From the corner of my eye - Locomotion complexity and single-target visual search

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Jobs in many fields are evolving to include simultaneous cognitive and motor load – such as walking in a warehouse while receiving and processing visual information about the whereabouts of a specific parcel via data glasses. In many situations though, it is important to process and respond to incoming visual information appearing not only at the central point of view but also when that information is presented more peripherally. Yet, little is known about the cognitive underpinnings of processing peripheral visual information during locomotion. It was shown that cognitive and motor tasks draw from the same pool of limited cognitive resources (e.g. Al-Yahya et al., 2011; Beurskens et al., 2016; Reiser et al., 2019) so that increasing load in either domain lead to behavioral decrements when reaching a certain threshold. This phenomenon is called cognitive-motor interference (CMI). Still, a few studies that investigated visual processing of peripheral information found that walking might enhance attention in peripheral regions of the visual field (Benjamin et al., 2018; Cao & Händel, 2019). To get to the bottom of these rather contradictory findings, we wanted to investigate in how far different degrees of motor complexity (standing, walking, perturbed walking) affected the cognitive processing of single central (0°-4° visual angle), macular (4-18° visual angle), and peripheral stimuli (18-40° visual angle) using manual response measures and mobile EEG. Besides response times and accuracies, we analyzed event-related potentials (ERPs) that are known to give insights into early visual sensory processing (posterior contralateral N1; Schneider & Wascher, 2013) as well as more general cognitive resource distribution (parietal P3; Kok, 2001).

To this end, 21 participants (18-33 years; 12 female, 9 male) performed a CMI dual-task. The whole experiment took place in the institute's Gait Real-time Analysis Interactive Laboratory (GRAIL, Motek, NL). In a block-wise manner, participants either stood on a treadmill, walked with a speed of 1.2 m/s (regular, automatic walking), or walked with 1.2 m/s while being perturbed either to the left or right by a quick sideway of the treadmill (perturbed walking). During each block, they performed 300 trials in which they were presented with a single Landolt ring with an upward or downward facing opening (see Figure 1). Participants had to identify this opening by a left-hand or right-hand response button press (hand-assignments were balanced throughout participants). Landolt rings were projected onto a 180° curved projection screen in a continuous range between -40° and +40° visual angle. For analysis purposes, these continuously presented stimuli were binned into three categories: central (0°-4°), macular (4°-18°), and peripheral (18°-40°). Each trial lasted between 1500 and 2000 ms; a trial started with a 250 ms fixation cross, followed by a 250 ms presentation of the rings, and ended with a jittered inter trial interval with a duration of 1250 – 1750 ms in which participants could give their manual response. Neurophysiological data were recorded using a 64-channel mobile EEG set-up. All data was collected in one session per participant. The order of conditions was balanced to prevent bias.

EEG measures were calculated time-locked to stimulus presentation only using correct trials. To evaluate underlying cognitive processes, we computed ERPs, namely parietal P3 at Pz, and parieto-occipital N1pc at PO7/PO8. We quantified those components using 50% fractional area amplitudes (FAA). Those values were then jack-knifed and entered into 3*3 or 3*2 (movement complexity * eccentricity) repeated measures ANOVAs. Post-hoc paired sample *t*-tests were conducted. ANOVA results were Greenhouse-Geisser corrected if necessary. Also, all derived p-values were FDR corrected (Cramer et al., 2016).

Behavioral measures showed several detailed differences: increased motor complexity increased response times, whereas increased eccentricity led to increasing response times, and impaired accuracy. Early ERPs showed a different pattern. Here, we found a main effect of eccentricity. N1pc FAA decreased significantly with increasing eccentricity. Interestingly, when looking at post-hoc differences, the N1pc FAA was increased when walking as compared to standing and perturbed walking in both eccentricity manipulations. P3 amplitudes, on the other hand, showed main effects for movement complexity and stimulus eccentricity. The ANOVA results indicated higher P3 FAA for standing in comparison to regular and perturbed walking as well as for central and macular stimuli compared to peripheral ones.

In short, the findings highlight distinct differences of the interplay between motor complexity and stimulus eccentricity in both behavioral and neurophysiological data. Looking at the elevated N1pc amplitudes for macular stimuli during regular walking as compared to standing and perturbed walking, this could indicate that macular stimuli were processed faster and with a higher proportion of shared cognitive resources. With peripheral stimuli, this advantage is still evident, though highest N1pc FAA are found during standing. Also, we found a reduction in P3 amplitude for locomotive conditions as compared to standing. As this component is related to later processing stages and resource distribution, this finding might suggest that shared resources were increasingly depleted while participants were moving, be it automatic or perturbed, in comparison to standing – replicating previous CMI findings in the field (Reiser et al., 2019, 2020). This difference in cognitive processing does not find expression in behavioral measures though, as response times were only elevated when participants walked with perturbations.

Looking at real-world applications, these results highlight that simple, unperturbed locomotion does not necessarily impair CMI performance, it might even elevate early sensory processing. Increasing the eccentricity of visual stimuli in head-up displays or other visual screens in mobile working environments without complex surface conditions might therefore not impair work performance.

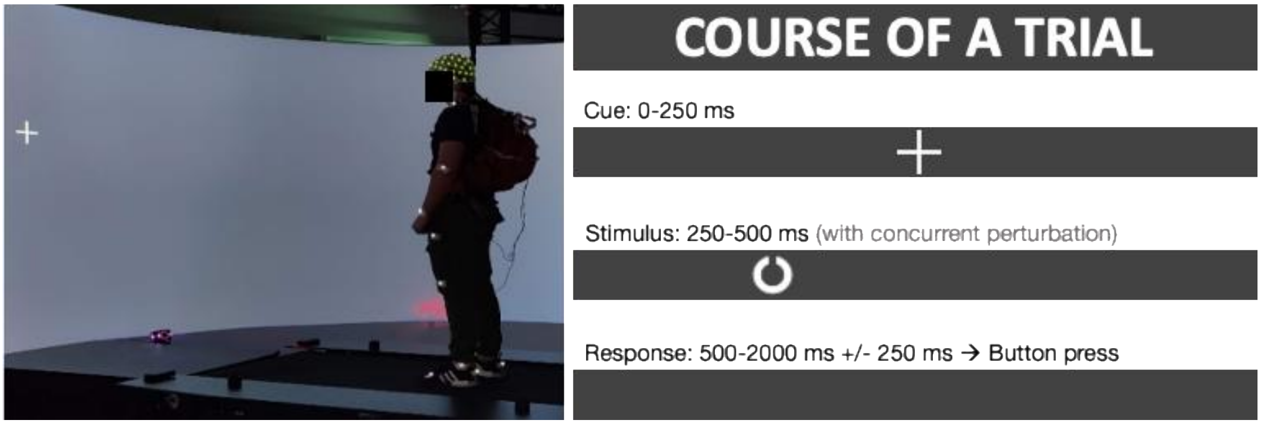

Figure 1. Left: GRAIL facilities at the Leibniz Research Centre for Working Environment and Human Factors. Participants wore a 64-channel mobile EEG (LiveAmp 64, Brain Products GmbH, GER), motion tracking markers and one self-made response button in each hand. They were presented with Landolt ring stimuli in various degrees of visual angle eccentricities (0-40°) on a 180° curved projection screen. Right: The course of a trial. First, a fixation cross was presented for 250 ms, followed by a Landolt ring stimulus for 250ms. Finally, participants had to respond manually in a 1500 ms with a jitter of +/- 250 ms.

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