

ABSTRACT

Title of Document:

A PROGRAMMATIC RESEARCH
APPROACH TO UNDERSTANDING THE
IMPACT OF TEAM ENVIRONMENT ON
CEREBRAL CORTICAL DYNAMICS AND
ATTENTION

Matthew Walker Miller, Ph. D., 2012

Directed By:

Dr. Bradley D. Hatfield, Professor and Chair,
Department of Kinesiology

This dissertation describes a programmatic research approach to understanding how team environments alter individuals' brain dynamics so as to produce variations in individuals' cognitive-motor performances. This research is of fundamental interest as humans frequently perform in team environments. Specifically, the central purpose of this research was to determine if adaptive team environments are conducive to efficient brain dynamics such that tasks are accomplished with minimal neural costs.

The dissertation is comprised of four studies (papers), each of which makes a unique contribution to the dissertation's central objective. The first paper reports a positive directional relationship between cerebral cortical activation as well as networking and task load. The second paper describes a new neurophysiological method for indexing attentional reserve, which is positively related to the efficiency of cerebral cortical activation and networking.

The third paper describes the development of a paradigm employed to investigate the impact of team environment on neurocognitive functioning. This study used non-physiological techniques to index neurocognitive functioning while participants performed a cognitive-motor task in various team environments. Results suggest that, relative to neutral environments, maintaining performance in maladaptive team environments comes at a neurocognitive cost, while adaptive team environments enhance performance without such a cost.

The final study applied the neurophysiological methods described in the first two studies to the team environment paradigm employed in the third study to provide neurobiological evidence in support of the conclusions reached in the third paper. Additionally, the final paper provides insight into the neurobiological changes underlying the alterations in neurocognitive functioning and task performance reported in the third paper. Specifically, the final paper reports that, relative to neutral environments, maintaining performance in maladaptive team environments comes at the expense of the efficiency of cerebral cortical activation and attentional reserve, while adaptive team environments enhance performance without such costs. Additionally, the final paper suggests that adaptive team environments may generate more optimal states of arousal, leading to performance enhancement. By comprehending the impact of team environments on brain dynamics, humans performing as members of teams in a variety of settings may be better equipped to maximize their performances.

A PROGRAMMATIC RESEARCH APPROACH TO UNDERSTANDING THE
IMPACT OF TEAM ENVIRONMENT ON CEREBRAL CORTICAL
DYNAMICS AND ATTENTION

By

Matthew Walker Miller

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
2012

Advisory Committee:

Professor Bradley D. Hatfield, Chair

Professor Rodolphe J. Gentili

Professor William J. Idsardi, Dean's Representative

Professor Seppo E. Iso-Ahola

Professor Craig G. McDonald

Professor Tracy Riggins

© Copyright by
Matthew Walker Miller
2012

Dedication

To my wonderful wife, Carolina Sofia Miller, whose unwavering support for me during the graduate school process has allowed us to realize our dreams, and to our families for their support.

Acknowledgements

My adviser, Dr. Bradley D. Hatfield, for taking a chance in supporting a graduate student who was a track and field coach with no background in cognitive neuroscience.

My student mentor, Dr. Jeremy C. Rietschel, for being the best student mentor I can imagine anyone ever having.

Dr. Craig G. McDonald for being like a second adviser to me.

Dr. Elizabeth Y. Brown for giving me the opportunity to develop my teaching in order to become a true teacher-scholar.

Dr. Tracy Riggins for being with me from my Initial Advisory Committee to the completion of my dissertation.

Drs. Seppo E. Iso-Ahola and Rodolphe J. Gentili for their expert advice regarding team environments and cerebral cortical dynamics, respectively.

Alessandro Presacco for his work on the fourth study of this dissertation.

The undergraduate students with whom I have worked on this dissertation: Tanner Nelson, Sean Bur, and, especially, Lawrence Groman, for his work on the third and fourth studies of this dissertation.

The students, faculty, staff, and alumni of the Department of Kinesiology who I have not yet acknowledged for all of their support.

The members of the Neuroscience and Cognitive Science (NACS) Program who I have not yet acknowledged, especially the members of my student cohort and the NACS Coordinator, Pam Komarek, for their support.

Table of Contents

List of Tables.....	vi
List of Figures	vii
Study 1.....	1
Abstract	2
Introduction	2
Materials and Methods	8
Cognitive-Motor Task.....	8
Participants	8
Procedures	8
Data Collection and Signal Processing	9
Statistical Design.....	10
Control (Cognitive) Task	11
Participants	11
Procedures	12
Data Collection, Signal Processing, and Statistical Analysis	12
Results	12
Cognitive-Motor Task.....	12
Performance Results.....	13
Spectral Power Results.....	13
Delta.....	13
Theta	13
Low-Alpha	13
High-Alpha	14
Beta	14
Gamma.....	14
Coherence Results	14
Control (Cognitive) Task	16
Performance Results.....	16
Spectral Power Results.....	17
Delta.....	17
Theta	17
Low-Alpha	17
High-Alpha	17
Beta	17
Gamma.....	17
Coherence Results	17
Discussion	18
Study 2.....	24
Abstract	25
Introduction	26
Materials and Methods	29
Participants	29
Procedures.....	29
Data Collection and Signal Processing.....	30
Statistical Design	31

Results	32
N1 Component	32
P2 Component	32
P3 Component	33
LPP Component	33
Discussion	35
Study 3	38
Abstract	39
Introduction	40
Methods	42
Participants	42
Design and Variables	42
Cognitive-Motor Task	43
Oddball Task (Attentional Resource Allocation)	44
NASA-TLX (Cognitive Workload)	46
Experimental Conditions	47
Experimental Manipulations	48
Experimental Protocol	51
Statistical Analysis	53
Results	54
Manipulation Checks	54
Validation of Attentional Resource Allocation Metric	54
Tetris® and Oddball Performance	54
NASA-TLX	55
Discussion	58
Study 4	63
Abstract	64
Introduction	66
Methods	71
Participants	71
Cognitive-Motor Task	72
Experimental Conditions	73
Experimental Manipulations	74
Cerebral Cortical Dynamics and Attentional Reserve	77
Psychophysiological recording and signal processing	77
Cerebral cortical dynamics: cortical activation (EEG spectral power) and networking (EEG coherence)	77
Attentional reserve (ERPs)	78
Experimental Protocol	80
Statistical Analysis	81
Results	82
Manipulation Checks	82
Cognitive-Motor Task (Tetris®) Performance	82
Psychophysiological (Cerebral Cortical Dynamics and Attentional Reserve) Results	83

Cerebral cortical activation (EEG spectral power).....	83
Theta.....	83
Low-alpha.....	83
High-alpha.....	84
Beta.....	84
Gamma	87
Cerebral cortical networking (EEG coherence).....	87
Attentional Reserve (ERPs).....	87
N1	87
P2.....	87
Novelty-P3	87
LPP	88
Discussion	89
Appendices.....	98
Appendix A	98
References	38

List of Tables

Study 2

Table 1: Means and summary of statistical results.

List of Figures

Study 1

Figure 1. Experimental setup. The scalp montage reflects those electrodes included in the spectral power analyses. Additionally, the pairing of each electrode to the shaded diamond (Fz electrode) is representative of the coherence analyses.

Figure 2. Spectral power results. A. Theta power results for the a priori contrasts (comparing Easy and Hard conditions at the frontal regions) and the ANOVA main effect. B., C., D., Each graph corresponds to a different frequency bandwidth, Upper Alpha, Beta, and Gamma, respectively. Each contrast compares Easy and Hard conditions at each of the five regions, frontal (F), central (C), temporal (T), parietal (P), and occipital (O), * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 3. Spectral coherence results comparing Easy and Hard conditions for each of the four frequency bandwidths, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Study 2

Figure 1. A) Grand-average ERPs recorded from the Fz, Cz, and Pz electrode locations time-locked to the auditory probes. Data from the three experimental conditions are superimposed. B) Average amplitude of the N1, P2, P3, and LPP components as a function of experimental conditions (View, Easy, and Hard).

Study 3

Figure 1. The experimental set-up demonstrating a participant engaging in the cognitive-motor task (Tetris®) with his right hand and responding to the oddball task with his left hand. The participant is receiving recommendations from his teammate, who is seated to his right.

Figure 2. Cognitive-motor performance for the different experimental conditions.

Figure 3. Oddball performance (attentional resource allocation) for the different experimental conditions.

Figure 4. TLX scores (level of cognitive workload) in each experimental condition.

Figure 5. **A.** TLX scores for each source of cognitive workload in each experimental condition. **B.** The relative contribution of each source of cognitive workload to total cognitive workload across experimental conditions.

Study 1

Cerebral-cortical networking and activation increase as a function of cognitive-motor task difficulty

Abstract

Excessive increases in task difficulty typically result in marked attenuation of cognitive-motor performance. The psychomotor efficiency hypothesis suggests that poor performance is mediated by non-essential neural activity and cerebral cortical networking (inefficient cortical dynamics). This phenomenon may underlie the inverse relationship between excessive task difficulty and performance. However, investigation of the psychomotor efficiency hypothesis as it relates to task difficulty has not been conducted. The present study used electroencephalography (EEG) to examine cerebral cortical dynamics while participants were challenged with both Easy and Hard conditions during a cognitive-motor task (Tetris®). In accord with the psychomotor efficiency hypothesis, it was predicted that with increases in task difficulty, participants would demonstrate greater ‘neural effort,’ as indexed by EEG spectral power and cortical networking (i.e., EEG coherence) between the premotor (motor planning) region and sensory, executive, and motor regions. Increases in neural activation and cortical networking were observed during the Hard condition relative to the Easy condition, thus supporting the psychomotor efficiency hypothesis. To further determine the unique contributions of cognitive versus sensory-motor demands, a control experiment was conducted in which cognitive demand was increased while sensory-motor demand was held constant. This experiment revealed that regionally-specific neural activation was influenced by changes in cognitive demand, whereas cortical networking to the motor planning region was sensitive only to changes in sensory-motor demand. Crucially, the present study is the first, to our knowledge, to characterize the separate impact of cognitive versus sensory-motor demands on cerebral cortical dynamics. The findings further inform the dynamics of the cortical processes that

underlie the quality of cognitive-motor performance particularly with regard to task difficulty. A broader understanding of the brain and muscle interactions during varying levels of challenge may inform the design of effective training protocols aimed at optimizing cognitive-motor performance.

Introduction

Excessive increases in task difficulty typically compromise performance. The psychomotor efficiency hypothesis suggests that superior performance is resultant of economic neural activation in motor and non-motor regions and efficient networking between motor and non-motor regions. On the other hand, poor performance is mediated by non-essential levels of neural activation in motor and non-motor regions and unrefined cortico-cortical communication between motor and non-motor regions. Moreover, non-essential cortical activity may impair motor output by disrupting the recruitment of first order motor neurons and hinder sensory input via maladaptive attentional resource allocation (Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). The psychomotor efficiency hypothesis, although specific to inputs and activations involving motor planning and execution, is a component of a broader body of literature referred to as ‘neural efficiency.’ The neural efficiency hypothesis posits a trait-like streamlined cortical ‘wiring’ as an essential constituent of the neural substrate of cognitive skill. As such, an adaptive brain is efficient and accomplishes the work of ‘intelligence’ (i.e., adaptive information processing) with less effort (lower activity). This idea has generally been supported by the literature (Babiloni et al., 2010; Del Percio et al., 2008; Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004). Although the general notion of neural efficiency is relevant to psychomotor performance, the psychomotor efficiency hypothesis has specifically focused on the role of cortical dynamics underlying learning and expertise in the psychomotor domain. It follows that excessive increases in cognitive-motor task difficulty may disrupt the efficient cortical dynamics associated with task

mastery and result in degraded performance. However, investigation of this notion is lacking.

Investigation of the cognitive-motor task difficulty-psychomotor efficiency relationship may yield insights into costly performance failures as well as provide direction to strategies aimed at enhancing performance under a wide range of task difficulties. A number of studies have employed electroencephalography (EEG) to determine the impact of cognitive-motor task difficulty on cerebral cortical dynamics. However, these studies have constrained their analyses to the examination of isolated cortical activation in a limited number of cortical regions (Mizuki, Takii, Tanaka, Tanaka, & Inanaga, 1982; Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007; Sterman & Mann, 1995). To better characterize the cognitive-motor task difficulty-cortical dynamics relationship, the present study examined both cortical activation (EEG spectral power) and cerebral cortical networking (EEG coherence) with motor regions at multiple frequency bandwidths across the scalp topography.

EEG spectral power analyses provide an index of the degree of synchronous neural activity within a frequency bandwidth of interest (greater synchrony results in greater power). Different psychological processes have been characterized by both regionally and bandwidth-specific neural activity. Previous studies have examined the impact of task difficulty on spectral power through analyses of electrode sites overlying regions of interest. Specifically, prior work has examined frontal lobe theta synchrony, which indexes attention to stimuli for sensory encoding, and revealed a positive relationship between cognitive-motor task difficulty and theta synchrony (Mizuki et al., 1982; Sauseng et al., 2007). Previous research has also examined parietal alpha

desynchrony, which indexes multimodal sensory integration, and observed a positive relationship between cognitive-motor task difficulty and alpha desynchrony (Sternan & Mann, 1995). In both the frontal theta and parietal alpha analyses, increases in task difficulty were accompanied by decreases in performance. As these studies reveal a positive relationship between cognitive-motor task difficulty (task demand) and cortical activation (neural effort) along with concomitant performance decrements, they are consistent with the psychomotor efficiency hypothesis.

While these spectral power studies have been useful in understanding the neural underpinnings mediating the cognitive-motor task difficulty-performance relationship, they focus on isolated regionally-specific cortical activation as opposed to global cerebral cortical networking. From a cognitive neuroscience perspective, it is largely agreed upon that the brain operates through disperse interconnected regions (i.e., networks) (see Laughlin & Sejnowski, 2003; Sporns, Tonini, Kötter, 2005). Thus, examination of cortical networking, with particular focus centered on motor regions, could further inform the cognitive-motor task difficulty-performance relationship. Specifically, the metric EEG coherence, a statistical measure of the degree of repeated linear correlation of the spectral power in a specified bandwidth between two separate electrodes, provides an index of cortical networking. High coherence implies a large degree of cortico-cortical communication between different brain regions whereas low coherence posits relative independence.

As networking is a key component of the brain's function, it is surprising that there have been few reports of changes in coherence due to changes in cognitive-motor task difficulty. However, differences in cortical networking between expert performers

and those with less skill have been reported for cognitive-motor tasks. For example, Deeny, Hillman, Janelle, and Hatfield (2003) reported that expert marksmen exhibited less networking between cognitive and motor regions during the aiming period of a rifle shooting task relative to less skilled marksmen. In addition, networking has been demonstrated to change as a function of learning a cognitive-motor task. For example, Bell and Fox (1996) studied networking in infants learning to crawl and observed that, with gains in crawling experience, networking was reduced. Additionally, Busk and Gailbrith (1975) observed that practicing a cognitive-motor task in a performance-enhancing manner led to decreases in networking. In summary, these studies examining networking as a function of cognitive-motor skill level illustrate that superior performance by experts is associated with refinements in cortical networking. Given that task mastery is associated with refined networking, as illustrated by the aforementioned studies, it follows that excessive increases in cognitive-motor task difficulty may lead to less refined cortical networking as indexed by increases in EEG coherence due to the disruption of task mastery.

In accord with this notion, it was hypothesized that cognitive-motor task difficulty would be positively related to cortical networking to the premotor (motor planning) region. To test this hypothesis, task difficulty was varied while holding expertise constant to control for the influence of motor learning during a cognitive visuomotor challenge (playing the game Tetris®). Tetris® is a videogame that requires players to manipulate different-shaped game pieces in order to place them in their optimal location on the game board (computer screen). While a player is manipulating a piece, the subsequent piece is displayed on the screen so that the player may better place the current piece with

consideration of the next piece. Given the inherent cognitive-motor challenge of playing Tetris® and consistent with the psychomotor efficiency hypothesis, higher coherence between the motor planning area and distributed non-motor (sensory & executive) regions during the more difficult task condition was predicted. Additionally, while previous work examining changes in spectral power (cortical activation) due to variations in cognitive-motor task difficulty has largely limited its reported findings to frontal theta synchrony and parietal alpha desynchrony, the present study considered multiple bandwidths across the scalp topography. However, given the extant literature cited above, frontal theta synchrony and parietal high-alpha desynchrony during the more difficult condition compared to the less difficult was predicted.

