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Research report

Cognitive performance under motor demands – On the influence of task difficulty and postural control

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ABSTRACT

We often walk around when we have to think about something, but suddenly stop when we are confronted with a demanding cognitive task, such as calculating 1540*24. While previous neurophysiological research investigated cognitive and motor performance separately, findings that combine both are rare. To get a deeper understanding of the influence of motor demands as well as the difficulty of a simultaneously performed cognitive task, we investigated 20 healthy individuals. Participants performed two cognitive tasks with different levels of difficulty while sitting or standing on one leg. In addition to behavioral data, we recorded the electroencephalogram from 26Ag/AgCI scalp electrodes. The critical time-windows, predefined by visual inspection, yielded an early (200–300 ms, P2) and a subsequent positivity (350–500 ms, P3). Statistical analysis of the early time window registered a motor × cognition interaction. Resolution of this interaction revealed an effect of the cognitive task in the one-legged stance motor condition, with a more pronounced positivity for the difficult task. No significant differences between cognitive tasks emerged for the simple motor condition. The time-window between 350 and 500 ms registered main effects of the motor task and a trend for the cognitive task. While the influence of cognitive task difficulty (in the P3) is in accordance with previous studies, the motor task effect is specific to one-legged stance (cf. no effects for running in previous research). The motor-cognition interaction found in the P2 indicates that the more difficult motor task (one-legged stance) facilitates cognitive task performance.

1. Introduction

We often walk around when we have to think about something, but abruptly stop when we are confronted with a demanding cognitive task, such as calculating 1540*24. Although numerous previous behavioral studies reported interference from combining motor and cognitive tasks in an applied context (for reviews cf. e.g. Woollacott and Shumway-Cook, 2002; Liebherr et al., 2016 for review), it is inevitable to investigate the simultaneous processing of motion and cognition in a more fundamental way. With the current research, we present a neurophysiological investigation of the interplay of simultaneous motor and cognitive demands. In particular, we examine dual-task interference by varying the levels of a cognitive task (simple vs. difficult decisions) and a concurrent motor demand (sitting vs. one-legged stance) during an event-related brain potential (ERP) study.

Previous research on the simultaneous processing of motor and cognitive tasks has yielded mixed results. For example, Kemper et al. (2003) showed that younger adults reduced sentence length and grammatical complexity in response to questions while walking and finger tapping. Beyond tapping exercises, the inclusion of walking or balancing tasks in motor/cognitive dual-task studies is often based on a more applied level and mostly used in age- or disease-related research. For instance, a study by Hollman and Colleagues (2007) investigated parameters of gait during walking while simultaneously performing a cognitive task in three age groups (20–35, 40–55, 70+ years). The older group walked slower and had an increased variability in stride velocity compared to the group of middle-aged and young participants. The authors suggested that the restricted walking performance was associated with limited cognitive performance in dual-task walking. While many other studies supported the findings of age-related differences (e.g. Lindenberger et al., 2000; Dubost et al., 2006; Priest et al., 2008), Springer et al. (2006) found a decreased gait variability under different dual-task conditions in both younger and

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healthy older adults. A significant group-effect due to dual-tasking became only apparent when an additional factor was taken into account, namely reported incidences of falls in the elderly group. Similar findings were shown in postural control studies (e.g. Teasdale et al., 1993; Shumway-Cook et al., 1997; Brown et al., 1999; Rankin et al., 2000). For instance, Rankin et al. (2000) reported that muscle activity while reacting on platform perturbations is significantly affected by a secondary task and that this effect is more pronounced in a group of elderly participants. As stated by Shumway-Cook et al. (1997), higher discriminative effects between healthy younger and healthy older participants come along with increasing task-complexity, which was confirmed by subsequent studies (Shumway-Cook & Woollacott, 2000; Bernard-Demanze et al., 2009). In contrast, Prado et al. (2007) found an impact of dual-tasking on postural control parameters, but crucially no difference between younger and elderly participants with regard to the dual-task setting.

While there is ample evidence for dual-task interferences, the explanations for the underlying processes differ substantially. The bottleneck theory assumes that parallel processing is not possible and that only one task at a time has access to a central cognitive operation (Welford, 1952; Pashler, 1994). According to the capacity sharing approach, the two tasks compete for the same processing resources, and more demands on one task reduce the amount of available resources for the other task (e.g. Kahneman, 1973; Navon & Miller, 2002). Furthermore, cross-talk models focuses on the content of the combined tasks and suggest that it is more difficult to perform two tasks when they involve similar information (see Pashler, 1994 for overview). For example, Navon and Miller (1987) showed that situations in which the distractor of one task is similar to the target category of a second task lead to higher interferences compared to situations with clear differences in the content. A more recent study - conducted by Koch (2009) – investigated the effects of a non-speeded visual task (different objects) and an auditory-manual reaction-time task combination. Based on their results, the authors suggested stronger cross-talk in compatible vs. incompatible trials. Overall, allocation of resources is therefore a central concern for the investigation of dual-tasking.

