Quantifying mental fatigue with behavioral and psychophysiological indexes: evidence from three experiments

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Résumé

Introduction

Acute mental fatigue is characterized by a transient reduced capacity and/or willingness to exert effort, occurring during or after prolonged, demanding cognitive activity, and often leading to impaired performance. In sports, managing mental fatigue effectively is essential to sustain performance during prolonged endurance events and to cope with stress and anxiety in competitions settings. However, individuals respond differently to mental fatigue: some increase their effort to maintain performance or adopt less effortful strategies that still achieved task goals, while others disengage, leading to performance decrements. This variability underscores the need for understanding the mechanisms underlying mental fatigue and effort regulation. This series of three studies aims to investigate effort investment in response to mental fatigue by integrating behavioral and psychophysiological measures of effort. We also explore alternative mechanisms, such as reduced motivation, and boredom.

Methodology

Three experimental studies were conducted: (1) the first included a 30-min modified Stroop task to induce mental fatigue, followed by a handgrip endurance task; (2) in the second, participants performed a 30-min simultaneous interpreting task followed by a working memory task; (3) in the third, a 30-min visuo spatial working memory task (i.e., dual 2-back task) followed by a letter 2-back task. Effort was assessed through psychophysiological markers, including the pre-ejection period (i.e., a cardiac measure of sympathetic activity) and EEG indices such as event related potentials (ERPs) and event related prefrontal theta density.

Results

Across these three experiments, specific behavioral performance declines were observed among participants as time on task and also on the subsequent task. In the first experiment, participants exhibited a significant decline in performance during the Stroop task, and subsequently

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during the physical performance. Pre-ejection period during the Stroop task declined as time on task suggesting disengagement of effort. Notably, these physiological changes did not correlate with self-reported and performance measures, indicating a potential disconnection between behavioral and psychophysiological indexes of effort.

The second experiment revealed a decline in performance during the simultaneous interpreting task asses with long pauses ($>$ 2secs), and after this task, with a concomitant decrease in pre-ejection period. Again, no significant correlation was found between psychophysiological and behavioral indexes of effort.

In the third experiment, performance decreased over time, accompanied by a reduction in P300 amplitude and an increase in event-related theta activity. No changes were observed in pre-ejection period. These mixed results may be attributed to a high interindividual variability in responses to mental fatigue. Additionally, behavioral and psychophysiological measures did not correlate. Cluster analysis of the large participant group (N = 69) revealed two primary subgroups: (1) good conservative responders, high performers who exhibited a decline in performance over time; (2) inaccurate liberal responders, which are participants who performed poorly from the outset and did not show a decrease of performance over time.

Discussion

This series of three experiments demonstrates that mental fatigue can be experimentally induced with many experimental precautions and its effects can be observed both as time on task and in subsequent tasks. However, assessing the effort invested remains more challenging. Our findings reveal a dissociation between psychophysiological indicators of effort and behavioral performance. In particular, the pre-ejection period (PEP), commonly used as a marker of sympathetic activation and effort, appears to be influenced by additional factors beyond effort investment, such as stress and task habituation. Furthermore, other mechanisms such as motivation, or boredom did not show significant associations with psychophysiological indexes or performance changes, implying that these factors are not the driven factor behind mental fatigue. These results highlight the need for further research to identify more specific and sensitive measures of effort investment. Finally, the emergence of distinct participant profiles emphasizes the importance of accounting for individual variability in responses to mental fatigue.