggest that this area might indeed be far more important than parietal and frontal zones.

In a different set of experiments, when the FEF was reversibly inactivated using muscimol, contralateral hemi-inattention was again associated with greatest

reduction in activity in the same region within the STS. Finally, when the authors inactivated this area of the STS directly with muscimol, they were able to produce selective contralateral visual inattention, demonstrating that this region plays a causal role in deploying spatial attention. Furthermore, these effects of reversible inactivation of the STS were not accompanied by any effects on eye movements (unlike what happened with inactivation of the SC or FEF, which appear to have a role in both overt shifts of gaze as well as covert shifts of attention).

Bogadhi *et al.* [1] consider this part of the STS to be potentially homologous to the temporo-parietal junction (TPJ) of human brains (Figure 1), an area which, when lesioned, has been implicated in a severe disorder of attention known as the neglect syndrome in humans [2–4]. Patients with neglect have typically suffered a stroke and fail to be aware of stimuli located contralateral to their brain damage — a contralesional deficit. However, a crucial puzzle that remains to be solved is why it is that neglect is far more severe and persistent after right hemisphere strokes, while inattention in monkey models occurs just as frequently with either left or right brain lesions.

One key insight might come from the fact that it has actually been difficult to produce a syndrome as severe as human neglect in monkey models of inattention (see [5]). Neglect in humans is defined by a deficit in the ability to be aware of contralesional stimuli *even when given unlimited time to explore*. By contrast the impairments reported by Bogadhi *et al.* [1] with temporary inactivation of the STS, as

well as some previous work with permanent lesions [6], describe effects which consist of difficulties in detecting briefly presented stimuli, not with free viewing. Moreover, such deficits were accompanied by visual extinction: failure to be aware of a transient contralesional stimulus when there is a simultaneous, competing stimulus presented on the same side (ipsilesional) as the lesion [1,6].

Research in humans has converged on a consensus that considers the neglect syndrome to consist of several different components [2–4,7]. Different patients might suffer from different combinations of cognitive deficits (Figure 2), but for neglect to manifest, a single deficit on its own might not be sufficient. One core component of neglect appears to be a directional bias in orienting attention towards the ipsilesional side. This might occur as a result of imbalance between homologous regions in the left and right hemispheres after unilateral brain damage, although it might also be due to an ipsilesional shift of the centre of attention [8]. The directional bias is evident when neglect patients view a homogenous visual array [9] or even in the dark [10].

A second component deficit commonly observed in neglect is a directional bias in the competition for selection, such that ipsilesional objects win over contralesional ones for selection [9,11]. This echoes the phenomenon of visual extinction [12,13]. The bias in competition in neglect can be overcome by making contralesional items more physically salient, for example, brighter [9]. But neither the directional bias in orienting attention nor the bias in the competition for selection provides a compelling explanation for why, with unlimited viewing time, neglect patients' contralesional exploration of space is so limited.

One strategy deployed to establish other component deficits in neglect has been effectively to test performance without the confounding effect of any directional bias. This has been achieved by presenting stimuli centrally, at fixation or in a vertical line. Under these circumstances, it has been possible to reveal that some patients with left-sided visual neglect following right hemisphere stroke also have impairments in deploying attention when stimuli are presented in a