In addition to the contribution of particular task demands on simultaneously performing motor and cognitive tasks, the way of measuring the arising effects might also play a significant role. Previous studies mostly assessed cognitive/motor task-combinations on a behavioral level, whereas neurophysiological methods allow us to get a better understanding of the underlying mechanisms. Electroencephalography (EEG), and especially the recording of event-related potentials – which reflect direct responses of a specific sensory, cognitive, or motor event – offers a method to get a deeper insight into the contribution of more difficult motor tasks (e.g. balancing) on cognitive processes. In this regard, the P3/300, a component that is linked either to the third positive peak after a stimulus or to a positive deflection 300 ms after stimulus onset has been associated inter alia with attention (e.g. Herrmann & Knight, 2001 for an overview) and cognitive demand (for a comprehensive overview see Polich, 2007). For investigations of the P3/300, the oddball task has become a frequently used paradigm in both single- and dual-task studies. Originally described by Ritter and Vaughan (1969), the task comprises of the presentation of sequences of repetitive stimuli, which are infrequently interrupted by a deviant stimulus. Within dual-task studies, the oddball-task (as secondary task) has been used in combination with visual tracking tasks (Wickens et al., 1977; Isreal et al., 1980a), simulator tasks (Kramer et al., 1987), or visuomotor force-tracking tasks (Kida et al., 2012). Results showed that the amplitude of the P3/300, which is triggered by deviating stimuli, depends on the difficulty of the primary task only under the premise that the difficulty is manipulated within the perceptual-central domain. In addition, increasing task difficulty within the dual-task paradigm can also lead to a reduction in P3/300 latency (Brookhuis et al., 1981; Hoffman et al., 1983; van Dellen et al., 1985; Wijers et al., 1987; Smid et al., 1991; Lorist et al., 1996; Kok, 2001 for review). Combining motor demands (standing, walking and running) with an additional oddball-task, Gramann et al. (2010) showed no influence of different motor demands on P3/300 amplitude. The authors suggested that the motor demands were too simple to trigger a resource conflict. This proposal is in accordance with previous behavioral findings that showed no interruption of the maintenance of postural control in healthy young adults during dual- or multi-tasking (e.g. Woollacott & Shumway-Cook, 2002).

Another candidate signature for differences in dual-task performance may be an earlier positivity between 200 and 300 ms (P2/200). Previous studies strengthened the relevance of P2/200 in the context of attention (e.g. Maeno et al., 2004), resource allocation (Sugimoto & Katayama, 2013; Campbell & Sharma, 2015), type of stimulus (e.g. Shahin et al., 2005), probability (e.g. Roth et al., 1976), memory (e.g. Dunn et al., 1998; Lefebvre et al., 2005) and language processing (e.g. Tonnquist-Uhlen, 1996). Similar to the P3/300, attention plays a significant role in the amplitude of the P2/200. Amongst others, Maeno et al. (2004) provided support for this assumption by demonstrating a change within the P200 in parietal and frontal regions related to the amount of attention allocated to a particular stimulus. A few studies also investigated P200 effects in the context of motor and sensorimotor processing (Sibley et al., 2010, Huang & Hwang, 2013; Huang et al., 2014). Investigating postural instability, Sibley et al. (2010) showed no differences in the P2/200 as a function of increasing postural demand. Within their study, participants had to react to perturbations while standing at ground level and on an elevated platform (160 cm). While the authors used only bipedal stance, participants in the study conducted by Huang and Hwang (2013) had to perform two stance conditions (bipedal and unipedal stance) under static and dynamic force-matching maneuvers. In contrast to Sibley et al. (2010), Huang and Hwang (2013) reported differences in the P2/200 across conditions. They showed a smaller P2/200 in the right parietal cortex for the dynamic force-matching but no P2 modulation from the variation of stance. Another study conducted by Huang et al. (2014) investigated neural control of a postural-supra-postural procedure when postural focus strategy varied between an internal focus (visual feedback linked to angular movement of the participant's ankle) and an external focus (visual feedback linked to stabilometer angle). Comparing visual internal and visual external focus, the authors demonstrated an increase in P2-amplitude around the bilateral fronto-central and ipsilateral temporal areas in the visual external focus condition.

While most EEG-studies investigated the simultaneous performance of two cognitive tasks (e.g. Stipacek et al., 2003), a comprehensive understanding of the effects of cognitive/motor task-combinations is still missing. Since the demands in everyday situations are ever growing (e.g. we are standing in the railway while calling a colleague and checking our appointments or we carry out our daily workout while listening to music and writing text messages to our friends), a thorough understanding in particular of the interaction of these tasks will be of utmost importance. Crucial questions to be addressed in this regard are how many tasks humans can perform, how much information they can process, and how this is influenced by the type and difficulty of the involved information. While previous studies addressed these questions from a behavioral perspective and asked for the amount of information that humans are able to process (e.g. Halford et al., 2005), the main goal of the present study is to investigate potential task