Neuropsychologia 51 (2013) 2251–2260

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

The functional neuroanatomy of multitasking: Combining dual tasking with a short term memory task

Sabine Deprez [a,b,c,*], Mathieu Vandenbulcke [c,d,e], Ron Peeters [a,b,c], Louise Emsell [a,b,c], Frederic Amant [f,g], Stefan Sunaert [a,b,c]

[a] Department of Radiology, UZ Leuven, Herestraat 49, Leuven, Belgium
[b] Department of Imaging & Pathology, KU Leuven, Herestraat 49, Leuven, Belgium
[c] Leuven Research Institute for Neuroscience & Disease (LIND), KU Leuven, Herestraat 49, Leuven, Belgium
[d] Department of Psychiatry, UZ Leuven, Herestraat 49, Leuven, Belgium
[e] Department of Neurosciences, KU Leuven, Herestraat 49, Leuven, Belgium
[f] Multidisciplinary Breast Cancer Center, UZ Leuven, Herestraat 49, Leuven, Belgium
[g] Department of Oncology, KU Leuven, Herestraat 49, Leuven, Belgium

ARTICLE INFO

Article history:
Received 20 November 2012
Received in revised form
25 July 2013
Accepted 30 July 2013
Available online 11 August 2013

Keywords:
MRI
fMRI
Executive functioning
Memory
Attention
Multitasking
Dual-tasking

ABSTRACT

Insight into the neural architecture of multitasking is crucial when investigating the pathophysiology of multitasking deficits in clinical populations. Presently, little is known about how the brain combines dual-tasking with a concurrent short-term memory task, despite the relevance of this mental operation in daily life and the frequency of complaints related to this process, in disease. In this study we aimed to examine how the brain responds when a memory task is added to dual-tasking. Thirty-three right-handed healthy volunteers (20 females, mean age 39.9 ± 5.8) were examined with functional brain imaging (fMRI). The paradigm consisted of two cross-modal single tasks (a visual and auditory temporal same-different task with short delay), a dual-task combining both single tasks simultaneously and a multi-task condition, combining the dual-task with an additional short-term memory task (temporal same-different visual task with long delay). Dual-tasking compared to both individual visual and auditory single tasks activated a predominantly right-sided fronto-parietal network and the cerebellum. When adding the additional short-term memory task, a larger and more bilateral frontoparietal network was recruited. We found enhanced activity during multitasking in components of the network that were already involved in dual-tasking, suggesting increased working memory demands, as well as recruitment of multitask-specific components including areas that are likely to be involved in online holding of visual stimuli in short-term memory such as occipito-temporal cortex. These results confirm concurrent neural processing of a visual short-term memory task during dual-tasking and provide evidence for an effective fMRI multitasking paradigm.

1. Introduction

Doing two things at the same time whilst trying not to forget a third one is a part of everyday life for most of us. However, this ability to effectively distribute and coordinate attentional resources to perform multiple tasks can become impaired. Patients with cancer who received chemotherapy (Deprez et al., 2011, 2012; O'Farrell, Mackenzie, & Collins, 2013; Ribi, 2012; Wefel & Schagen, 2012), patients with traumatic brain injury (Fortin, Godbout, & Braun, 2002; Toyokura, Nishimura, Akutsu, Mizuno, & Watanabe, 2012) and mild cognitive impairment (Makizako et al., 2013) often complain about subtle cognitive deficits, especially during "multitasking", despite normal performance on traditional neuropsychological tests. Multitasking deficits have mainly been assessed through neuropsychological evaluation. For example by combining executive tasks (Baddeley, Della Sala, Papagno, & Spinnler, 1997), memory tasks (Smith-Conway, Chenery, Angwin, & Copland, 2012), memory and motor tasks (MacPherson, Parra, Moreno, Lopera, & Della Sala, 2012), everyday tasks involving cooking (Fortin et al., 2002; Frisch, Forstl, Legler, Schope, & Goebel, 2012) and walking and talking (Rochester et al., 2004), or a combination of tasks in a multitasking framework (Burgess, 2000; Wetherell, Atherton, Grainger, Brosnan, & Scholey, 2012). These tasks were mostly assessed using paper-and-pencil or

