Neuropsychologia 48 (2010) 3252–3261

Contents lists available at ScienceDirect

Neuropsychologia

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

Dual-task conditions modulate the efficiency of selective attention mechanisms in Alzheimer's disease

Elena K. Festa[a,*], William C. Heindel[a], Brian R. Ott[b]

[a] Department of Cognitive, Linguistic and Psychological Sciences, Brown University, United States
[b] Department of Neurology, Brown University, United States

ARTICLE INFO

Article history:
Received 23 December 2009
Received in revised form 22 May 2010
Accepted 2 July 2010
Available online 17 July 2010

Keywords:
Divided attention
Dementia
Executive control
Spatial orienting
Visual search
Response interference

ABSTRACT

Given previous demonstrations of both selective and divided attention deficits in Alzheimer's disease (AD) patients, understanding how declines in the integrity of component processes of selective attention in these patients interact with impairments to executive processes mediating dual-task performance has both theoretical and practical relevance. To address this issue, healthy elderly and AD patients performed computerized tasks of spatial orienting, Simon response interference, and visual search both in isolation and while simultaneously engaged in a visuomotor tracking task (i.e., maintaining car position within a simulated driving environment). Results from the single-task conditions confirmed previous demonstrations of selective attention deficits in AD. Dual-task conditions produced in AD patients (but not healthy elderly) a change in the efficiency of the selective attention mechanisms themselves, as reflected in differential effects on cue or display conditions within each task. Rather than exacerbating the selective attention deficits observed under single-task conditions, however, dual-task conditions produced an apparent diminution of these deficits. We suggest this diminution is due to the combination of deficient top-down inhibitory processes along with a decrease in the attention-capturing properties of cue information under dual-task conditions in AD patients. These findings not only increase our understanding of the nature of the attentional deficits in AD patients, but also have implications for understanding the processes mediating attention in neurologically intact individuals.

1. Introduction

Attentional disturbances are frequently the first nonmemory impairment to appear in patients with Alzheimer's disease (AD), and a growing number of investigations have served to identify the specific aspects of attention that are affected in the disease (for reviews, see Amieva, Phillips, Della Sala, & Henry, 2004; Parasuraman, Greenwood, & Sunderland, 2002; Parasuraman & Haxby, 1993; Perry & Hodges, 1999). In their comprehensive review, Perry and Hodges (1999) classified the pattern of impairments observed in AD in terms of three broad subtypes of attention: (1) selective attention (the ability to focus on a single relevant stimulus or process while ignoring irrelevant stimuli); (2) divided attention (the ability to distribute attention across multiple stimuli or processes); and (3) sustained attention (the ability to maintain attentional focus over time). Based on the then-available evidence, the authors concluded that while sustained attention was relatively well-preserved early in AD (but see a more recent study by Berardi, Parasuraman, & Haxby, 2005), aspects of both selective attention and divided attention were particularly susceptible to disruption. Specifically, disengagement and set-shifting abilities at both the sensory- and response-selection levels in selective attention tasks seemed to be affected, as well as the ability to effectively distribute and coordinate attentional efforts necessary to perform multiple tasks or attend to multiple stimuli simultaneously in divided attention tasks.

The majority of studies investigating the nature of the divided attention deficit in AD have utilized dual-task paradigms in which tasks are performed both singly and in combination (e.g., Baddeley, Baddeley, Bucks, & Wilcock, 2001; Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Grober & Sliwinski, 1991; Logie, Cocchini, Della Sala, & Baddeley, 2004; MacPherson, Della Sala, Logie, & Wilcock, 2007; Nestor, Parasuraman, & Haxby, 1991; Nestor, Parsuraman, Haxby, & Grady, 1991; Ramsden, Kinsella, Ong, & Storey, 2008; Sebastian, Menor, & Elosua, 2006); these studies have consistently found AD patients to demonstrate a disproportionate impairment performing two tasks simultaneously relative to healthy elderly controls (but see Crossley, Hiscock, & Foreman, 2004; Lonie et al., 2008). This dual-task impairment has been observed even when single-task difficulty is adjusted to match

* Corresponding author at: Department of Cognitive, Linguistic and Psychological Sciences, Brown University, 89 Waterman Street, Providence, RI 02912, United States. Tel.: +1 401 863 2727; fax: +1 401 863 1300.
E-mail address: Elena_Festa@Brown.edu (E.K. Festa).

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doi:10.1016/j.neuropsychologia.2010.07.003

performance levels across the groups. Indeed, a recent study (Logie et al., 2004) found that while increasing the demands of the single task produced comparable effects on performance decrements in AD and healthy elderly control groups, AD patients nevertheless showed a disproportionate decrement in performance under dual-task conditions across both easy and difficult single-task demand levels. Healthy elderly, in contrast, have been found to display either no dual-task impairments relative to young controls under similar conditions, or slight age-related costs under conditions in which the tasks share perceptual modalities or require the concomitant generation and execution of similar motor programs (see Riby, Perfect, & Stollery, 2004 for review).

Taken together, these findings suggest that the dual-task deficit in AD may be due more to a specific inability to effectively coordinate processing across attentional networks (Baddeley et al., 2001; Logie et al., 2004) than to a general deficit in cognitive function or reduction in available attentional resources (Crossley et al., 2004). This impairment has been interpreted as a deficit in a specific dual-task coordination function of the central executive component of working memory as proposed by Baddeley and Hitch (1974) and Repovš and Baddeley (2006). The presence of a specific dual-task coordination deficit in AD patients suggests that the ability to execute concomitantly two competing tasks may prove to be a particularly sensitive marker of subtle changes in cognitive status associated with AD.

