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Multitasking in aging: ERP correlates of dual-task costs in young versus low, intermediate, and high performing older adults

Sven Thönes[a,b,c,*], Michael Falkenstein[a,d], Patrick D. Gajewski[a]

[a] Leibniz Research Centre for Working Environment and Human Factors, Dortmund, Germany
[b] Experimental Psychology, Department of Psychology, Johannes Gutenberg-Universität Mainz, Germany
[c] Occupational and Engineering Psychology, Department of Psychology, Technische Universität Darmstadt, Germany
[d] Institute for Work, Learning and Aging, Bochum, Germany

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ABSTRACT

With large inter-individual variability, older adults show a decline in cognitive performance in dual-task situations. Differences in attentional processes, working memory, response selection, and general speed of information processing have been discussed as potential sources of this decline and its between-subject variability. In comparison to young subjects ($n = 36$, mean age: 25 years), we analyzed the performance of a large group of healthy elderly subjects ($n = 138$, mean age: 70 years) in a conflicting dual-task situation (PRP paradigm). Based on their dual-task costs (DTCs), the older participants were clustered in three groups of high, medium, and low performing elderly. DTCs differed between groups and increased linearly from young subjects to low performing elderly. The groups did not differ with respect to ERP-components related to task preparation (CNV) and recall of stimulus-response mappings (P2). Peak latencies of the frontocentral P2 and N2 were shorter in young as compared to older adults but did not differ between elderly performance groups. However, differences in N2 amplitude between short and long SOA were correlated with the corresponding DTCs, suggesting more efficient S-R implementation in subjects with lower DTCs. Based on our results, between-subject differences in dual-task interference can be explained in terms of individual differences in selection of an appropriate response in dual-task situations.

1. Introduction

In many everyday-life situations including working environments, multiple and conflicting tasks require a high level of cognitive resources. However, performance in multitasking situations decreases with increasing age (e.g., McAlister and Schmitter-Edgecombe, 2013; Zanto and Gazzaley, 2014). This impairment in elderly may lead to serious problems in daily life like enhanced risk for traffic accidents or falls when, for example, walking and speaking is required (Neider et al., 2011). Interestingly, older adults show larger inter-individual variability in their cognitive performance (e.g., Hultsch et al., 2002) than young adults due to long-term neurobiological and environmental influences (Li and Lindenberger, 1999) but little is known about the underlying neuronal mechanisms of these performance differences (Grady, 2012). A more profound understanding of specific differences between cognitively impaired and unimpaired elderly may help to prevent age-related decline in the ability to manage two or more tasks simultaneously. In the present study, we investigated age-related differences in performance and event-related EEG potentials in a dual-task situation. Moreover, we investigated the specific cognitive processes that differ between high, medium, and low performing elderly when two tasks have to be performed simultaneously.

When people have to perform several tasks at the same time or in close temporal succession, the different tasks usually interfere with one another, leading to decreased performance. The psychological refractory period (PRP) paradigm is an experimental task that has frequently been used to investigate capacity limitation in multitasking (e.g., Miller, 2017; Pashler, 1994; Schubert, 1999; Telford, 1931). In the PRP paradigm, two stimuli are presented with a stepwise varied delay (stimulus onset asynchrony; SOA), usually between 0 and 700 ms. The subject has to respond to each stimulus separately. Typically, the response to the second stimulus is delayed as a function of SOA, with increasing response latencies at shorter SOAs (i.e., the classical PRP effect). This effect is considered to accrue mainly from a bottleneck on the level of the response-selection stage (e.g., Pashler, 1994; Reimer et al., 2017) as at this stage only one response at a time can be selected

* Correspondence to: Leibniz Research Centre for Working Environment and Human Factors, Ardeystr. 67, 44139 Dortmund, Germany.
E-mail address: thoenes@ifado.de (S. Thönes).

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and the second task has to wait until the response selection in task one has been completed (but see also Janczyk et al., 2017).

In line with general difficulties in multitasking at advanced age, the PRP effect is increased in elderly subjects (Allen et al., 2014, 1998; Glass et al., 2000). This age-related increase in dual-task interference may be explained in terms of slowed information processing (Glass et al., 2000), a decline in attentional processes (Allen et al., 1998), and difficulties in retrieving response mappings from working memory and selecting the required response (Maquestiaux et al., 2004; Mayr, 2001). Indeed, based on the performance of older adults in a variety of cognitive tasks, both a decline of attentional and working memory capacities as well as a deficit in general processing speed are well documented (e.g., Craik and Salthouse, 2011; Gajewski et al., 2010; Wasylyshyn et al., 2011). However, there is also growing evidence for preserved attentional control in older adults (Lien et al., 2011) even in the PRP paradigm (Allen et al., 2002; Hartley, Seaman et al., 2015) suggesting that resource decrements may be rather task specific with substantial variability between subjects. To date, it remains unresolved which specific impairment(s) in the cognitive processes involved in dual tasks are causing the age-related performance decline (and its inter-individual variability) and whether specific compensatory processes (in a subgroup of older adults) help to maintain a high level of performance even at advanced age.

