ABSTRACT

Title of Dissertation:	EFFECT OF SPATIAL WORKING MEMORY DEPLETION ON CEREBRAL CORTICAL DYNAMICS OF COGNITIVE-MOTOR PERFORMANCE
	Emma Patricia Shaw, Doctor of Philosophy, 2020
Dissertation directed by:	Assistant Professor Rodolphe J. Gentili, Department of Kinesiology

Prior work has validated the use of resource depletion to directly probe the role of specific cognitive functions on human performance. Specifically, intensive recruitment of cognitive resources to successfully perform a task has been shown to result in performance decrements and decreased neural activation on subsequent tasks. Much of this work, however, was not conducted within the context of cognitive-motor performance and/or did not examine the underlying brain dynamics. Therefore, this study examined the effects of depleted spatial working memory (SWM) resources, critical for spatial information processing, on performance and brain dynamics (attentional reserve and cognitive-motor effort). Performance and electroencephalography were collected as thirty-five individuals, randomly assigned to an experimental or control group, with minimal prior videogame experience completed a cognitive-motor task at an easy and a hard level of difficulty before and after undergoing SWM resource depletion (experimental) or non-depletion (control). The SWM depletion protocol required intensive mental rotation, while the non-depletion protocol did not. Attentional reserve was assessed via the novelty-P3 component of the event-related potential and cognitive-motor effort was assessed via spectral power within the theta, low- and high-alpha frequency bandwidths. The results revealed both groups exhibited similar performance improvement on the cognitive-motor task post-compared to pre-SWM depletion/non-depletion. This was accompanied with a more efficient engagement of attentional resources (decreased novelty-P3) and a refinement of cortical activity (low-/high-alpha synchrony), which may reflect a practice effect. Furthermore, the control group exhibited theta synchrony under the hard compared to the easy level of challenge across all cortical regions regardless of when the cognitive-motor task was performed. This adaptive response, however, was absent within the frontal and temporal cortical regions (important for working memory, attentional control and visuospatial processes) for the experimental group post-SWM depletion. Additionally, the experimental group, post-relative to pre-SWM depletion, exhibited temporal theta desynchrony and synchrony during the hard and easy level of challenge, respectively. These findings collectively suggest intensive cognitive task performance has a combined neurocognitive benefit (i.e., practice effect) and cost (i.e., lack of adaptive response due to depleted resources) during subsequent cognitive-motor performance requiring similar cognitive processes as that of the depleting task.

EFFECT OF SPATIAL WORKING MEMORY DEPLETION ON CEREBRAL CORTICAL DYNAMICS OF COGNITIVE-MOTOR PERFORMANCE

by

Emma Patricia Shaw

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2020

Advisory Committee:
  Assistant Professor Rodolphe J. Gentili, Chair
  Associate Professor Donald J. Bolger
  Professor Bradley D. Hatfield
  Faculty Research Director Bradford D. Hendershot
  Associate Professor Craig G. McDonald

Acknowledgements

I would first and foremost like to thank my adviser, Dr. Rodolphe Gentili, for his mentorship, training and encouragement. I am truly fortunate as well as grateful for having had the opportunity to work with you over the past five years.

I would also like to thank my committee members, Dr. Donald Bolger, Dr. Bradley Hatfield, Dr. Bradford Hendershot and Dr. Craig McDonald, for their guidance and expertise. Their feedback was instrumental in the completion of my Ph.D. dissertation. Furthermore, I would like to thank Dr. Hyuk Oh for all of his technical support.

I would like to thank my parents, Joseph and Patricia Shaw, for always putting my interests first. None of this would have been possible without your love and support. I would like to also thank my siblings, Kerri and Joseph Shaw, for being my biggest fans and for always providing encouragement. I would like to specially thank my partner, Joshua Hanna, for his unwavering support throughout the entire process. Without him, this process would have been infinitely more difficult.

Lastly, I would like to acknowledge and thank all of the students, faculty, and staff of the Department of Kinesiology as well as the Neuroscience and Cognitive Science (NACS) program for their support.

Table of Contents

List of Figures

Chapter 1: Introduction

Humans have the remarkable capability to maintain a stable level of cognitive-motor performance when facing elevated and unfamiliar task demands. This adaptive nature of the human brain is highly dependent on the efficiency in which limited neural resources are allocated. In situations where the performer is confronted with excessive task demands, resources are further recruited in an attempt to maintain performance. If this recruitment exceeds a certain threshold and resources become substantially depleted, critical cognitive-motor processes underlying performance can become compromised, resulting in an increased risk for human error as well as the inability to attend to unexpected task demands (Babiloni et al., 2010; Berka et al., 2007; Miller et al., 2011; Murray & Janelle, 2007; Rietschel et al., 2012; Shaw et al., 2018).

Prior work has validated the use of electroencephalography (EEG) to assess changes in resource allocation related to attention and cognitive-motor processes during the performance of sensorimotor tasks (Bradford et al., 2019; Gentili et al. 2018; Shaw et al., 2018). In particular, residual attentional resources not allocated to the primary task at hand (i.e., attentional reserve) can be assessed by evaluating the amplitude of the novelty-P3 component of the event-related potential (ERP) elicited by intermittently presented task-irrelevant novel complex auditory stimuli (Dyke et al., 2015; Gentili et al. 2018; Miller et al., 2011; Rietschel et al., 2014; Shaw et al., 2018). The use of novel complex sounds has been demonstrated to be more robust in capturing attention compared to pure tones due to their resemblance to real-world novel and unexpected events (Dyke et al., 2015). The amplitude of the novelty-P3 component reflects the magnitude of involuntary orienting of attention to task-irrelevant stimuli, which is believed to be constrained by attentional reserve. Specifically, when primary task demands are high, there are fewer residual attentional resources left over to allocate to task-irrelevant stimuli, resulting in an attenuated novelty-P3 component amplitude. This novel ERP approach is considered superior over behavioral dual-task paradigms, as it avoids interfering with performance on the primary task. Previous work has successfully employed this novel ERP approach within the context of cognitive-motor performance and learning (Deeny et al., 2014; Gentili et al., 2018; Rietschel et al., 2014; Shaw et al., 2018). For instance, Shaw et al. (2018) assessed attentional reserve as individuals performed a cognitive task under varying difficulty while seated as well as walking. The authors observed an attenuated novelty-P3 component amplitude (i.e., a diminished attentional reserve) as the cognitive-motor demands became elevated either due to an increase in cognitive task difficulty or the type of task performed (walking compared to being seated). In another study conducted within a learning context, Rietschel et al. (2014) observed a progressive increase in novelty-P3 component amplitude (i.e., an increased attentional reserve), along with improvement in performance over the course of adaptation to a visual distortion applied to movement trajectories during a reaching task. It must be also be noted that a relationship between the level of task engagement and the novelty-P3 component amplitude has also been observed, such that individuals who report higher levels of task engagement exhibit smaller novelty-P3 component amplitudes (i.e., decreased attentional reserve). These findings suggest the novelty-P3 component may also serve as an objective measure of participant task engagement (Leiker et al., 2016). Collectively, these studies demonstrate fluctuations in the amplitude of the novelty-P3 component can serve as a robust index of attentional reserve under a varied range of settings. Furthermore, the N1 and P2 components of the ERP have also been previously shown to be modulated by attention, such that their amplitudes are attenuated when attention to stimuli is diminished (Hillyard et al., 1973; Picton & Hillyard, 1974). Thus, these components can also serve as a measure of attentional resource allocation during cognitive-motor performance (Deeny et al., 2014; Miller et al., 2011; Shaw et al., 2018).

In addition to ERP analyses, it has been demonstrated that fluctuations in EEG spectral power within the theta (4-7 Hz) and alpha (8-13 Hz) frequency bandwidths reflect changes in the engagement of cognitive-motor processes and thus the overall magnitude of cognitive-motor effort. Specifically, elevations in cognitive-motor task demands have been affiliated with decreased alpha (both low and high components) power and increased theta power. Decreased alpha power is inversely related to cerebral cortical activation and is believed to reflect the recruitment of neural processes (in particular high-alpha) to compensate for increased task demands (Gentili et al., 2018; Gevins et al., 1997; Jaquess et al., 2017; Klimesch, 1999; Rietschel et al., 2012; Shaw et al., 2018; Shaw et al., 2019). Conversely, increased theta power (in particular frontal theta synchrony) is positively related to cerebral cortical activation and is thought to reflect an increase in engagement of working memory, attentional control and action monitoring (Chuang et al., 2013; Coombes et al., 2005; Gentili et al., 2018; Gevins & Smith, 2000; Gevins et al., 1997, 1998; Klimesch, 1999; Rietschel et al., 2012; Sauseng et al., 2007; Shaw et al., 2018, 2019). The ratio of theta to alpha power at the frontal and parietal midline sites has also been shown to serve as a robust measure of cognitive-motor effort during tasks involving upper and lower extremity performance (Gentili et al., 2018; Holm et al., 2009; Jaquess et al., 2017; Pruziner et al., 2018; Shaw et al., 2018, 2019). Collectively, the aforementioned spectral analyses have been previously demonstrated to reflect critical cortical processes underlying cognitive-motor performance and learning across a diverse set of tasks under varying levels of challenge (e.g., Gentili et al., 2011; Hatfield et al., 2004; Malcolm et al., 2015). However, the majority of this prior work has mainly been conducted within the context of mental workload assessment, which is characterized by fluctuations in resource recruitment (related to attention, working memory, motor coordination, etc.) by the performer under varying task demands and learning challenges. The current work was conducted to assess a related, but much less studied approach which consisted of depleting resources to examine its effect on cognitive-motor processes underlying performance.

Resource depletion refers to the notion that recruitment of cognitive resources to successfully perform a task will temporarily diminish the availability of these resources, resulting in performance decrements on subsequent tasks (Baumeister et al., 1998; Persson et al., 2007, 2013; Schmeichel, 2007). Seminal work by Baumeister et al. (1998) first developed the resource depletion paradigm to investigate the phenomenon of an individual’s temporary reduction in willingness to engage in volitional acts due to prior acts of self-control. Since then, behavioral and neuroimaging studies have not only validated the use of resource depletion (Doris et al., 2012; Inzlicht & Gutsell, 2007; Wagner et al., 2013), but have also extended its use to directly probe the role of specific executive functions (i.e., cognitive processes responsible for the control of goal-directed behavior; Baddeley, 1986; Miller & Cohen, 2001) on human performance (Persson et al., 2007, 2013; Schmeichel, 2007). Work by Persson et al. (2007) for example, employed a series of behavioral experiments to evaluate the effect of intensive task performance (i.e., resource depletion) on the subsequent performance of a task requiring similar or different cognitive processes as that of the depletion task. Specifically, two groups of participants performed a verb-generation task before and after completing an item recognition task (resource depletion task). One group of participants completed a high interference item recognition task while the other group completed a low interference item recognition task. The verb-generation and item recognition tasks have been previously demonstrated to activate overlapping regions of the left inferior frontal gyrus and require interference control. In a second experiment, participants were required to perform the same verb-generation task, but instead completed a resource depletion task that did not require the same executive demands or recruited the same brain regions. As predicted, depletion effects were demonstrated only when the two tasks shared the same cognitive resources (activated overlapping brain regions). However, these effects were only apparent if the resource depletion task was challenging. Thus, performance on the verb-generation task in the first experiment was significantly worse if the high interference item recognition task was performed previously. This work not only provided evidence in support of the resource depletion paradigm as a tool to study executive function, but more importantly demonstrated that the depletion of executive resources are ‘process specific’ such that specific cognitive processes can be targeted and depleted independently from others.

Currently, a limited amount of neural evidence in support of the phenomena of resource depletion exists (Inzlicht & Gutsell, 2007; Persson et al., 2013; Wagner et al., 2013). Generally, this work has reported decreased neural activation in brain regions relevant to the cognitive processes whose resources were temporarily depleted. In particular, Persson et al. (2013) expanded their behavioral work by conducting a functional magnetic resonance imaging (fMRI) study to investigate the neural basis of executive resource depletion. The same experimental set-up from their earlier work (Persson et al., 2009) was employed such that two groups of participants performed a verb-generation task before and after completing a resource depleting or non-depletion item recognition task. Changes in the magnitude of neural activation related to depletion were reported, indicating that activation in task-relevant regions (e.g., left inferior frontal gyrus) was significantly decreased while participants performed the verb-generation task after compared to before they had completed the resource depleting high interference item recognition task. Importantly, decreases in the magnitude of neural activation correlated with behavioral performance impairment. These findings provide further support for a ‘process specific’ account of resource depletion. Furthermore, the neuroimaging results suggest the resource depletion paradigm limits the resources available for subsequent tasks requiring similar cognitive processes. Notably, increased activation in brain regions not typically related to the tasks employed in this study (e.g., right inferior frontal gyrus) was reported after participants underwent resource depletion, reflecting a possible compensatory mechanism. Overall, the previously discussed behavioral and neuroimaging literature demonstrates the validity of the resource depletion framework. While informative, most of this work was not conducted within a cognitive-motor context.

Working memory has been suggested to serve as an important process in the successful performance and learning of various cognitive-motor tasks (Anguera et al., 2010, 2012; Seidler et al., 2012; Shaw et al., 2018, 2019). Working memory is a temporary storage and processing system necessary for the performance of complex cognitive tasks. Following the model originally proposed by Baddeley & Hitch (1974) and Baddeley (1986), working memory is divided into three components. These include the central executive which controls, coordinates and integrates information from its two slave systems (the phonological loop and the visuospatial sketchpad). A modified version of the model was proposed to consist of a third slave system referred to as the episodic buffer (Baddeley, 2000; see Figure 1). The central executive may play a critical role in cognitive-motor performance and learning, such that when encountering elevated or unfamiliar task demands, the central executive reduces the allocation of attentional resources to task-irrelevant information in order to maintain information in working memory related to task-relevant goals (SanMiguel, et al., 2008; Simon et al., 2016). This is in line with reductions in involuntary orienting

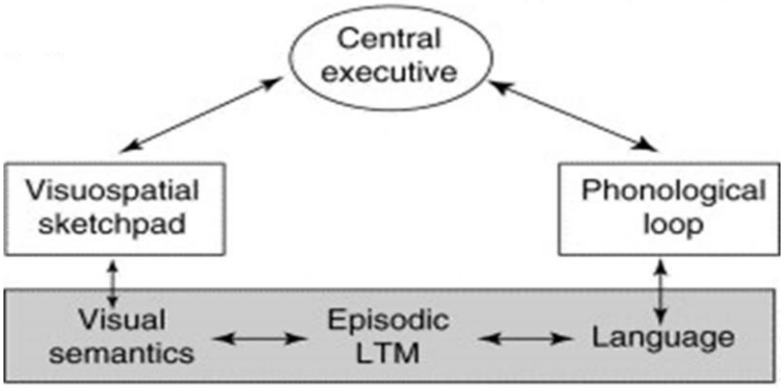


Figure 1. Baddeley's updated model of working memory (figure borrowed from Baddeley, 2000).

of attention, as reflected by an attenuated novelty-P3 component amplitude, during early sensorimotor learning (Rietschel et al., 2014) and as task demands increase during cognitive-motor performance (Miller at al., 2011; Gentili et al., 2018; Shaw et al., 2018). Furthermore, of the three slave systems, the visuospatial sketchpad is likely an essential component of successful cognitive-motor performance and learning, as it is responsible for the storage and manipulation of visual and spatial information. The visuospatial sketchpad has since been termed visuospatial working memory (Cornoldi & Vecchi, 2003; Logie, 1995) and support to break down the visuospatial sketchpad into spatial and visual subcomponents has been garnered.