To better understand the relationship between cognitive-motor task difficulty and cerebral cortical dynamics, a control experiment was conducted in which sensory-motor demand was held constant while cognitive demand was varied. Specifically, participants performed a *n*-back task under conditions of varied difficulty, consisting of a 1-back and 3-back, respectively. Variations in cortical dynamics solely due to changes in cognitive demand (i.e., *n*-back) were contrasted to those changes associated with modulations in sensory-motor demand (i.e., Tetris®). This contrast between the tasks served to isolate the influence of sensory-motor demand on cortical dynamics.

Materials and Methods

Cognitive-Motor Task

These data were collected as part of a larger effort and the materials and methods presented here reflect only those procedures relevant for the present analysis. The

comprehensive methodology is described in Miller, Rietschel, McDonald, and Hatfield (2011).

Participants. Twelve men and 11 women were recruited from a large metropolitan area. The data from three of the participants were removed due to poor electrophysiological recordings, so the final sample contained 20 individuals (10 women, with a mean age of 24.4(4.1) and a range of 20–33 years). Self-reported Tetris® playing experience varied from never having previously played to having played more than 50 hours. All participants were right-handed and provided informed written consent.

Procedures. Participants sat in front of a 15” computer monitor and used a computer keyboard to play Tetris® while the song “Korobeiniki”(“Music A” in the standard Tetris® game) was played (72 - 76 dB SPL) from a speaker next to the monitor. Participants engaged in one easy condition of Tetris® and one hard condition. Each condition lasted approximately 8 min. During the Easy condition, participants began play at level 1. During the Hard condition, participants began play at level 8. After completing a level (i.e., completing 10 horizontal lines of pieces with no gaps), participants immediately advanced to the next level of the game. For each successive level, the game became more challenging as the pieces fell at increasing speeds. At level 1, the pieces fell at a velocity of 1.67 cm/s, while at level 8 they fell at a velocity of 3.56 cm/s. Although the game allows the player to manually increase the speed at which the pieces fall, speed was held constant within a level as the participants were instructed not to manually advance the pieces. The change in speed was believed to impact task difficulty as the participants had to more rapidly determine where to place the current piece, execute the placement, and update their planning for the successive pieces. In the event that a

participant could not complete a level, the experimenter restarted the game at the level at which the participant began. This occurred rapidly (under 3 s). Despite individual differences in game playing experience, no participant advanced beyond level 3 during the Easy condition or level 11 during the Hard condition.

Data Collection and Signal Processing. Scalp EEG was collected using tin electrodes housed within a stretchable lycra cap, (Electro-Cap International, Inc.). Data were acquired from following electrode sites: Fz, F3, F4, C3, C4, T3, T4, P3, P4, O1, and O2 and were referenced to linked earlobes and a common ground (FPz). Electrode placement was adapted from the 10-20 international system (Jasper, 1958). Additional electrodes were placed above and below the right eye over the orbicularis oculi muscle and the outer canthi of both eyes to record eye blinks. Impedances were kept below 10 k Ω throughout the experiment. All channels were amplified 500 times using Neuroscan Synamps 1, linked to Neuroscan acquisition/edit software (version 4.3). Online bandpass filters were set at 0.01-100 Hz with a sampling rate of 1,000 Hz. Offline, data were processed with the Neuroscan software. A zero-phase shift low-pass filter at 50 Hz (24 dB octave/slope) was applied followed by an ocular artifact algorithm (Semlitsch et al., 1986). Data from each condition were epoched into 1-s sweeps. These epochs were linear detrended and baseline corrected using the mean of the pre-stimulus interval. Epochs containing amplitudes of more than 75 μ V were discarded, the data were spline fit (1024 data points). Spectral average was calculated across 1-Hz bins and averaged across the frequency bandwidths delta (1 -3 Hz), theta (3 – 8 Hz), low-alpha (8 – 10 Hz), high-alpha (10 – 13 Hz), beta (13 – 30 Hz), and gamma (30 – 44 Hz). These averages were then natural log transformed prior to statistical analysis.

Coherence was defined as $C_{xy}(f)^2$, computed across 1-Hz bins, and averaged across the frequency bandwidths theta (3 – 8 Hz), alpha (8 – 13 Hz), low-beta (13 – 20 Hz), and high-beta (20 – 30 Hz) between electrode Fz, which overlies the motor planning region and the following electrodes: F3, F4, C3, C4, T3, T4, P3, P4, O1, and O2. All coherence values were subjected to a Fisher z-transformation prior to statistical analysis to approximate a normal distribution. Please see Figure 1 for a graphical description of the experimental setup and montage.

Statistical Design. The number of game restarts for Easy and Hard conditions were subjected to a paired samples t-test. Spectral averages and coherence values for the aforementioned bandwidths were subjected to separate $2 \times 2 \times 5$ (Condition x Hemisphere x Region) repeated measures ANOVAs. Significant interaction effects were followed by Student Newman-Keuls post-hoc tests. Conventional degrees of freedom are reported throughout the results, and the Huynh-Feldt correction is provided when sphericity was violated. The p-values reported are based upon the corrected degrees of freedom. The a priori predictions for frontal theta and parietal high-alpha were assessed using separate paired sample t-tests. For theta, left frontal (F3) during the Easy condition was compared to left frontal (F3) during the Hard condition. Right frontal (F4) was also compared between the Easy and Hard conditions. For high-alpha, similar analyses were run for left and right parietal regions (P3 & P4, respectively). Cohen's d effect sizes are also provided when appropriate.

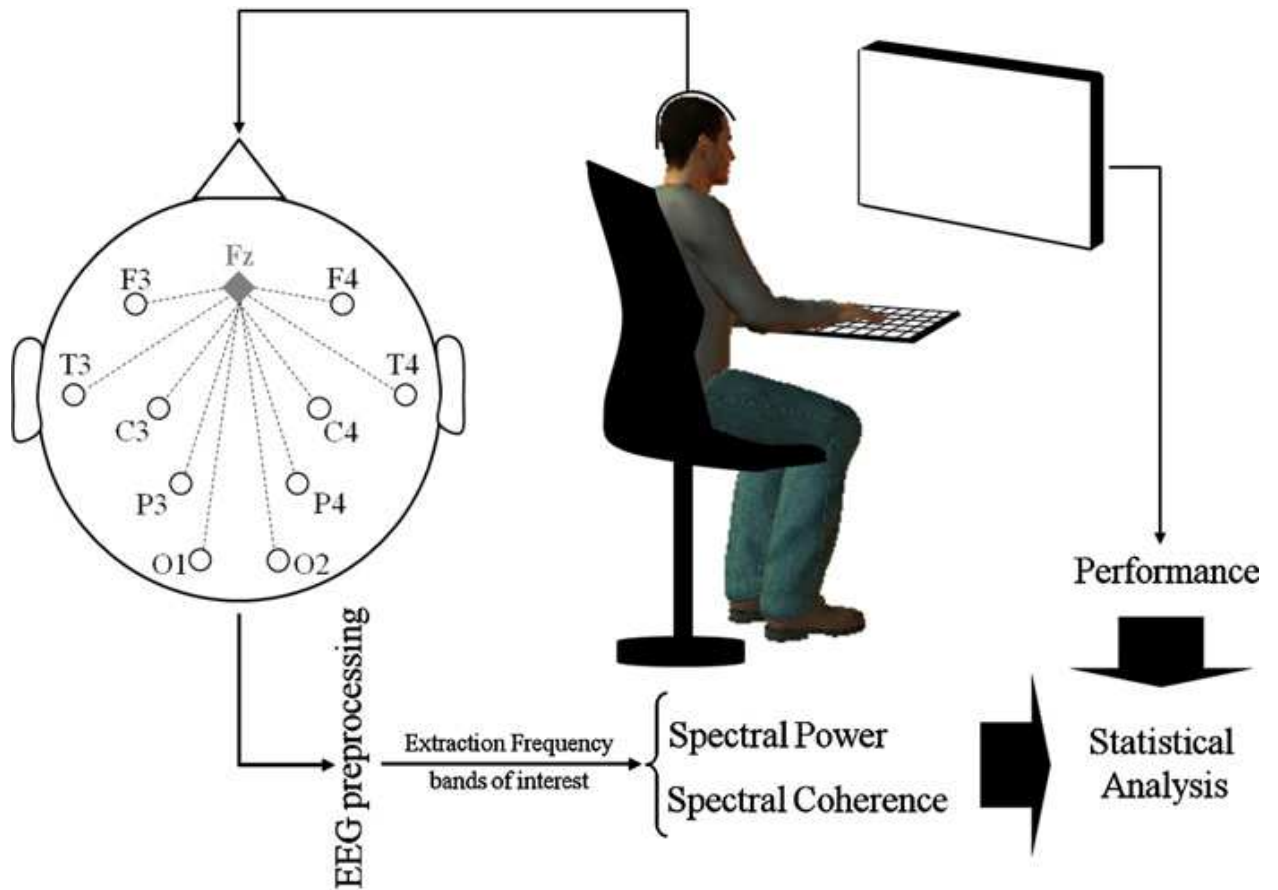


Fig. 1. Experimental setup. The scalp montage reflects those electrodes included in spectral power analyses. Additionally, the pairing of each electrode to the shaded diamond (Fz electrode) is representative of the coherence analyses.

Control (Cognitive) Task

Participants. Seven men and five women (different individuals from those who performed the cognitive-motor task) were recruited from a large metropolitan area. The data from one of the participants were removed due to his failure to follow task instructions, so the final sample contained 11 individuals (5 women, with a mean age of 27.1(3.7) ranging from 22 - 33 years). All participants were right-handed and provided informed written consent.

Procedures. Participants sat in front of a 15" computer monitor and used a computer keyboard to engage in Easy (1-back) and Hard (3-back) conditions of the

visual, sequential letter n -back task. Participants were presented with a series of letters and responded to targets by pressing the space bar on the computer keyboard. In the Easy condition, the target letter was any letter matching the one directly preceding it. In the Hard condition, the target letter was any letter matching the one three letters back. Both conditions consisted of five blocks of 54 letter presentations, 25% of which were targets. Each letter was displayed for 500 ms; the participant then had 1500 ms to respond before the next letter was presented.

Data Collection, Signal Processing, and Statistical Analysis. The data collection, signal processing, and statistical analysis procedures were the same as for the Tetris® experiment, with the exceptions that the EEG signal was referenced to averaged mastoids as opposed to linked ear lobes, and performance was indexed by the rate of false alarms (i.e., the number of times the participant responded to a non-target) and missed targets. Please see Figure 1 for a graphical description of the experimental setup and montage.

Results

Cognitive-Motor Task

Grand average spectra for the cognitive-motor task are provided on the left side of Figure 2.

Performance Results. A paired sample t-test revealed that participants failed to complete a level more frequently during the Hard condition ($M = 2.3$) than the Easy condition ($M = 0.15$) ($t(19) = 10.302$; $p < .001$), suggesting a successful manipulation of task difficulty.

Spectral Power Results.

Delta. No significant results for contrasts of interest were found for the delta bandwidth.

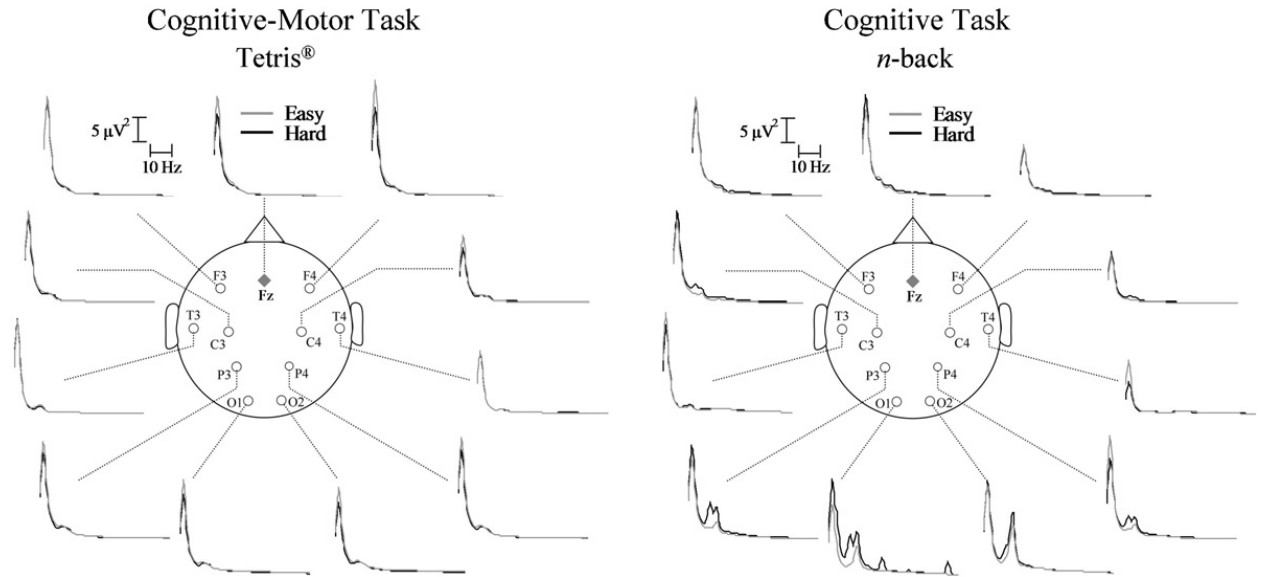


Fig. 2. Grand average spectra across the topography for each condition.

Theta. Theta synchrony as a function of task difficulty showed an elevation that approached significance ($F(1,19) = 3.98$; $p = 0.061$; $d = 0.045$). Additionally, the a priori prediction that frontal theta power would be significantly elevated during the Hard condition relative to the Easy condition was confirmed exclusively for the right hemisphere ($t(19) = 2.99$; $p = 0.008$; $d = 0.205$), see Figure 3A.

Low-Alpha. No significant results for contrasts of interest were found for the low-alpha bandwidth.

High-Alpha. The statistical analysis revealed a significant main effect of condition for the high-alpha bandwidth ($F(1,19) = 6.17$; $p = 0.022$). This effect revealed high-alpha desynchrony due to an increase in task difficulty. However, the main effect was superseded by a significant Condition x Region interaction ($F(1,19) = 3.18$; $p =$

0.047; $\epsilon = 0.558$). This interaction revealed that the high-alpha desynchrony during the Hard condition was confined to the central ($p < 0.001$; $d = 0.142$) and parietal regions ($p = 0.01$; $d = 0.110$), see Figure 3B. Additionally, the a priori prediction that parietal high-alpha desynchrony would be significantly elevated due to task difficulty was confirmed in both hemispheres (left hemisphere: $t(19) = 4.56$; $p < 0.001$; $d = 0.085$; right hemisphere: $t(19) = 3.13$; $p < 0.001$; $d = 0.119$).

Beta. Beta synchrony related to task difficulty revealed an elevation that approached significance ($F(1,19) = 2.68$; $p = 0.059$; $\epsilon = 0.709$), thus post-hoc analyses were conducted. These analyses revealed beta synchrony in the occipital regions during the Hard condition ($p < 0.001$; $d = 0.102$), see Figure 3C.

Gamma. The statistical analysis revealed a significant Condition x Region interaction for the gamma bandwidth ($F(1,19) = 4.12$; $p = 0.012$; $\epsilon = 0.711$). This interaction revealed gamma synchrony due to task difficulty, but this elevation was confined to the temporal ($p = 0.03$; $d = 0.122$), parietal ($p = 0.041$; $d = 0.094$), and occipital regions ($p = 0.002$; $d = 0.231$), see Figure 3D.