Given that AD is associated with impairments in selective attention as well as divided attention, it is critical to understand how declines in the component processes of selective attention (e.g., spatial attention, perceptual filtering, and inhibitory control) interact with the impairments in the executive processes coordinating dual-task performance in these patients. To date, however, there have been relatively few studies that have directly examined interactions between different attentional mechanisms in AD (e.g., Fernandez-Duque & Black, 2006; Festa-Martino, Ott, & Heindel, 2004; Nestor, Parasuraman, & Haxby, 1991; Nestor, Parsuraman, & Haxby et al., 1991; Parasuraman, Greenwood, & Alexander, 2000; Tales, Snowden, Brown, & Wilcock, 2006), with only two of these studies specifically comparing attentional effects in single-task to dual-task conditions (Nestor, Parasuraman, & Haxby, 1991; Nestor, Parsuraman, & Haxby et al., 1991).

Behaviorally, dual-task impairments on selective attention tasks could be manifested in different ways. First, dual-task conditions could lead to an overall increase in error rate and/or response time due to difficulty in coordinating and executing performance of the selective attention task under dual-task conditions. Based on their previously documented dual-task deficits, it is anticipated that AD patients would display both types of impairment relative to healthy elderly across a range of selective attention tasks. In addition, dual-task conditions could lead to a change in the efficiency of the selective attention mechanisms themselves, as reflected by a differential effect on different cue or display conditions within a given task. In a covert orienting task, for example, the magnitude of the spatial orienting effect can (regardless of the presence of overall slowing) either remain unchanged or increase (or decrease) due to the differential effect of dual-task conditions on response times to validly- versus invalidly-cued trials. To the degree that specific selective attention mechanisms are impaired in AD patients, the corresponding cue or stimulus conditions should be differentially affected in these patients relative to healthy elderly under dual-task conditions.

It is important to note that while there may be specific cognitive control mechanisms concerned with the coordination of multiple tasks, successful dual-task performance is ultimately an emergent property of effective processing both within and across multiple attentional and working memory components. Consistent with this notion, Lavie and colleagues (e.g. Lavie, 1995; Lavie & de Fockert, 2005; Lavie, Hirst, de Fockert, & Viding, 2004) have developed a general cognitive framework for understanding the interplay between cognitive control, working memory, and selective attention processes. These authors propose two mechanisms of selective attention within their load theory: (1) a relatively early and passive perceptual selection mechanism that excludes irrelevant stimuli under conditions of high perceptual load, based simply upon insufficient processing capacity; and (2) a relatively late attentional control mechanism that actively inhibits irrelevant stimuli when they are perceived under conditions of low perceptual load. (e.g., Lavie, 1995; Lavie & de Fockert, 2005; Lavie, Hirst, de Fockert, & Viding, 2004)

In support of this view, a number of empirical studies have found that conditions of high perceptual load that exhaust perceptual capacity lead to a reduction in interference from distracting stimuli, while conditions of low perceptual load lead to an increase in the demands placed on inhibitory control processes (e.g., Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000). Load theory has also been used to examine age-related changes in selective attention, with older adults displaying greater interference from distracting information than younger adults under low perceptual load conditions, but displaying a more rapid reduction of interference with increasing perceptual load than younger adults (Maylor & Lavie, 1998). Based on these findings, Maylor and Lavie proposed the presence of two age-related deficits in attention: (1) a decline in inhibitory control reflected in increased interference under low perceptual loads; and (2) a decline in perceptual capacity reflected in greater improvement in selective attention with increasing perceptual load.

More recently, Lavie and colleagues have extended their findings to examine the effects of changes in cognitive control load as well as perceptual load on selective attention (Lavie & de Fockert, 2003; Lavie et al., 2004). In contrast to the more passive early selection mechanisms associated with high perceptual load, low perceptual load conditions require active cognitive control mechanisms to effectively inhibit irrelevant but perceived stimuli. In a series of studies, Lavie et al. (2004) examined the effects of two types of cognitive control load (working memory and dual-task coordination) on a selective attention task; in both cases, increased cognitive control load produced increased sensitivity to irrelevant distractor information. Thus, increases in perceptual load and cognitive load produce opposite effects on selective attention: While increases in perceptual load lead to decreased interference, increases in cognitive control load lead to increased interference due to an inability to actively inhibit irrelevant information. Moreover, these findings also indicate that both increased working memory load and dual-task coordination load were effective in increasing distractor interference on selective attention tasks.

Based both on these findings and on the previous demonstrations of a dual-task coordination deficit in AD patients, one could predict that the impairments that AD patients exhibit on selective attention tasks under single-task conditions would be further exacerbated under dual-task conditions. However, other findings suggest that dual-task conditions may not in fact increase the selective attention deficits observed in AD patients, but rather may produce an apparent amelioration or "normalization" of these deficits. While increases in perceptual load have consistently been found to produce decreased interference effects in selective attention tasks as predicted by load theory, increases in cognitive control load have proved to be more variable, producing either increases or decreases in interference depending on the relationship between the nature of the selective attention task and the nature of the cognitive control mechanism being manipulated. Park, Kim, and Chun (2007), for example, found that working memory load can either impair or facilitate selective attention depending on whether the working memory items shared processing resources with the tar-