We therefore investigated event-related EEG components (ERPs) that reflect distinct cognitive processes in the PRP paradigm in a large sample of elderly and young subjects. There are only a few previous studies on ERPs in the PRP paradigm. Some of these evaluated the lateralized readiness potential (LRP) associated with preparation of a response but not with its execution. Osman and Moore (1993) and Sommer et al. (2001) observed a correlation between the behavioral PRP effect and the LRP activity related to the processing of the second target. Other studies focused mainly on the well-established P3 component previously associated with stimulus categorization and context updating (Donchin and Coles, 1988) to evaluate the central bottleneck account. Luck (1998), for example, analyzed the PRP effect on the P3 latency and did not find any substantial changes in latency but a reduction of the P3 amplitude at short SOAs and concluded that the bottleneck occurs after the processes of stimulus identification and categorization. In contrast, Arnell et al. (2004) as well as Dell'Acqua et al. (2005) found a clear P3 latency effect, with delayed peak amplitudes at short vs. long SOA. Arnell et al. (2004) concluded that RT delays at short SOAs in the PRP paradigm result from a combination of processing delays during stimulus identification and response selection.

Interestingly, in some of the previous studies (Arnell et al., 2004; Dell'Acqua et al., 2005; Luck, 1998), the frontocentral negativity (the N2 preceding the P3) seemed to be delayed and partly reduced at short vs. long SOA. Dell'Acqua et al. (2005), for example, applied a PRP task in two separate experiments with SOA levels of 800, 350, and 100 ms. Based on the depicted grand average wave forms, which have been locked to the onset of the second target stimulus, the N2 peaks seem to be delayed by up to 100 ms in the short as compared to the long SOA condition. As the frontal N2 has recently been associated with response-selection mechanisms (see below, e.g., Berchicci et al., 2016), the data by Dell'Acqua and colleagues may correspond to the idea of a central bottleneck at the stage of response selection. Whereas the N2 has not been targeted and analyzed statistically in the previous studies (e.g., Luck, 1998), it seems to be an important ERP component in the context of the PRP paradigm.

To fill this gap and to answer the question at which stage of information processing the age-related performance deficit occurs and whether performance variations between older subjects are reflected in distinct ERP components, we analyzed behavioral and ERP data that focus on the frontocentral components CNV, P2 and N2. Specifically, we evaluated preparatory processes including effortful preparation for the forthcoming task and expectation of an upcoming stimulus as well as motivational aspects of processing as reflected by the Contingent Negative Variation (CNV). Moreover, we focused on the frontocentral P2 and N2 components. The ERPs were compared between younger and older subjects and between three performance groups of older subjects (high, medium, and low performers) to evaluate the source of the age- and performance-related PRP effect.

An enhanced amplitude of the CNV (in elderly subjects) during the anticipation of a cognitive task, such as a choice-reaction task, has been interpreted as an index of effortful preparation (Hohnsbein et al., 1998; Wild-Wall et al., 2007) and motivation (Hughes et al., 2013). In the present study, we tested whether performance differences between elderly subjects can be explained by enhanced preparatory processes (larger CNV amplitudes) in high performing elderly subjects. Such a result would account for the idea of maintained attentional preparation in high performing elderly subjects. However, it would not specifically relate to dual-task situations as effortful preparation and motivation should facilitate performance in any cognitive task. Moreover, the cue stimulus, which "elicits" the CNV, does not convey any specific information about the upcoming trial (whether or not the two targets are presented simultaneously). Therefore, potential effects on the CNV amplitude would provide evidence for differences in preparatory or motivational aspects of task processing but only limited insight into the specific cognitive mechanisms that are related to age differences in dual-task interference.

More interestingly, differences in the P2 and N2 components, especially in response to simultaneously presented target stimuli, would indicate differences in executive control mechanisms, like memory retrieval and response selection, which are essential and specific for reaching a high performance level in the PRP task. The subjects need to recall the instructed S-R mappings efficiently from working memory and implement the selected responses accordingly. Whereas the P2 component of the event-related EEG has been related to the evaluation of task relevant stimuli and the retrieval of task-related information from working memory (e.g., recall of S-R mappings) (Finke et al., 2011; Gajewski et al., 2008; Potts, 2004), the N2 was associated with conflict processing and cognitive control (Folstein and Van Petten, 2008; Van Veen and Carter, 2002). Generally, larger N2 amplitudes have been interpreted as correlates of enhanced cognitive control during conflict (e.g., Larson et al., 2014). Moreover, the N2 has been linked to later processes of response selection, that is, the implementation of the retrieved S-R mappings to activate a correct response in speeded (choice) reaction tasks (Berchicci et al., 2016; Beste et al., 2010; Di Russo et al., 2006; Gajewski et al., 2008; Hohnsbein et al., 1998; Karch et al., 2010; Ritter et al., 1982). Larger N2 amplitudes have been observed during improved response selection in task switching, leading to enhanced performance after cognitive training in middle-aged (Gajewski et al., 2017) and old adults (Gajewski and Falkenstein, 2012). Moreover, simple tasks with low response-selection demands elicit large N2 amplitudes compared to difficult tasks with overlapping S-R sets (Gajewski and Falkenstein, 2015; Schapkin et al., 2014). Consequently, temporally overlapping tasks should lead to a lower N2 amplitude than none overlapping tasks. Transferred to the PRP paradigm, we would expect generally lower and delayed N2 amplitudes at short compared to long SOAs when interference during response selection is diminished. To date, none of the previous studies investigated the N2 component and only one focused on the P2: Dell'Acqua et al. (2005) reported a latency delay and smaller P2 amplitudes with shorter SOAs, suggesting that the retrieval of S-R mappings may be affected by temporally overlapping tasks.

We therefore investigated whether P2 and N2 amplitudes and latencies especially in response to the target stimuli in a short SOA condition differ between young and older subjects and between high and low performing elderly in order to relate potential differences in dual-task costs to particular electrophysiological indices. As it has been reported previously, the N2 component shows larger amplitude and shorter latency in young relative to older subjects (e.g., Friedman, 2008). Regarding the P2, the findings are less consistent, but some