In a behavioral study by Anguera et al., (2012), a spatial working memory (SWM) resource depletion paradigm was employed to examine the relationship between cognitive and sensorimotor mechanisms during sensorimotor adaptation. To our current knowledge, this is the only study that has employed a SWM resource depletion protocol to examine the role of SWM within a cognitive-motor context contrary to the previously discussed work which employed this depletion technique using tasks that were mainly cognitive in nature. SWM resources were selectively depleted by having participants perform a demanding SWM task requiring mental rotation for 20 minutes (depletion task) before having to perform a visuomotor task in which participants had to adapt to a 30° clockwise visual distortion applied to their movement trajectories. Changes in performance across the SWM resource depletion protocol were reported to moderately correlate with a reduced rate of subsequent early visuomotor adaptation. Thus, the depletion of SWM resources resulted in learning impairments on the visuomotor adaptation task. Overall, the finding reported here not only suggests that SWM is an important component of successful sensorimotor learning, but also provides support for the successful employment of a resource depletion paradigm within a cognitive-motor context to examine the role of specific cognitive processes underlying motor behavior.

While interesting, this study was purely behavioral and no inferences were made about the underlying brain dynamics. The direct assessment of brain dynamics related to the depletion of SWM is critical since it would provide a more complete characterization of the relationship between cognitive and sensorimotor processes. However, in order to fully appreciate the examination of brain dynamics within a learning context which is by nature a dynamic process, it is important to first determine the underlying brain dynamics of resource depletion on cognitive-motor performance alone. In particular, there is a need to further investigate the role of SWM during cognitive-motor performance when task demands increase since the central executive is likely critical for the management of attentional resource allocation to maintain task-relevant information in working memory. Thus, further evaluation of how SWM resource depletion affects cognitive-motor behavior under varying levels of challenge is warranted. Lastly, a control group was not included in the experimental design, making it difficult to ensure the significant correlation reported was truly due to the depletion of SWM rather than general fatigue. Including a control group would have enabled a stronger experimental design by providing a clearer understanding of the effects SWM resource depletion.

Therefore, the current study aimed to examine the effect of SWM resource depletion on subsequent cognitive-motor performance by evaluating mental workload through a combined assessment of the underlying brain dynamics and behavioral performance. A resource depletion paradigm, along with an EEG assessment of attentional reserve (indexed by novelty-P3 component amplitude) and cognitive-motor effort (indexed by theta and low/high-alpha spectral power) were employed to provide a more complete characterization of the role SWM plays in cognitive-motor performance. Specifically, EEG and performance metrics were evaluated as individuals assigned to an experimental group performed an easy and hard level of a cognitive-motor task requiring SWM (see methods for further detail) before and after resource depletion. To serve as a baseline for comparison, a control group performed the same set of tasks, but did not undergo resource depletion and instead performed a non-depletion protocol. Based on prior mental workload literature that recruited healthy individuals (e.g., Gentili et al., 2018; Shaw et al., 2018), it was hypothesized that prior to SWM resource depletion/non-depletion, all participants (experimental and control) would exhibit poorer performance (e.g., increased number of game overs), reduced attentional reserve (decreased novelty-P3 amplitude) and elevated cognitive-motor effort (increased theta and decreased low/high-alpha power) for the hard compared to the easy level of cognitive-motor challenge. This pattern in behavior and brain dynamics was also expected to be observed for the control group after the completion of the SWM resource non-depletion protocol. Limited prior neuroimaging work on resource depletion has reported reduced performance as well as neural activation in brain regions relevant to the cognitive processes whose resources were temporarily depleted (Inzlicht & Gutsell, 2007; Persson et al., 2013; Wagner et al., 2013). Thus, for the experimental group, it was hypothesized that performance would be impaired to a greater extent after compared to before undergoing SWM resource depletion. This would coincide with a reduced cortical activation (low- and high-alpha synchrony) and impaired ability to recruit resources related to working memory and attentional control (frontal theta desynchrony), which collectively would reflect a decrease in cognitive-motor effort. Furthermore, if the central executive and visuospatial sketchpad are closely related as suggested by the Baddeley model (Baddeley, 2000), it was expected that the central executive would be affected by SWM resource depletion and would no longer be able to effectively suppress attentional resources to task-irrelevant information. This would result in an increased allocation of attentional resources to task-irrelevant information (elevated novelty-P3 amplitude). Importantly, the detrimental effects of SWM resource depletion on behavioral performance as well as the brain dynamics were expected to be heightened for the hard compared to the easy level of cognitive-motor challenge, as it is expected that more neural resources are required to successfully maintain performance under elevated task demands.

Chapter 2: Methods

Participants

Forty-two right-handed individuals with normal or corrected-to-normal vision completed the study after proving written informed consent approved by the Institutional Review Board at the University of Maryland. However, data from six participants were excluded due to either poor electrophysiological recordings or failure to follow instructions. After the removal of these participants, the final sample size consisted of 35 participants who were randomly assigned to an experimental (8 male and 11 female; M age ± SD: 20.053 ± 3.135 years) or control (8 male and 8 female; M age ± SD: 24.313 ± 4.316 years) group, described below. All participants reported not being on psychotropic medication as well as being free of drug and alcohol use prior to completing the study. Furthermore, participants reported playing less than four hours per week of video games over the past year and had less than ten hours prior experience having played Tetris®.

Experimental procedure and tasks

Participants were seated in front of a 27” computer monitor at a 70 cm viewing distance while performing a series of tasks (further described below) presented in a methodical order to examine changes in performance and brain dynamics before and after undergoing SWM depletion (Figure 2). All participants followed the same experimental procedures, with the exception that participants assigned to the experimental group underwent a depleting SWM protocol, whereas participants assigned to the control group underwent a non-depleting SWM protocol.

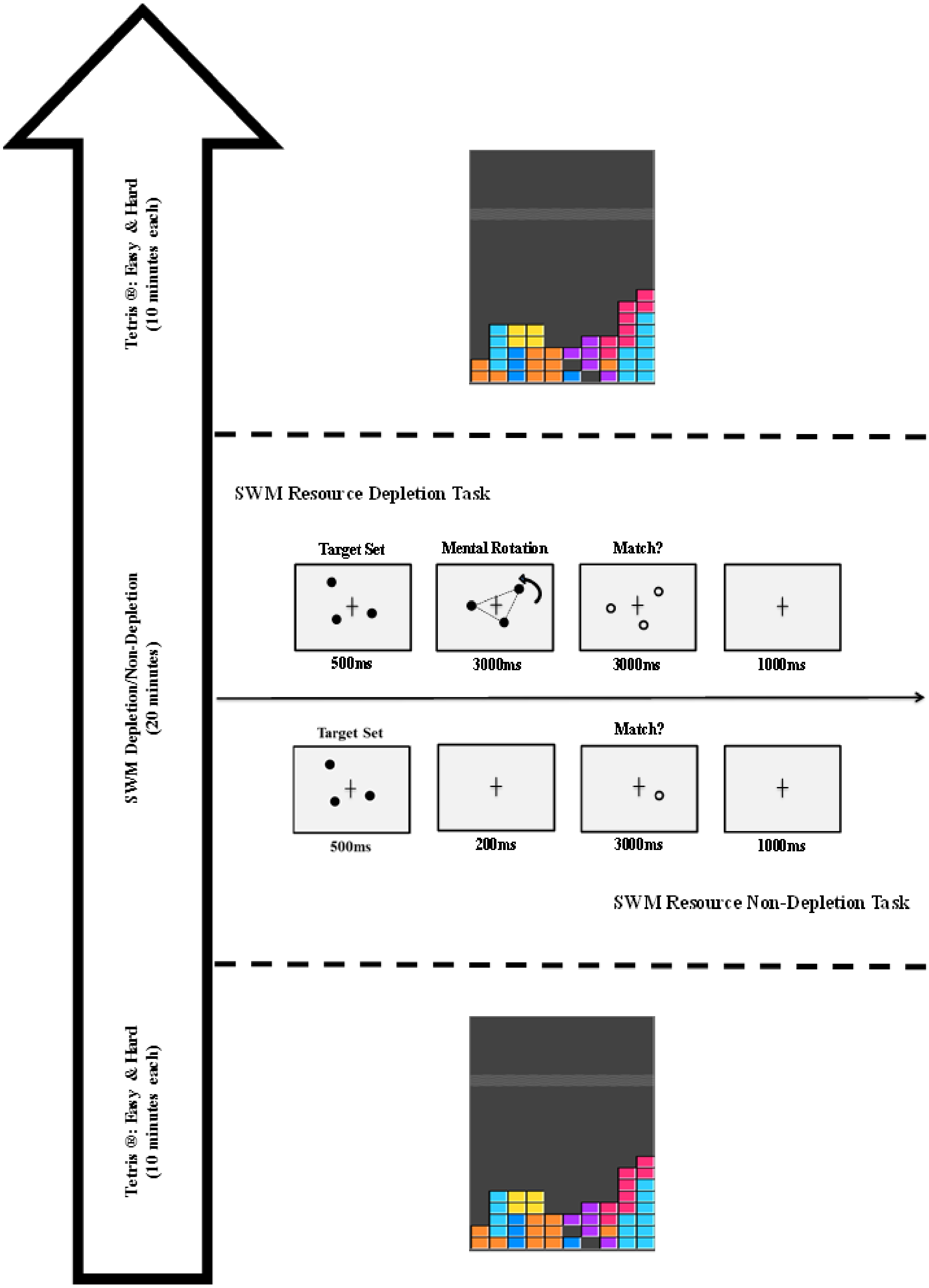


Figure 2. Experimental tasks presented in a systematic order. Pariticpants played Tetris® at an easy and hard level of challenge before and after completing a SWM resource depletion (experimental) or SWM resource non-depletion (control) protocol.

Cognitive-motor task

Participants played the videogame Tetris® (http://www.britannica.com/topic/Tetris) under two levels of challenge (easy or hard) once before and once after undergoing the SWM resource depletion/non-depletion protocol (Figures 2 and 3). Tetris® is a videogame that requires the manipulation (movement up and down, counter-clockwise rotation) of 'falling' game pieces taking the form of various shapes in order to place them in an optimal location on the computer screen. Previous work has demonstrated training on Tetris® can lead to improved 2-dimensional mental rotation abilities (De Lisi & Wolford, 2002; Okagaki & Frensch, 1994) and that performance on Tetris® correlates with measures of visuospatial working memory (Lau-Zhu et al., 2017). Given the previous findings, it is likely that the game Tetris® requires the recruitment of SWM, serving as an appropriate experimental task for the current study. The difficulty of the game was defined by the rate the Tetrominoes (i.e., pieces) advanced on the screen, as the change in speed requires participants to more rapidly decide where to place the current piece, execute the placement, and update planning for the successive pieces. The Tetrominoes fell at a velocity of 1.67 cm/s and 3.56 cm/s during the easy and hard conditions, respectively. These times were determined based on previous work that have employed the same experimental task (Miller et al., 2011; Rietschel et al., 2014). The order in which each level of challenge was played before and after the SWM resource depletion/non-depletion protocol, was counterbalanced across all participants. Furthermore, a sequence of Tetrominoes was predetermined and employed for all participants in order to compare performance between the participants as well as between the easy and hard levels of challenge. Participants manipulated the Tetrominoes using three keys on a keyboard located directly in front of them. The left and right arrow keys corresponded to moving the Tetrominoes left and right on screen, while the upper key corresponded to the counter-clockwise rotation of the Tetrominoes. Although normal game play allows individuals to manipulate the speed in which the Tetrominoes move down the screen, the velocity of the Tetrominoes in the current experiment were held constant within a level of challenge and could not be manipulated by the participants. When the Tetrominoes were stacked above line 15 of 20, the game automatically restarted at the same level of difficulty so that participants could plan their movements and have time to place the Tetrominoes in the desired position and location. Experimental conditions (pre-easy, pre-hard, post-easy and post-hard) lasted 10 min each.

Attentional reserve was assessed by employing task-irrelevant complex auditory probes intermittently presented (ISI range: 6-30 s) throughout each experimental condition (Dyke et al., 2015; Miller et al., 2011; Rietschel et al., 2014). The auditory probes consisted of a set of 30 sounds obtained from a larger collection from the New York State Psychiatric Institute (Fabiani et al., 1996) and were randomly presented at a comfortable decibel (dB) level (less than 95 dB) through two speakers located 70 cm from the participants. At the end of each experimental condition, a visual analog scale (VAS) and a NASA-Task Load Index (TLX) questionnaire were administered in order to obtain a self-report assessment of perceived task demands (see

Appendices A and B for a description of the questions employed in these questionnaires; Hart & Staveland (1988)).

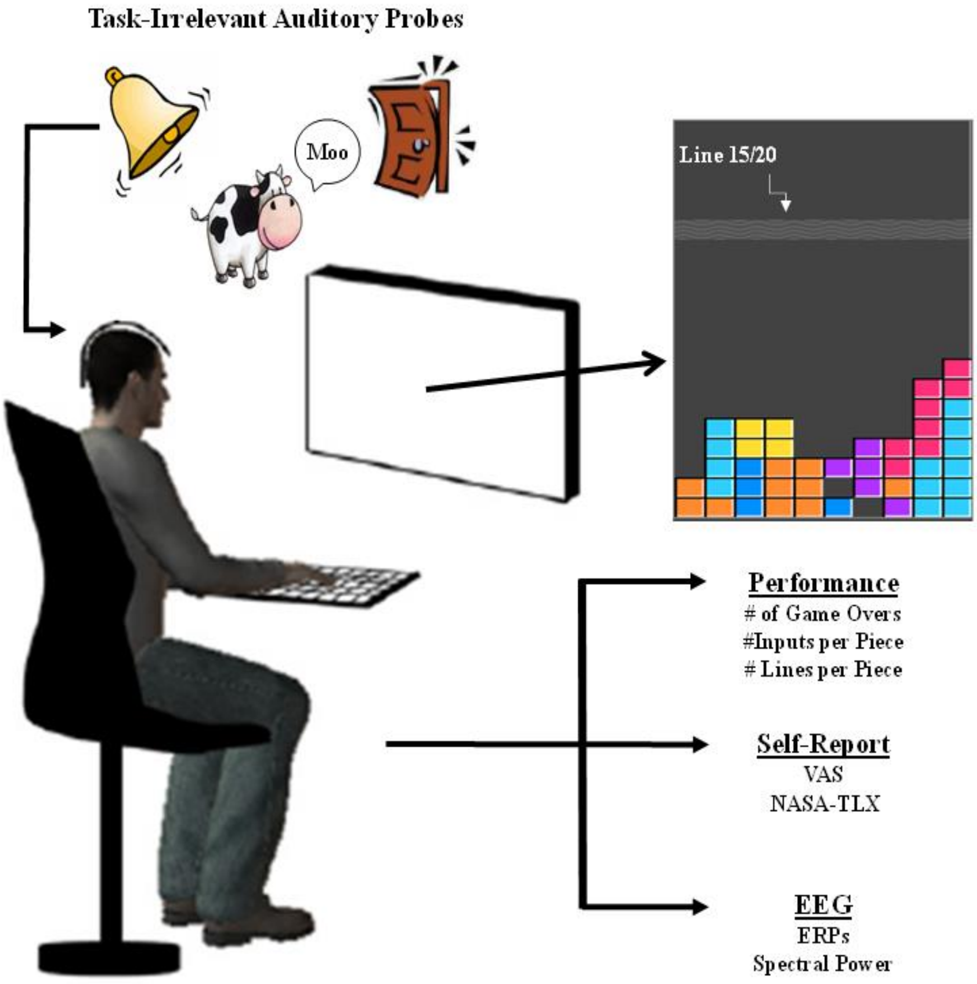


Figure 3. Experimental set-up in which participants played Tetris® at an easy and a hard level of challenge both before and after undergoing SWM resource depletion/non-depletion. Throughout each condition, attentional reserve was assessed by probing participants with task-irrelevant novel auditory stimuli intermittently presented as performance and EEG signals were concurrently recorded.