Coherence Results. The statistical analysis revealed a significant main effect for condition for all bandwidths (theta: $F(1,19) = 7.57$; $p = 0.013$; $d = 0.411$; alpha: $F(1,19) = 11.63$; $p = 0.003$; $d = 0.359$; low-beta: $F(1,19) = 14.60$; $p = 0.001$; $d = 0.469$; high-beta: $F(1,19) = 22.93$; $p < 0.001$; $d = 0.611$). These main effects revealed that coherence was greater in the Hard condition than in the Easy condition, see Figure 4.

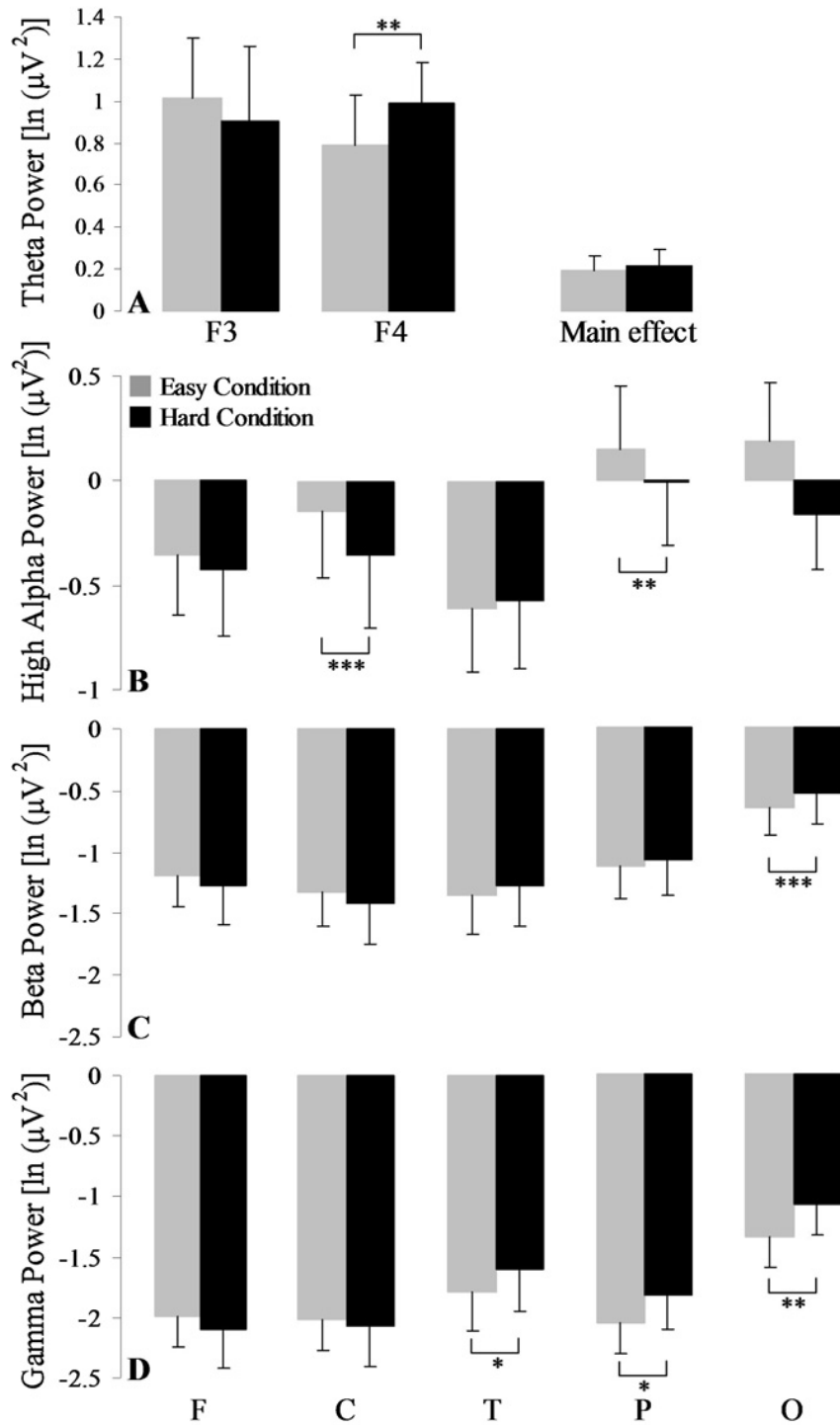


Fig. 3. Spectral power results. A. Theta power results for the a priori contrasts (comparing Easy and Hard conditions at the frontal regions) and the ANOVA main effect. B., C., D., Each graph corresponds to a different frequency bandwidth, high-alpha, beta, and gamma, respectively. Each contrast compares Easy and Hard conditions at each of the five regions, frontal (F), central (C), temporal (T), parietal (P), and occipital (O), * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

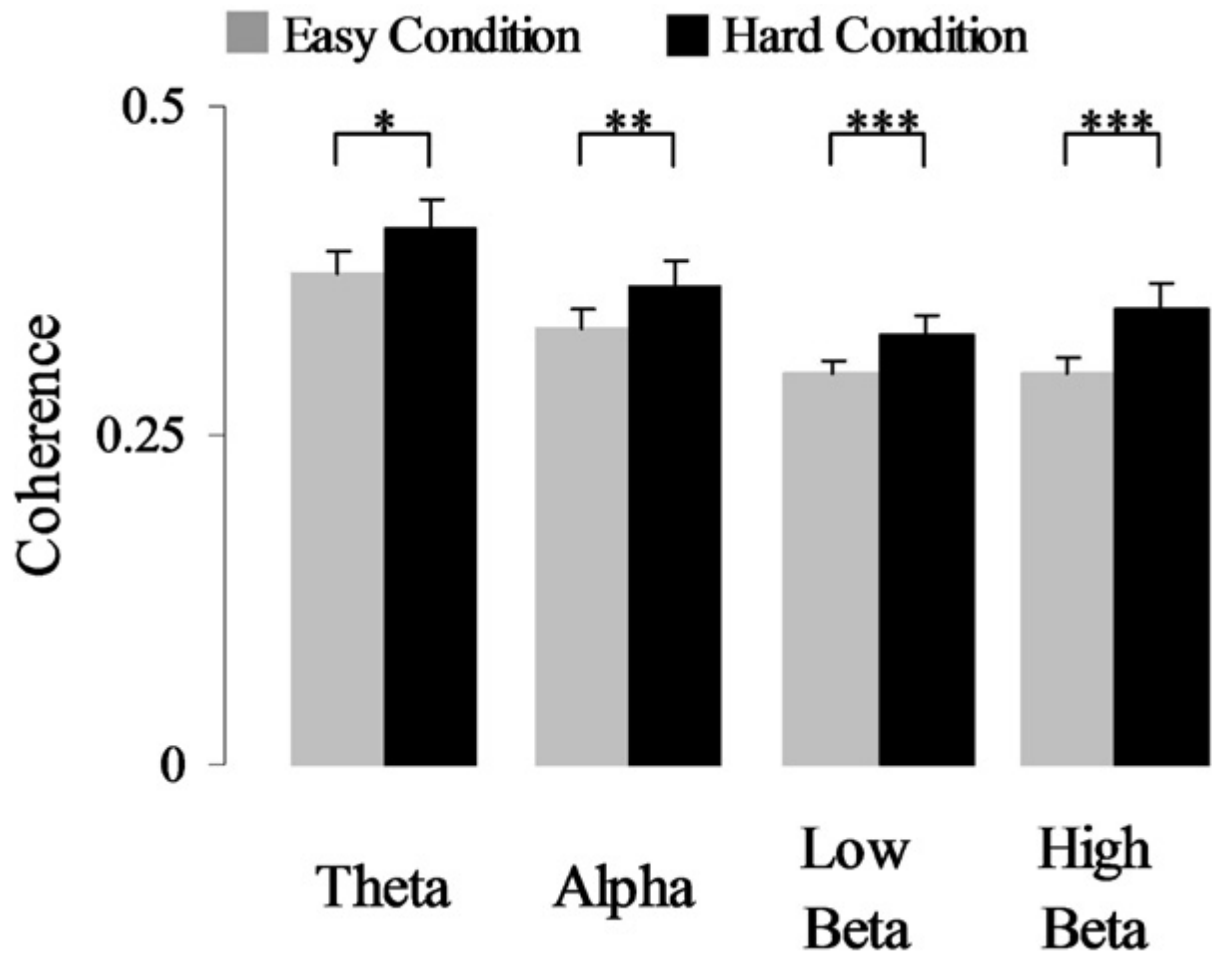


Fig. 4. Spectral coherence results comparing Easy and Hard conditions for each of the four frequency bandwidths, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Control (Cognitive) Task

Grand average spectra for the cognitive task are provided on the right side of Figure 2.

Performance Results. The paired sample t-test revealed that participants performed worse during the Hard condition as compared to the Easy condition. Specifically, the hit rate was lower during the Hard condition ($M = 59.25$) than the Easy condition ($M = 99.02$) ($t(10) = 12.77$; $p < .001$) and the rate of false alarms was higher during the Hard condition ($M = 6.60$) as compared to the Easy condition ($M = 0.13$)

($t(10) = 6.69$; $p < .001$). These results suggest a successful manipulation of task difficulty.

Spectral Power Results.

Delta. No significant results for contrasts of interest were found for the delta bandwidth.

Theta. No significant results for contrasts of interest (including the a priori contrasts) were found for the theta bandwidth

Low-Alpha. The statistical analysis revealed a significant main effect of condition for low-alpha power $F(1,10) = 6.72$; $p = .027$; $d = 0.32$. This effect revealed low-alpha desynchrony due to an increase in task difficulty (see Figure 5B).

High-Alpha. The statistical analysis revealed a significant main effect of condition for high-alpha power ($F(1,10) = 9.75$; $p = .011$; $d = 0.33$). This effect revealed high-alpha desynchrony due to an increase in task difficulty. Additionally, the a priori prediction that parietal high-alpha desynchrony would significantly elevate due to task difficulty was confirmed in both hemispheres (left hemisphere: $t(10) = 3.50$; $p = 0.006$; $d = 0.28$; right hemisphere: $t(10) = 2.60$; $p = 0.027$; $d = 0.36$) (see Figure 5C).

Beta. No significant results for contrasts of interest were found for the beta bandwidth.

Gamma. No significant results for contrasts of interest were found for the gamma bandwidth.

Coherence Results. The statistical analysis revealed no significant findings for any bandwidth with regard to coherence.

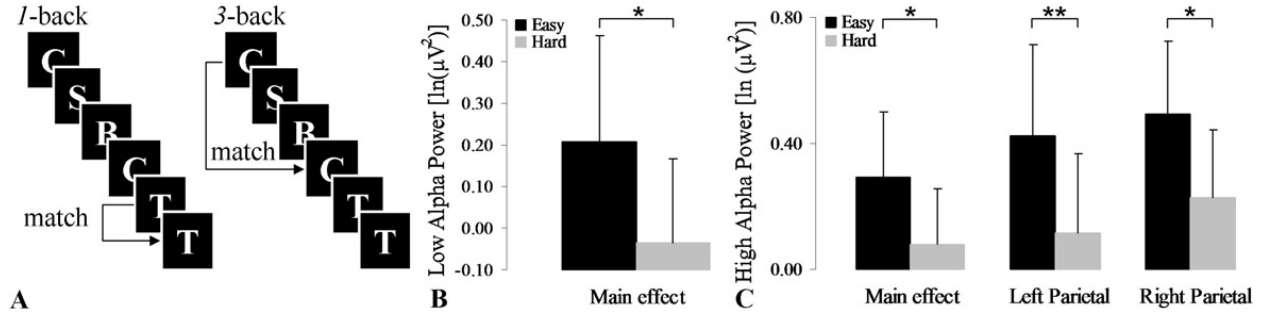


Fig. 5. Cognitive task description and spectral power results. A. Description of cognitive task. B. Low-alpha power results for ANOVA main effect, comparing spectral power observed during Easy and Hard conditions for this frequency bandwidth. C. High-alpha power results for the ANOVA main effect and the a priori contrasts (comparing Easy and Hard conditions at the parietal regions), * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Discussion

As predicted, with increased cognitive-motor task difficulty, elevations in neural effort as indexed by both regional cerebral cortical activation and networking with the motor planning region were observed, thus supporting the psychomotor efficiency hypothesis. Further, the control experiment revealed that as difficulty of the cognitive task increased there were corresponding elevations in regionally-specific cerebral cortical activation, but no changes in networking to the motor planning region. Importantly, by comparing the two analyses using the measures of activation (EEG spectral power) and networking (EEG coherence) within multiple bandwidths and across a distributed scalp topography, the present study advances the understanding of cerebral cortical dynamics that relate to cognitive-motor performance, particularly by characterizing the specific effects of increased cognitive versus sensory-motor demands.

First, the cognitive-motor task (Tetris®) results reveal a tendency for theta synchrony due to an increase in task difficulty regardless of region. These results are consistent with the visuomotor task performance work of Rebert, Low, & Larsen (1984).

Further, when limiting the theta band statistical analysis to the frontal region, it was found that increases in task difficulty resulted in frontal theta synchrony that was driven by the right hemisphere. Conversely, no changes in theta synchrony were observed due to changes in cognitive task (*n*-back) difficulty. This was surprising as changes in frontal theta due to differences in *n*-back difficulty have been previously described (Gevins & Smith, 2008). However, the results observed for the cognitive-motor task are consistent with previous observations of right hemisphere dominance during visuomotor performance (see Hatfield, Landers, & Ray, 1984; Rebert et al.) and suggest that frontal asymmetry may be a component of the enhanced cortical processing necessitated by increasing cognitive-motor task difficulty. Additionally, since modulations in frontal asymmetry have been associated with changes in affect (see Davidson, 1984), it is possible that the observed asymmetry could be a result of changes in cognitive-motor task difficulty and/or changes in affect, which may have contributed to the differences observed between the two tasks. More specifically, the cognitive-motor task was likely more engaging than the cognitive task and thus changes in difficulty (and thus performance) elicited a greater influence on affect.

Second, no changes in low-alpha synchrony with regard to difficulty were observed for the cognitive-motor task. However, low-alpha desynchrony was observed as difficulty increased for the cognitive task. Low-alpha synchrony is believed to index changes in cortical activation due to general arousal as opposed to the changes in cortical activation induced by task-specific demands associated with high-alpha synchrony (see Kerick, Hatfield, & Allender, 2007; Klemisch, 1999). Collectively, these findings suggest that increases in cognitive task difficulty increased general arousal but increases in

cognitive-motor task difficulty did not. It may be that the engaging nature of the cognitive-motor task produced relatively high arousal during the easier condition, which prevented detection of difficulty-dependent changes in general arousal.

Third, the cognitive-motor analysis revealed a positive relationship between high-alpha desynchrony and task difficulty in both the parietal and central regions, whereas increases in difficulty of the cognitive task resulted in high-alpha desynchrony across the entire topography. As mentioned above, high-alpha desynchrony has been associated with elevated cortical activation due to task-specific demands (see Pfurtscheller, Stancak, & Neuper, 1996). Thus, the cognitive-motor results are reasonable given the central and parietal regions involvement in multimodal sensory integration, object recognition, and the sensorimotor transformations necessary to act upon the recognized objects, all of which are cognitive-motor processes demanded by Tetris® (Goodale & Milner, 1992; Kerick et al., 2007; Klemisch, 1999). The lack of regionally-specific alterations observed for the cognitive task might be explained by evidence that the *n*-back engages multiple cognitive processes (Kane, Conway, Miura, & Colflesh, 2007), some of which may be distinct from those required by Tetris®. As such, differences in the cognitive requirements between the two tasks may be a limitation in interpreting which cerebral cortical processes are distinctly modulated by changes in cognitive rather than sensory-motor difficulty. However, of note, global high-alpha power during the cognitive task changed in the expected direction (i.e., was reduced during the harder condition), and the a priori analysis concerning parietal high-alpha was consistent with the extant literature (see Gevins & Smith, 2008).