* Corresponding author at: Department of Radiology, University Hospital of the Catholic University of Leuven, Herestraat 49, B-3000 Leuven, Belgium.
Tel.: +32 16 34 90 70; fax: +32 16 34 37 69.
E-mail addresses: sabine.deprez@uzleuven.be (S. Deprez), mathieu.vandenbulcke@uzleuven.be (M. Vandenbulcke), ronald.peeters@uzleuven.be (R. Peeters), louise.emsell@med.kuleuven.be (L. Emsell), stefan.sunaert@uzleuven.be (S. Sunaert).

0028-3932/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2013.07.024

have been implemented on a computerized platform. Only a limited number of studies have used functional Magnetic Resonance Imaging (fMRI) to study multitasking deficits, mostly involving a simple dual-task (Rasmussen et al., 2008; Wu & Hallett, 2008).

The purpose of the present study was to investigate the neural substrates of multitasking in healthy volunteers using fMRI with a multitasking paradigm we developed, which could later be applied to study subtle cognitive deficits in specific patient groups. We aimed to develop a multitasking paradigm that combines dual-tasking (including dividing attention and switching between two types of information, i.e. auditory and visual stimuli) with on-line holding of a third stimulus. These processes are broadly classified under the umbrella of working memory, which refers to the cognitive capacity to hold and manipulate information in memory. Although we have a relatively good understanding of the neural underpinnings of different working memory operations separately, it remains largely unknown how these are combined. This study examines the functional neuroanatomy of combining dual-tasking with an additional short-term memory task.

Mesulam (2000) described working memory as a predominantly attentional function under the control of a fronto-parietal network where the prefrontal and posterior parietal cortex are involved in the online maintenance of information, and the prefrontal dorsolateral cortex in controlling the executive aspects (e.g. task ordering and switching between tasks).

Several neuroimaging studies have analyzed the neuroanatomical correlates of cognitive demands in dual-tasking and divided attention (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Dux, Ivanoff, Asplund, & Marois, 2006; Johnson & Zatorre, 2006; Loose, Kaufmann, Auer, & Lange, 2003; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006; Szameitat, Schubert, Muller, & Von Cramon, 2002). They describe the involvement of a fronto-parietal attention network with a specific role for the dorsolateral prefrontal cortex in the coordination of concurrent processes. More specifically, cortical areas along the inferior frontal sulcus (IFS) (Nebel et al., 2005; Szameitat et al., 2002; Vohn et al., 2007), the middle frontal gyrus (MFG) (Johnson & Zatorre, 2006; Nebel et al., 2005; Szameitat et al., 2002; Vohn et al., 2007) and the intraparietal sulcus (IPS) (Dux et al., 2006; Szameitat et al., 2002; Vohn et al., 2007) have been shown to be involved in dual-tasking. Additionally the IFS and MFG are also involved in task switching (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000) and task inhibition (Konishi, Chikazoe, Jimura, Asari, & Miyashita, 2005; Konishi, Nakajima, Uchida, Sekihara, & Miyashita, 1998) suggesting that these areas are implicated in general control over task coordination. Areas along the IPS have previously been associated with attentional functions, like visual attention and more multimodal sensory attention (Corbetta & Shulman, 2002; Gillebert et al., 2011; Molenberghs, Mesulam, Peeters, & Vandenberghe, 2007; Vandenberghe et al., 2005). Attentional demands are specifically high in dual-task situations where attention has to be divided and switched rapidly between tasks and modalities. Both the IPS and dorsolateral prefrontal cortex are part of the dorsal attention network (Corbetta & Shulman, 2002), also termed the executive control network (Seeley et al., 2007).