SWM resource depletion and non-depletion protocol

The SWM resource depletion and non-depletion tasks employed in this study were modeled after those employed in Anguera et al. (2010, 2012). For the SWM resource depletion task, participants assigned to the experimental group completed 17 blocks of 10 trials. Each trial required participants to memorize a target set consisting of three solid circles (1 cm in diameter) within a period of 500 ms. The circles were randomly positioned in three out of four possible locations centered around a fixation cross, with radii subtending anywhere from 3-6˚ of visual angle. After the presentation of the target set, a blank screen was presented for 3000 ms in which participants were instructed to first mentally connect the circles to form a shape and then rotate the shape 60˚ counter-clockwise around the fixation cross. Following mental rotation, a set of three open circles (1 cm in diameter) were presented. Participants were given 3000 ms to decide whether the open circles formed the same shape as the original mentally rotated target set by pressing the "F" and "J" keys on a keyboard located directly in front of them. Response keys corresponded to "yes" or "no" and were counterbalanced across participants. Once a response was made, the next trial began after a 1000 ms inter-trial interval and a new target set was presented. Congruent trials composed 70% of the total number of trials such that the mentally rotated target set matched the subsequently presented open circles. The remaining 30% of the trials were composed of incongruent trials in which one out of the three open circles presented was displaced slightly (4˚) or greatly (8˚) from the original mentally rotated target location.

For the SWM resource non-depletion protocol, participants assigned to the control group completed 17 blocks of 22 trials. Participants were provided 500 ms for each trial to memorize a target set consisting of three solid circles of the same size and spatial locations as the SWM depletion task. After the presentation of the target set, a blank screen was presented for 200 ms. The shortened period of time (200 ms rather than 3000 ms) was implemented to prevent participants from engaging in mental rotation. Next, participants were presented with a single open circle and had 3000 ms to indicate whether the circle was in the same spatial location as one of the solid circles in the original target set. Participants had 3000 ms to respond by pressing either the "F" or "J" key (i.e., 'yes' or 'no'), counterbalanced across participants. Similar to the SWM resource depletion task, 70% of the trials were composed up of congruent trials, such that the open circle was located in the same spatial location as one of the three solid circles originally presented in the target set. The remaining 30% of the trials were composed up of incongruent trials, in which the open circle was displaced slightly (4˚) or greatly (8˚) from one of the original solid circle spatial locations. Breaks lasting 20 s were given between each block of trials for the SWM resource depletion and non-depletion protocols, with both tasks lasting approximately 20 min (Figure 2).

Electrophysiological data acquisition

EEG data were continuously recorded from 64 scalp sites (extended 10-20 system) using an actiCAP EEG system (Brain Products GmbH, Germany) at a sampling frequency of 1000 Hz throughout all Tetris® conditions. The EEG data were online referenced to the left earlobe and a common ground was employed at the FPz site on the scalp. Band pass filters were set at 0.01-100 Hz and all electrode impedances were maintained below 10 kΩ throughout the entirety of the study. The EEG signal was amplified and digitized using a BrainAmp DC Amplifier (Brain Products GmbH, Germany) linked to Brain Vision Recorder software version 2.1 (Brain Products GmbH, Germany).

Data processing

Performance

Performance for each block of trials on the SWM resource depletion/non-depletion protocol was evaluated by assessing accuracy (percentage of correct responses) as well as response time (RT; (i.e., how long it took participants to respond "yes" or "no") for correct responses only. In order to assess changes in performance over time, accuracy and RT were averaged across the first three (early), 8th-10th (middle), and last three (late) blocks. These behavioral measures were assessed as a manipulation check to confirm depletion of SWM resources occurred as well as to validate the use of the SWM resource depletion protocol. For Tetris®, performance was evaluated for each level of challenge (easy and hard) before and after the SWM resource depletion/non-depletion protocol by measuring the number of times participants failed (game overs) and had to restart the task (i.e., when Tetrominos were stacked above line 15). To provide a more sensitive evaluation of performance on Tetris®, additional normalized outcome measures were evaluated which included the number of lines completed per Tetromino and the number of keyboard inputs per Tetromino (Gentili et al., 2018).

Self-report

For each level of difficulty on Tetris® before and after SWM resource depletion/non-depletion, VAS and NASA-TLX scores were computed for each item and dimension, respectively. The VAS was administered to assess self-reported mental workload and task difficulty via five questions (Q1: "How mentally loaded did I feel while performing the task?”; Q2: “How overwhelmed was I by the task?”; Q3: “How easy was the task?”; Q4: “How much did I have to concentrate to perform the task?”; Q5: “How tired was I after the task?”). The NASA-TLX was administered to assess perceived overall workload via six dimensions which included mental, physical and temporal task demands, as well as, effort, frustration and perception of performance (Hart, 2006; Hart & Staveland, 1988).

Electrophysiological data

EEG signal processing was conducted using BrainVision Analyzer software version 2.0 (Brain Products GmbH, Munich, Germany). Data recorded for all Tetris® conditions were re-referenced offline to an averaged ears montage prior to further processing of the ERPs and spectral power.

Electrophysiological data: ERPs

After re-referencing, EEG data were low-pass filtered at 20 Hz with a 48-dB rolloff using a zero-phase Butterworth filter offline. The data were then visually inspected and pruned (Onton et al., 2006) to remove non-stereotyped artifact from further analysis and improve the subsequent independent component analysis (ICA) conducted. An ICA-based approach was employed to reduce eye movement artifact using an ocular artifact rejection function embedded within Brain Vision Analyzer software (BrainProducts, 2013). Following ICA-based ocular artifact rejection, the data were epoched into 1-s sweeps surrounding the presentation of the auditory stimuli (-100 ms before and 900 ms after auditory stimulus presentation). The data were baseline corrected using the mean of the pre-stimulus interval and all epochs were visually inspected for any remaining artifact. The remaining epochs after artifact rejection were averaged for each participant and Tetris® condition (pre-easy, pre-hard, post-easy and post-hard). All averages consisted of at least 20 epochs to obtain an adequate signal to noise ratio (Cohen & Polich, 1997). The grand-average waveform, collapsed across all participants and Tetris® conditions was employed to determine the latency of N1, P2, and novelty-P3 peak amplitudes. Peak amplitude was maximal at electrode Cz for the N1 and P2 components and was maximal at electrode FCz for the novelty-P3 component. Time windows centered on the peak amplitude for each ERP component of interest were determined and mean amplitudes were extracted using a 20 ms time window for the N1 (159-179 ms) component and a 40 ms time window for the P2 (252-292 ms) and novelty-P3 (345-385 ms) components. The extracted mean amplitudes were then tested for statistical analysis. Additionally, current source densities were computed and projected onto the scalp to ensure the observed topographic distribution for each window was consistent with those described in the literature (see Figure 7).

Electrophysiological data: Spectral power

EEG data were low-passed filtered at 50 Hz with a 48-dB rolloff and notch filtered at 60 Hz using a zero-phase shift Butterworth filter offline. The pruning technique was employed and eye movement artifact was reduced using ICA-based ocular artifact rejection (as discussed in the ‘Electrophysiological data: ERPs’ section). After ICA-based ocular artifact rejection, the data were epoched into 1 s sweeps and baseline corrected using the mean potential (0-1000 ms). Epochs were subsequently visually inspected to remove any remaining artifact. Spectral power was computed across 1-Hz bins and summed across the frequency bandwidths theta (4-7 Hz), low-alpha (8-10 Hz) and high-alpha (11-13 Hz). In addition, the FT/FA ratio power as well as the FT/PA ratio power were computed. These spectral measures were assessed as they have previously been demonstrated to serve as robust indices of cognitive-motor effort (Gentili et al., 2018; Holm et al., 2009; Jaquess et al., 2017). Spectral power values were then natural log transformed prior to statistical analysis.

Statistical analysis

Performance and self-report

Accuracy and RT for the SWM resource depletion/non-depletion protocol were each subjected to a 2 x 3 (Group [Experimental vs. Control] x Time [Early, Middle, Late]) mixed-factorial ANOVA with Time as a within-subjects factor and Group as a between-subjects factor. Furthermore, measures of performance on Tetris® (number of game overs, number of lines completed per Tetromino and number of inputs per Tetromino), along with self-report measures via the five items on the VAS and six dimensions on the NASA-TLX, were subjected to a series of 2 x 2 x 2 (Group [Experimental vs. Control] x Time [Pre vs. Post] x Difficulty [Easy vs. Hard]) mixed-factorial ANOVAs with Time and Difficulty as within-subjects factors and Group as a between-subjects factor. When necessary post-hoc analyses were computed using the Tukey's honest significant difference (HSD) test. If sphericity was violated, the Greenhouse-Geisser correction was employed when the epsilon (ε) estimate was below 0.75 (Verma, 2015). Otherwise, the Huynh–Feldt correction was employed. The *p*-values reported were based upon the corrected degrees of freedom. Partial eta squared (η_p^2) and Cohen's d effect sizes were also provided when appropriate. All criterion alpha levels were set to $p < 0.05$. The same corrective approach, post-hoc procedure, significance level and computation of effect size were employed for the EEG measures.

ERPs

Mean amplitudes for each ERP component of interest (N1, P2 and novelty-P3) were subjected to a 2 x 2 x 2 x 4 (Group [Experimental vs. Control] x Time [Pre vs. Post] x Difficulty [Easy vs. Hard] x Region [Fz, FCz, Cz, Pz]) mixed-factorial ANOVA with Time, Difficulty and Region as within-subjects factors and Group as a between-subjects factor.

Spectral power

Spectral power values for each frequency bandwidth, with the exception of the theta/alpha ratios, were subjected to a 2 x 2 x 2 x 2 x 5 (Group [Experimental vs. Control] x Time [Pre vs. Post] x Difficulty [Easy vs. Hard] x Hemisphere [Left vs. Right] x Region [Frontal, Central, Temporal, Parietal, Occipital]) mixed-factorial ANOVA with Time, Difficulty, Hemisphere and Region as within-subjects factors and Group as a between-subjects factor. The FT/FA and FT/PA ratios were each subjected to a 2 x 2 x 2 (Group [Experimental vs. Control] x Time [Early vs. Late] x Difficulty [Easy vs. Hard]) mixed-factorial ANOVA with Time and Difficulty as within-subjects factors and Group as a between-subjects factor[1].

---

[1] For all behavioral and EEG metrics, a series of 2 x 2 (Group (Experimental vs. Control] x Difficulty [Easy vs. Hard]) mixed-factorial ANOVAs were conducted on the data collected prior to the experimental manipulation (i.e., pre-SWM resource depletion/non-depletion) to test for potential baseline differences between the two groups. Statistical analyses revealed no significant differences between the two groups across all metrics examined here.

Chapter 3: Results

Performance

When considering performance during the SWM resource depletion/non-depletion protocol, a significant Group x Time interaction (F (2, 66) = 3.934, $p = 0.024$, $\eta_p^2 = 0.107$) was revealed for RT. Subsequent post-hoc analyses revealed an increased RT for middle compared to early ($p < 0.001$, $d = 0.209$) as well as for late compared to early ($p = 0.001$, $d = 0.201$) SWM resource depletion for the experimental group. No significant difference in RT was observed for the control group ($p > 0.05$). Furthermore, no significant results of interest were detected for accuracy on the SWM resource depletion/non-depletion protocol ($p > 0.05$). Although both groups performed similarly on Tetris®, significant differences were apparent between the timing in which the tasks were completed (pre vs. post) as well as the level of challenge (easy vs. hard). In particular, a significant Time x Difficulty interaction was detected for the number of game overs (F (1, 33) = 6.915, $p = 0.013$, $\eta_p^2 = 0.173$). Post-hoc analyses revealed the number of game overs increased during the hard compared to the easy level of challenge before ($p < 0.001$, $d = 4.809$) and after ($p < 0.001$, $d = 4.946$) participants underwent the SWM resource depletion/non-depletion protocol. Post-hoc analyses also revealed the number of game overs decreased post- compared to pre-SWM resource depletion/non-depletion for the hard level of challenge ($p = 0.001$, $d = 0.241$), while no such difference was detected for the easy level of challenge ($p = 0.954$). Furthermore, a main effect of Time was observed for the number of lines completed per Tetromino piece (F (1, 33) = 12.344, $p = 0.001$, $\eta_p^2 = 0.272$), revealing a greater number of lines completed while participants played Tetris® post- compared to pre-SWM resource depletion/non-depletion. Lastly, a main effect of Difficulty was revealed for the number of inputs (*F* (1, 33) = 18.391, $p < 0.001$, $\eta_p^2 = 0.358$) as well as the number of lines completed (*F* (1, 33) = 255.482, $p < 0.001$, $\eta_p^2 = 0.886$) per Tetromino piece, such that there was a decreased number of inputs and number of lines completed during the hard compared to the easy level of challenge (Figure 4).

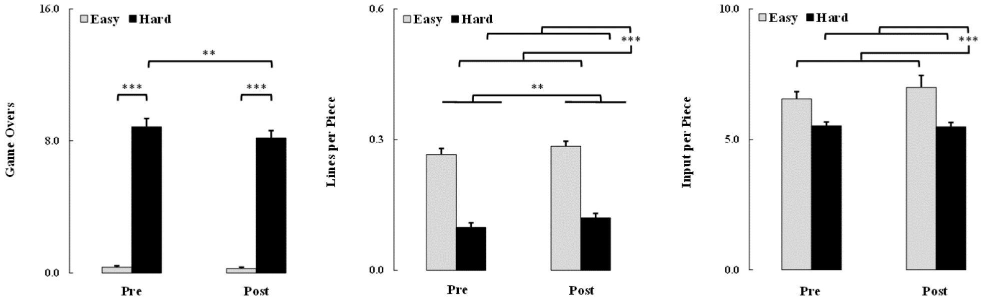


Figure 4. Performance pre- and post-SWM resource depletion/non-depletion while participants played Tetris® at an easy (gray bars) and hard (black bars) level of difficulty. The number of times the participants failed and had to restart the task (i.e., game overs), the number of lines completed per piece, and the number of inputs per piece are represented in the left, middle, and right panels, respectively. *p<0.05; **p<0.01; ***p<0.001.

