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Research report

The impact of cognitive load on reward evaluation

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ABSTRACT

The neural systems that afford our ability to evaluate rewards and punishments are impacted by a variety of external factors. Here, we demonstrate that increased cognitive load reduces the functional efficacy of a reward processing system within the human medial–frontal cortex. In our paradigm, two groups of participants used performance feedback to estimate the exact duration of one second while electroencephalographic (EEG) data was recorded. Prior to performing the time estimation task, both groups were instructed to keep their eyes still and avoid blinking in line with well established EEG protocol. However, during performance of the time-estimation task, one of the two groups was provided with trial-to-trial-feedback about their performance on the time-estimation task and their eye movements to induce a higher level of cognitive load relative to participants in the other group who were solely provided with feedback about the accuracy of their temporal estimates. In line with previous work, we found that the higher level of cognitive load reduced the amplitude of the feedback-related negativity, a component of the human event-related brain potential associated with reward evaluation within the medial–frontal cortex. Importantly, our results provide further support that increased cognitive load reduces the functional efficacy of a neural system associated with reward processing.

1. Introduction

When we learn, we do not learn in isolation. Typically, the neural systems that underpin human learning are forced to evaluate performance outcomes in complex environments that require several actions to be performed simultaneously. For example, the dangers brought about by talking on a cellphone while driving are well known (Horrey et al., 2006; Pickrell and Ye, 2013; Singh, 2010). Multi-tasking while we drive, or while we do any other activity in which we wish performance to be optimal, is well known to result in behavioral performance decrements for both tasks (Heenan et al., 2014; Kahneman, 1973; Ishigami and Klein, 2009; Ma and Kaber, 2005; McCarley et al., 2004; Strayer et al., 2003; Wickens, 1981). Here, we extend previous work (Krigolson et al., 2012) examining the impact of increased cognitive load on the neural systems that subserve human learning and demonstrate that the increased cognitive load brought about

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by multi-tasking reduces the functional efficacy of an error evaluation system within the medial–frontal cortex.

The impact of cognitive load on performance in general is a well studied phenomenon (Andersson et al., 2002; Broadbent, 1958; Kahneman, 1973; Knowles, 1963; Park et al., 2011; Sweller, 1994). In dual-task paradigms, cognitive load is induced by having people perform two tasks simultaneously that compete for cognitive resources (e.g., Wickens, 1981), for example, performing a visual stimulus-response task while at the same time having to listen for auditory cues. While typically the performance decrements associated with dual-task conditions are explained in terms of attention (c.f., Wickens, 1992), one can also simply think of a dual or multi-task condition in terms of cognitive load. In other words, in a dual-task condition a participant experiences greater cognitive load relative to a single-task condition and it is the increased cognitive load that leads to performance decrements. Of course, this is a moot point and one could also explain the performance decrement in terms of attention – the point, however, is simple – people perform worse in dual task conditions. Here, we are interested in how increased cognitive load impacts the function of neural systems other than attentional processes. For instance, a growing body of evidence suggests that human learning is principally driven by a reinforcement learning system within the human medial–frontal cortex that utilizes performance feedback to optimize behavior (Holroyd and Coles, 2002; Holroyd et al., 2005). Only recently has the impact of cognitive load on reward processing within the medial–frontal cortex been examined.

In a previous experiment (Krigolson et al., 2012) we sought to do just this – examine the impact of cognitive load on reward-processing within the human medial–frontal cortex. In our experiment, we had participants perform a simple time estimation task (c.f., Miltner et al., 1997) during which they learned to accurately guess the duration of one second via a trial and error feedback driven shaping process. The experiment was split into two separate counter-balanced experimental blocks, and within each the feedback provided to participants varied in terms of cognitive load – one feedback condition was considered to be "low-load" whereas the other was considered to be "high-load". In the low-load condition the feedback provided to participants simply consisted of a check mark that indicated a correct temporal estimate or a cross mark that indicated an incorrect temporal estimate. In the high-load condition the feedback following a participant's guess consisted of two integers – the participants mentally summed the numbers and an even sum indicated a correct temporal estimate whereas an odd sum indicated an incorrect temporal estimate. Not surprisingly, in terms of behavioral performance participants performed worse in the high-load condition relative to the low-load condition. Of principle interest however was the finding that the amplitude of the feedback-related negativity (FRN) – the difference in the event-related brain potentials (ERPs) evoked by positive and negative outcomes 200–300 ms following feedback delivery – was also reduced in the high-load condition relative to the low-load condition. In other words, increasing the cognitive load of the feedback stimulus reduced the functional efficacy of the medial–frontal learning system (Holroyd and Coles, 2002) – a result that suggests people may not learn as effectively in high cognitive load conditions because the neural system responsible for learning is impaired.

In the present experiment, we sought to extend our original work (Krigolson et al., 2012) by examining the impact of cognitive load induced by multi-tasking on reward processing within the medial–frontal cortex. In the present experiment, we had two groups of participants complete a time estimation task similar to the one we employed in our previous work while we recorded both ocular and EEG data. To induce a higher level of cognitive load on one of the groups of participants we added a second task to their paradigm that they performed concurrently with the time estimation task. More specifically, while we instructed both groups of participants to try and keep their eye movements to a minimum and avoid blinking, we also told participants in the high-cognitive load group (HCL) that we would be tracking their eye movements and providing them with feedback in order to train them to not move their eyes while they performed the time estimation task. Our logic here was simple: while both groups of participants were given the same instruction to not move their eyes, we believed that because of the feedback induced training for HCL participants they would be performing two tasks simultaneously and thus would experience a higher level of cognitive load.

Given our previous results (Krigolson et al., 2012), we predicted that behavioral performance and the amplitude of the FRN would be impacted by increased cognitive load. More specifically, we predicted that behavioral performance and FRN amplitude would be reduced for HCL participants relative to LCL participants.

2. Results

2.1. *Behavioral data*

Given our performance based manipulation on the size of the response window (see Section 5 for more detail), mean accuracy did not differ between the LCL (49% [48% 50%]) and HCL (49% [48% 50%]) conditions ($p>0.05$). We also examined the mean window size for both the LCL (139 ms [109 ms 165 ms]) and the HCL groups (163 ms [102 ms 224 ms]) and found that this did not differ, $t(13)=0.40$, $p>0.05$. In line with our previous work we examined the percent change in participants' estimates following correct and error feedback. Not surprisingly, we found a large effect of feedback valence – participants made larger changes to their temporal estimates following error feedback (25.6% [20.0% 31.1%]) as opposed to correct feedback (13.8% [11.0% 16.6%]) ($F(1,26)=50.31$, $p<0.001$, partial $\eta^2=0.66$). However, we observed no effect of cognitive load on the change on participants' estimates following error (LCL 251 ms [176 ms 326 ms] versus HCL 261 ms [173 ms 349 ms]) or correct (LCL 140 ms [95 ms 183 ms] versus HCL 136 ms [99 ms 174 ms]) feedback ($p>0.05$).

2.2. *Ocular data*

To examine the effect of eye movement feedback on eye movements, we calculated each participant's overall proportion of trials in which an eye movement occurred either 400–600 ms before feedback or while the time estimation feedback was displayed for 1000 ms. Not surprisingly, participants that