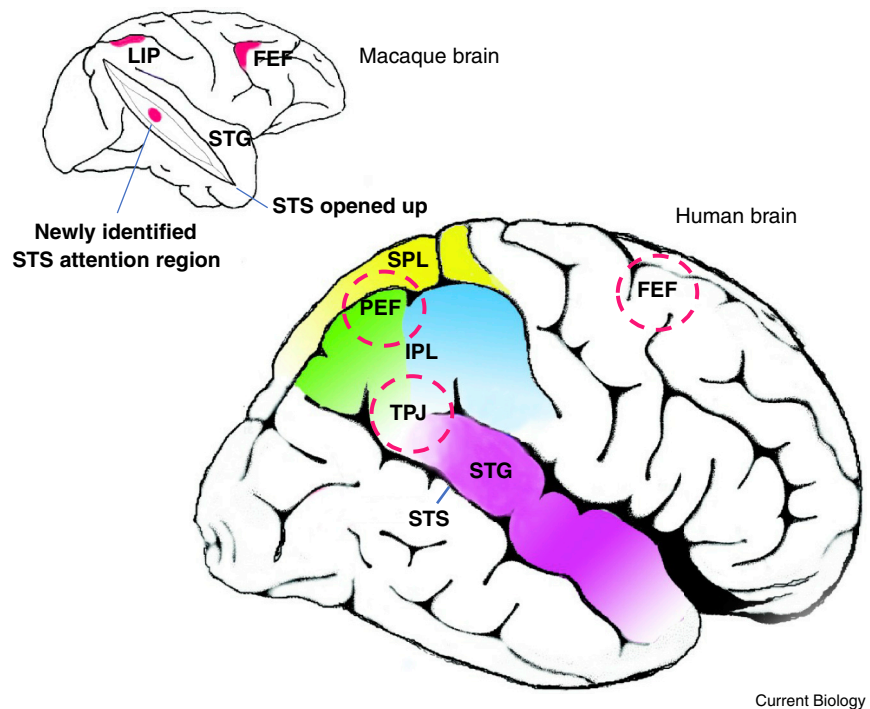


Figure 1. The attention network.

Attention-related areas on the lateral surface of the macaque brain (shown in red) and potential homologues in the human brain (red dashed circles). The newly identified attention region in the macaque lies on the floor of the STS; it might correspond to the human TPJ. PEF, parietal eye fields; SPL, superior parietal lobule; IPL, inferior parietal lobule; STG, superior temporal gyrus.

rapid stream at fixation [14]. Other patients have extremely limited spatial working memory, so they cannot keep track of locations they have already attended to [15]. Still others are unable to sustain attention over time [16]. When one or more of these components are combined with a directional bias in orienting or selection (Figure 2), an ipsilesional orienting of attention with little likelihood of contralesional exploration would be expected.

Such a multi-component model of neglect is consistent with the fact that many different brain regions are often compromised by natural lesions such as stroke [2–4,17]. By contrast, most monkey models have used highly focal lesions and therefore may give rise to only one component of the neglect syndrome, as is likely in the work of Bogadhi *et al.* [1]. Indeed, when focal lesions occur to the attention network in humans, it is possible to demonstrate such components without the full-blown neglect syndrome (for example [2,12,13,18,19]).

But such an explanation, on its own, is unlikely to account fully for the differences

between inattention observed in monkey models and natural human lesions. Even large strokes in monkeys do not reproduce the full neglect syndrome that is observed in humans [20]. What seems to be required for neglect in humans is large right hemisphere strokes. This suggests that some key cognitive components associated with neglect might be lateralised to the right hemisphere. The emergence of language in the left hemisphere of humans is often invoked as the evolutionary pressure for differentiation between the two cerebral hemispheres. But what is it that the right hemisphere is specialized for?

The possibility that right hemisphere systems might be specialized for early orienting of attention or competition for selection seems unlikely because directional biases in these parameters can be observed after either left or right hemisphere damage to humans [19] — as well as monkeys [1,6]. Some have argued for a special role of the human right TPJ in reorienting attention to salient new events, rather like an interrupt switch [3].

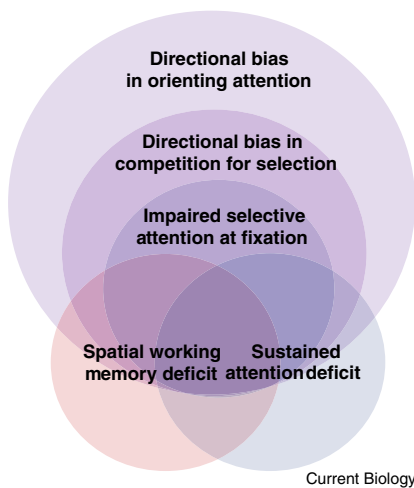


Figure 2. Component deficits of the neglect syndrome in humans.

Several component deficits have been identified that might contribute to the neglect syndrome. None on their own is likely to lead to the full-blown syndrome. Different individuals might have different combinations of deficit depending upon the extent of their brain lesion.

Others consider human right hemispheric specialisation for spatial working memory or sustained attention to be crucial [15,16]. When combined with directional biases, deficits in spatial working memory or sustained attention might be sufficient to lead to neglect.