Self-report

VAS

Statistical analyses revealed a main effect of Time for the third (ease: *F* (1, 33) = 8.654, $p = 0.006$, $\eta_p^2 = 0.208$) and fifth (tiredness: *F* (1, 33) = 15.858, $p < 0.001$, $\eta_p^2 = 0.325$) items on the VAS. In particular, participants reported decreased perception of task difficulty as well as increased tiredness after compared to before completing the SWM resource depletion/non-depletion protocol. A main effect of Difficulty was also detected for the first (mental load: *F* (1, 33) = 105.280, $p < 0.001$, $\eta_p^2 = 0.761$), third (ease: *F* (1, 33) = 252.611, $p < 0.001$, $\eta_p^2 = 0.884$) and fifth (tiredness: *F* (1, 33) =

46.153, $p < 0.001$, $\eta_p^2 = 0.583$) items on the VAS. Participants reported increased levels of perceived mental load, task difficulty and tiredness for the hard (relative to easy) level of challenge. When examining the second (overwhelmed) item on the VAS, a significant Time x Difficulty interaction (F (1, 33) = 6.420, $p = 0.016$, $\eta_p^2 = 0.163$) was observed. Subsequent post-hoc analyses revealed all participants reported feeling more overwhelmed as the level of challenge became elevated (hard vs. easy) before ($p < 0.001$, $d = 2.710$) and after ($p < 0.001$, $d = 1.555$) SWM resource depletion/non-depletion. Additionally, participants reported feeling more overwhelmed when playing Tetris® at the hard level of challenge post- compared to pre-SWM resource depletion/non-depletion ($p = 0.047$, $d = 0.311$). Lastly, a significant Group x Time x Difficulty interaction for the fourth (concentration) item on the VAS was detected (F (1, 33) = 5.210, $p = 0.029$, $\eta_p^2 = 0.136$). The post-hoc analyses revealed participants in both groups reported elevated levels of concentration for the hard compared to the easy level of challenge before (experimental: $p < 0.001$, $d = 1.898$; control: $p < 0.001$, $d = 1.527$) and after (experimental: $p < 0.001$, $d = 1.596$; control: $p < 0.001$, $d = 1.918$) completing the SWM resource depletion/non-depletion protocol. Furthermore, participants in the control group reported decreased levels of concentration while playing Tetris® at the easy level of challenge after compared to before completing the SWM resource depletion/non-depletion protocol ($p < 0.001$, $d = 0.674$); Figure 5.

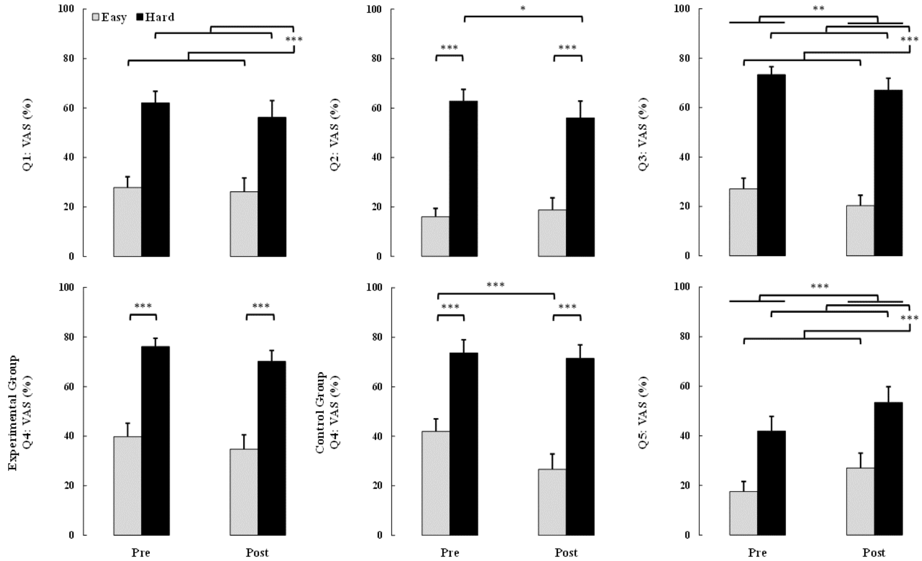


Figure 5. Mean and standard error self-report scores on the VAS obtained for the easy (solid grey bars) and hard (solid black bars) levels of challenge before and after SWM resource depletion/non-depletion for the experimental (Q4; left column, bottom row) and control (Q4; middle column, bottom row) group as well as collapsed across both groups of participants (Q1, Q2, Q3, Q5). See Appendix A or main text for a description of the questions. $*p<0.05$; $**p<0.01$; $***p<0.001$.

NASA-TLX

The NASA-TLX scores revealed a significant main effect of Time, as participants reported decreased levels of frustration (F (1, 33) = 5.111, $p = 0.030$, $\eta_p{}^2 = 0.134$) post- compared to pre-SWM resource depletion/non-depletion. A significant main effect of Difficulty was also revealed, such that participants reported significantly higher levels of mental demand (F (1, 33) = 189.716, $p < 0.001$, $\eta_p{}^2 = 0.852$), physical demand (F (1, 33) = 31.788, $p < 0.001$, $\eta_p{}^2 = 0.491$), effort (F (1, 33) = 118.863, $p < 0.001$, $\eta_p{}^2 = 0.783$) and frustration (F (1, 33) = 128.852, $p < 0.001$, $\eta_p{}^2 = 0.796$) for the hard compared to the easy level of challenge. Furthermore, a significant Time x Difficulty interaction was observed for the temporal demand (F (1, 33) = 5.274, $p = 0.028$, $\eta_p{}^2 = 0.138$) and performance (F (1, 33) = 4.301, $p = 0.046$, $\eta_p{}^2 = 0.115$)

dimensions. Subsequent post-hoc analyses revealed participants reported increased temporal demand and decreased performance during the hard compared to the easy level challenge before (temporal demand: $p < 0.001$, $d = 5.729$; performance: $p < 0.001$, $d = 3.389$) and after (temporal demand: $p < 0.001$, $d = 2.948$; performance: $p < 0.001$, $d = 2.669$) SWM resource depletion/non-depletion. Furthermore, participants reported decreased temporal demand and increased performance post- relative to pre-SWM resource depletion/non-depletion during the hard level of challenge only (temporal demand: $p = 0.002$, $d = 0.636$; performance: $p = 0.002$, $d = 0.680$); see Figure 6.

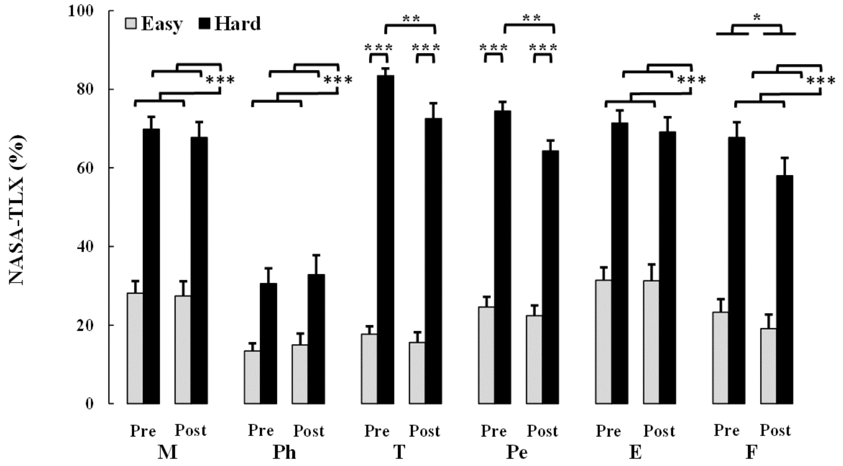


Figure 6. Mean and standard error NASA-TLX scores for each dimension obtained for both easy (solid grey bars) and hard (solid black bars) levels of challenge before and after SWM resource depletion/non-depletion. M: Mental demand; Ph: Physical demand; T: Temporal demand; Pe: Performance; E: Effort; F: Frustration (see Appendix B or Hart and Staveland, 1988 for the description of each question). *:p < 0.05; **: p < 0.01; ***: p < 0.001.

ERPs

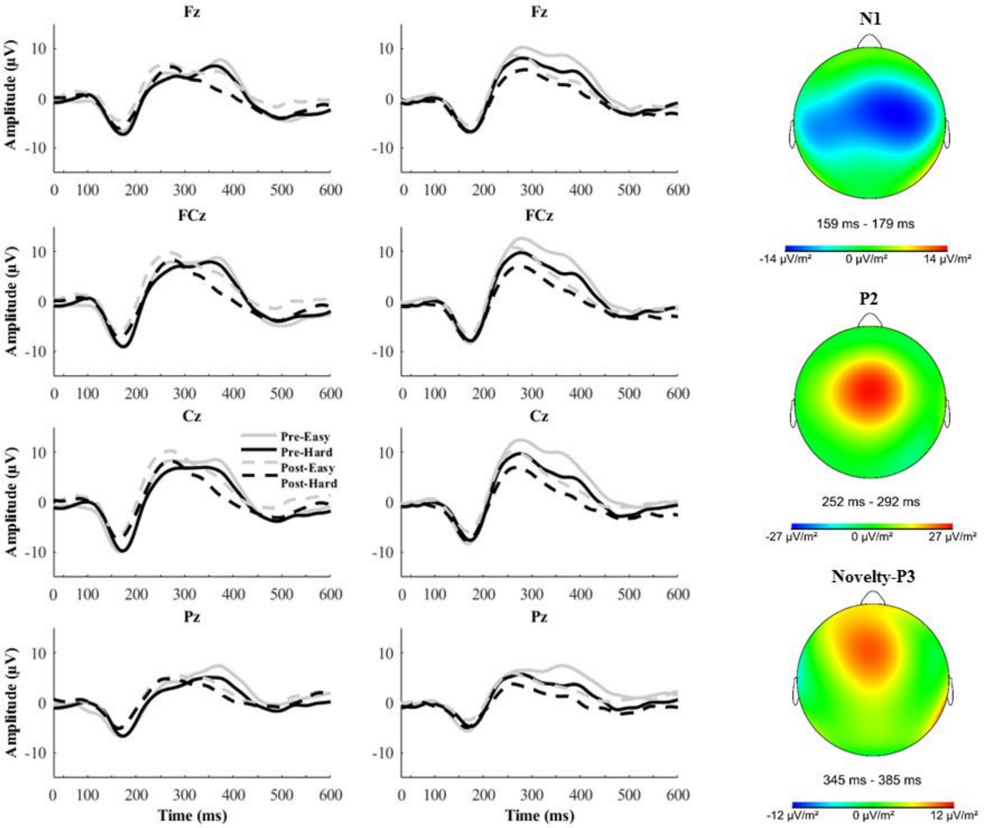


Figure 7. The first two columns represent the grand-average ERP waveforms for the easy (gray lines) and hard (black lines) level of Tetris® challenge before (solid lines) and after (dashed lines) SWM resource depletion//non-depletion for the experimental (first column) and control (second column) group at the four scalp sites (Fz, FCz, Cz and Pz). The last column represents the current source density plots projected onto the scalp topography for the N1, P2 and novelty-P3 components.

N1

When examining the N1 component, a main effect of Time (F (1, 33) = 9.208, p = 0.005, η_p^2= 0.218) was detected. In particular, N1 amplitude was significantly attenuated while participants played Tetris® after compared to before completing the SWM resource depletion/non-depletion protocol (Figure 8).

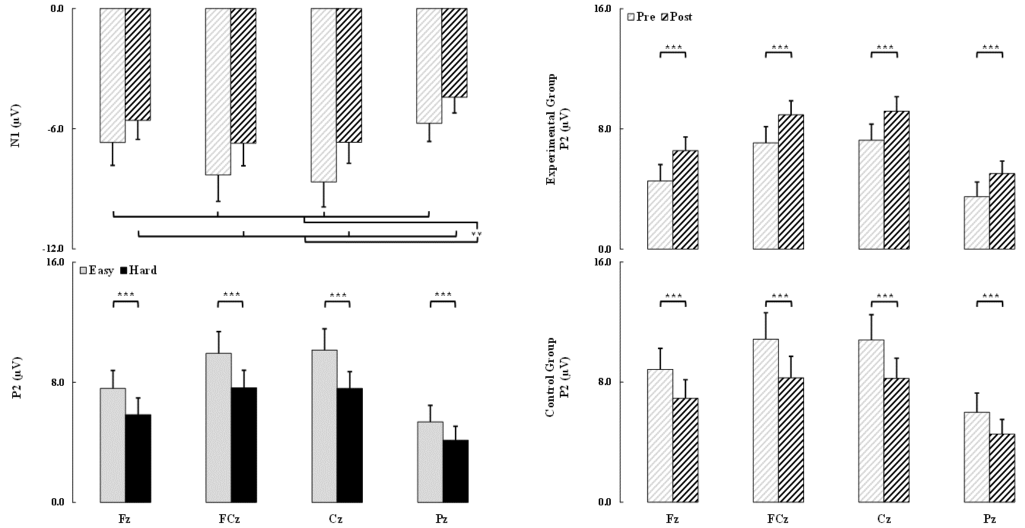


Figure 8. Mean amplitudes recorded at all scalp sites of interest (Fz, FCz, Cz, Pz) while participants played Tetris®: i) under an easy (solid grey bars) and hard (solid black bars) level of challenge for the P2 component (left column, bottom row) as well as ii) before (grey stripped bars) and after (black stripped bars) SWM resource depletion/non-depletion for the N1 component collapsed across both groups (left column, top row) and for the P2 component in the experimental group (right column, top row) as well as the control group (right column, bottom row). *p < 0.05; **p < 0.01; ***p < 0.001.

P2

For the P2 component, a significant Difficulty x Region interaction (*F* (1.848, 60.970) = 8.340, $p = 0.001$, $\eta_p^2 = 0.202$, $\varepsilon = 0.616$) was observed. Subsequent post-hoc analyses revealed a reduced P2 amplitude at all electrode sites of interest (Fz, FCz, Cz and Pz) for the hard compared to the easy level of challenge ($p < 0.001$, $0.327 \leq d \leq 0.535$). Additionally, a significant Group x Time x Region interaction (*F* (1.890, 62.360) = 4.173, $p = 0.022$, $\eta_p^2 = 0.112$, $\varepsilon = 0.630$) was detected. The post-hoc analyses revealed an increased P2 amplitude post- relative to pre-SWM resource depletion at all four electrode sites for the experimental group ($p < 0.001$, $0.471 \leq d \leq 0.532$).

Conversely, a decreased P2 amplitude after compared to before SWM resource non-depletion was detected at all four electrode sites for the control group ($p < 0.001$, $0.365 \leq d \leq 0.450$); see Figure 8.

Novelty-P3

Statistical analysis of the novelty-P3 component revealed a significant Group x Time x Difficulty x Region interaction (F (1.620, 53.453) = 3.432, $p = 0.049$, $\eta_p{}^2 = 0.094$, $\varepsilon = 0.540$). To further investigate this four-way interaction, separate Time x Difficulty x Region ANOVAs were conducted for each group. For the experimental group, a significant Time x Difficulty x Region interaction was detected (F (1.333, 23.987) = 7.133, $p = 0.008$, $\eta_p{}^2 = 0.284$, $\varepsilon = 0.444$). Post-hoc analyses revealed a decreased novelty-P3 amplitude for the hard compared to the easy level of challenge at electrode sites Cz ($p = 0.003$, $d = 0.330$) and Pz ($p < 0.001$, $d = 0.414$) pre-SMW resource depletion and at electrode sites Fz ($p < 0.001$, $d = 0.662$), FCz ($p < 0.001$, $d = 0.632$) and Cz ($p < 0.001$, $d = 0.604$) post-SMW resource depletion. Furthermore, novelty-P3 amplitude was significantly reduced post- compared to pre-SWM resource depletion at all four electrode sites for both the easy ($p < 0.001$, $0.396 \leq d \leq 0.868$) and hard ($p < 0.001$, $0.533 \leq d \leq 0.827$) level of challenge. When examining the control group, a main effect of Difficulty (F (1, 15) = 6.367, $p = 0.023$, $\eta_p{}^2 = 0.298$) was revealed. In particular, the novelty-P3 amplitude was attenuated during the hard compared to the easy level of challenge. A significant Time x Region interaction (F (1.939, 29.080) = 3.476, $p = 0.046$, $\eta_p{}^2 = 0.188$, $\varepsilon = 0.646$) was also observed for the control group. The subsequent post-hoc analyses revealed a reduced novelty-P3 amplitude at all four electrode sites of interest (Fz, FCz, Cz and Pz) post- compared to pre-SWM resource non-depletion ($p < 0.001$, $0.936 \leq d \leq 1.153$); Figure 9.

