cortex 48 (2012) 654–663

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Research report

Attention networks and their interactions after right-hemisphere damage

Ana B. Chica [a,*], *Michel Thiebaut de Schotten* [a,b], *Monica Toba* [a], *Paresh Malhotra* [c], *Juan Lupiáñez* [d] and *Paolo Bartolomeo* [a,e,f]

[a] *INSERM-U 975, Centre de Recherche de l'Institut du Cerveau et de la Moëlle Epinière (CRICM), Université Pierre et Marie Curie (UPMC), Groupe Hospitalier Pitié-Salpêtrière, Paris, France*
[b] *Natbrainlab, Department of Forensic and Neurodevelopmental Sciences, Institute of Psychiatry, King's College London, UK*
[c] *Centre for Neuroscience, Division of Experimental Medicine, Imperial College London, UK*
[d] *Department of Experimental Psychology, University of Granada, Spain*
[e] *AP-HP, Groupe Hospitalier Pitié-Salpêtrière, Fédération de Neurologie, Paris, France*
[f] *Department of Psychology, Catholic University, Milan, Italy*

ARTICLE INFO

Article history:
Received 3 September 2010
Revised 14 December 2010
Accepted 17 January 2011
Action editor Carlo Umiltà
Published online 3 February 2011

Keywords:
Neglect
Attentional networks
Alertness
Orienting
Conflict resolution

ABSTRACT

Unilateral spatial neglect is a disabling condition, frequently observed after right-hemisphere damage (RHD), and associated with poor functional recovery. Clinical and experimental evidence indicates that attentional impairments are prominent in neglect. Recent brain imaging and behavioral studies in neglect patients and healthy individuals have provided insights into the mechanisms of attention and have revealed interactions between putative attentional networks. We recruited 16 RHD patients and 16 neurologically intact observers to perform a lateralized version of the Attention Network Test devised by Posner and co-workers (Fan et al., 2002). The results showed evidence of interaction between attentional networks during conflict resolution. Phasic alertness improved the orienting deficit to left-sided targets, reducing the interference of distracters in the neglected visual field, thus facilitating conflict resolution in the majority of patients. Modulating alertness may be an important way of improving basic deficits associated with neglect, such as those affecting spatial orienting.

1. Introduction

Attention refers to a family of cognitive functions that prepare the individual to respond quickly and accurately to incoming information by selecting relevant and ignoring irrelevant stimuli. Traditionally conceived as a uniform concept, attention is now viewed as a composite function based on discrete neural substrates (Posner and Petersen, 1990). For example, Posner and his co-workers have proposed that three separate but linked brain networks contribute to the following attentional processes: orienting, alerting and executive control (Fan et al., 2002).

The orienting function has been traditionally studied by presenting stimuli preceded by orienting cues. When the cues correctly indicate the location of the upcoming target, participants' responses are faster and/or more accurate, indicating that spatial attention improves the processing of

* *Corresponding author*. CRICM, Hôpital de la Salpêtrière, 47 Bd de l'Hôpital, 75651 Paris Cedex 13, France.
E-mail address: anachica@ugr.es (A.B. Chica).
0010-9452/$ – see front matter © 2011 Elsevier Srl. All rights reserved.
doi:10.1016/j.cortex.2011.01.009

information (Posner, 1980). Influential functional Magnetic Resonance (fMRI) models propose a dorsal fronto-parietal network (including the bilateral intraparietal sulcus and frontal eye fields), involved in the orienting of attention, and a ventral fronto-parietal network (including the temporo-parietal junction – TPJ, and the inferior and middle frontal gyri) supporting attentional re-orienting to unexpected events (Corbetta and Shulman, 2002). Recent evidence has however demonstrated the causal role of TPJ (part of the ventral network) during the orienting of exogenous or involuntary attention (Chica et al., 2011).

The alerting system is believed to produce a general alert state that would be responsible for spreading attention over a broad area of space and is modulated by the locus coeruleus/norepinephrine system (Coull et al., 1999). A higher alert state allows faster processing of information, independently of its spatial location (Fernandez-Duque and Posner, 1997). We can voluntarily maintain our level of alertness over time, a function known as "sustained attention", which involves the right frontal cortex, inferior parietal lobe (IPL) and subcortical structures (Sturm and Willmes, 2001). The alertness level can also be modulated experimentally by presenting warning signals that carry information about when, but not where, targets will appear ("phasic alertness"). In addition to the (mainly right-lateralized) neural structures involved in sustained attention, phasic alertness is associated with activity in the left frontal cortex and thalamus (Sturm and Willmes, 2001).

