Reorganization of neural resources and its downstream effects on exercise in stressful dual task conditions

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Synopsis

This study investigates how cognitive stress impacts the cortical regulation of a fatiguing elbow flexion task. Participants performed a submaximal intermittent elbow flexion task with and without a cognitive stressor. Participants' performance and fatigability metrics were collected in each condition along with cortical activation and functional connectivity between prefrontal cortex (PFC) and motor areas (M1). Exercise related activation in PFC and M1 were reduced, but small world properties of the cortical network increased with stress leading to delayed fatigue and impaired motor performance suggesting that cognitive stressors impacts the proper regulation of exercise and fatigue.

Background

Physical task performance and muscle fatigue are impacted by high cognitive workload and stress. This may be due to the perturbation of cortical functions that are involved in regulating exercise. The prefrontal cortex (PFC) plays a key role in regulating exercise performance by integrating afferent information from the muscles with physical, emotional, and motivational contexts (Robertson & Marino, 2016) as well as in generating the intention to exert force. Once a decision to exert is made, the pre-motor cortex (PM) and the supplementary motor area (SMA; Eliasmith et al., 2012) are further involved in the planning and coordination of complex movement relaying the information to the primary motor cortex (M1) which then sends out a voluntary drive to the muscles (DeWolf & Eliasmith, 2011). Therefore, the prefrontal cortex as well as the premotor areas of the brain are involved both in exercise performance as well as in cognitive task performance. However, in instances of multitasking physical and cognitive effort, the PFC must allocate its limited neural resources between motor and cognitive demands (Johnson et al., 2007). . However, the distribution of neural and attention resources during exercise and their continued use with fatigue development is not very well understood in dual task conditions.

Methods

A total of 30 right-handed young adults (15 male and 15 female) aged 18 to 55 performed an intermittent elbow flexion task till voluntary fatigue at 30% of their maximum strength with and without a cognitively challenging mental math task aimed at inducing stress. Participants' endurance time, strength loss, and force steadiness was measured. Functional near-infrared spectroscopy (fNIRS) was used to measure hemodynamic activity in the following regions of interest middle, right and left prefrontal cortex (M/R/L PFC), left and right primary motor cortex (L/R M1), supplementary motor area (SMA), and left and right premotor areas (L/R PM). Channelwise functional connectivity of the entire cortical network was also calculated using pairwse pearson correlations. The small-world properties of these networks were also evaluated in each condition by calculating Clustering coefficient (C_p), global efficiency (E_glob), and modularity (Q) of these networks using the brain connectivity toolbox in MATLAB (http://www.brain-connectivity-toolbox.net/).

A Repeated Measures ANOVA was performed with condition (Control, Stress) as within-subject factors, and sex as a between-subject factor on endurance time and strength loss. A Repeated Measures ANOVA was performed with condition (Control, Stress) and phase (Before fatiguing task, after fatiguing task) as within-subject factors, and sex as a between-subject factor on the state scores of STAI. A Repeated Measures ANOVA was performed with condition (Control,

Stress) and phase (Early, Middle, Late) as within-subject factors, and sex as a between-subject factors on all other dependent variables.

Results

There was a significant main effect of condition (F (1, 23) = 8.309; p = 0.008; η_p^2=0.265) on the endurance time which was higher in stress condition than the control condition. Force CV was significantly higher in the stress condition as compared to the control condition (F (1, 23) = 10.947; p = 0.003; η_p^2=0.322). Activation under stress was also reduced in the following brain areas: MPFC (F (1, 23) = 9.303; p = 0.006; η_p^2=0.288), LPFC (F (1, 23) = 5.009; p = 0.035; η_p^2 =0.179), RPFC (F (1, 23) = 7.623; p = 0.011; η_p^2=0.249), LPM (F (1, 23) = 9.167; p = 0.006; η_p^2 =0.285), RPM (F (1, 23) = 7.369; p = 0.012; η_p^2=0.243), ad LM1 (F (1, 23) = 16.452; p < 0.001; η_p^2 =0.417). Clustering coefficient also increased under stress (F (1, 23) = 7.734; p = 0.011; η_p^2 =0.252). A significant interaction effect of condition × phase (F (2, 46) = 3.303; p = 0.046; η_p^2= 0.126) was observed for modularity, which was higher in stress condition compared to control condition during middle and late phases. For the purpose of brevity, significant effects of phase and sex are not discussed here.

Discussion

Our findings revealed that exercise-related activation in the PFC and motor areas was lower under stress. Conversely, clustering and modularity was higher in the stress condition. As a result, participants exhibited lower joint steadiness but were able to prolong the fatiguing exercise under stress while also exhibiting lower strength loss. This indicates that task related involvement of the cognitive and motor areas was reduced leading to impaired motor performance and a delayed onset of fatigue under stress.

The dual-task condition required both cognitive control and physical effort, and therefore, physical exercise received fewer processing resources than in the single-task condition as evidenced by the lower activation and subsequent impaired performance. The reduced engagement of the PFC and motor areas in the physical task under the stress condition likely disrupted the PFC's role in regulating exercise performance including making decisions about modifying exercise intensity or terminating the task (Patelaki et al., 2022; Robertson & Marino, 2016). On the other hand, small world properties were significantly higher under the stress condition indicating a more efficient network organization, that can contribute to improved task performance outcomes (Bullmore & Sporns, 2009).

These findings collectively indicate a task demand related impairment of relevant cortical regions involved in exercise performance as well as compensatory restructuring of cortical networks to maximize efficiency. The disruption in the prefrontal and motor activity led to a delayed onset of fatigue and impaired performance highlighting the key role played by cortical areas of the brain in fatigue perception.

Disclosures

Authors report no conflicts of interest

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