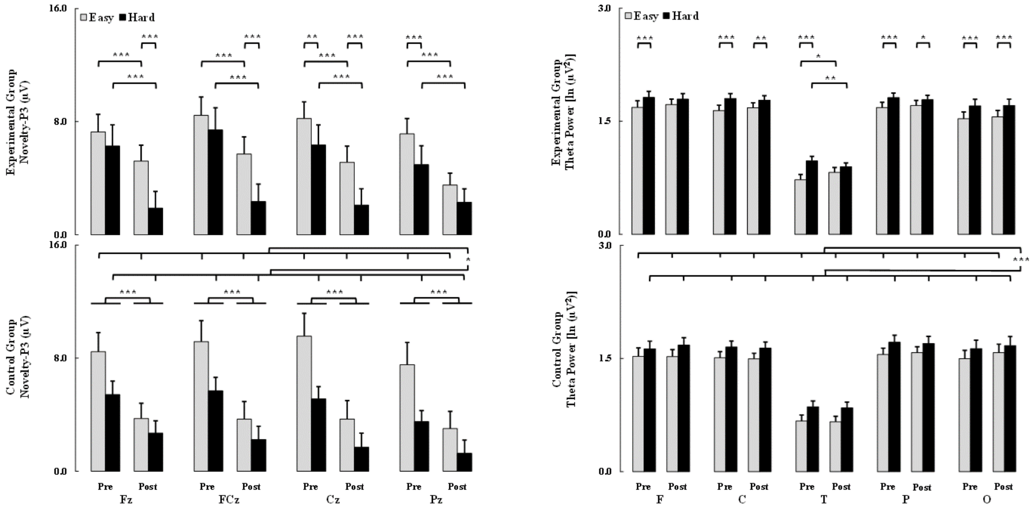


Figure 9. Mean amplitudes for the novelty-P3 component recorded at scalp sites Fz, FCz, Cz and Pz (left column) and spectral power for the theta (4-7 Hz) frequency bandwidth recorded in the frontal (F), central (C), temporal (T), parietal (P) and occipital (O) regions (right column) while participants in the experimental group (top row) and the control group (bottom row) played Tetris® under an easy (grey bars) and hard (black bars) level of challenge pre- and post-SWM resource depletion/non-depletion. $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Spectral power

Theta

A significant Group x Time x Difficulty x Region interaction (F (2.610, 86.118) = 3.333, $p = 0.029$, $\eta_p{}^2 = 0.092$, $\varepsilon = 0.652$) was revealed for theta power. Separate Time x Difficulty x Region ANOVAs were conducted for each group to further investigate this four-way interaction. For the experimental group, a significant Time x Difficulty x Region interaction (F (2.470, 44.464) = 4.313, $p = 0.014$, $\eta_p{}^2 = 0.193$, $\varepsilon = 0.618$) was detected. Subsequent post-hoc analyses revealed theta power was elevated for the hard compared to the easy level of challenge at the frontal, central, temporal, parietal and occipital cortical regions ($p < 0.001$, $0.358 \leq d \leq 0.886$) before SWM resource depletion as well as at the central ($p = 0.001$, $d = 0.362$), parietal ($p = 0.033$, $d = 0.284$) and occipital ($p < 0.001$, $d = 0.414$) cortical regions after SWM resource depletion. Furthermore, a significant increase in temporal theta power during the easy level of challenge ($p = 0.001$, $d = 0.344$) and a significant decrease in temporal theta power during the hard level of challenge was observed ($p = 0.039$, $d = 0.323$) post- compared to pre-SWM resource depletion. For the control group, a main effect of Difficulty (F (1, 15) = 27.739, $p < 0.001$, $\eta_p^2 = 0.649$) was revealed, such that theta power was significantly greater for the hard compared to the easy level of challenge (Figure 9).

Low-alpha

For low-alpha power, a main effect of Time (F (1, 33) = 6.993, $p = 0.012$, $\eta_p^2 = 0.175$) was revealed. In particular, low-alpha power increased post- compared to pre-SWM resource depletion/non-depletion. Additionally, a significant Group x Difficulty x Region interaction (F (3.556, 117.354) = 3.321, $p = 0.016$, $\eta_p^2 = 0.091$, $\varepsilon = 0.774$) was detected. Post-hoc analyses revealed an increased low-alpha power for the experimental group during the hard relative to the easy level of challenge localized to the frontal ($p = 0.029$, $d = 0.228$) as well as the central, temporal, parietal and occipital ($p < 0.001$, $0.355 \leq d \leq 0.690$) cortical regions. Similarly, low-alpha power was elevated for the control group during the hard compared to the easy level of challenge localized to the central ($p = 0.020$, $d = 0.226$), temporal ($p < 0.001$, $d = 0.466$), parietal ($p < 0.001$, $d = 0.304$) and occipital ($p = 0.002$, $d = 0.222$) cortical regions. No significant differences were observed when directly comparing low-alpha power between the two groups (*p* > 0.05); see Figure 10.

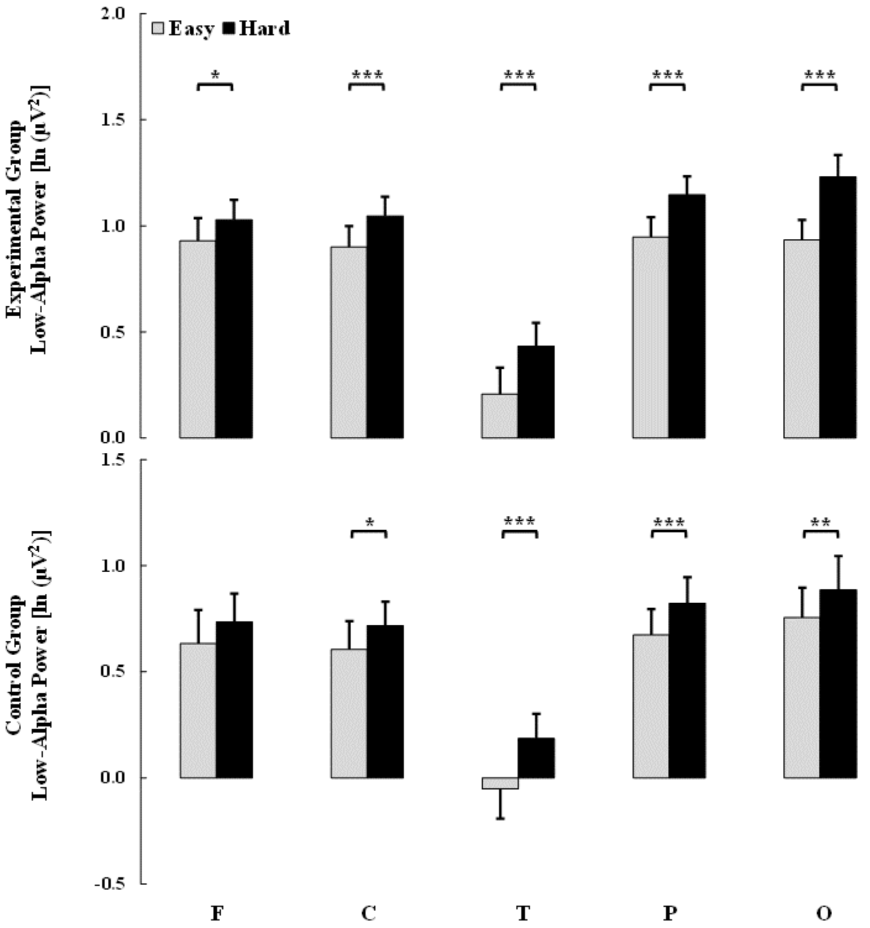


Figure 10. Spectral power for the low-alpha (8–10 Hz) frequency bandwidth recorded in the frontal (F), central (C), temporal (T), parietal (P) and occipital (O) regions while participants in the experimental group (top row) and the control group (bottom row) played Tetris® under an easy (solid grey bars) and hard (solid black bars) level of challenge collapsed across pre- and post-SWM resource depletion/non-depletion. *p < 0.05; **p < 0.01; ***p < 0.001.

High-alpha

When examining high-alpha power, a significant Time x Difficulty x Hemisphere x Region interaction (F (2.047, 67.543) = 3.159, p = 0.048, $\eta_p{}^2$= 0.087, ε = 0.512) was observed. To further investigate this four-way interaction, separate Time x Difficulty x Hemisphere ANOVAs were conducted for each cortical region of interest. For the frontal cortical region, a significant Time x Difficulty x Hemisphere interaction (F (1, 34) = 9.253, $p = 0.005$, $\eta_p^2 = 0.214$) was detected. The subsequent post-hoc analyses revealed increased frontal high-alpha power localized to the right hemisphere for the hard compared to the easy level of challenge ($p = 0.032$, $d = 0.185$) after participants completed the SWM resource depletion/non-depletion protocol. Additionally, frontal high-alpha power localized to the right hemisphere was elevated post- compared to pre-SWM resource depletion/non-depletion ($p = 0.018$, $d = 0.222$) for the hard level of challenge only. When examining the central cortical region, no significant results of interest were detected ($p > 0.05$). For the temporal cortical region, a significant Time x Difficulty interaction (F (1, 34) = 9.513, $p = 0.004$, $\eta_p^2 = 0.219$) was observed. Post-hoc analyses revealed elevated temporal high-alpha power for the hard compared to the easy level of challenge pre-SWM resource depletion/non-depletion ($p < 0.001$, $d = 0.634$). A main effect of Time (F (1, 34) = 5.649, $p = 0.023$, $\eta_p^2 = 0.142$) was detected for the parietal cortical region, such that high-alpha power increased post- compared to pre-SWM resource depletion/non-depletion. Furthermore, a significant Difficulty x Hemisphere interaction (F (1, 34) = 6.030, $p = 0.019$, $\eta_p^2 = 0.151$) was observed for the parietal cortical region. Subsequent post-hoc analyses did not reveal any significant results of interest ($p > 0.05$). For the occipital cortical region, a main effect of Time (F (1, 34) = 4.171, $p = 0.049$, $\eta_p^2 = 0.109$) was observed, revealing increased high-alpha power after compared to before participants completed the SWM resource depletion/non-depletion protocol (Figure 11).

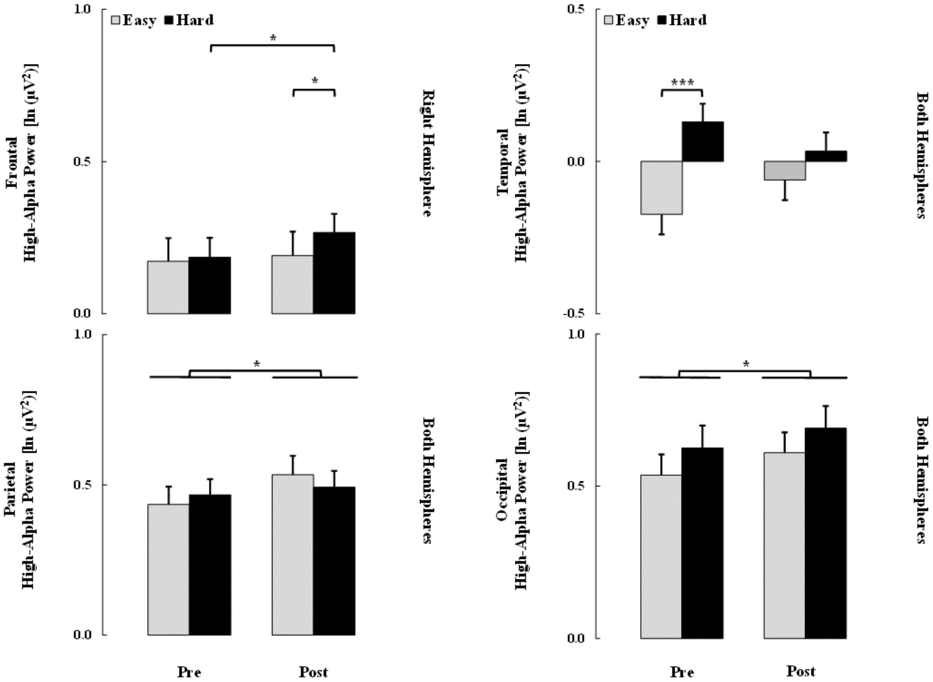


Figure 11. Spectral power for the high-alpha (11–13 Hz) frequency bandwidth recorded in the frontal, central (not depicted here), temporal, parietal and occipital regions while participants played Tetris® under an easy (solid grey bars) and hard (solid black bars) level of challenge before and after completing the SWM resource depletion/non-depletion paradigm. The top row reflects frontal high-alpha power in the right hemisphere and temporal high-alpha power across both hemispheres. The bottom row reflects parietal and occipital high-alpha power across both hemispheres. $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

Theta/alpha ratio

Statistical analysis of the FT/PA ratio power did not reveal any significant results of interest. However, a main effect of Time (F (1, 33) = 12.246, $p = 0.001$, $\eta_p{}^2 = 0.271$) revealed the FT/FA ratio power significantly decreased as participants in both groups played Tetris® after relative to before completing the SWM resource depletion/non-depletion protocol (Figure 12).

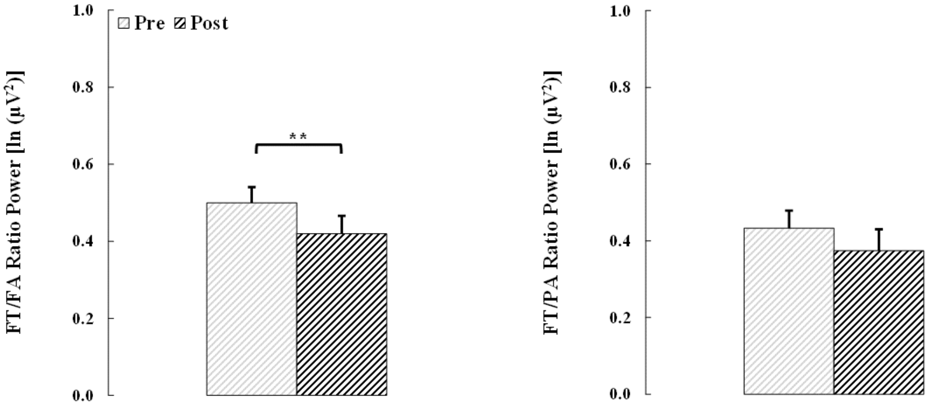


Figure 12. Spectral power ratios for the frontal and parietal regions pre- compared to post-SWM resource depletion/non-depletion collapsed across groups of participants (experimental vs. control) and levels of challenge (easy vs. hard). The left and right columns represent the frontal theta/frontal alpha ratio spectral power and the frontal theta/parietal alpha ratio spectral power, respectively. *p<0.05; **p<0.01; ***p<0.001

Chapter 4: Discussion

This study examined the effect of SWM resource depletion on subsequent cognitive-motor performance through a combined assessment of temporal and spectral EEG measures to better understand the role of SWM in cognitive-motor behavior. Two groups of participants underwent the same experimental procedures with the exception that participants assigned to the experimental group underwent a depleting SWM protocol, while participants assigned to the control group underwent a non-depleting SWM protocol. The findings revealed similarities between both groups as a function of: i) cognitive-motor difficulty independent of the main experimental manipulation (i.e., SWM resource depletion) as well as ii) the timing in which the tasks were performed (i.e., pre- vs. post-SWM resource depletion/non-depletion) possibly due to a practice effect. Additionally, between-group differences were apparent as a result of the timing in which the tasks were performed. This suggests there may be a neurocognitive benefit as well as cost related to SWM resource depletion which is dependent on the level of subsequent cognitive-motor challenge.