Fourth, for the cognitive-motor task, beta synchrony was observed as a function of increased task difficulty in the occipital region only, whereas no changes in beta synchrony were observed for the cognitive task with regard to difficulty. As beta synchrony indicates cerebral cortical activation and the occipital region is the primary visual area, this finding is reasonable (Piantoni, Kline, & Eagleman, 2010; Singer, 1993). Specifically, the occipital beta synchrony was likely due to the faster rate of stimuli presentation and consequent increased visual demand during the Hard condition of the cognitive-motor task, while the sensory demand imposed by the cognitive task was held constant across conditions.

Similarly, for the cognitive-motor task, gamma synchrony was observed in the parietal, occipital, and temporal regions during the Hard condition relative to the Easy, while no changes in gamma power for the cognitive task with respect to difficulty were detected. Gamma activity is associated with localized sensory integration and has been observed to increase with sensory processing demands (von Stein & Sarnthein, 2000). Right temporal activity is indicative of visuospatial processing, and the functions of the parietal and occipital regions have already been noted (Goodale & Milner, 1992; Hatfield et al., 1984). Thus, given the high degree of sensory integration, particularly visuospatial processing, required by Tetris® in order to process the game pieces, gamma synchrony as a function of task difficulty seems reasonable. Accordingly, as sensory demand was fixed across conditions in the cognitive task, no such changes in gamma synchrony were observed.

Collectively, the observed changes in spectral power within multiple bandwidths and across the scalp topography as cognitive-motor task difficulty increased are in accord

with the psychomotor efficiency hypothesis. Specifically, increases in cognitive-motor task demand resulted in greater neural effort as indexed by the observed changes in spectral power. Importantly, the control analysis allowed for the ability to detect changes in cerebral cortical activation specific to increases in sensory-motor versus cognitive demands.

While the spectral power results illustrate increases in neural activation as a function of cognitive-motor task difficulty, they focus on specific brain regions in isolation. Given the consensus that the brain operates through disperse interconnected regions (see Laughlin & Sejnowski, 2003; Sporns et al., 2005), it is surprising that we were unable to find any previous reports of changes in cortical networking due to alterations in cognitive-motor task difficulty. Addressing this gap and consistent with our prediction, we observed elevated cortical networking, as indexed by coherence, between the sensory and executive brain regions with the motor planning area across all frequency bandwidths. This likely reflects an increase in the amount of information conveyed from sensory and executive regions to the motor planning region during more difficult conditions, which was expected given the increase in sensory-motor demand. Additionally, the results occurred in bandwidths (theta, alpha, low-beta, & high-beta) previously found to be involved in mid- to long-range cortical networking required for communication between the aforementioned brain regions (von Stein & Sarnthein, 2000). Crucially, no changes in networking to the motor planning region were observed as a function of cognitive (*n*-back) task difficulty, which was expected as motor demand was held constant across the two conditions. This outcome illustrates the specificity of

increased networking with the motor planning region during increases in sensory-motor demands rather than cognitive demands.

The present study supports the psychomotor efficiency hypothesis as increases in task difficulty elicited increased neural effort as indexed by regionally-specific cerebral cortical activation and networking to the motor planning region. Crucially, the present study is the first to report changes in the cortical networking due to modulations in cognitive-motor task difficulty. Of note, the specific increases observed in neural effort were dependent upon the dimensions of the task that were changed to manipulate difficulty. For example, elevated networking to the motor planning area was observed when sensory-motor demand increased, but remained constant when cognitive demand only was increased. Such specificity highlights that one must consider the underlying function of neural processes when predicting the nature of the change in neural effort elicited during varying task-demand.

The present study's findings elucidate how EEG-indexed changes in cortical dynamics may provide a window to the psychophysiological mechanisms that underlie the variability observed in cognitive-motor performance. Importantly, the results also inform the popular interest in measuring cognitive workload (see Shanker & Richtel, 2011). Increases in task difficulty are accompanied by increases in cognitive workload, which, when measured using EEG, has historically been indexed by the event-related potential technique or spectral power. Given that the present results reveal coherence to be more sensitive, as indicated by effect size, to changes in task difficulty than spectral power, future studies may want to explore the use of coherence as a method for gauging cognitive workload. A deeper understanding of the relationship between cortical

dynamics and cognitive-motor performance may inform the measurement of cognitive workload and aid in the design of techniques aimed at enhancing performance across a wide range of task difficulty.

Study 2

A novel approach to the physiological measurement of mental workload and attentional
reserve

Abstract

While performing a visuo-motor task under incrementally-varied levels of difficulty, individuals were probed with a variety of novel, task-irrelevant, auditory stimuli. To determine the effect of task load on the attentional reserve available for the cerebral-cortical processing of these stimuli, event-related potentials were recorded while participants performed the task. We found that N1, P2, P3 and late positive potential (LPP) component amplitudes were inversely related to task-difficulty. This suggests that a variant of the oddball paradigm—in which the stimulus stream comprises novel sounds—is capable of providing a reliable index of mental workload and attentional reserve.

Introduction

The efficient allocation of neural resources is crucial while individuals perform mentally demanding tasks. Such a need is based on the inverse relationship between mental workload and attentional reserve (Wickens, Kramer, Vanasse, & Donchin, 1983), which when depleted can be expected to limit cognitive processing for any additional demands, resulting in performance decrement. Thus, the manner by which neural resources are allocated during the performance of a task is a question of fundamental interest. Such an understanding is dependent upon the attainment of an objective measure of mental workload and attentional reserve.

Beginning with the seminal work by Wickens, Isreal, and Donchin (1977), a number of studies have employed the event-related potential (ERP) technique to assess mental workload and attentional reserve. These early efforts (e.g., Isreal, Chesney, Wickens, & Donchin, 1980; Isreal, Wickens, Chesney, & Donchin, 1980; Kramer, Sirevaag, & Braune, 1987; Sirevaag, Kramer, Coles, & Donchin, 1989) employed dual-task paradigms in which ERPs to a secondary task were measured while participants performed a primary task of interest (e.g., attending to auditory stimuli while solving arithmetic problems as the primary task). Many of these studies revealed an inverse relationship between amplitude of the parietal-P3 component and difficulty of the primary task. However, such dual-task paradigms are not optimal for assessing the mental workload required and attentional reserve consumed by a primary task given that the addition of a secondary task may inherently change the primary task, thus compromising the assessment of the demand it imposes and the reserves it consumes (Kramer, Wickens, & Donchin, 1985).

In order to avoid the limitation of dual-task paradigms, ERPs to task-irrelevant stimuli should be measured while participants focus exclusively on a given task (Papanicolaou & Johnstone, 1984). Several studies have employed such an irrelevant-probe technique and reported decreases in N1 and/or P3 component amplitudes with changes in task difficulty (Bauer, Goldstein, & Stern, 1987; Kramer, Trejo, & Humphrey, 1995; Sirevaag et al., 1993; Ullsperger, Freude, & Erdmann, 2001; Wilson & McCloskey, 1988). However, some of these studies used visual probes, which may not have been detected by participants (e.g., Bauer et al.; Wilson & McCloskey), while others did not report graded difficulty-dependent changes with respect to task demands (e.g., Bauer et al.; Kramer et al.) or were limited in the number of participants and recording sites analyzed (Sirevaag et al.). As such, further research employing the task-irrelevant probe technique was warranted.

Building upon the previous work, recent studies have also employed task-irrelevant probes to measure mental workload and attentional reserve (e.g., Allison & Polich, 2008; Ullsperger et al., 2001). Ullsperger et al. challenged participants in four task conditions: an oddball task, a visuo-motor task, an arithmetic task, and a simultaneous performance of the visuo-motor and arithmetic tasks. Throughout each condition participants were presented with common and rare pure tones as well as rare novel sounds. The authors reported greater parietal-P3 amplitude to rare tones and greater novelty-P3 amplitude to novel sounds during the oddball task relative to the other three conditions. Further, the novelty-P3 tended to decrease slightly as a function of task complexity (although this trend failed to reach statistical significance), whereas this trend was not observed for the parietal-P3. This finding posits novel sounds as being

advantageous over pure tones in gauging mental workload and attentional reserve. The lack of a significant graded difficulty-dependent effect may be due to the fact that task difficulty was manipulated by having participants perform one of two primary tasks in two separate blocks, and in a third block having them simultaneously perform both tasks. It seems reasonable to suggest that incrementally varying the difficulty of a single primary task might be more efficacious in demonstrating significant monotonic differences in relation to task difficulty.

More recently, Allison and Polich (2008) published a study using the task-irrelevant probe technique (specifically, a modified oddball using pure tones) in which the difficulty of a single task was incrementally varied. In this study, participants viewed a video game and also played the game at easy, moderate and hard levels of difficulty. Although the authors reported a significant reduction in the amplitude of a number of ERP components between play (regardless of difficulty) and view conditions, they found little evidence of reductions with respect to changes in game difficulty. Specifically, the authors reported larger P2, N2, and P3 component amplitudes during the view condition relative to all the playing conditions as well as a decrease in N2 amplitude during the hard condition relative to the medium condition. It is possible that the lack of significant graded difficulty-dependent differences in component amplitude might be attributable to the relatively low salience of pure tones, resulting in modest attentional capture (Friedman, Cycowicz, & Gaeta, 2001).

Therefore, in the present study we combined the strengths of the approaches taken by Allison and Polich (2008) and Ullsperger et al. (2001). Specifically, we used a single task that was incrementally varied with respect to difficulty while probing participants

with novel sounds. We reasoned that novel stimuli would be more effective in indexing mental workload and attentional reserve as they have been shown to be more effective in capturing attention than simple tones (Friedman et al., 2001). In the current study participants played Tetris®, a video game that requires executive control (planning), visual-spatial processing, and motor execution under two levels of difficulty, and in a third condition viewed the game, but did not engage in play. Throughout each condition participants were intermittently presented with a set of novel, task irrelevant, auditory stimuli (e.g., a woman coughing, the sound of breaking glass). One-second epochs of the EEG time-locked to each auditory stimulus were extracted and the resultant epochs were averaged within each condition. Based on the prior literature, we predicted that the amplitude of ERP components elicited by the probes would be inversely related to task difficulty.

Materials and Methods

Participants

Twenty-three, right-handed young adults (11 women) were recruited from a large Mid-Atlantic metropolitan area. Because the data from three of the participants were discarded due to poor electrophysiological recordings, the final sample was comprised of 20 individuals (10 women, with an age range of 20-33, $M = 24.4$, $SD = 4.1$ years). Tetris® playing experience ranged from never having previously played to having played more than 50 hours. All participants provided informed written consent.

Procedures

Participants were seated in front of a 15" monitor and played Tetris® while the song "Korobeiniki" ("Music A" in the standard Tetris® game) was played (72 - 76 dB

SPL) from a speaker next to the monitor. During the view condition participants fixated on a paused game while the music continued to play. During the easy and difficult conditions, game play began at levels 1 and 8, respectively. After completing a level (i.e., completing 10 lines), the participants immediately advanced to the next level of the game. For each successive level, the game became more difficult due to an increased rate of speed with which the game pieces fell. Although the game allows the player to manually increase the speed of the pieces, speed was held constant within a level as the participants were instructed not to manually advance the pieces. The change in speed was thought to impact upon mental workload and attentional reserve as the participants had to more quickly decide where to place the current piece, execute the placement, and update their planning for the successive pieces. In the event that a participant could not complete a level, the experimenter restarted the game at the level at which the participant began. This occurred rapidly (under 3 seconds) so as to minimize the probability of a sound being presented during this interruption. A paired sample t-test revealed that there were more restarts during the hard condition ($M = 2.3$) than the easy condition ($M = 0.15$) ($t(19) = 10.302$, $p < .001$), suggesting a successful manipulation of difficulty. Despite individual differences in game playing experience, all participants ranged between levels 1 and 3 during the easy condition and between levels 8 and 11 in the hard condition.

In each experimental condition, participants were probed with a set of 30 familiar auditory stimuli randomly selected from a larger collection obtained from the New York State Psychiatric Institute (Fabiani, Kazmerski, Cycowicz, & Friedman, 1996). The

stimuli were presented in random order (87 – 96 dB SPL; interstimulus interval = 6 – 30 secs.) from two speakers positioned 70 cm behind the participants.

Data Collection and Signal Processing

Scalp EEG was collected using tin electrodes housed within a stretchable lycra cap, (Electro-Cap International, Inc.). Data were acquired from 30 sites referenced to linked earlobes and a common ground (FPz). Electrode placement was adapted from the 10-20 international system (Jasper, 1958). Additional electrodes were placed above and below the right eye over the orbicularis oculi muscle and the outer canthi of both eyes to record eyeblinks. Impedances were kept below 10 k Ω for electrodes of interest (Fz, Cz, Pz) throughout the experiment. All channels were amplified 500 times using Neuroscan Synamps 1, linked to Neuroscan acquisition/edit software (version 4.3). Online bandpass filters were set at .01-100 Hz with a sampling rate of 1,000 Hz. Offline, data was processed with the Neuroscan software. After setting a zero-phase shift low-pass filter at 20 Hz (24 dB octave/slope), an ocular artifact algorithm was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986). ERPs were obtained by extracting the epoch of 100 ms prior to stimulus onset through 900 ms post-stimulus, then baseline corrected with reference to the pre-stimulus interval. Next, each of the 30 trials was visually inspected and any trials containing marked artifact were excluded from subsequent analysis. The remaining trials were then averaged. Each ERP was based on at least 20 trials. The mean amplitude for each component was calculated using the approach suggested by Handy (2005), which recommends the use of narrow time windows centered around the peaks of the components in the grand average waveform. Accordingly, the time windows used

were as follows: N1= 140 – 160 ms; P2= 225 – 255 ms; P3= 290 – 320 ms; LPP= 570 – 610 ms for each of the three midline electrodes of interest (Fz, Cz, & Pz).

Statistical Design

Mean amplitude of each component was subjected to separate 3 x 3 (Condition x Electrode) repeated measures ANOVAs. Significant interaction effects were followed by one-way ANOVAs applied to each electrode. Finally, all simple mean effects were determined using paired t-tests. Conventional degrees of freedom are reported throughout the results, and the Greenhouse-Geisser correction is provided when sphericity was violated. The p-values reported are based upon the corrected degrees of freedom. Additionally, Cohen's *d* effect sizes are also provided when appropriate.

Correlational analyses were also conducted between Tetris experience and all component amplitudes as well as Tetris performance and all component amplitudes.

Results

Figure 1A illustrates the grand average ERPs recorded from the midline electrodes Fz, Cz, and Pz for each condition. The N1, P2, P3, and LPP (late positive potential) components are evident. The statistical analysis revealed a Condition x Electrode interaction for the N1 component ($F(4,76) = 4.072$; $p = .013$, $\epsilon = .685$), the P3 component ($F(4,76) = 5.371$; $p = .004$; $\epsilon = .650$) and the LPP component ($F(4,76) = 4.891$; $p = .001$). Additionally, there was a main effect for Condition for the P2 component ($F(2,38) = 6.026$; $p = .010$, $\epsilon = .757$).

N1 Component

Post hoc analyses revealed that for the N1 at the Cz electrode, the mean amplitude was significantly larger in both the view and easy conditions than that in the hard

condition (Figure 1B) (view > hard, $p = .003$, $d = 0.717$; easy > hard, $p = .045$, $d = 0.473$). The N1 component is believed to reflect compulsory, early sensory processing, exhibit a frontocentral scalp distribution, and to be sensitive to attention (Hillyard, Hink, Schwent, & Picton, 1973; Parasuraman & Beatty, 1980).

