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Research report

Increase of posterior connectivity in aging within the Ventral Attention Network: A functional connectivity analysis using independent component analysis

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A B S T R A C T

Multiple studies have found neurofunctional changes in normal aging in a context of selective attention. Furthermore, many articles report intrahemispheric alteration in functional networks. However, little is known about age-related changes within the Ventral Attention Network (VAN), which underlies selective attention. The aim of this study is to examine age-related changes within the VAN, focusing on connectivity between its regions. Here we report our findings on the analysis of 27 participants' (13 younger and 14 older healthy adults) BOLD signals as well as their performance on a letter-matching task. We identified the VAN independently for both groups using spatial independent component analysis. Three main findings emerged: First, younger adults were faster and more accurate on the task. Second, older adults had greater connectivity among posterior regions (right temporoparietal junction, right superior parietal lobule, right middle temporal gyrus and left cerebellum crus I) than younger adults but lower connectivity among anterior regions (right anterior insula, right medial superior frontal gyrus and right middle frontal gyrus). Older adults also had more connectivity between anterior and posterior regions than younger adults. Finally, correlations between connectivity and response time on the task showed a trend toward connectivity in posterior regions for the older group and in anterior regions for the younger group. Thus, this study shows that intrahemispheric neurofunctional changes in aging also affect the VAN. The results suggest that, in contexts of selective attention, posterior regions increased in importance for older adults, while anterior regions had reduced centrality.

1. Introduction

Because our environment contains hundreds of visual stimuli, it is impossible for the human brain to analyze them all at once. Instead, it relies on selective attention to focus only on stimuli that are relevant to the task at hand and ignore irrelevant or distracting stimuli. Tasks requiring selective attention activate numerous networks, including the Ventral Attention Network (VAN) (Corbetta et al., 2008; Scalf et al., 2014; Vossel et al., 2012). The VAN allows us to direct our attention toward a stimulus that shares similar characteristics with the anticipated target, especially when the searched-for object appears somewhere unexpected (Bays et al., 2010; Chica et al., 2013; Corbetta et al., 2008; Corbetta and Shulman, 2011; Fox et al., 2006; Indovina and Macaluso, 2007; Macaluso and Doricchi, 2013). The VAN can also act as a circuit-breaker either to interrupt the detection process when the target is located or when our expectations are no longer in line with our environment (Parks and Madden, 2013; Scalf et al., 2014; Shulman et al., 2003). It has further been proposed that this network analyzes the features of stimuli on a trial-by-trial basis to judge their relevance to the ongoing task (Macaluso and Doricchi,

Abbreviations: VAN, Ventral Attention Network; DAN, Dorsal Attention Network; DMN, Default Mode Network; ICA, Independent Component Analysis.

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2013), which allows one to focus on features that help detect a target and inhibit those that do not. Thus, the VAN both mediates sensory-driven (bottom-up) target discovery by allowing detection in unexpected locations and also contributes to controlled (top-down) search by adjusting our expectations to our environment (Macaluso and Doricchi, 2013). Not surprisingly, neurological lesions in regions of the VAN have a severe impact on everyday functioning (Corbetta and Shulman, 2011; Foldi et al., 2002; He et al., 2007; Ptak, 2012; Vecera and Rizzo, 2003). The VAN is a frontoparietal network that has been associated mainly with the right frontal and parietal regions of the human brain, including the temporoparietal junction and ventral prefrontal cortex (Corbetta et al., 2008; Fox et al., 2006; Hahn et al., 2006; Kucyi et al., 2012; Li et al., 2011; Shulman et al., 2010). Since frontal and parietal cortices are the two areas most affected by healthy aging (Raz et al., 1998), it is hardly surprising that selective attention processing declines with age.

It has been reported that healthy older adults perform slower and less accurately on selective attention tasks than young adults (Madden et al., 2014). However, not all attention processes are equally affected in aging. Older adults benefit as much as if not more than younger adults from guiding cues (Geerligs et al., 2014; Madden et al., 2014; Madden and Whiting, 2004; Müller-Oehring et al., 2013). On the other hand, older adults' attention is more easily captured by distracting stimuli (Geerligs et al., 2014; Porter et al., 2012; Whiting et al., 2007). These results have led many authors to believe that the top-down ability to direct attention based on prior information is preserved in aging, but the capacity to inhibit attention capture by distractors declines (Madden, 2007; Porter et al., 2012). This suggests that the VAN would become less efficient in aging as it would be less efficient in its ability to resist attentional capture towards distracters. Alternatively, it could be that the attentional processes of older adults could rely more heavily on the cognitive abilities supported by the VAN. In this case, a more active VAN could help to redirect the attention locus towards the target (Corbetta and Shulman, 2002) but would increase the vulnerability to distractors (Shulman et al., 2003). However, there is a lack of behavioral data to support either hypothesis (Madden, 2007). Similarly, Chica et al. (2013) reported that studies showing vulnerability to distractors in aging had hitherto used experimental designs that did not differentiate between task-relevant and irrelevant distractors. Because the VAN reacts only to task-relevant distractors (Corbetta et al., 2008; Corbetta and Shulman, 2011; Geng and Mangun, 2011) even when task-unrelated distractors are highly salient (Kincade et al., 2005), it is impossible to determine whether the obtained results are caused by a dysfunction in this network or an inability to inhibit salient but task-irrelevant distractors. As such, to our knowledge, there are no data available about possible age-related changes that could specifically implicate the cognitive abilities supported by the VAN.