The more demanding the dual-tasks, the more extensive the recruited network is to successfully complete the task. Vohn et al. (2007) studied differences between within-modal (same modality, e.g. visual/visual) and cross-modal (different modality, e.g. visual/auditory) divided attention tasks. Under the cross-modal condition the right prefrontal–parietal network, that was also active during the within-modal task, was more extensive and more bilateral. Also the activation in the right anterior cingulate cortex and the thalamus was stronger during the auditory/visual task. This supplementary activation could reflect an additional demand for the coordination of two ongoing cross-modal cognitive processes when compared to the within-modal tasks.

Very few studies however have examined how the brain combines dual-tasking with a memory task, so-called "multitasking". Findings from lesion studies suggest an association with damage in the frontal lobe (lateral prefrontal cortex, the anterior cingulate, BA10) and impaired multitasking (Burgess, 2000; Dreher, Koechlin, Tierney, & Grafman, 2008). Santangelo & Macaluso (2013) studied the contribution of working memory to divided attention. They reported increased activation in the left and right intraparietal sulcus during object-based divided attention tasks as the number of objects to be held in working memory increased. This increased activation reflects the recruitment of additional resources to enable dual-task performance under conditions of high working memory load and attentional demands. In the remainder of the manuscript, we will use the term 'dual-tasking' to refer to the simultaneous execution of two tasks and 'multitasking' to refer to the simultaneous execution of more than two tasks.

It is evident that the interdependence of the individual-tasks plays a major role in multitasking paradigms. In other words, the neuro-cognitive architecture of multitasking is critically dependent on the tasks that are performed. In this fMRI study, we address how the brain combines dual-tasking, consisting of two cross-modal competing tasks (a visual and auditory temporal same-different task with short delay (TSD_S)) with another short-term memory task (a visual temporal same-different task with long delay (TSD_L)).

Theoretically, several scenarios with different neural correlates could occur (Sigman & Dehaene, 2008). In the first scenario, the TSD_L task does not interfere with the execution of the dual-task. This could imply for example (1) serial processing of the different tasks: encoding of the presented visual stimulus of the TSD_L task, execution of the dual-task (DT) and finally retrieval of the visual stimulus and response; or (2) involvement of different neural networks for the distinctive tasks and/or automated processes. In this case we would not observe differences in brain activation or connectivity between the execution of the DT task in the DT paradigm and the execution of the DT task when combined with our memory task. In the second scenario, the TSD_L task actively interferes with the execution of the dual-task. In this case, we would observe differences in brain activation and/or connectivity between the execution of DT with the memory task compared to DT without the memory task. This scenario would show that the fMRI paradigm that we developed can be used to measure brain activation linked to multitasking. Differences in activation between the dual-task and the multitask condition could be related to the extra demands on attentional and coordinating processes as well as to the process of actively keeping the visual stimuli online during a longer delay. For example, the fronto-parietal brain network involved in the coordination of concurrent processes (Santangelo & Macaluso, 2013; Szameitat et al., 2002), could show enhanced activity during multitasking when compared to dual-tasking. Additionally, brain regions involved in maintaining memoranda in visual short term memory (like occipito-temporal cortex) (Song & Jiang, 2006) could be recruited. Alternatively both processes (i.e. the online holding of the encoded stimulus in visual-sort-term memory and the dual-task) could occur in parallel with no enhancement of activity involved in DT.

A better understanding of the neural substrates of multitasking in healthy volunteers will help us with the future evaluation of patients with subtle cognitive complaints that score well on classical neuropsychological tests, but have difficulties with more complex tasks like multitasking.

2. Material and methods

2.1. Participants

Thirty-three right-handed healthy volunteers (20 females, mean age 39.9 ± 5.8) participated in the study. Subjects were recruited through advertisement on local websites. All participants had normal or corrected-to-normal vision and were not