P2 Component

Post hoc analyses revealed that for the P2 regardless of electrode, the mean amplitude was significantly larger in both the view and easy conditions than that in the hard condition (Figure 1B) (view > hard, $p < .01$, $d = 0.740$; easy > hard, $p < .05$, $d = 0.697$). Like the N1, the P2 component is believed to reflect compulsory, early sensory processing and exhibit a frontocentral scalp distribution, and to be sensitive to attention (Peters, Suchan, Zhang, & Daum, 2005; Picton & Hillyard, 1974).

P3 Component

As predicated mean amplitudes of the P3 at the Pz electrode differed across all three experimental conditions in a graded difficulty-dependent manner (Figure 1B) (view > easy, $p = .046$, $d = 0.402$; view > hard, $p = .003$, $d = 0.906$; easy > hard, $p = .012$, $d = 0.674$). The P3 is believed to represent non-obligatory, cognitive evaluation of stimuli and generate a parietal maximal distribution (Parasuraman & Beatty, 1980; Ruchkin, Johnson, Jr., Mahaffey, & Sutton, 1988). Importantly, the P3 at Pz reflects cognitive processes independent of variations in motor processes (Makeig et al., 2004).

LPP Component

Like the P3, mean amplitudes of the LPP at the Pz electrode differed across all three experimental conditions in a graded difficulty-dependent manner (Figure 1B) (view > easy, $p = .003$, $d = 0.652$; view > hard, $p < .001$, $d = 1.717$; easy > hard, $p = .004$, $d = 1.037$). Similar to the P3, the LPP is believed to represent non-obligatory, cognitive evaluation of stimuli and generate a parietal maximal distribution (Ruchkin et al., 1988). However, it has been reported much less frequently in the literature than the P3.

See Table 1 for all means and post hoc analyses.

The correlational analysis revealed that neither Tetris® experience nor task performance was significantly correlated with any of the ERP component amplitudes.

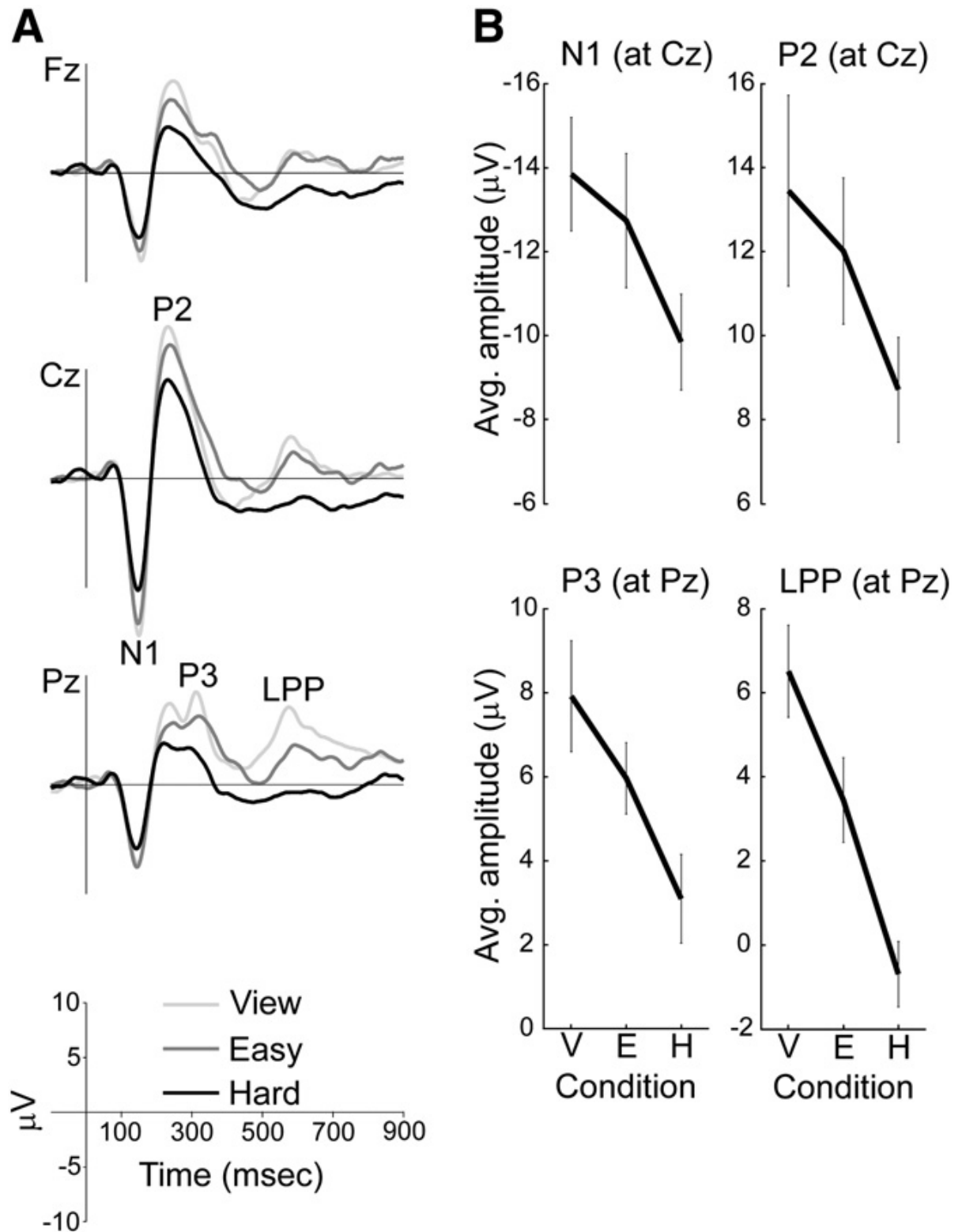


Fig. 1. A. Grand-average ERPs recorded from the Fz, Cz, and Pz electrode locations time-locked to the auditory probes. Data from the three experimental conditions are superimposed. B. Average amplitude of the N1, P2, P3, and LPP components as a function of experimental condition (View, Easy, and Hard).

Table 1
Means and summary of statistical results.

Component	Electrode	Condition		
		View	Easy	Hard
N1	Fz	− 7.425	− 6.933	− 5.815
	Cz	− 13.844	− 12.738	− 9.846 ^{a, b}
	Pz	− 6.871	− 7.090	− 5.454
P2	Main Effect	9.632	8.030	5.419 ^{a, b}
P3	Fz	4.034	4.040	2.224 ^{a, b}
	Cz	6.220	7.102	3.940 ^b
	Pz	7.918	5.964 ^a	3.094 ^{a, b}
LPP	Fz	1.893	1.578	− 1.756 ^{a, b}
	Cz	3.481	2.181	− 2.026 ^{a, b}
	Pz	6.513	3.445 ^a	− 0.699 ^{a, b}

^a Significantly different from view.

^b Statistically different from easy.

Table 1. Means and summary of statistical results.

Discussion

For more than three decades, researchers have been using the ERP technique to measure mental workload and attentional reserve. The assessment protocols were greatly improved with the use of the task-irrelevant probe technique. Two contemporary studies have further advanced the measurement of mental workload and attentional reserve by incrementally-varying task difficulty or using intermittently presented novel sounds (Allison & Polich, 2008 and Ullsperger et al., 2001, respectively). The present study combined elements of these two innovations by incrementally-varying task difficulty while probing participants with novel, task-irrelevant auditory stimuli.

The results demonstrate the utility of this ERP paradigm in indexing mental workload and attentional reserve. Unlike many of the prior efforts to index workload and reserve, the present approach provided compelling evidence of an inverse relationship between incremental changes in task demands and ERP component amplitude. Due to their psychometric similarity, the Easy vs. Hard comparison was this study's critical

contrast of interest. All of the evaluated ERP components differed significantly between the Easy and Hard conditions. Additionally, the P3 and LPP differed between the View and Easy conditions. Although the LPP appears to have provided the most robust index of task load and attentional reserve (in terms of effect size and sensitivity to all experimental manipulations), it is difficult to relate this finding to previous work. Allison and Polich (2008) report the existence of a slow wave with a similar time course to that of the LPP; however, the slow wave was not sensitive to differences in task demands. The present findings indicate that future investigation of the LPP is warranted.

Given that mental workload is inversely related to attentional reserve and N1 and P2 have been shown to be modulated by attention (Hillyard et al., 1973; Picton & Hillyard, 1974), it is likely that the reduction in N1 and P2 represent a reduction in the allocation of attention to the probe stimuli. This putative reduction in attentional resource allocation can be expected to diminish the stimulus information available to the higher order processes indexed by P3 and LPP, leading to a reduction in amplitude of these components as well.

The uniqueness of these findings likely resulted from taking advantage of select innovations developed by Allison and Polich (2008) and Ullsperger et al. (2001). Specifically, the use of novel, environmental sounds as opposed to pure tones appears to have elicited increased electrocortical activity to the sounds. Additionally, incrementally varying the difficulty on a single task, as opposed to switching tasks or concurrently performing multiple tasks, likely facilitated the detection of monotonic differences in relation to task load and attentional reserve. Future work should examine more gradations of task difficulty to determine if reductions in electrocortical activity are concomitant

with increases in mental workload and decreases in attentional reserve when performance remains relatively stable.

This measure of mental workload and attentional reserve has broad implications and is also easy to implement in that it requires a small number of trials (30) to generate an informative index. Notably, such a measure could be employed to assess the demands of various cognitive tasks (e.g., reading, operating a machine) which could then be applied to various learning environments and human-machine interfaces. In summary, the present effort provided a unique contribution to the assessment of mental workload using the ERP technique. By building upon previous innovations, the current study was able to capture graded difficulty-dependent reductions in the ERP.

Study 3

The effects of team environment on attentional resource allocation and cognitive workload

Abstract

Attentional resource allocation and cognitive workload impact human performance when individuals perform tasks in the absence of teammates (i.e., in non-team environments). However, individuals often perform tasks as members of teams (i.e., in team environments). Team environments vary in regards to their quality such that adaptive team environments, which can be characterized by high levels of perceived competence of and trust in one's teammates, as well as task cohesiveness with one's teammates, are associated with superior individual performance, whereas maladaptive team environments are associated with poor individual performance. Despite the frequency with which individuals perform in team environments of variable quality as well as the robust relationship between attentional resource allocation/cognitive workload and performance, the impact of team environment on attentional resource allocation and cognitive workload has only recently begun to be investigated. Employing a dual-task paradigm and recording phenomenological reports, we observed that individuals performing a task in adaptive and neutral team environments allocated their attentional resources more efficiently and experienced less cognitive workload as compared to performing in maladaptive team environments. Additionally, individuals engaging in adaptive team environments exhibited superior task performance relative to individuals performing in neutral and maladaptive team environments. These results illustrate the importance of (1) avoiding maladaptive team environments so as to prevent team members from inefficiently allocating their attentional resources and experiencing excessive levels of cognitive workload and (2) generating adaptive team environments in order to enhance task performance.

Introduction

Attentional resource allocation and cognitive workload impact human performance such that the efficient allocation of attentional resources and the maintenance of manageable levels of cognitive workload are associated with superior performance, whereas inefficient attentional resource allocation and excessive levels of cognitive workload are associated with poor performance (see Hillyard & Kutas, 1983; Navon & Gopher, 1979). Individuals' attentional resource allocation and cognitive workload have been examined in a number of settings wherein individuals perform tasks in the absence of teammates (i.e., in non-team environments). For example, distracted-driving research has investigated how individuals' performance of a secondary task (e.g., using a mobile device) while driving reallocates attention away from driving and increases cognitive workload (Strayer, Watson, & Drews, 2011).

However, humans frequently perform tasks as members of teams (i.e., in team environments) consisting of one or more other individuals. Examples of such team environments are apparent in military, law enforcement, medical, sport, and industrial settings. Team environments vary in regard to their quality such that adaptive team environments, which can be characterized by high levels of perceived competence of and trust in one's teammates, as well as task cohesiveness¹ with one's teammates, are associated with superior individual performance, whereas maladaptive team environments, which can be characterized by low levels of perceived competence of and trust in one's teammates, as well as a lack of task cohesion with one's teammates, are

¹ Task cohesiveness refers to the degree to which a team member feels that his/her teammate(s) and s/he are effectively working together to accomplish a task. This type of cohesion is different from social cohesion, which refers to how much a team member enjoys the companionship and camaraderie resultant of his/her membership on a team (see Carron, Widmeyer & Brawley, 1985).

associated with poor individual performance (Carron, Colman, & Wheeler, 2002; Dirks, 1999; Marcos, Miguel, Oliva, & Calvo, 2010).

It is surprising that the impact of team environment on attentional resource allocation and cognitive workload has only recently begun to be investigated (e.g., Stevens, Galloway, Berka, & Sprang, 2009). We believe this area of investigation is important given (1) the frequency with which humans perform in team environments and (2) the strength of the relationship between attentional resource allocation/cognitive workload and performance.

To assess the impact of team environment on individuals' attentional resource allocation, we employed a dual-task paradigm. Specifically, we observed each participant's performance on an oddball auditory discrimination task (Squires, Squires, & Hillyard, 1975) while s/he engaged in a cognitive-motor task in neutral, adaptive, and maladaptive team environments. To investigate the effects of team environment on cognitive workload, we evaluated participants' subjective workload using the NASA-Task Load Index (TLX) after they engaged in each of the aforementioned team environments.

The purpose of this study was to investigate the effects of team environment on attentional resource allocation and cognitive workload. More specifically, the study was designed to determine whether the quality of team environment would influence participants' attentional resource allocation and cognitive workload while performing a cognitive-motor task in adaptive, maladaptive, and neutral team environments. As maladaptive team environments and inefficient attentional resource allocation/cognitive workload are generally associated with poor performance, it was predicted that

participants would exhibit less efficient attentional resource allocation, as indexed by oddball performance, higher levels of cognitive workload, as measured by NASA-TLX scores, and poorer performance on the cognitive-motor task while performing in a maladaptive team environment relative to an adaptive team environment. Additionally, it was predicted that while performing in a neutral team environment, the efficiency of participants' attentional resource allocation, the level of their cognitive workload, and their cognitive-motor task performance would fall in between those observed in the adaptive and maladaptive team environments.

Methods

Participants

Ten right-handed young adults (6 women) recruited from a large Mid-Atlantic university gave informed consent prior to the study, which was approved by an Institutional Review Board. Due to illness, one participant withdrew shortly after beginning the study, leaving a final sample of nine participants (5 women, with an age range of 18 – 26, $M = 21.8$, $SD = 2.2$ years).

Design and Variables

The design of the study was within-subjects. The independent variable was Team Environment, and the dependent variables were Cognitive-Motor Task Performance, Attentional Resource Allocation (Oddball Score), and Cognitive Workload (NASA-TLX Score). Details on the statistical design and variables can be found in the subsequent sections.

Cognitive-Motor Task

For the cognitive-motor task, participants used their right-hand to play the videogame Tetris® while the song “Korobeiniki”(“Music A” in the standard Tetris® game) was played (72 - 76 dB SPL) from a speaker next to the computer monitor on which Tetris® was being played. Tetris® asks individuals to manipulate different-shaped game pieces presented on a video screen (in the present case, a computer monitor screen) in order to place them in their optimal location on the game board (monitor screen). Tetris® can be played at various difficulty levels, which are modulated by the velocity at which the game pieces move down the monitor screen (e.g., at level 1, the pieces fall at a velocity of 1.67 cm/s, while at level 8, the pieces fall at a velocity of 3.56 cm/s). Each participant established a Tetris® difficulty level and played at that level throughout the experiment. The establishment of Tetris® level was determined by having participants begin play at level one, five, or seven, dependent upon each participant’s responses to a Tetris® expertise questionnaire (beginner, advanced beginner, or fairly good, respectively).