Variations in cognitive-motor demand independent of SWM resource depletion

As expected, behavioral performance was degraded for the hard compared to the easy level of challenge across both groups, irrespective of the timing in which the task was performed. Similar findings in performance have been reported in prior work that employed the same cognitive-motor task (i.e., Tetris®) under varying levels of demand (Gentili et al., 2018; Miller et al., 2011; Rietschel et al., 2012). The observed impairment in performance under elevated cognitive-motor challenge was accompanied with an elevation of the perceived demand (via self-report) as well as a diminished attentional reserve. In regard to the latter, our findings revealed an attenuated novelty-P3 amplitude for both groups as task difficulty increased, regardless of the timing in which participants performed the task. The reduction in novelty-P3 amplitude likely reflects a decreased attentional reserve, such that fewer residual attentional resources were available to allocate to the task-irrelevant sounds as the cognitive-motor task demands became elevated. This finding is in line with prior work which revealed a similar modulatory response in novelty-P3 amplitude under varying levels of task demand (Dyke et al., 2015; Gentili et al. 2018; Miller et al., 2011; Rietschel et al., 2014; SanMiguel et al., 2008; Shaw et al., 2018; Ullsperger et al., 2001) and provides further support for the use of the task-irrelevant novel auditory probe technique to assess changes in novelty-P3 component amplitude as a function of cognitive-motor challenge. Although our main analysis was focused on the novelty-P3 component due to its sensitivity in attentional reserve assessment (Dyke et al., 2015; Gentili et al., 2018; Jaquess et al., 2017; Miller et al., 2011; Rietschel et al., 2014; Ullsperger et al., 2001), N1 and P2 components were also examined as they have been shown to be modulated by attention (Hillyard et al., 1973; Miller et al., 2011; Picton & Hillyard, 1974). The results revealed reduced P2 amplitude during the hard compared to the easy level of challenge across both groups and the timing of task completion. This finding is also in agreement with other prior work which reported decreased P2 amplitude under elevated levels of task demand and aligns with the novelty-P3 findings in this study (Allison & Polich, 2008; Miller et al., 2011).

Similar to the ERP results, analyses of spectral power within the theta frequency bandwidth revealed changes as a function of cognitive-motor challenge. Here, we examined theta due to its sensitivity in detecting fluctuations in resource allocation related to cognitive-motor processes under varying task demands (e.g., Chuang et al., 2013; Rietschel et al., 2012; Shaw et al., 2018; 2019). The findings for theta power generally corresponded with the results for performance, self-report and the ERPs. In particular, enhanced theta power was observed for the control group across all cortical regions (frontal, central, temporal, parietal and occipital) and time periods (pre- and post-SWM resource non-depletion) as cognitive-motor difficulty increased. Similar patterns in theta synchrony were apparent for the experimental group, with a few notable exceptions post-SWM resource depletion (see below the section "The neurocognitive cost of SWM resource depletion" for further detail). The increase in theta power as cognitive-motor demand became elevated was not unexpected as theta synchrony, in particular frontal theta synchrony, could reflect an increased engagement of working memory and attentional control (Chuang et al., 2013; Coombes et al., 2005; Gentili et al., 2018; Gevins & Smith, 2000; Gevins et al., 1997, 1998; Klimesch, 1999; Rietschel et al., 2012; Sauseng et al., 2007; Shaw et al., 2018, 2019). Overall, the detected changes in theta power, along with the pattern of change in behavior and the ERP amplitudes, validate cognitive-motor challenge was successfully altered across both groups of participants independent of the main experimental manipulation (i.e., resource depletion).

Time-dependent similarities between groups due to an effect of practice

In addition to the observed difficulty-dependent changes previously discussed, changes were apparent in relation to the timing in which participants performed the cognitive-motor task. In particular, a significant reduction in N1 and novelty-P3 amplitude was observed post- compared to pre-SWM resource depletion/non-depletion for both groups of participants and levels of task demand which may reflect a diminished sensory and early attentional processing of the auditory stimuli (Hillyard et al., 1973; Mangun, 1995; Picton & Hillyard, 1974) as well as a decreased attentional reserve (e.g., Miller et al., 2011; Rietschel et al., 2014), respectively. This pattern of electro-cortical activity may reflect a possible reduction in participants' attentional capacities resulting in a numbing of the reflexive orienting of attention to the auditory probes due to the SWM resource depletion protocol. However, contrary to expectations, the same findings were observed for the control group. The SWM non-depletion paradigm employed in this study for the control group may have had unintended depleting effects as participants were expected to memorize target locations and maintain this information in working memory for a brief amount of time (200 ms). Thus, the attenuated novelty-P3 amplitudes may suggest both groups exhibited a reduced attentional capacity overall, but could still allocate attentional resources in a graded manner based on the level of cognitive-motor challenge. One may argue that the decrease in N1 and novelty-P3 amplitude post- compared to pre-SWM resource depletion/non-depletion is a result of habituation to the sounds (Naatanen & Picton, 1987; Ritter et al., 1968). Although this is possible, there are two counterarguments as to why this observed reduction in amplitudes may not solely reflect habituation. First as previously discussed, difficulty-related modulation of the novelty-P3 component amplitude was apparent, with a significantly attenuated amplitude for the hard compared to the easy level of challenge, irrespective of the timing in which the task was executed. If habituation to the sounds did indeed occur, it is likely that modulation of the novelty-P3 component between the levels of challenge would have been absent after the completion of the SWM resource depletion/non-depletion protocol (Allison & Polich, 2008; Dyke et al., 2015; Miller et al., 2011). However, this was not observed. Second, intermittently presented novel and complex auditory probes were employed in the current investigation which was previously demonstrated to be a more robust approach in capturing attention compared to pure tones (Dyke et al., 2015; Miller et al., 2011).

It is important to note that although behavioral performance on the SWM resource depletion protocol became worse over time (i.e., increase in RT) for the experimental group, no such impairment in performance on the SWM resource non-depletion protocol was detected for the control group. Further analyses of the underlying cortical dynamics are warranted, but the behavioral data alone may suggest resource depletion did not occur in the control group and thus is not the cause for the reduction in novelty-P3 amplitude. Furthermore, the behavioral analyses for the cognitive-motor task revealed that both groups improved similarly in performance (e.g., decreased number of game overs and increased lines per Tetromino) and reported a decrease in perceived task demands as well as an improved performance on the hard level of challenge post- compared to pre-SWM resource depletion/non-depletion. When considering performance and self-report measures for both groups, the interpretation that the observed reduction in attentional reserve reflects decreased attentional capacity due to the SWM resource depletion/non-depletion protocol is unlikely. As previously mentioned, the SWM resource non-depletion paradigm employed for the control group likely engaged working memory and visuomotor processing to some extent. Thus, the SWM resource depletion/non-depletion protocol may have resulted in an unexpected positive transfer of skill relevant to the successful completion of Tetris® (e.g., rotation of the Tetrominoes; maintaining the shape of the Tetrominoes in working memory for assembly) due to practice which also had some neurocognitive benefit. Namely, training of working memory on the SWM resource depletion/non-depletion protocol enhanced the efficacy of the central executive to inhibit attentional resource allocation to task-irrelevant information (i.e., auditory probes) in order to maintain information in working memory related to the primary task (i.e., Tetris®) post- compared to pre-SWM resource depletion/non-depletion (SanMiguel et al., 2008; Simon et al., 2016). In line with this notion, it is likely the participants were able to better engage in the cognitive-motor task after compared to before SWM resource depletion/non-depletion (Leiker et al., 2016). This aligns with the observed reduction in novelty-P3 amplitude as well as the attenuated N1 amplitude post-SWM resource depletion/non-depletion. Notably, all participants reported playing videogames less than four hours on average per week over the past year and had minimal-to-no prior Tetris® experience. Since all participants were novices, it is also feasible that the mere act of playing Tetris® a second time (i.e., post-SWM resource depletion/non-depletion) at each level of difficulty may have also contributed to an improved performance independent of the SWM resource depletion/non-depletion protocol.

Further support is provided by an increased low-and high-alpha power post- compared to pre-SWM resource depletion/non-depletion, which may be indicative of cortical refinement often observed within the context of practice and expert performance (Baumeister et al., 2008; Gentili et al., 2011; Gevins & Smith, 2000; Gevins et al., 1997; Haufler et al., 2000; Smith et al., 1999). The increased low- and high-alpha power observed under elevated task demand as well as post- compared to pre-SWM resource depletion/non-depletion likely reflects variations in cortical activation related to general (low-alpha) as well as task-specific (high-alpha) arousal (Haufler et al., 2000; Klimesch, 1999; Rietschel et al., 2012; Smith et al., 1999). In particular, the population recruited in this study (novice video gamers) exhibited elevated levels of unspecific arousal (low-alpha desynchrony) across the entire scalp before compared to after SWM resource depletion/non-depletion, which has been suggested to reflect the first step in skill acquisition (Baumeister et al., 2008). Interestingly, this elevation in global unspecific arousal corresponded with an increased novelty-P3 component amplitude (i.e., more attentional resources were allocated to task-irrelevant auditory probes) pre- relative to post-SWM resource depletion/non-depletion. It can be speculated that when performing the task for the first time, participants were unfamiliar with what specific information/detail was pertinent for successful performance and thus purposefully elevated their arousal to attend to as much information as possible. Furthermore, the increased high-alpha power localized to the frontal (specific to the hard challenge), parietal and occipital cortical regions post-SWM resource depletion/non-depletion may reflect a decreased engagement of task-relevant processes (e.g., high-level multisensory integration, object recognition), reflecting a refinement of cortical dynamics possibly due to practice via the SWM resource depletion/non-depletion protocol and/or from repeated performance of game play (Baumeister et al., 2008; Smith et al., 1999; Vanni et al., 1997).

There was also an increase in low- and high-alpha power for the hard relative to the easy level of challenge. This finding was unexpected, as prior work has linked elevated task demands with alpha desynchrony due to an increased engagement of cognitive-motor processes necessary to overcome the challenge (e.g., Gentili et al., 2018; Rietschel et al., 2012; Shaw et al., 2018). However, this increase in low- and high-alpha may in part reflect a cortical disengagement for the hard level of challenge pre-SWM resource depletion/non-depletion as a result of the game being too difficult for the population recruited in this study (novice video gamers). In particular, temporal high-alpha power was elevated during the hard compared to the easy level of challenge on Tetris® before participants underwent the SWM resource depletion/non-depletion protocol, but no such difference was apparent after SWM resource depletion/non-depletion. The increase in temporal high-alpha power observed in both groups may reflect participants' failure to engage in task-specific processes (e.g., visuospatial processing) due to their prior inexperience playing Tetris® (Haufler et al., 2000). However, the lack of temporal high-alpha modulation post-SWM resource depletion/non-depletion may reflect participants' enhanced ability to engage these processes under the difficult level of challenge possibly due to practice. Notably, the cortical refinement discussed here, mirrored the improvement in performance (e.g., decreased number of game overs post- compared to pre-SWM resource depletion/non-depletion for the hard level of difficulty). It must be noted that the observed increase in low-alpha power for the hard compared to the easy level of challenge across both time periods (pre- and post-SWM resource depletion/non-depletion) may reflect a combination of cortical disengagement and cortical refinement pre- and post-SWM resource depletion, respectively. Collectively, the elevated low- and high-alpha power observed in the current investigation likely reflects a combination of general as well as task-specific cortical refinement post-SWM resource depletion/non-depletion as well as disengagement from the task pre-SWM resource depletion/non-depletion. There was also a significant decrease in the FT/FA ratio power post- compared to pre-SWM resource depletion/non-depletion. However, this was likely driven by the enhanced alpha power discussed here, as frontal theta synchrony was not observed post- relative to pre-SWM resource depletion/non-depletion.

The neurocognitive cost of SWM resource depletion

While similarities in brain dynamics were apparent, there were also a few notable discrepancies between the two groups. First, a time-dependent dissociation in the modulation of P2 amplitude was observed between the two groups. The amplitude of the P2 component significantly increased for the experimental group, but significantly decreased for the control group post- compared to pre-SWM resource depletion/non-depletion. While the exact nature of P2 is not as well understood as the other components examined in this study, P2 is believed to reflect obligatory early sensory processing that is sensitive to attentional demands (Miller et al., 2011; Picton & Hillyard, 1974). Prior work has shown that when compared to controls, special populations with attentional and cognitive function impairments (e.g., children with attention deficit hyperactivity disorder and reading impairments) exhibit increased P2 amplitude elicited by both targets and non-targets in an auditory oddball task. Such a finding has been suggested to reflect deficiencies in these populations' ability to withdraw attentional resource allocation from task-irrelevant information (Bernal et al., 2000; Senderecka et al., 2012). Thus, it is possible that the increase in P2 amplitude for the experimental group may suggest the SWM resource depletion paradigm weakened attentional processing to some extent.

Second, the source of the differences in novelty-P3 modulation between the easy and hard level of challenge varied depending on the timing in which the task was executed for the experimental group, while no such difference was observed for the control group. In particular, modulation in novelty-P3 amplitude was localized to the central and parietal scalp sites (electrodes Cz and Pz) pre-SWM resource depletion, but had a more fronto-central localization (electrodes Fz, FCz and Cz) post-SWM resource depletion. It is possible SWM resource depletion resulted in this differentiation between the two groups, however future work employing source localization methods (e.g., sLORETA; Jatori et al., 2014) is needed to provide further insight. Lastly, the control group exhibited elevated theta power across all cortical regions as the level of cognitive-motor challenge increased irrespective of the time in which participants performed the task. This is in line with prior work which has reported elevated theta power for the maintenance of cognitive and cognitive-motor performance under increased task demands (Gevins et al., 1997; Gentili et al., 2018; Klimesh, 1999; Sauseng et al., 2007; Shaw et al., 2018, 2019). Although similar difficulty-dependent increases in theta power were apparent for the experimental group pre-SWM resource depletion, this adaptive response was absent within the frontal and temporal cortical regions post-SWM resource depletion. The SWM resource depletion protocol may have resulted in a lack of modulatory response in frontal and temporal theta synchrony for the experimental group as the level of challenge became elevated, thus reflecting a failure to engage specific cognitive-motor processes (e.g., working memory, attentional control, visuospatial) important for successful task performance (Chuang et al., 2013; Coombes et al., 2005; Gentili et al., 2018; Rietschel et al., 2012; Sauseng et al., 2007; Shaw et al., 2018, 2019). This lack of engagement may have resulted in a weakened attentional system as reflected by the P2 component previously discussed.

Additionally, the modulation of temporal theta power pre- compared to post-SWM resource depletion in the experimental group differed depending on the level of cognitive-motor challenge. Prior neuroimaging work has reported elevated levels of theta synchrony in expert performers as well as during the acquisition of a skill (Baumeister et al., 2008; Caplan et al., 2003; Doppelmayr et al., 2008; Gentili et al., 2011; Gevins et al., 1997; Haufler et al., 2000; Smith et al., 1999). While most of this work focused on frontal theta synchrony, reports of elevated theta power has also been extended to other cortical regions during cognitive-motor learning (Gentili et al., 2011; Jaquess et al., 2017; Perfetti et al., 2011). This increase in theta, along with increases in alpha have been suggested to reflect elevated engagement with task demands while also exhibiting economical resource allocation (Haufler et al., 2000). In the current investigation participants exhibited a significant decrease and increase in temporal theta power during the hard and easy level of challenge, respectively. Given prior reports, the decrease in temporal theta for the hard level of challenge may be indicative of successful resource depletion, such that resource depletion led to decreased engagement of specific cognitive-motor processes (spatial memory, visuospatial processes) commonly associated with the temporal cortical region (Chauviere et al., 2009; Haufler et al., 2000). Interestingly, the increase in temporal theta power for the easy level of challenge may suggest the SWM resource depletion protocol also served as intensive training which translated in an enhanced capability to recruit resources related to these same cognitive-motor processes critical for successful Tetris® performance. Thus, despite the associated neural cost mentioned above, these findings suggest there is also a benefit related to the intensive recruitment of specific cognitive-motor processes on subsequent tasks requiring the same processes in novice performers. It is important to note that no significant differences were apparent between the two groups for all outcome measures assessed in the current investigation (behavior and EEG) prior to undergoing SWM resource depletion. Thus, it is likely the differences in brain dynamics between the two groups discussed here is a result of the experimental manipulation employed in this work (i.e., resource depletion).