A distinct dimension of attentional processes involves executive control, which requires both monitoring and conflict solving (e.g., flankers task, Eriksen and Eriksen, 1974). Brain areas associated with the executive control system are the dorsal anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) (Bush et al., 2000), although more extensive areas are implicated when complex tasks are used (Fan et al., 2005).

Although behavioral and fMRI evidence support the theoretical independence of these attentional subsystems (Fan et al., 2005, 2002; Fernandez-Duque and Posner, 1997), other studies in neglect patients and healthy participants have emphasized the importance of their interactions (Posner and Petersen, 1990). These discrepancies with older studies were likely due to the paradigms used, which were not ideal to study the interactions between the three attentional networks. These studies measured alerting by using the presence/absence of spatial visual cues, which allows studying the main effect of each network, but not the interaction between alerting and orienting. Callejas et al. (2005, 2004) modified this paradigm in order to study not only the main effect of each network but also their interactions, by using a separate measure of alerting, manipulating the presence/absence of an auditory cue. They reported behavioral evidence supporting an interaction between the networks in a reaction time (RT) paradigm, where greater orienting effects were observed after the presentation of a warning tone that induced phasic alertness. Robertson et al. (1997) also showed that sustained attention deficits might predict the occurrence and severity of the orienting deficits demonstrated by neglect patients. Remarkably, modulating the alertness level by an alerting tone could overcome the spatial bias in visual awareness in eight neglect patients (Robertson et al., 1998).

Several studies have demonstrated that the degree of impairment of sustained attention is a strong predictor for the persistence of neglect (Hjaltason et al., 1996; Samuelsson et al., 1998). Alertness training can also improve lateralized spatial deficits in brain damaged patients by means of self-instructional (Robertson et al., 1995) or computerized methods (Sturm et al., 1997). Thimm et al. (2006, 2009) have reported ameliorations of neglect that are associated to increased activity in bilateral fronto-parietal regions such as the frontal gyri, the cuneus and precuneus, the angular gyrus, and the ACC (see also Manly et al. (2005), and Fimm et al. (2006), for the effects of alertness in sleep-deprived healthy participants).

In addition, there is increasing neurophysiological and anatomical evidence of these interactions between the alerting and the orienting systems. Clark et al. (1989) modulated the noradrenergic (NA) system by injecting intravenous drugs in healthy participants, producing changes in orienting attention on a cuing RT paradigm. Malhotra et al. (2006) have also observed an improvement of neglect with NA stimulation. Morrison and Foote (1986) studied the innervations of brain structures in monkeys and showed high density NA innervations in cortical and subcortical regions involved in attentional orienting (e.g., posterior parietal lobe – PPL).

The present study attempts to provide further behavioral data in right brain damaged patients emphasizing the importance of the interplay between attentional networks, which might contribute to the development of more efficient rehabilitation methods for patients presenting attentional deficits. We modified a computerized battery test (Attention Network Test – ANT) originally designed to determine the functional independence and efficiency of the three attentional networks discussed above (Fan et al., 2002). As in Callejas et al. (2004), we introduced an alerting tone before the cue was presented. This manipulation allows us studying not only the efficiency and independence of each network but also their interactions. Given that we were interested in studying lateralized spatial deficits (left- and rightward orienting of attention) as well as non-spatial deficits (alertness), and that we were especially interested in investigating their interactions, a lateralized version of the test proposed by Callejas et al. (2004) was designed. Based on previous research, we expected an abnormal orienting of attention to left-sided targets in right brain damaged patients (Bartolomeo and Chokron, 2001). If the attentional networks interact, the phasic alerting produced by the tone could ameliorate this orienting deficit in the patients, who might be faster and/or more accurate for validly cued left-targets. This better orienting might be able to improve conflict resolution at the attended location. Contrary, if the attentional networks do not interact, we will find faster RTs when the alerting tone is presented, but this will not influence neither orienting nor conflict resolution.

2. Methods

2.1. *Participants*

Sixteen patients (6 women; Table 1) and sixteen healthy controls (8 women) participated in the study. Patients were selected on the basis of the presence of unilateral damage to the right hemisphere, as assessed by magnetic resonance imaging (MRI) or computed tomography (CT) scans. For nine of the patients, high-resolution MRIs were obtained, and