After beginning play at the appropriate level, participants played until they failed at the task (i.e., the Tetris® pieces accumulated to the top of the monitor screen) twice. If a participant completed 10 horizontal lines that contained no gaps between the pieces, the current level was completed and the participant advanced to the next level. If a participant advanced to a new level and then failed at that level, s/he began play at the level at which s/he failed the first time and continued until s/he failed a second time. The level at which the participant failed a second time became the difficulty level employed throughout the remainder of the experiment unless s/he had not completed any lines at

this level, in which case s/he played at the previous level (e.g., the participant made it to level 8 but failed to complete any lines at this level, so his/her difficulty level was set at 7). Participants' mean Tetris® difficulty level was 6.5 with a standard deviation of 1.5, indicating that they were playing at medium levels of difficulty (6 being about halfway between the lowest level, 1, and the highest level, 10). Tetris® Score was determined by giving each participant one point for each horizontal line of game pieces completed and subtracting five points each time the participant failed at the task².

Oddball Task (Attentional Resource Allocation)

Assessing individuals' speed and accuracy on the oddball task while they concurrently perform another task is a common method of inferring their attentional resource allocation (see Karatekin, Couperus, & Marcus, 2004; Maclin et al., 2011). Specifically, faster and more accurate responses on the oddball task indicate that attentional resources formerly dedicated to the other task (in the present case, the cognitive-motor task) have been freed up and reallocated to the oddball task, thus signifying efficient attentional resource allocation (see Kahneman, 1973; Karatekin et al.; Maclin et al.).

For the oddball task, participants engaged in a difficult version of the oddball paradigm (Troche, Houlihan, Stelmack, & Rammsayer, 2009). This version of oddball asked participants to use their left-hand to press the spacebar on a keyboard (different from the one they were using to play Tetris®) every time a target tone (1000 Hz, 275 ms) was played through speakers positioned 75 cm behind the participants and to withhold a

²During piloting of the experiment, subjects reported becoming frustrated and losing motivation to play Tetris® when their scores became negative. Thus, based on participants' Tetris® performance during piloting, we determined a five point penalty to be the maximum we could impose without risking that participants' scores would be negative (i.e., participants typically completed at least five lines before failing at the task).

response when non-target tones (1000 Hz, 200 ms) were played. Three-hundred tones (60 targets and 240 non-targets, 2000 ms interstimulus interval) were played (92 dB SPL) in each experimental condition. So as to avoid the possibility of speed-accuracy trade-offs due to different strategies among the different conditions (Fitts, 1954), each participant's Oddball Score was determined by summing his/her standardized (z-scores calculated across all task conditions) median reaction times³ and standardized accuracy scores (error rates: false alarms + missed targets). Thus, Oddball Score was calculated as follows: standardized median reaction time + standardized accuracy score, with lower Oddball Scores indicating better performance (shorter reaction times and fewer errors). For a visual description of the experimental set-up, please refer to Figure 1.

³ As the purpose of employing the oddball was to infer neurocognitive processing (i.e., attentional resource allocation), median reaction times were analyzed as opposed to mean reaction times due to the former's stronger correlation with direct (e.g., electrophysiological) measurement of neurocognitive processes (see Handy, 2005).

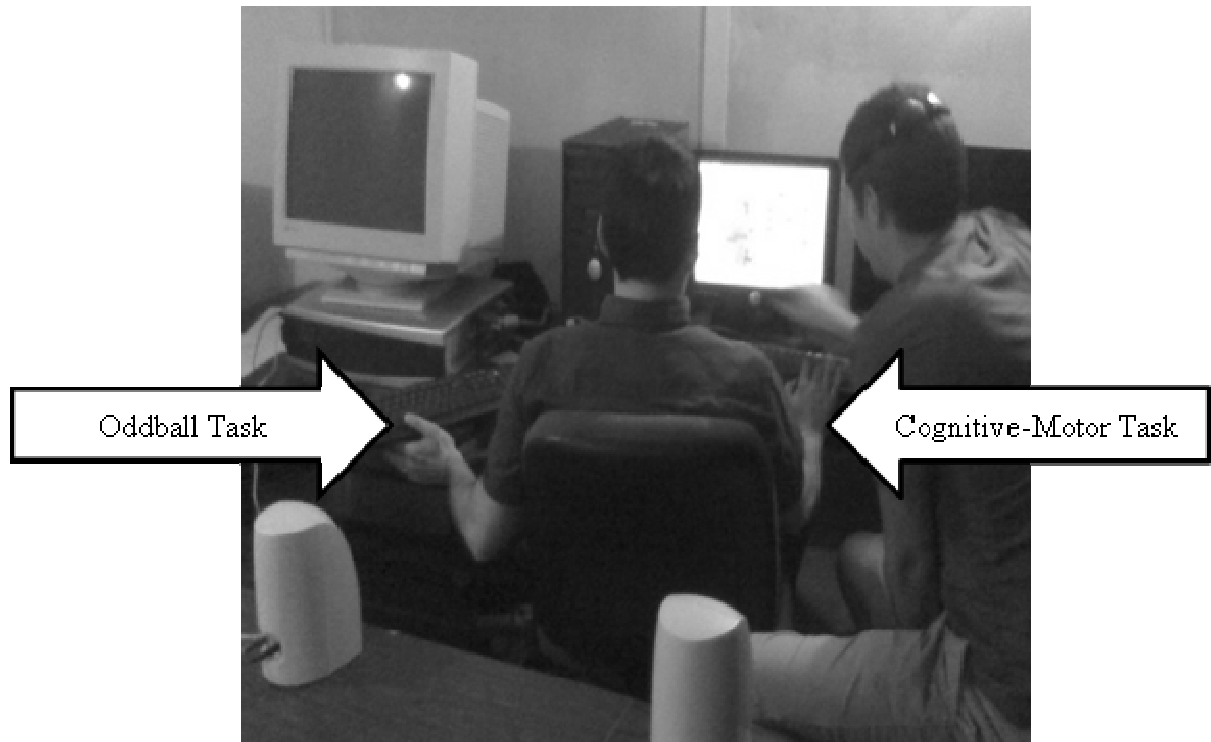


Fig. 1. The experimental set-up demonstrating a participant engaging in the cognitive-motor task (Tetris®) with his right hand and responding to the oddball task with his left hand. The participant is receiving recommendations from his teammate, who is seated to his right.

NASA-TLX (Cognitive Workload)

The NASA-TLX is a questionnaire that asks participants to rate their perceptions of the cognitive workload imposed by a given task (or task condition) (Hart & Staveland, 1988). To fill out the questionnaire, participants rate the magnitudes of six sources of cognitive workload (mental demand, physical demand, temporal demand, performance, effort, and frustration) on scales from 0 to 100 (100 indicating the greatest magnitude), thus providing a score for each source. Upon completing the questionnaire, participants make pair-wise comparisons between each of the sources of cognitive workload to indicate which source contributed more to the overall workload imposed by the task. Each source of cognitive workload is then weighted by multiplying each source's score by the number of pair-wise comparisons each source "won" (had a greater relative

contribution to workload than the source to which it was compared). The weighted source scores are then summed together and divided by 15 (the total number of pair-wise comparisons made), thus yielding a NASA-TLX score between 0 and 100. This NASA-TLX score indicates the level of perceived (subjective) cognitive workload such that a high score indicates a high level of workload, whereas a lower score signifies a lower level of workload (Hart, 2006; Hart & Staveland). The NASA-TLX is considered to be one of the most effective measures of cognitive workload and is highly correlated with other subjective cognitive workload metrics (Rubio, Diaz, Martin, & Puente, 2004; Warm, Dember, & Hancock, 1996). Participants completed a NASA-TLX immediately after performing in each team environment (neutral, adaptive, and maladaptive).

Experimental Conditions

Each participant engaged in four experimental task conditions: Oddball, Neutral Team Environment, Adaptive Team Environment, and Maladaptive Team Environment. During the Oddball condition, participants engaged in the oddball task while watching Tetris® being played (but not playing it themselves). During the Neutral Team Environment condition, participants engaged in the Tetris® and oddball tasks concurrently (performed a dual-task) in the presence of the two teammates (both of whom were male) with whom they would play/had played in the Adaptive and Maladaptive Team Environment conditions. The task in the Adaptive and Maladaptive Team Environment conditions was the same as in the Neutral Team Environment condition, but one of the teammates offered the participants recommendations on how to maneuver the Tetris® game pieces (details on these teammate recommendations to follow) while the other teammate was present but did not offer any advice. In the

Adaptive Team Environment condition, we assigned one teammate to offer advice to the participant and the other teammate to be present but not offer advice. In the Maladaptive Team Environment condition, we assigned the teammate who offered/would offer advice in the Adaptive Team Environment to be present but not offer advice, while the teammate who did not/would not offer advice in the Adaptive Team Environment was assigned to offer it. Henceforth, the teammate who offered advice in the Adaptive Team Environment will be referred to as the “good teammate,” and the teammate who offered advice in the Maladaptive Team Environment will be referred to as the “bad teammate.”

Experimental Manipulations

Prior research has revealed that one’s perception of his/her teammates’ competency at performing a task is positively correlated with one’s reported task cohesiveness with his/her teammates (Marcos et al., 2010). Accordingly, prior to beginning either the Adaptive or Maladaptive conditions, we sought to alter the perceptions of the teammates’ skill levels. We undertook a pilot experiment ($N = 15$) employing a similar protocol to the one utilized in the present study and replicated Marcos et al.’s observation that perceived competence and task cohesion were positively correlated ($r = 0.93$, $p < 0.001$, M.W.M. et al., unpublished data). Additionally, we observed that trust in one’s teammates’ abilities to help one successfully perform a task was positively correlated with perceived competence and task cohesion ($r = 0.84$, $p < 0.001$; $r = 0.79$, $p = 0.001$, respectively, M.W.M. et al.). Thus, we were confident that, by manipulating participants’ perceptions of their teammates’ competency at Tetris®, we would be able to alter their trust in their teammates’ abilities to help them successfully play Tetris® as well as their task cohesiveness with their teammates while engaging in

Tetris®. As these characteristics are associated with the quality of the team environment (Carron et al., 2002; Dirks, 1999; Marcos et al.) (i.e., whether the team environment is adaptive or maladaptive), we were confident that by manipulating participants' perceptions of their teammate's competence at Tetris®, we would be able to generate adaptive team environments for participants while performing with the good teammate and maladaptive team environments for participants while performing with the bad teammate.

We manipulated perceived competence in a three-step process. First, after participants entered the testing area and completed the informed consent and Tetris® expertise paperwork, they were introduced to both teammates. The good teammate informed participants that he was a much more experienced and, therefore, better Tetris® player than the bad teammate, who acknowledged this information. Second, in the Oddball condition, participants watched the good teammate play Tetris® for 5.5 min and the bad teammate play for 5.5 min. With the participants watching, the good teammate played Tetris® to the best of his ability, attempting to optimize the placement of every game piece. Conversely, the bad teammate did not play to the best of his ability, as he attempted to optimize the placement of only 25% of the game pieces, intentionally misplacing the other 75%. Finally, in the Adaptive Team Environment conditions, the good teammate offered advice to the best of his ability for every game piece presented, while, in the Maladaptive Team Environment condition, the bad teammate offered advice to the best of his ability for only 25% of the pieces, intentionally giving non-optimal advice for the other 75%.

As determined prior to the experiment, the teammates were comparable in regard to Tetris® ability (both played at the same Tetris® difficulty level), so that they could switch who played the role of the good teammate and who played the role of the bad teammate, thus controlling for differences beyond the accuracy of the advice they were offering. An additional attempt was made to control for communication style differences between the two teammates in that each teammate offered advice via the same three hand signals. These hand signals were drawing a circle in the air to indicate that participants should rotate game pieces, pointing directly on the screen to where participants should put game pieces, and giving a “thumbs-up” when participants had game pieces in the recommended location. We told participants that their teammates received the same incentive-based monetary reward (details on the reward system to follow) as the participants (i.e., if you win \$40, then so does your teammate). We told participants that, given this reward system, they should decide how much to follow their teammates’ recommendations because, if participants found better places for game pieces than their teammates had recommended, their teammates would benefit from this more optimal placement.

To determine whether the experimental manipulations were effective, we asked participants to fill out answers to a questionnaire about each teammate immediately after playing with that teammate. The Teammate Questionnaire asked participants to use a five-point Likert scale (highest scores equal to 5) to respond to one question regarding how competent they believed their teammate to be at Tetris®, a second question concerning how much they trusted their teammate’s abilities to help them successfully play Tetris®, and a third question inquiring about the level of task cohesiveness they felt

with their teammate (see Appendix A for specific questions). This novel and brief questionnaire was employed (as opposed to more traditional and longer questionnaires) because it asked questions about perceived competence, trust, and task cohesiveness specifically related to the cognitive-motor task being performed (Tetris®) and was minimally intrusive to the ecological validity of the experiment (i.e., it did not take a long time to complete and, thus, did not disrupt the flow of the experiment). We were confident in the construct validity of the questions (Chronbach & Meehl, 1955) contained in the questionnaire given that pilot data revealed significant (all p -values < 0.001) group differences in the expected directions for responses to the questionnaire [i.e., higher levels of perceived competence, trust, and task cohesion in the Adaptive Team Environment ($M = 4.067$, $SD = 0.458$; $M = 4.133$, $SD = 0.640$; $M = 4.333$, $SD = 0.617$, respectively) as compared to the Maladaptive Team Environment ($M = 2.667$, $SD = 0.617$; $M = 2.800$, $SD = 0.676$; $M = 2.600$, $SD = 0.828$, respectively)] (M.W.M et al., unpublished data). In order to try and ensure that participants felt comfortable responding honestly to the questionnaire, we told them that their responses would not be revealed to either teammate.

Experimental Protocol

Upon entering the testing preparation room (a room directly outside of the testing laboratory), participants completed informed consent and a Tetris® experience questionnaire (participants' lifetime Tetris® experience ranged from having played less than 10 hrs to having played more than 50 hrs). After completing the paperwork, we explained the experimental protocol and introduced the teammates to the participants. We told participants that they were competing against nine other participants in the study. We

told them that if their composite score (Tetris® Score combined with Oddball Score) placed them first among all participants, they would receive \$40; if they placed second, they would receive \$25; if they placed third, they would receive \$15. We informed participants that their Tetris® and Oddball Scores would receive equal weight in the calculation of the composite score so that they should prioritize performance on the two tasks equally.

Next, participants entered the testing laboratory and established their Tetris® difficulty levels, after which they practiced the oddball task (without concurrently playing Tetris®) for 1.5 min and then practiced performing both tasks simultaneously for 1.5 min. After this practice, participants engaged in the Oddball condition and then the other three conditions, which were counterbalanced with respect to order. Prior to beginning the Adaptive and Maladaptive Team Environment conditions, participants practiced engaging in the dual-task with the recommendations of the appropriate teammate (e.g., the good teammate prior to the Adaptive Team Environment condition) for 1.5 min. We gave participants a 30-s break halfway through each condition, at which point we told them to keep up the good work and reminded them to make sure they were prioritizing the Tetris® and the oddball tasks equally. Participants were given a 5 min break in-between each condition. After each condition, participants completed the NASA-TLX. After completing the Adaptive Team Environment and Maladaptive Team Environment conditions, participants completed the Teammate Questionnaire. After completing all conditions, we thanked participants for their time and told them that they would be contacted if they earned any prize money (i.e., if they finished in 1st, 2nd, or 3rd place).

Statistical Analysis

To determine whether the experimental manipulations (i.e., the generation of the adaptive and maladaptive team environments) were effective, we conducted three one-tailed paired sample *t*-tests to compare participants' responses to the questions about their (1) perceived competence of and (2) trust in their teammates, as well as their (3) task cohesiveness with their teammates. To validate the use of oddball performance as a metric of attentional resource allocation, we conducted a one-tailed paired sample *t*-test comparing Oddball Score in the Oddball condition to Oddball Score in the Neutral Team Environment condition⁴. Intuitively and in accordance with the extant literature (see Kahneman, 1973; Karatekin et al., 2004; Maclin et al., 2011), it was expected that Oddball Score would be higher in the Oddball condition as participants could give their undivided attention to the oddball task in this condition.

