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Research report

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Neural sources of performance decline during continuous multitasking

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ABSTRACT

Multitasking performance costs have largely been characterized by experiments that involve two overlapping and punctuated perceptual stimuli, as well as punctuated responses to each task. Here, participants engaged in a continuous performance paradigm during fMRI recording to identify neural signatures associated with multitasking costs under more natural conditions. Our results demonstrated that only a single brain region, the superior parietal lobule (SPL), exhibited a significant relationship with multitasking performance, such that increased activation in the multitasking condition versus the singletasking condition was associated with higher task performance (i.e., least multitasking cost). Together, these results support previous research indicating that parietal regions underlie multitasking abilities and that performance costs are related to a bottleneck in control processes involving the SPL that serves to divide attention between two tasks.

1. Introduction

Multitasking behavior is ubiquitous in today's technologically dense world (Foehr, 2006), and involves an attempt to accomplish a goal in the setting of another concurrent goal (Clapp & Gazzaley, 2010). Substantial evidence has shown multitasking performance deficits are characterized by response delays and errors, which result from attentional bottlenecks in cognitive processes such as perceptual encoding and response selection (Marois & Ivanoff, 2005; Pashler, 1994; Tombu et al., 2011). Several mechanisms have been proposed to underlie such bottlenecks, such as delays in distinct aspects of neural processing for the secondary task (e.g., stimuli identification, response selection, short term memory encoding) (Dux & Marois, 2009; Johnston, 1995; Pashler, 1994; Shapiro, Raymond, & Arnell, 1997), task-set reconfiguration (Rogers and Monsell, 1995), changing the weights in a competing cognitive system (Cohen et al., 1990; Gilbert and Shallice, 2002; Wylie et al., 2004) or advanced preparation in task switching (Jamadar et al., 2010;

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Q3 Karayanidis et al., 2010). Neuroimaging research has suggested these sources of multitasking interference may arise from shared executive resources in widespread frontal and parietal regions that include the superior parietal lobule (SPL), inferior parietal sulcus, inferior frontal junction, inferior frontal sulcus, as well as subregions within the superior, middle and inferior frontal gyri (Deprez et al., 2013; Herath, Klingberg, Young, Amunts, & Roland, 2001; Hesselmann, Flandin, & Dehaene, 2011; Jiang, 2004; Takeuchi et al., 2013; Tombu et al., 2011). Characterizing the source of interference that underlies multitasking costs has largely involved experimentation using two punctuated perceptual/response tasks (psychological refractory period – PRP paradigm: Telford, 1931,Welford, 1952; Pashler & Johnston, 1989; Pashler, 1994; Task-switching paradigm: Jersild, 1927; Rogers and Monsell, 1995; Kiesel et al., 2010). Thus, it is less clear whether similar neural regions are also associated with performance declines during a continuous multitasking paradigm, as is more common to everyday life.

The use of a continuous performance paradigm as a primary task may reveal unique features regarding task switching that occurs under more natural conditions compared to the discrete presentation paradigms routinely used to study multitasking. Continuous tasks have been shown to engage perception, visual-spatial deployment, and response-selection in parallel (Rushworth, Johansen-Berg, Göbel, & Devlin, 2003), providing a more naturalistic design that is not driven by discrete task structures. As previously described, typical instructions dictate an artificial task switch by imposing a constraint of performing separate responses to observe task switching (Pashler, 1994). Given that response order constraints have been shown to greatly increase multitasking costs (Israel & Cohen, 2011; Levy & Pashler, 2001; Ruthruff, Hazeltine, & Remington, 2006), here we use a continuous primary task to make response order instruction unnecessary.

To assess the neural correlates of multitasking performance decline, we collected functional magnetic resonance imaging (fMRI) data while participants were engaged in a custom-designed video game (NeuroRacer) (Anguera et al., 2013). Consistent with many memory and attention tasks (e.g., working memory: digit symbol task, speed of processing: letter comparison, pattern comparison) that have been shown to exhibit linear declines with age (Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Park et al., 2002), we have shown that continuous multitasking, as assessed via NeuroRacer, also results in performance declines across the adult lifespan (Anguera et al., 2013). Therefore, here we examined individuals in the 4th and 5th decades of life (30 yo & 40 yo), when significant decline has already begun. Neural and performance data was contrasted between a single task (sign detection) and a dual task (sign detection while driving a virtual car). Although widespread fronto-parietal regions have been previously associated with multitasking cost during two punctuated tasks, we designed this study to examine whether similar regions would be associated with multitasking performance declines when single and dual tasks are perceptually matched and is continuous in nature.

2. Methods

2.1. *Participants*

Thirty-one healthy, right-handed participants between 30 and 49 y.o. (mean age 38.4 ± 6.3 y, 14 females) took part in this experiment. All participants had normal or corrected-to-normal vision, gave informed written consent, and were monetarily compensated for participation in the study. All participants were screened to ensure they had no history of neurological or psychiatric disorders, not depressed, did not have strabismus or amblyopia, no history of substance abuse and were free of medication. Additionally, all participants were considered to be non-video game players, as defined by having less than 2 h of any type of video-game usage per month in the past two years. Approval of the study was given by the Committee on Human Research at the University of California, San Francisco.

2.2. *Paradigm*

Task stimuli were presented on a 32″ monitor placed at the back of the fMRI scanner bore and viewed via a headcoil-mounted mirror. Participants engaged in a custom designed video game (‘NeuroRacer’; Anguera et al., 2013) using a Current Designs game controller to control tracking (i.e., driving the car; right forefinger and thumb) and responding to sign stimuli (left index finger).

2.2.1. *Tasks*

The visuomotor tracking, or Drive Only (DO), task (Fig. 1A) involved keeping a car as accurately as possible within a target box drawn on a continuously moving road. A pseudo-randomized, counterbalanced selection of road segments (that is, right/left turns & inclining/declining hills) formed the tracks, with turn/hill severity being either mild or severe. The discrimination, or Sign Only (SO), task (Fig. 1B) involved responses to visual stimuli presented for 400 msec, two degrees above a fixation cross. During SO, participants were instructed to respond as quickly and accurately as possible only to green circles (33% frequency) with a right button press. Distractor (non-target) signs included an equal distribution of red or blue circles, as well as triangles, squares or pentagons that could be colored green, red or blue. In the ‘Sign with Road’ task (SWR; single task; Fig. 1C), the car was on autopilot and participants responded to the target signs as during SO. In the ‘Sign and Drive’ task (SD; dual task; Fig. 1D), participants were told to respond to the target signs (as in SO) and continuously drive (as in DO). The SWR and SD tasks served as our tasks of interest, as they were perceptually matched and only differed in task requirements (single or dual task). Sign discrimination events always coincided exactly with a road segment change and occurred randomly with a stimulus-onset-interval randomized between 4 and 12 sec. Road segment changes occurred randomly with a stimulus-onset-interval randomized between 2 and 4 sec. Thus, road segment changes occurred more frequently than sign events and helped minimize participants' ability to form expectations for sign event