The findings in the current work extend and support prior behavioral and neuroimaging studies on resource depletion which have generally reported decreased performance as well as neural activation (Inzlicht & Gutsell, 2007; Persson et al., 2009, 2013; Wagner et al., 2013). Although performance decrements specific to SWM resource depletion was not observed, performance in the subsequent task improved within the population considered here. Such an improvement in performance is likely due to an unintended effect of practice as novice performers were employed in this study. Although depletion effects were apparent, they were subtle and combined with possible practice effects. Prior work has mainly employed resource depletion within the context of purely cognitive performance and utilized tasks that were not novel to participants (e.g., Persson et al., 2009, 2013). The one behavioral study to employ SWM resource depletion within the context of cognitive-motor learning (i.e., visuomotor adaptation) reported a moderate correlation between SWM performance on the depletion task and the rate of adaptation. It is important to note that the visuomotor adaptation task entails the modification of a previously well-established motor plan which may be less involved compared to learning a brand new skill to be added to the individual's motor repertoire, as may have been the case in the current study (i.e., learn to play a new video game without any experience in this broadly defined area) (Krakaeur & Mazzoni, 2011; Shadmehr & Wise, 2005). Furthermore, in the visuomotor adaptation task employed by Anguera et al., (2012), visual feedback of movement trajectories were suddenly rotated 30° clockwise. The amplitude of this rotation is limited, as prior work has suggested the manner in which the distortion of movement trajectories is implemented may differentially recruit high-level cognitive processes (Buch, Young, & Contreras-Vidal, 2003; Ingram et al., 2000; Werner et al., 2014). Thus, the lack of a strong perturbation may have also weakened the magnitude of learning within this context.

Conclusions, limitations and future work

In the current investigation all participants were novice video game players who had limited prior Tetris® experience. This recruitment was strategic as participants who were experienced video game players (> 50 hours experience) in prior pilot work reported developing strategies that enabled them to bypass the mental rotation aspect of the SWM resource depletion task, thus limiting the efficacy of depletion. However, recruiting novices resulted in some unintended effects of practice which convoluted the evaluation of resource depletion. Although all participants had the opportunity to familiarize themselves with Tetris® before the start of data collection, future work may benefit from employing more intensive training on the task beforehand and/or recruiting individuals with moderate video game and Tetris® experience who would be less likely to develop strategies as well as exhibit effects of practice. In relation to this, there is evidence which suggests differences in executive capacity exists across individuals (de Fockert, 2013; Murphy et al., 2016; Simon et al., 2016). Potential differences in SWM abilities between participants were not accounted for here and could be considered as an additional limitation of this work. Future analyses should be conducted to examine how individual differences correspond to cognitive-motor performance following SWM resource depletion. It is possible that individuals with high compared to low SWM capacities were better capable to overcome SWM resource depletion. Furthermore, although the current investigation reported changes in behavioral performance during the SWM resource depletion/non-depletion task, further analysis of the underlying cortical dynamics is warranted and would provide further insight for performance on the subsequent cognitive-motor tasks. Prior neuroimaging work on resource depletion has mainly employed fMRI to evaluate neural activation at discrete time points (e.g., pre- and post-depletion). The underlying brain dynamics during resource depletion still remains unknown. The use of EEG could track the progression of cortical dynamics throughout the process of SWM resource depletion with high temporal resolution which would allow for the examination of brain dynamics throughout depletion in real time. Although one limitation of EEG is its limited spatial resolution, future work could also employ source localization methods (e.g., sLORETA) to better understand the source of the observed modulation in cortical dynamics. Lastly, this study assessed the effects of SWM resource depletion on cognitive-motor performance. This work could be further extended by examining the effects of depletion within a learning context, such as but not limited to, sensorimotor adaptation (Anguera et al., 2012; Gentili et al., 2011).

Overall, this work provides support for the employment of executive resource depletion to probe the role of specific cognitive processes within a cognitive-motor context. The results from the current study revealed that all participants, regardless of their group, exhibited improvements in task performance after compared to before completing the SWM resource depletion/non-depletion protocol. This improvement in performance corresponded with: i) decreased allocation of attentional resources to task-irrelevant information indexed by a decreased novelty-P3 component amplitude and ii) a general as well as task-specific refinement of cortical activity reflected by an increased low- and high-alpha power, respectively. These findings collectively suggest there may have been an effect of practice across the two groups. Differences between the two groups were also apparent, as a result of the SWM depletion protocol. In particular, the experimental group exhibited a larger P2 component amplitude after compared to before SWM resource depletion, which may be a reflection of an weakened attentional system. Furthermore, while the control group exhibited increased theta power across all cortical regions during the hard relative to the easy level of challenge irrespective to the timing participants executed the task (pre- and post-SWM resource non-depletion), this adaptive response was absent within the frontal and temporal cortical regions for the experimental group post-SWM resource depletion. The experimental group also exhibited a significant decrease in temporal theta power during the hard level of challenge post- compared to pre-SWM resource depletion. The lack of cortical modulation between the levels of challenge as well as decrease in temporal theta for the hard level of challenge, may reflect an inability of the experimental group to recruit resources related to working memory, attentional control and visuospatial processing, all of which are important in the successful performance of the cognitive-motor task employed in the current study. Lastly, the experimental group revealed an increase in temporal theta power during the easy level of challenge post- compared to pre-SWM resource depletion. Such a finding may indicate the SWM resource depletion protocol also served as intensive training, which translated in enhanced visuospatial skill observed while executing the easy level of task difficulty. Our findings collectively suggest that performing an intensive cognitive task can have a combined neurocognitive benefit and cost during the performance of a subsequent cognitive-motor task requiring overlapping cognitive processes as that of the depleting task. This work has the potential to aid in the development of training protocols aimed at enhancing cognitive-motor performance in healthy individuals as well as contribute to improve rehabilitative interventions aimed at optimizing cognitive-motor performance for various patient populations (e.g., stoke, traumatic brain injury, upper-limb amputation) who suffer from cognitive-motor disabilities.

Appendices

Appendix A.

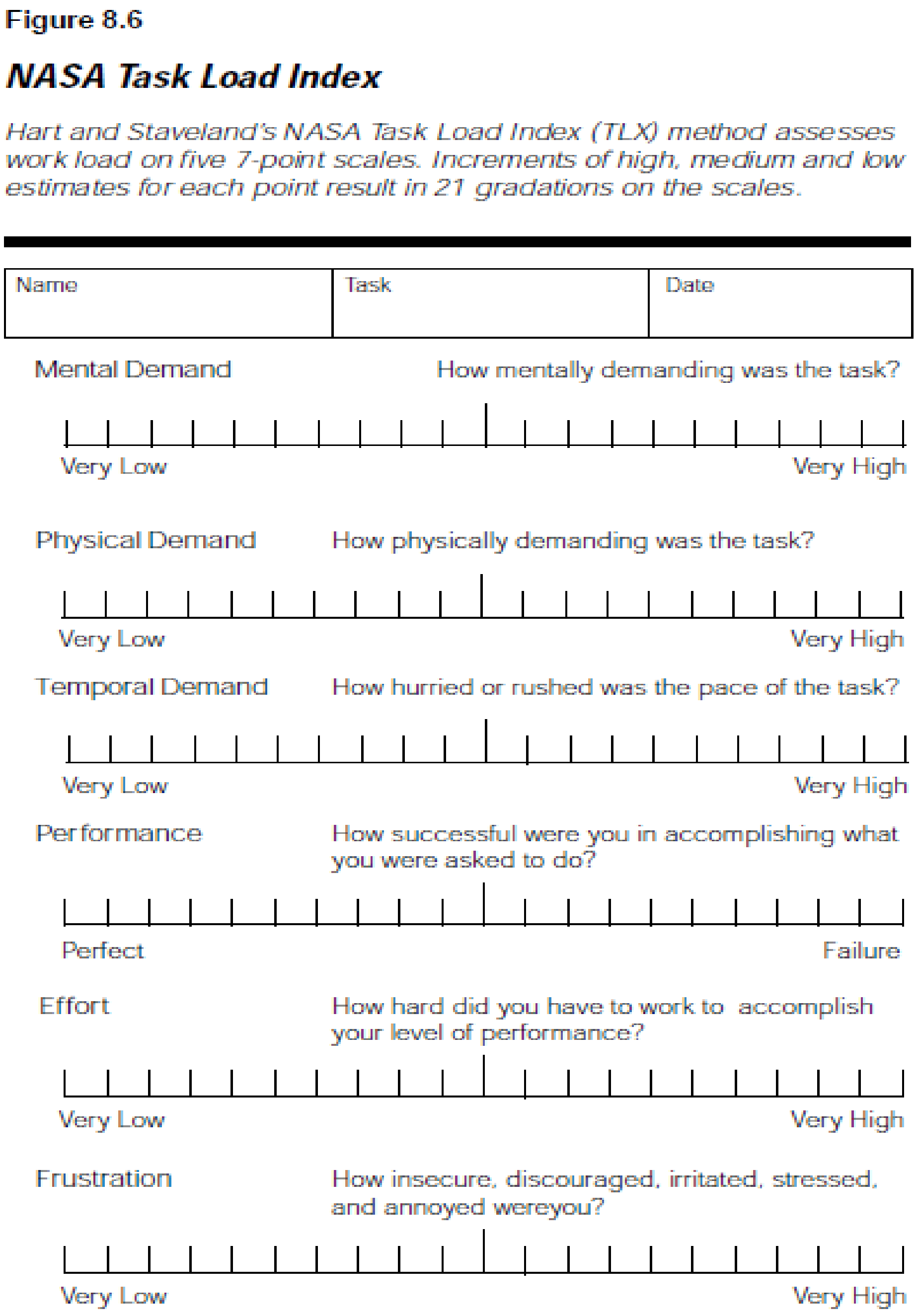


Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

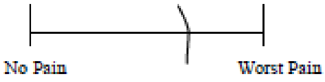
Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix B.

Visual Analog Scale

Please put a vertical line through the rectangle at the point that best represents how you feel right now. The ends of each rectangle represent the opposite extremes of the **same** variable. Ex.



How *mentally loaded* did I feel while performing the task?

Not Loaded

Completely Loaded

How *overwhelmed* was I by the task?

Not At All

Completely Overwhelmed

How *easy* was the task?

Extremely Easy
Not Easy At All

How much did I have to *concentrate* to perform the task?

A Little Concentrated
Concentrated A Lot

How *tired* was I after the task?

A Little Tired
Very Tired

Bibliography

Allison, B. Z., & Polich, J. (2008). Workload assessment of computer gaming using a single stimulus event-related potential paradigm. *Biological Psychology, 77*(3), 277-283. **https://doi.org/10.1016/j.biopsycho.2007.10.014**

Anguera, J. A., Bernard, J. A., Jaeggi, S. M., Buschkuehl, M., Benson, B. L., Jennett, S., Humfleet, J., Reuter-Lorenz, P., Jonides, J., & Seidler, R. D. (2012). The effects of working memory resource depletion and training on sensorimotor adaptation. *Behavioral Brain Research*, *228*(1), 107-115. **https://doi.org/10.1016/j.bbr.2011.11.040**

Anguera, J. A., Reuter-Lorenz, P. A., Willingham, D. T., Seidler, R. D. (2010). Contributions of spatial working memory to visuomotor learning. *Journal of Cognitive Neuroscience*, *22*(9), 1917–1930. **https://doi.org/10.1162/jocn.2009.21351**

Babiloni, C., Marzano, N., Infarinato, F., Iacoboni, M., Rizza, G., Aschieri, P., Cibelli, G., Soricelli, A., Eusebi, F., & Del Percio, C. (2010). “Neural efficiency” of experts’ brain during judgement of actions: A high-resolution EEG study in elite and amateur karate athletes. *Behavioural Brain Research, 207*(2), 466-475. **https://doi.org/10.1016/j.bbr.2009.10.034**

Baddeley, A. D. (1986). *Working memory.* Oxford University Press.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Science, 4*(11), 417-423. **https://doi.org/10.1016/S1364-6613(00)01538-2**

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 47–89). Academic Press.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology, 74*(5), *1252- 1265.* **https://doi.org/10.1037/0022-3514.74.5.1252**

Baumeister, J., Reinecke, K., Liesen, H., & Weiss, M. (2008). Cortical activity of skilled performance in a complex sports related motor task. *European Journal of Applied Physiology, 104*(4), 625-631. **https://doi.org/10.1007/s00421-008-0811-x**

Berka, C., Levendowski, D. J., Lumicao, M. N., Yau, A., Davis, G., Zivkovic, V. T., Olmstead, R. E., Tremoulet, P. D., & Craven, P. L. (2007). EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks. *Aviation, Space, and Environmental Medicine, 78*(5), B231–B244.

Bernal, J., Harmony, T., Rodriguez, M., Reyes, A., Yanez, G., Fernandez, T., Galan, L., Silva, J., Fernandez-Bouzas, A., Rodriguez, H., Guerrero, V., & Marosi, E. (2000). Auditory event-related potentials in poor readers. *International Journal of Psychophysiology, 36*(1), 11–23. **https://doi.org/10.1016/S0167-8760(99)00092-6**

Bradford, J. C., Lukos, J. R., Passaro, A., Ries, A., & Ferris, D. P. (2019). Effect of locomotor demands on cognitive processing. *Scientific Report*s, *9*, 9234 (2019). **https://doi.org/10.1038/s41598-019-45396-5**

BrainProducts (2013, December). *Ocular correction ICA.* **http://www.brainproducts.com/files/public/products/brochures_material/pr_articles/1304_OC-ICA.pdf**

Buch, E. R., Young, S., & Contreras-Vidal, J. L. (2003). Visuomotor adaptation in normal aging. *Learning & Memory, 10*(1), 55-63. **https://doi.org/10.1101/lm.50303**

Caplan, J. B., Madsen, J. R., Schulze-Bonhage, A., Aschenbrenner-Scheibe, R., Newman, E. L., & Kahana, M. J. (2003). Human theta oscillations related to sensorimotor integration and spatial learning. *The Journal of Neuroscience*, *23*(11), 4726–4736. **https://doi.org/10.1523/JNEUROSCI.23-11-04726.2003**

Chauvière, L., Rafrafi, N., Thinus-Blanc, C., Bartolomei, F., Esclapez, M., & Bernard, C. (2009). Early deficits in spatial memory and theta rhythm in experimental temporal lobe epilepsy. *The Journal of Neuroscience, 29*(17), **5402–5410. https://doi.org/10.1523/JNEUROSCI.4699-08.2009**

Chuang, L. Y., Huang, C. J., & Hung, T. M. (2013). The differences in frontal midline theta power between successful and unsuccessful basketball free throws of elite basketball players. *International Journal of Psychophysiology*, *90*(3), 321-328. **https://doi.org/10.1016/j.ijpsycho.2013.10.002**

Cohen, J., & Polich, J. (1997). On the number of trials needed for P300. *International Journal of Psychophysiology*, *25*(3), 249–255. **https://doi.org/10.1016/S0167-8760(96)00743-X**

Coombes, S. A., Janelle, C. M., Duley, A. R., & Conway, T. (2005). Adults with dyslexia: Theta power changes during performance of a sequential motor task. *International Journal of Psychophysiology*, *56*(1), 1-14. **https://doi.org/10.1016/j.ijpsycho.2004.09.011**

Cornoldi C., & Vecchi, T. (2003). *Visuo-spatial working memory and individual differences.* Psychology Press.