To assess the effects of team environment on Tetris® and oddball task performance, we conducted a one-way within-subjects MANOVA with Experimental Condition (Adaptive Team Environment, Neutral Team Environment, and Maladaptive Team Environment) as the independent variable and Tetris® and Oddball Scores as the dependent variables. We followed a significant result for the MANOVA with univariate ANOVAs, running one-way ANOVAs with Experimental Condition as the independent variable and Tetris® and Oddball Scores as the dependent variables. To contrast participants' cognitive workload among the Adaptive Team Environment, Neutral Team Environment, and Maladaptive Team Environment conditions, we conducted a univariate

⁴ As the teammates were present (but not engaging in the task with the participant) in both the Oddball and Neutral Team Environment conditions, we were able to attribute differences in Oddball Score between the two conditions to modulations in attentional resource allocation as opposed to alterations in the team environment.

ANOVA with TLX Score as the dependent variable and Experimental Condition as the independent variable. We followed all significant results for ANOVAs with Fisher's Least Significant Difference tests. We set alpha levels to 0.05 for all tests and provide Cohen's *d* effect sizes where appropriate.

Results

Manipulation Checks

Statistical analyses revealed that participants perceived the Tetris® competence of the good teammate ($M = 4.556$) to be significantly higher than the bad teammate ($M = 2.778$) ($t(8) = 6.4$, $p < 0.001$); participants had significantly more trust in the good teammate's abilities to help them successfully play Tetris® ($M = 4.556$ versus $M = 2.556$, $t(8) = 8.485$, $p < 0.001$); and participants reported significantly more task cohesion with the good teammate ($M = 4.556$ versus $M = 2.333$, $t(8) = 6.86$, $p < 0.001$). These results support that the experimental manipulations were effective in generating the Adaptive and Maladaptive Team Environment conditions.

Validation of Attentional Resource Allocation Measure

Participants performed significantly better on the oddball task (they had lower Oddball Scores- faster reaction times and fewer errors) when engaging in the Oddball condition ($M = 0.504$) versus the Neutral Team Environment condition ($M = 1.493$, $t(8) = 2.057$, $p = 0.037$). These results are consistent with previous studies and therefore indicate that the oddball task is a valid measure of attentional resource allocation.

Tetris® and Oddball Performance

A significant multivariate main effect for Experimental Condition in regards to participants' performances of Tetris® and Oddball was revealed (Wilks' $\lambda = 0.211$, F

(4,30) = 8.815, $p < 0.001$). Power to detect the effect was 0.997. Subsequent analyses revealed a significant univariate main effect for Experimental Condition in regards to both Tetris® Score ($F(2,16) = 9.014$, $p = 0.002$) and Oddball Score ($F(2,16) = 11.874$, $p = 0.001$). Power to detect the effects was 0.941 and 0.983, respectively. Post-hoc analyses revealed that participants' Tetris® Scores were higher in the Adaptive Team Environment condition than in both the Maladaptive ($p = 0.017$, $d = 1.005$) and Neutral Team Environment ($p = 0.009$, $d = 0.931$) conditions (see Figure 2). Post-hoc analyses also revealed that participants' Oddball Scores were lower in the Adaptive Team Environment condition than the Maladaptive Team Environment condition ($p = 0.001$, $d = 0.754$) and lower in the Neutral Team Environment condition than the Maladaptive Team Environment condition ($p = 0.004$, $d = 0.836$, see Figure 3).

NASA-TLX

Statistical analyses revealed that Experimental Condition had a significant effect on participants' TLX Scores ($F(2,16) = 9.445$, $p = 0.002$). Power to detect the effect was 0.951. Post-hoc analyses revealed that participants' TLX Scores were significantly lower in the Adaptive Team Environment condition than the Maladaptive Team Environment condition ($p = 0.002$, $d = 1.590$). Additionally, participants' TLX Scores were significantly lower in the Neutral Team Environment condition than the Maladaptive Team Environment condition ($p = 0.007$, $d = 1.229$, see Figure 4).

For descriptive purposes, Figure 5A illustrates the TLX scores of the sources of cognitive workload for the Neutral, Adaptive, and Maladaptive Team Environment conditions⁵. It appears that the greatest differences between conditions for sources of

⁵ As the purpose of this study was to examine differences in overall cognitive workload between conditions, no statistical analyses were conducted with regard to particular sources of workload.

cognitive workload are for mental demands, temporal demands, performance on the task, and frustration with the task. Also for descriptive purposes, Figure 5B displays the relative contributions of the sources of cognitive workload across the Neutral, Adaptive, and Maladaptive Team Environment conditions. The relative contribution of each source of cognitive workload was determined by summing the weights each participant assigned to the sources of cognitive workload (i.e., the total number of pair-wise comparisons each source of workload won- see NASA-TLX (Cognitive Workload) subsection in Methods) and then dividing each source's summed weight by the sum of all the sources' weights. It appears that all the sources of cognitive workload made fair contributions to workload with the exception of physical demands, which contributed minimally.

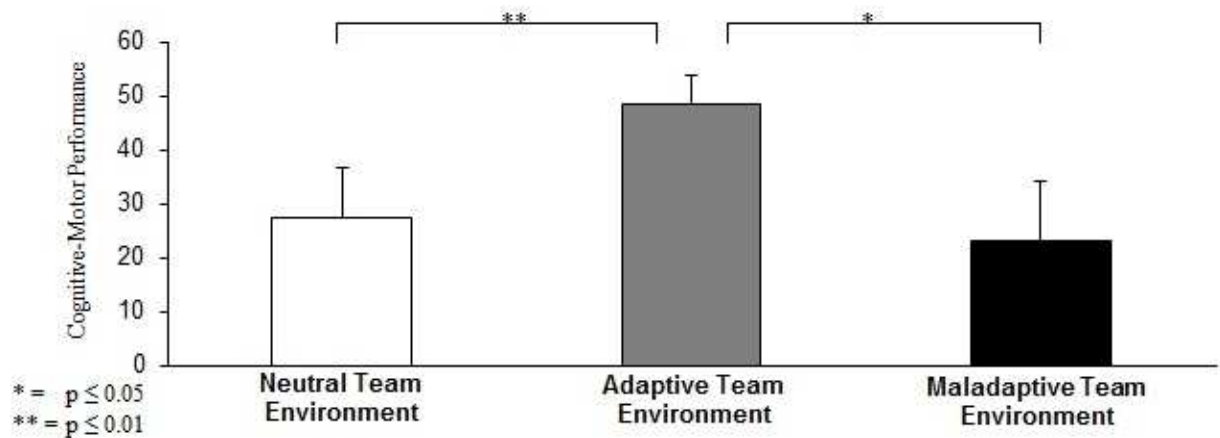


Fig. 2. Cognitive-motor performance for the different experimental conditions.

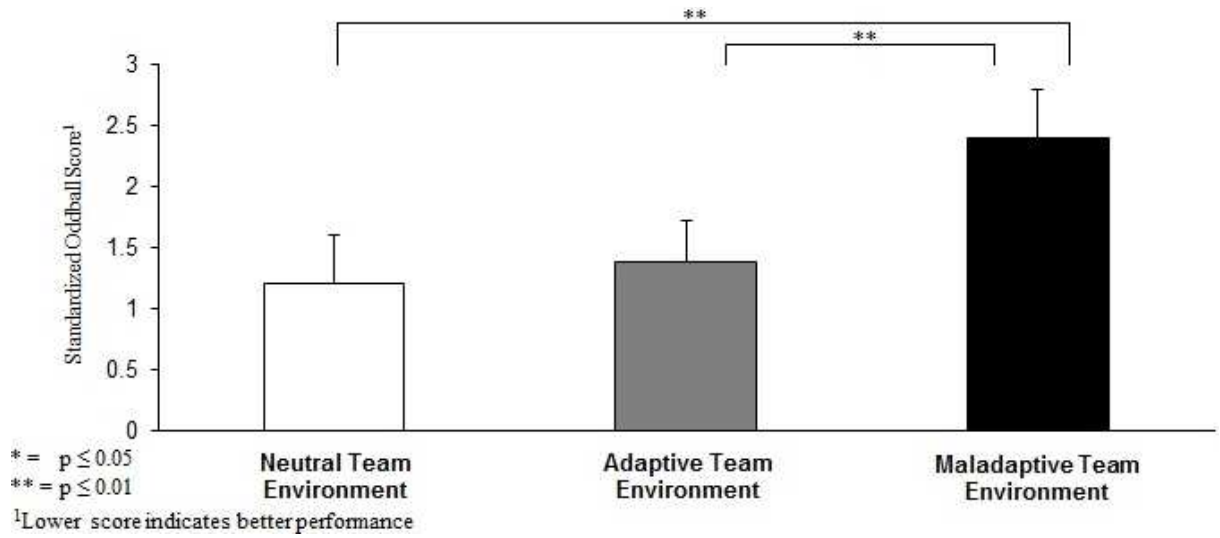


Fig. 3. Oddball performance (attentional resource allocation) for the different experimental conditions.

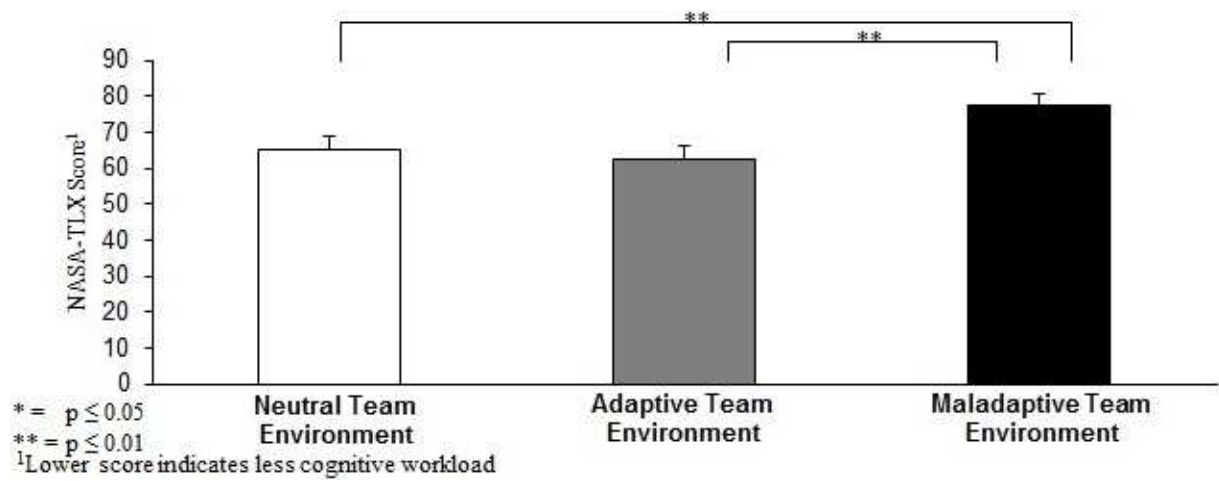


Fig. 4. TLX scores (level of cognitive workload) in each experimental condition.

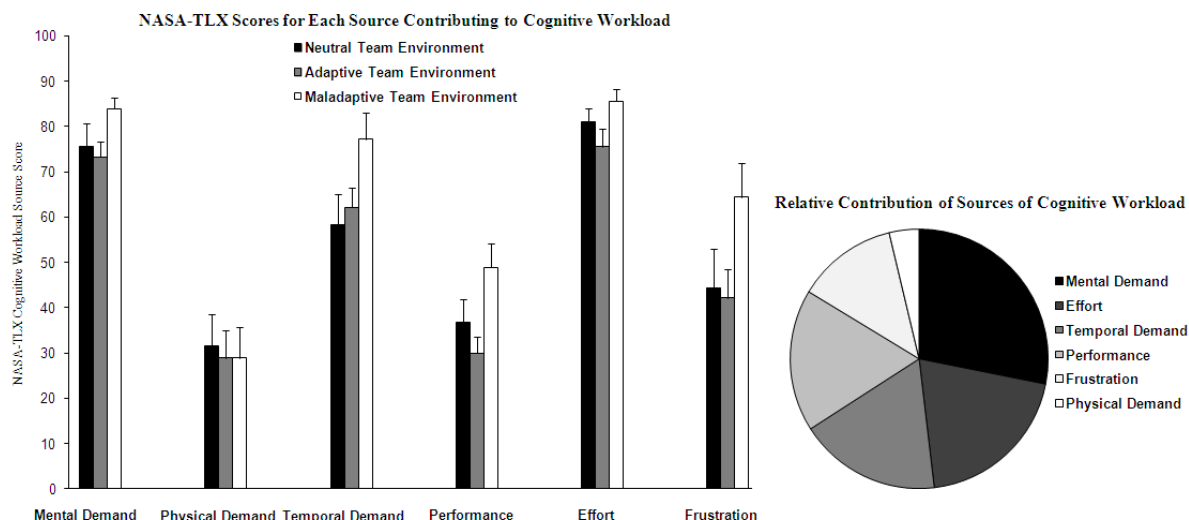


Fig. 5. A. TLX scores for each source of cognitive workload in each experimental condition. **B.** The relative contribution of each source of cognitive workload to total cognitive workload across experimental conditions.

Discussion

As predicted, participants engaging in the Adaptive Team Environment condition exhibited superior performance on the cognitive-motor task relative to when these same participants performed in the Neutral and Maladaptive Team Environment conditions.

However, contrary to the hypothesis, no significant difference in cognitive-motor task performance was observed when comparing participants' performances in the Neutral and Maladaptive Team Environment conditions.

As expected, participants engaging in the Adaptive and Neutral Team Environment conditions exhibited superior performance on the oddball task as compared to the Maladaptive Team Environment condition. These results suggest that participants more efficiently allocated their attentional resources in the Neutral and Adaptive Team Environment conditions. This follows because superior oddball performance (faster and more accurate responses to targets) indicates more efficient attentional resource

allocation (see Kahneman, 1973; Karatekin et al., 2004; Maclin et al., 2011). Contrary to predictions, no difference in attentional resource allocation (oddball performance) was observed when comparing participants' oddball performances in the Neutral and Adaptive Team Environment conditions.

As hypothesized, participants engaging in the Adaptive and Neutral Team Environment conditions reported lower TLX scores (levels of cognitive workload) than when they performed in the Maladaptive Team Environment condition. Contrary to expectations, no difference in cognitive workload was observed when comparing participants' workload in the Neutral and Adaptive Team Environment conditions.

Collectively, these results suggest that it was advantageous for participants to perform in adaptive or neutral team environments as compared to a maladaptive team environment. Specifically, participants performing in a maladaptive team environment incurred a cognitive burden (inefficient attentional resource allocation and elevated cognitive workload) relative to when they were engaging in adaptive or neutral team environments. This cognitive burden may be the result of ruminating about (second-guessing) the poor advice given by 'bad' teammates as well as being distracted by these teammates' faulty recommendations.

Participants exhibited no significant differences in attentional resource allocation and cognitive workload when comparing adaptive and neutral team environments. However, those performing in an adaptive team environment did exhibit superior cognitive-motor task performance, suggesting that they may, in fact, have retained more spare attentional resources while performing in this team environment relative to a neutral team environment. Specifically, participants engaging in an adaptive team

environment may have spared (‘freed up’) attentional resources while performing in this environment, which were then available to allocate to the cognitive-motor task. This would explain the increase in cognitive-motor task performance while maintaining performance on the oddball task. One possible explanation why participants chose to dedicate their surplus attentional resources to the cognitive-motor task is because of the collaborative nature of this task relative to the oddball (i.e., the cognitive-motor task was performed in collaboration with a teammate, while the oddball was not). It is important to note that humans have an inherent preference to work on collaborative activities versus non-collaborative ones (Rekers, Haun, & Tomasello, 2011). Regardless of this speculation, the results suggest that an adaptive team environment enhanced cognitive-motor task performance without a concomitant decrement to oddball performance or an elevation in cognitive workload.