Some information can, however, be obtained from a number of fMRI studies. Ansado and Monchi (2013), for example, have reported an age-related increase in BOLD signal in regions comprised within the VAN following a change in attention load. In this study, BOLD signals were compared between younger and older adults during a selective attention task with two attentional load levels (low-load vs. high-load condition). At a low attentional load condition, younger adults had higher metabolic activity in the occipital lobe when compared to older adults, while the latter had higher activity in prefrontal regions. When the task demand were high, then both groups showed an additional increase in activations of parietal regions, thus suggesting that these regions had an important contribution in mediating task difficulty. This study suggests that younger adults engage a parieto-occipital network during the task, whereas older adults would rather engage a frontoparietal network. While that study was a promising first step in examining functional variation of the frontoparietal network due to age, it remains unclear how the different regions of the VAN are affected since task-related paradigms do not quantify the relationship between the network's regions or how these relations differ in different age groups. Such a refinement in describing the changes in the involvement of the different regions of the VAN is part of the goals of the present study.

Unlike task-related paradigms, functional connectivity techniques can quantify relations between regions of functional networks by correlating their activity and then compare these connectivity ratios between groups. Functional connectivity has been used to study attention networks (Bastin et al., 2012; Betzel et al., 2014; Chou et al., 2013; Damoiseaux et al., 2008; Fox et al., 2006; Sun et al., 2012; Ystad et al., 2011), and age-related changes have been found. For instance, Geerligs et al. (2014) compared connectivity measures for different functional networks in young and older adults and found similar connectivity in an attention network, the Dorsal Attention Network (DAN), and higher connectivity between a cognitive-control network and a somatomotor network for older adults. Furthermore, elderly participants with the highest connectivity between the latter two networks achieved task performance levels similar to those of the younger adults. As such, these results suggest that there is an age-related neurofunctional modification in attention processes that are linked to cognitive performance. Attention networks were also found to be activated even when participants were not engaging in an attention task. Wu et al. (2011) selected brain regions known to be hypoactive during attention tasks, which form the Default Mode Network (DMN), and examined their negatively correlated areas. The resulting areas formed a network composed of multiple attention networks, including the VAN. Correlation coefficients were then compared between groups and showed an overall decrease in connectivity during aging in this super-network and the DMN. Thus, these results imply that aging is characterized by lessened deactivation between attention networks, possibly including the VAN, and the DMN. However, to our knowledge, functional connectivity has never been used to specifically investigate age-related changes in the VAN.

Instead, numerous studies have focused on the DMN. As mentioned above, the DMN is a large-scale system that is hypoactive during attention tasks and involves both anterior and posterior regions. This network has been linked to mental states such as remembering, planning and mental visualization (Andrews-Hanna, 2012; Buckner et al., 2008; Spreng, 2012). To assess changes in aging, Andrews Hanna et al. (2007) examined correlations between regions of the DMN in groups of younger and older adults and concluded that correlations within the network were decreased in the older group. Furthermore, the integrity of connectivity between anterior and posterior regions also decreased, suggesting that an anterior-posterior disconnection occurs in aging. Similar results were obtained by Tomasi and Volkow (2012), who found decreased connectivity in distant but functionally connected regions in both the DMN and the DAN for older participants. Also, Sun et al. (2012) found that older adults' frontal regions occupy a less central position in functional networks when compared to younger adults. Thus, it could expected that the VAN may undergo age-related intrahemispheric changes in connectivity, a change that could be different for the anterior and posterior regions of this network.

This study aims to investigate age-related alterations of interaction between regions of the VAN, both for the whole network and also for anterior and posterior regions only. To do this, the NetBrainWork toolbox was used (http://sites.google.com/site/netbrainwork/), a set of functional connectivity algorithms that apply Independent Component Analysis (ICA) to blood oxygena-