Deeny, S., Chicoine, C., Hargrove, L., Parrish, T., & Jayaraman, A. (2014). A simple ERP method for quantitative analysis of cognitive workload in myoelectric prosthesis control and human-machine interaction. *Public Library of Science*, *9*(11), e112091. **https://doi.org/10.1371/journal.pone.0112091**

de Fockert, J. W. (2013). Beyond perceptual load and dilution: A review of the role of working memory in selective attention. *Frontiers in Psychology, 4,* 287. **https://dx.doi.org/10.3389%2Ffpsyg.2013.00287**

De Lisi, R., & Wolford, J. L. Improving children's mental rotation accuracy with computer game playing. *The Journal of Genetic Psychology, 163*(3), 272-282. **https://doi.org/10.1080/00221320209598683**

Doppelmayr, M., Finkenzeller, T., & Sauseng, P. Frontal midline theta in the pre-shot phase of rifle shooting: Differences between experts and novices.*Neuropsychologia, 46*(5), 1463-1467. **https://doi.org/10.1016/j.neuropsychologia.2007.12.026**

Dorris, D. C., Power, D. A., & Kenefick, E. (2012). Investigating the effects of ego depletion on physical exercise routines of athletes. *Psychology of Sport and Exercise, 13*(2), 118-125. **https://doi.org/10.1016/j.psychsport.2011.10.004**

Dyke, F. B., Leiker, A. M., Grand, K. F., Godwin, M. M., Thompson, A. G., Rietschel, J. C., McDonald, C. G., & Miller, M. W. (2015). The efficacy of auditory probes in indexing cognitive workload is dependent on stimulus complexity. *International Journal of Psychophysiology, 95*(1), 56-62. **https://doi.org/10.1016/j.ijpsycho.2014.12.008**

Fabiani, M., Kazmerski, V. A., Cycowicz, Y. M., & Friedman, D. (1996). Naming norms for brief environmental sounds: Effects of age and dementia. *Psychophysiology, 33*(4), 462-475. **https://doi.org/10.1111/j.1469-8986.1996.tb01072.x**

Gentili, R. J., Bradberry, T. J., Oh, H., Hatfield, B. D., & Contreras-Vidal, J. L. (2011). Cerebral cortical dynamics during visuomotor transformation: Adaptation to a cognitive-motor executive challenge. *Psychophysiology, 48*(6), 813-824. **https://doi.org/10.1111/j.1469-8986.2010.01143.x**

Gentili, R. J., Jaquess, K. J., Shuggi, I. M., Shaw, E. P., Oh, H., Lo, L.-C., Tan, Y. Y., Domingues, C. A., Blanco, J. A., Rietschel, J. C., Miller, M. W., & Hatfield, B. D. (2018). Combined assessment of attentional reserve and cognitive-motor effort under various levels of challenge with a dry EEG system. *Psychophysiology, 55*(6), e13059. **https://doi.org/10.1111/psyp.13059**

Gevins, A., & Smith, M. E. (2000). Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. *Cerebral Cortex, 10*(9), 829-839. **https://doi.org/10.1093/cercor/10.9.829**

Gevins, A., Smith, M. E., Leong, H., McEvoy, L., Whitfield, S., Du, R., & Rush, G. (1998). Monitoring working memory load during computer-based tasks with EEG pattern recognition methods. *Human Factors, 40*(1), 79-91. **https://doi.org/10.1518%2F001872098779480578**

Gevins, A., Smith, M. E., McEvoy, L., & Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. *Cerebral Cortex, 7*(4), 374-385. **https://doi.org/10.1093/cercor/7.4.374**

Hart, S. G. (2006). NASA-task load index (NASA-TLX); 20 years later. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting* (pp. 904-908).

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload*. North Holland Press.

Hatfield, B. D., Haufler, A. J., Hung, T.-M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal of Clinical Neurophysiology, 21*(3), 144-156.

Haufler, A. J., Spalding, T. W., Santa Maria, D. L., & Hatfield, B. D. (2000). Neuro-cognitive activity during a self-paced visuospatial task: Comparative EEG profiles in marksmen and novice shooter. *Biological Psychology, 53*(2-3), 131-160. **https://doi.org/10.1016/s0301-0511(00)00047-8**

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T.W. (1973). Electrical signs of selective attention in the human brain. *Science, 182*(4108), 177–180. **https://doi.org/10.1126/science.182.4108.177**

Holm, A., Lukander, K., Korpela, J., Sallinen, M., & Muller, K. M. I. (2009). Estimating brain load from the EEG. *The Scientific World Journal, 9*, 639-651. **https://doi.org/10.1100/tsw.2009.83**

Ingram, H. A., van Donkelaar, P., Cole, J., Vercher, J.-L., Gauthier, G. M., Miall, R. C. (2000). The role of proprioception and attention in a visuomotor adaptation task. *Experimental Brain Research, 132*(1), 114-126. **https://doi.org/10.1007/s002219900322**

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological Science*, *18*(11), 933-937. **https://doi.org/10.1111%2Fj.1467-9280.2007.02004.x**

Jaquess, K. J., Gentili, R. J., Lo, L.-C., Oh, H., Zhang, J., Rietschel, J. C., Miller, M. W., Tan, Y. Y., & Hatfield, B. D. (2017). Empirical evidence for the relationship between cognitive workload and attentional reserve. *International Journal of Psychophysiology, 121*, 46-55. **https://doi.org/10.1016/j.ijpsycho.2017.09.007**

Jatori, M. A., Kamel, N., Malik, A. S., & Faye, I. (2014). EEG based brain source localization comparison of sLORETA and eLORETA. *Australasian Physical & Engineering Sciences in Medicine, 37*(4), 713-721. **https://doi.org/10.1007/s13246-014-0308-3**

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research*, *29*(2-3), 169-195. **https://doi.org/10.1016/S0165-0173(98)00056-3**

Krakauer, J. W., & Mazzoni, P. (2011). Human sensorimotor learning: Adaptation, skill, and beyond. *Current Opinion in Neurobiology, 21*(4), 636-644. **https://doi.org/10.1016/j.conb.2011.06.012**

Lau-Zhu, A., Holmes, E. A., Butterfield, S., & Holmes, J. (2017). Selective association between tetris game play and visuospatial working memory: A preliminary investigation. *Applied Cognitive Psychology, 31*(4), 438-445. **https://doi.org/10.1002/acp.3339**

Leiker, A. M., Miller, M., Brewer, L., Nelson, M., Siow, M., & Lohse, K. (2016). The relationship between engagement and neurophysiological measures of attention in motion-controlled video games: A randomized controlled trial. *JMIR Serious Games, 4*(1), e4. **https://dx.doi.org/10.2196%2Fgames.5460**

Logie, R. H. (1995). *Visuo-spatial working memory.* Lawrence Erlbaum Associates.

Malcolm, B. R., Foxe, J. J., Butler, J. S., & De Sanctis, P. (2015). The aging brain shows less flexible reallocation of cognitive resources during dual-task walking: A mobile brain/body imaging (MoBI) study. *NeuroImage, 117,* 230–242. **https://doi.org/10.1016/j.neuroimage.2015.05.028**

Mangun, G. R. (1995). Neural mechanism of visual selective attention. *Pyschophysiology, 32*(1), 4-18. **https://doi.org/10.1111/j.1469-8986.1995.tb03400.x**

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167-202. **https://doi.org/10.1146/annurev.neuro.24.1.167**

Miller, M. W., Rietschel, J. C., McDonald, C. G., & Hatfield, B. D. (2011). A novel approach to the physiological measurement of mental workload. *International Journal of Psychophysiology, 80*(1), 75-78. **https://doi.org/10.1016/j.ijpsycho.2011.02.003**

Murphy, G., Groeger, J. A., & Greene, C. M. (2016). Twenty years of load theory- where are we now, and where should we go next? *Psychonomic Bulletin & Review, 23*(5), 1316-1340. **https://doi.org/10.3758/s13423-015-0982-5**

Murray, N. P., & Janelle, C. M. (2007). Event-related potential evidence for the processing efficiency theory. *Journal of Sports Sciences, 25*(2), 161-171. **https://doi.org/10.1080/02640410600598505**

Naatanen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375-425. **https://doi.org/10.1111/j.1469-8986.1987.tb00311.x**

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology, 15*(1), 33-58. **https://doi.org/10.1016/0193-3973(94)90005-1**

Onton, J., Westerfield, M., Townsend, J., & Makeig, S. (2006). Imaging human EEG dynamics using independent component analysis. *Neuroscience and Biobehavioral Reviews, 30*(6), 808-822. **https://doi.org/10.1016/j.neubiorev.2006.06.007**

Perfetti, B., Moisello, C., Landsness, E. C., Kvint, S., Lanzafame, S., Onofrj, M., Di Rocco, A., Tononi, G., & Ghilardi, M. F. (2011). Modulation of gamma and theta spectral amplitude and phase synchronization is associated with the development of visuo-motor learning. *Journal of Neuroscience, 31*(41), 14810-14819. **https://doi.org/10.1523/JNEUROSCI.1319-11.2011**

Persson, J., Larsson, A., & Reuter-Lorenz, P. A. (2013). Imaging fatigue of interference control reveals the neural basis of executive resource depletion. *Journal of Cognitive Neuroscience, 25*(3), 338-351. **https://doi.org/10.1162/jocn_a_00321**

Persson, J., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. A. (2007). Cognitive fatigue of executive processes: Interaction between interference resolution tasks. *Neuropsychologia, 45*(7), 1571-1579. **https://doi.org/10.1016/j.neuropsychologia.2006.12.007**

Picton, T. W., & Hillyard, S. A. (1974). Human auditory evoked potentials II: Effects of attention. *Electroencephalography and Clinical Neurophysiology, 36*(2), 191-199. **https://doi.org/10.1016/0013-4694(74)90156-4**

Pruziner, A. L., Shaw, E. P., Rietschel, J. C., Hendershot, B. D., Miller, M. W., Wolf, E. J., Hatfield, B. D., Dearth, C. L., & Gentili, R. J. (2019). Biomechanical and neurocognitive performance outcomes of walking with transtibial limb loss while challenged by a concurrent task. *Experimental Brain Research, 237*(2), 477-491. **https://doi.org/10.1007/s00221-018-5419-8**

Rietschel, J. C., McDonald, C. G., Goodman, R. N., Miller, M. W., Jones-Lush, L. M., Wittenberg, G. F., & Hatfield, B. D. (2014). Psychological support of increasing attentional reserve during the development of motor skill. *Biological Psychology, 103*, 349-356. **https://doi.org/10.1016/j.biopsycho.2014.10.008**

Rietschel, J. C., Miller, M. W., Gentili, R. J., Goodman, R. N., McDonald, C. G., & Hatfield, B. D. (2012). Cerebral-cortical networking and activation increase as a function of cognitive-motor task difficulty. *Biological Psychology*, *90*(2), 127-133. **https://doi.org/10.1016/j.biopsycho.2012.02.022**

Ritter, W., Vaughan, H. G., & Costa, L. D. (1968). Orienting and habituation to auditory stimuli: A study of short terms changes in average evoked responses. *Electroencephalography and Clinical Neurophysiology*, *25*(6), 550-556. **https://doi.org/10.1016/0013-4694(68)90234-4**

SanMiguel, I., Corral, M.-J., & Escera, C. (2008). When loading working memory reduces distraction: Behavioral and electrophysiological evidence from an auditory-visual distraction paradigm. *Journal of Cognitive Neuroscience, 20*(7), 1131-1145. **https://doi.org/10.1162/jocn.2008.20078**

Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C., & Hummel, F. C. (2007). Dissociation of sustained attention from central executive functions: Local activity and interregional connectivity in the theta range. *The European Journal of Neuroscience, 25*(2), 587-593. **https://doi.org/10.1111/j.1460-9568.2006.05286.x**

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology: General, 136*(2), 241-255. **https://psycnet.apa.org/doi/10.1037/0096-3445.136.2.241**

Seidler, R. D., Bo, J., & Anguera, J. A. (2012) Neurocognitive contributions to motor skill learning: The role of working memory. *Journal of Motor Behavior, 44*(6), 445-453. **https://doi.org/10.1080/00222895.2012.672348**

Senderecka, M., Grabowska, A., Gerc, K., Szewczyk, J., & Chmylak, R. Event-related potentials in children with attention deficit hyperactivity disorder: An investigation using an auditory oddball task. *International Journal of Psychophysiology, 85*(1), 106-115. **https://doi.org/10.1016/j.ijpsycho.2011.05.006**

Shadmehr, R., & Wise, S. P. (2005). *Computational neuroscience. The computational neurobiology of reaching and pointing: A foundation for motor learning.* MIT Press.

Shaw, E. P., Rietschel, J. C., Hendershot, B. D., Pruziner, A. L., Miller, M. W., Hatfield, B. D., & Gentili, R. J. (2018). Measurement of attentional reserve and mental effort for cognitive workload assessment under various task demands during dual-task walking. *Biological Psychology, 134,* 39-51. **https://doi.org/10.1016/j.biopsycho.2018.01.009**

Shaw, E. P., Rietschel, J. C., Hendershot, B. D., Pruziner, A. L., Wolf, E. J., Dearth, C. L., Miller, M. W., Hatfield, B. D., & Gentili, R. J. (2019). A comparison of cognitive workload in individuals with transtibial and transfemoral lower limb loss during dual-task walking under varying demand. *Journal of the International Neuropsychological Society, 25*(9), 985-997. **https://doi.org/10.1017/S1355617719000602**

Simon, S. S., Tusch, E. S., Holcomb, P. J., & Daffner, K. R. (2016). Increasing working memory load reduces processing of cross-modal task-irrelevant stimuli even after controlling for task difficulty and executive capacity. *Frontiers in Human Neuroscience, 10,* 27536226. **https://doi.org/10.3389/fnhum.2016.00380**

Smith, M. E., McEvoy,L. K., & Gevins, A. (1999). Neurophysiological indices of strategy development and skill acquisition. *Cognitive Brain Research*, *7*(3), 389-404. **https://doi.org/10.1016/s0926-6410(98)00043-3**

Vanni, S., Revonsuo, A., & Hari, R. (1997). Modulation of the parieto-occipital alpha rhythm during object detection. *The Journal of Neuroscience, 17*(18), 7141-7147. **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6573275/**

Verma, J. P. (2016). *Repeated measures design for empirical researchers.* John Wiley & Sons, Inc.

Wagner, D. D., Altman, M., Boswell, R. G., Kelley, W. M., & Heatherton, T. F. (2013). Self-regulatory depletion enhances neural responses to rewards and impairs top-down control. *Psychological science*, *24*(11), 2262–2271. **https://doi.org/10.1177/0956797613492985**

Werner, S., Schorn, C. F., Bock, O., Theyshohn, N., & Timmann, D. (2014). Neural correlates of adaptation to gradual and to sudden visuomotor distortions in humans.

Experimental Brain Research, 232(4), 1145-1156. **https://doi.org/10.1007/s00221-014-3824-1**

Ullsperger, P., Freude, G., & Erdmann, U. (2001). Auditory probe sensitivity to mental workload changes- an event-related potential study. *International Journal of Psychophysiology, 40*(3), 201–209. **https://doi.org/10.1016/S0167-8760(00)00188-4**