Bogadhi *et al.* [1] argue that the STS region they have identified is a major player in directing spatial attention. It is clearly one node in a network that includes FEF, LIP and the SC. Future studies might profitably extend this work to examine what happens with reversible inactivation of parietal cortex and, perhaps more importantly, whether larger

scale simultaneous inactivations of attentional nodes across a hemisphere in macaques can produce anything like the neglect syndrome in humans.

REFERENCES

- Bogadhi, A., Bollimunta, A., Leopold, D., and Krauzlis, R. (2019). Spatial attention deficits are causally linked to an area in macaque temporal cortex. *Curr. Biol.* 29, 726–736.e4.
- Vandenberghe, R., Molenberghs, P., and Gillebert, C.R. (2012). Spatial attention deficits in humans: The critical role of superior compared to inferior parietal lesions. *Neuropsychologia* 50, 1092–1103.
- Corbetta, M., and Shulman, G.L. (2011). Spatial neglect and attention networks. *Annu. Rev. Neurosci.* 34, 569–599.
- Husain, M., and Rorden, C. (2003). Non-spatially lateralized mechanisms in hemispatial neglect. *Nat. Rev. Neurosci.* 4, 26–36.
- Gaffan, D., and Hornak, J. (1997). Visual neglect in the monkey. Representation and disconnection. *Brain* 120, 1647–1657.
- Luh, K.E., Butter, C.M., and Buchtel, H.A. (1986). Impairments in orienting to visual stimuli in monkeys following unilateral lesions of the superior sulcal polysensory cortex. *Neuropsychologia* 24, 461–470.
- Bartolomeo, P. (2007). Visual neglect. *Curr. Opin. Neurol.* 20, 381–386.
- Karnath, H.-O. (2015). Spatial attention systems in spatial neglect. *Neuropsychologia* 75, 61–73.
- Bays, P.M., Singh-Curry, V., Gorgoraptis, N., Driver, J., and Husain, M. (2010). Integration of goal- and stimulus-related visual signals revealed by damage to human parietal cortex. *J. Neurosci.* 30, 5968–5978.
- Fruhmann-Berger, M., and Karnath, H.-O. (2005). Spontaneous eye and head position in patients with spatial neglect. *J. Neurol.* 252, 1194–1200.
- Morrow, L.A., and Ratcliff, G. (1998). The disengagement of covert attention and the neglect syndrome. *Psychobiology* 16, 261–269.
- Posner, M.I., Walker, J.A., Friedrich, F.J., and Rafal, R.D. (1984). Effects of parietal injury on covert orienting of attention. *J. Neurosci.* 4, 1863–1874.
- Friedrich, F.J., Egly, R., Rafal, R.D., and Beck, D. (1998). Spatial attention deficits in humans: a comparison of superior parietal and temporal-parietal junction lesions. *Neuropsychology* 12, 193–207.
- Husain, M., Shapiro, K., Martin, J., and Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature* 385, 154–156.
- Malhotra, P., Jäger, H.R., Parton, A., Greenwood, R., Playford, E.D., Brown, M.M., *et al.* (2004). Spatial working memory capacity in unilateral neglect. *Brain* 128, 424–435.
- Malhotra, P., Coulthard, E.J., and Husain, M. (2009). Role of right posterior parietal cortex in maintaining attention to spatial locations over time. *Brain* 132, 645–660.
- Toba, M.N., Rabuffetti, M., Duret, C., Pradat-Diehl, P., Gainotti, G., and Bartolomeo, P. (2018). Component deficits of visual neglect: “Magnetic” attraction of attention vs. impaired spatial working memory. *Neuropsychologia* 109, 52–62.
- Gillebert, C.R., Mantini, D., Thijs, V., Sunaert, S., Dupont, P., and Vandenberghe, R. (2011). Lesion evidence for the critical role of the intraparietal sulcus in spatial attention. *Brain* 134, 1694–1709.
- Peers, P.V., Ludwig, C.J.H., Rorden, C., Cusack, R., Bonfiglioli, C., Bundesen, C., Driver, J., Antoun, N., and Duncan, J. (2005). Attentional functions of parietal and frontal cortex. *Cereb. Cortex* 15, 1469–1484.
- Marshall, J.W.B., Ridley, R.M., Baker, H.F., Hall, L.D., Carpenter, T.A., and Wood, N.I. (2003). Serial MRI, functional recovery, and long-term infarct maturation in a non-human primate model of stroke. *Brain Res. Bull.* 61, 577–585.