Attentional resource allocation and cognitive workload have been observed to have a strong impact on the performance of individuals challenged with tasks in non-team environments (see Hillyard & Kutas, 1983; Navon & Gopher, 1979). However, individuals frequently perform in team environments of variable quality. Yet, the relationship between attentional resource allocation/cognitive workload and performance in team settings has rarely been investigated. The present study addressed this shortcoming in the literature and revealed that a maladaptive team environment negatively impacted attentional resource allocation, cognitive workload, and performance relative to an adaptive or neutral team environment. Additionally, an adaptive team environment was associated with superior performance relative to a neutral team environment. These results are novel and informative in that they shed light upon

psychological mechanisms underlying the frequently reported positive correlation between group cohesion and task performance (for a review of this relationship, see Carron et al., 2002). Despite the robustness of the cohesion-performance relationship, the psychological mechanisms mediating it are not well-understood (see Cox, 2011). The results of the present study suggest that attentional resource allocation and cognitive workload mediate the cohesion-performance relationship. To directly address this possibility, future research could involve conducting a mediation analysis (Barron & Kenny, 1986) of a larger data set collected from a paradigm similar to that of the present study.

As this study revealed that high levels of perceived competence of and trust in one's teammates, as well as task cohesiveness with one's teammates, constituted an adaptive team environment, the reasons these factors are adaptive are worthy of discussion. One reason perceived competence and trust are beneficial to team environment may be that they encourage a form of "cognitive outsourcing." Specifically, a team member is likely to outsource certain aspects of a task to his/her teammates if s/he perceives his/her teammates as being competent and trusts his/her teammates to perform well in these areas. Such outsourcing enables a team member to reallocate his/her attention to other elements of the task, consequently improving his/her performance. Additionally, as s/he is no longer managing the outsourced components of the task, the team member's cognitive workload is rendered more manageable. In accord with this notion, Dirks (1999) suggests that trust influences performance by channeling team members' resources to distinct objectives of a task. In a team environment in which team members perceive one another as being competent and trustworthy, team members are

likely to experience increased task cohesion (Marcos et al., 2010). Increases in task cohesion have been associated with increases in motivation, which can enhance performance (Bray & Whaley, 2001).

The present study illustrates the importance of generating adaptive team environments wherein team members perceive one another as being competent and trustworthy and work cohesively. Fortunately, a large number of studies have examined means by which to create adaptive team environments (see Gorman, Cooke, & Amazeen, 2010; Salas, Cooke, & Rosen, 2008; Wheelan, 2009). The results of the present study underscore the importance of this research and indicate that methods to augment perceived competence, trust, and task cohesiveness should receive particular consideration. If future research continues to shed further light on cognitive processes impacted upon by team environment, human performance in a number of settings may be enhanced and costly performance failures averted.

Study 4

The effects of team environment on cerebral cortical dynamics and attentional reserve

Abstract

Cerebral cortical dynamics and attentional reserve impact cognitive-motor performance when individuals perform cognitive-motor tasks in the absence of teammates (i.e., in non-team environments). Specifically, efficient cortical dynamics and large attentional reserves are associated with high-quality performance. Yet, individuals often perform cognitive-motor tasks as members of teams (i.e., in team environments). Team environments differ in regards to their quality such that adaptive team environments, which can be characterized by high levels of perceived competence of and trust in one's teammates, as well as task cohesiveness with one's teammates, are associated with superior individual performance, whereas maladaptive team environments are associated with poor individual performance. Despite the frequency with which individuals perform in team environments of differing quality as well as the robust relationship between cerebral cortical dynamics/attentional reserve and cognitive-motor performance, the impact of team environment on cortical dynamics and attentional reserve has not been investigated. Employing electroencephalography, it was observed that individuals performing a task in adaptive and neutral team environments exhibited more efficient cerebral cortical dynamics and attenuated attentional reserves as compared to performing in maladaptive team environments. Additionally, individuals engaging in adaptive team environments exhibited superior task performance, possibly facilitated by more optimal states of arousal, relative to individuals performing in neutral and maladaptive team environments. Thus, the results suggest that, relative to neutral team environments, maintaining performance in maladaptive team environments comes at the

expense of neural and attentional resources, while adaptive team environments enhance performance without an additional cost to neural and attentional resources. These results illustrate the importance of (1) avoiding maladaptive team environments so as to prevent team members from squandering neural and attentional resources and (2) generating adaptive team environments in order to enhance task performance.

Introduction

Cerebral cortical dynamics impact cognitive-motor performance such that efficient dynamics are associated with superior performance, whereas inefficient dynamics are associated with inferior performance (see Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). Specifically, economical cerebral cortical activation and refined networking (cortical communication) to the premotor (motor planning) brain region accompany quality cognitive-motor performance, whereas excessive (more than is ideally necessary for successful task performance) cortical activation and networking to the premotor region are linked to poor performance due to disruption of sensory input, higher-order cognitive processing (e.g. information analysis), and motor output. For example, exceedingly high cortical activation and networking to the premotor region has been revealed to underlie the inferior performances exhibited by less-skilled marksmen relative to their more-skilled counterparts (Deeny, Hillman, Janelle, & Hatfield, 2003; Haufler, Spalding, Santa Maria, & Hatfield, 2000). This relationship between inefficient cortical dynamics and poor performance has been postulated to be an outcome of non-essential cortical activity excessively activating first-order motor neurons, leading to inefficient motor unit recruitment and, consequently, non-optimal motor output (inferior performance) (see Hatfield & Kerick).

Cerebral cortical dynamics also impact attention, which refers to the directed allocation of neural resources, such that efficient dynamics spare neural resources necessary for attention (attentional resources), whereas inefficient dynamics consume attentional resources (see Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). The amount of spare attentional resources (attentional reserve) is associated with cognitive-

motor task performance (Beilock, Wierenga, & Carr, 2002; Smith & Chamberlin, 1992; Strayer, Drews, & Johnson, 2003). Specifically, the quantity of attentional reserve is positively related to one's ability to cognitively process novel stimuli, which is critical to cognitive-motor performance in that it facilitates the management of unexpected events (Miller, Rietschel, McDonald, & Hatfield, 2011; Ullsperger, Freude, & Erdmann, 2001). Thus, as the efficiency of cortical dynamics increases, attentional reserve is augmented, enhancing the ability to process novel stimuli and improving cognitive-motor performance.

Individuals' cerebral cortical dynamics and attentional reserve have been examined in a number of settings wherein individuals perform cognitive-motor tasks in the absence of teammates (i.e., in non-team environments). For example, participants' cerebral cortical efficiency and attentional reserve while engaging in videogames in single-player modes has been observed to decrease as a function of task difficulty (Allison & Polich, 2008; Miller et al., 2011; Rietschel et al., 2012). Similarly, individuals' attentional reserve during solo flight simulations has been reported to attenuate due to increased task demands (Kramer, Sirevaag, & Braune, 1987; Sirevaag et al., 1993).

However, humans often perform cognitive-motor tasks as members of teams (i.e., in team environments) consisting of one or more other individuals. Examples of such team environments are apparent in sport, military, medical, law enforcement, and industrial settings. Team environments differ in terms of their quality such that adaptive team environments, which can be characterized by high levels of perceived competence

of and trust in one's teammates, as well as task cohesiveness⁶ with one's teammates, are associated with superior individual cognitive-motor performance, whereas maladaptive team environments, which can be characterized by low levels of perceived competence of and trust in one's teammates, as well as a lack of task cohesion with one's teammates, are associated with poor individual performance (Carron, Colman, & Wheeler, 2002; Dirks, 1999; Marcos, Miguel, Oliva, & Calvo, 2010).

It is surprising that the impact of team environment on cerebral cortical dynamics and attentional reserve has not been examined. This area of investigation is important given (1) the regularity with which humans perform cognitive-motor tasks in team environments and (2) the robustness of the relationship between cerebral cortical dynamics, attentional reserve, and cognitive-motor performance.

Although the impact of team environment on cerebral cortical dynamics and attentional reserve has not been investigated, the effect of team environment on attentional resource allocation and subjective cognitive workload, which are associated with cortical dynamics and attentional reserve (Brookings, Wilson, & Swain, 1996; Wickens, Kramer, Vanasse, & Donchin, 1983), has been examined. Specifically, Miller et al. (under review) examined the effects of neutral, adaptive, and maladaptive team environments on participants' attentional resource allocation, as indexed by secondary task performance, and cognitive workload, as measured by a questionnaire, while the participants performed a cognitive-motor task. The authors observed that individuals performing in the adaptive team environment exhibited superior cognitive-motor task

⁶ Task cohesiveness refers to the degree to which a team member feels that his/her teammate(s) and s/he are effectively working together to accomplish a task. This type of cohesion is different from social cohesion, which refers to how much a team member enjoys the companionship and camaraderie resultant of his/her membership on a team (see Carron, Widmeyer & Brawley, 1985).

performance relative to performing in the neutral and maladaptive team environments. The authors further observed that individuals performing in the maladaptive team environment allocated their attentional resources less efficiently and reported increased cognitive workload in comparison to performing in the neutral and adaptive team environments. As inefficient attentional resource allocation and high levels of cognitive workload are associated with inefficient cerebral cortical dynamics and diminished attentional reserve (Brookings et al.; Wickens et al.), Miller et al.'s observations indirectly suggest that cerebral cortical efficiency and attentional reserve decrease in maladaptive team environments while cognitive-motor task performance increases in adaptive team environments.

Although informative, Miller et al. (under review)'s results *do not directly reveal* information about cerebral cortical dynamics and attentional reserve. In order to *directly assess* the impact of team environment on cerebral cortical dynamics and attentional reserve, cortical activity and attentional reserve must be measured directly from the brain. Therefore, in the present study, participants' electroencephalographic (EEG) signals were recorded while they engaged in a cognitive-motor task in neutral, adaptive, and maladaptive team environments. Specifically, each participant's cortical activation (EEG spectral power) and networking (EEG coherence) with the premotor region were evaluated to assess cortical dynamics while event-related potentials (ERPs) time-locked to task-irrelevant, novel auditory stimuli were evaluated to assess attentional reserve.

EEG spectral power provides an index of the degree of synchronous neural activity within a frequency bandwidth of interest (greater synchrony results in greater power). The power within a given bandwidth is indicative of the degree of cortical

activation in the brain region underlying the electrode from which the EEG signal was recorded (Ray, 1990). High levels of theta, beta, and gamma bandwidth power indicate high degrees of task-related cortical activation while *low levels* of low-alpha and high-alpha power indicate high degrees of general arousal and task-related cortical activation, respectively (Başar-Eroglu, Strüber, Schiormann, Stadler, & Başar, 1996; Gevins, Smith, McEvoy, & Yu, 1997; Klimesch, 1999; Ray & Cole, 1985). EEG coherence is a measure of the degree of repeated linear correlation of the spectral power in a specified bandwidth between two separate electrodes (two different brain regions). High coherence in the theta, alpha, low-beta, and high-beta frequency bandwidths implies a large degree of mid- to long-range networking between different brain regions whereas low coherence posits relative independence (Deeny, Haufler, Saffer, & Hatfield, 2009; Nunez & Srinivasan, 2005; von Stein & Sarnthein, 2000).

There is evidence that attentional reserve can be reliably indexed by the cognitive processing of novel stimuli, as reflected by ERP component amplitudes (Miller et al., 2011; Ullsperger et al., 2001). The amplitude of the novelty-P3 ERP component, which represents the reflexive orienting of attention to novel stimuli, has been observed to be particularly effective at indexing attentional reserve (Miller et al.; Rietshcel, *dissertation*; Ullsperger et al.). This is due to the fact that the amplitude of the novelty-P3 is constrained by the neural resources available for attending to novel stimuli, thus rendering this component sensitive to the magnitude of attentional reserve.

The purpose of the present study was to investigate the effects of team environment on cerebral cortical dynamics and attentional reserve. More specifically, the study was designed to determine whether the quality of team environment would

influence participants' cerebral cortical activation, cerebral cortical networking with the premotor region, and attentional reserve while performing a cognitive-motor task in adaptive, maladaptive, and neutral team environments. In accord with Miller et al. (under review)'s observations, it was predicted that participants in the present study would exhibit less efficient cerebral cortical activation and networking, as indexed by EEG spectral power and coherence, respectively, as well as attenuated attentional reserve, as measured by novelty-P3 amplitude, in maladaptive team environments relative to neutral and adaptive team environments. Also in agreement with Miller et al.'s observations, it was predicted that participants in the present study would exhibit superior cognitive-motor task performance in adaptive team environments in comparison to neutral and maladaptive team environments.

Methods

Participants

Twenty right-handed young adults (4 women) recruited from a large Mid-Atlantic university gave informed consent prior to the study, which was approved by an Institutional Review Board. Four participants met the exclusion criteria of performing the cognitive-motor task at a difficulty level beyond which their teammates could assist them (details on the cognitive motor task, task difficulty levels, and team environments to follow). Specifically, during piloting of the experiment, it was determined that teammates could not assist participants who performed at a task difficulty level of 10 or higher due to the exceptionally rapid pace with which the task proceeded at such levels (i.e., teammates were unable to keep up with their duties in assisting participants at task difficulty levels of 10 or higher). Additionally, the data of four of the remaining

participants were discarded due to poor electrophysiological recordings, leaving a final sample of 12 individuals (2 women, with an age range of 20 – 31, $M = 22.6$, $SD = 3.2$ years).

Cognitive-Motor Task

For the cognitive-motor task, participants used their right-hand to play the videogame Tetris® while the song “Korobeiniki” (“Music A” in the standard Tetris® game) was played (72 - 76 dB SPL) from a speaker built into the computer monitor on which Tetris® was being performed. Tetris® asks individuals to use a computer keyboard to maneuver different-shaped game pieces presented on a video screen (in the present case, a computer monitor screen) in order to position them in their ideal location on the game board (monitor screen). Tetris® can be played at various difficulty levels, which are altered by the velocity at which the game pieces move down the monitor screen (e.g., at level 1, the pieces fall at a velocity of 1.67 cm/s, while at level 8, the pieces fall at a velocity of 3.56 cm/s). Each participant established a Tetris® difficulty level and played at that level through the experiment. The establishment of Tetris® level was determined by having participants commence play at level one, five, or seven, dependent upon each participant’s responses to a Tetris® expertise questionnaire (beginner, advanced beginner, or fairly good, respectively).

After beginning play at the proper level, participants played until they failed at the task (i.e., the Tetris® pieces accumulated to the top of the monitor screen) twice. If a participant completed 10 horizontal lines that contained no gaps between the pieces, the current level was finished and the participant advanced to the next level. If a participant progressed to a new level and then failed at that level, s/he began play at the level at

which s/he failed the first time and continued until s/he failed a second time. The level at which the participant failed a second time became the difficulty level employed throughout the remainder of the experiment unless s/he had not completed any lines at this level, in which case s/he played at the prior level (e.g., the participant made it to level 8 but failed to complete any lines at this level, so his/her difficulty level was set at 7). Participants' mean Tetris® difficulty level was 5.7 with a standard deviation of 2.5, indicating that they were playing at medium levels of difficulty (5.7 being about halfway between the easiest, 1, and the hardest, 10, possible starting difficulty levels). Tetris® Score was established by giving each participant one point for each horizontal line of game pieces completed and subtracting five points each time the participant failed at the task.⁷

Experimental Conditions

Each participant engaged in three experimental task conditions: Neutral Team Environment, Adaptive Team Environment, and Maladaptive Team Environment. During the Neutral Team Environment condition, participants played Tetris® in the presence of the two teammates (both of whom were male) with whom they would play/had played in the Adaptive and Maladaptive Team Environment conditions⁸. The task in the Adaptive and Maladaptive Team Environment conditions was the same as in the Neutral Team Environment condition, but one of the teammates offered the participants recommendations on how to maneuver the Tetris® game pieces (details on these

⁷ Tetris® score was determined in accordance with Miller et al. (under review), who observed that, during piloting of their experiment, subjects reported becoming frustrated and losing motivation to play Tetris® when their scores became negative. Thus, based on participants' Tetris® performance during piloting, Miller et al. determined a five point penalty to be the maximum that could be imposed without risking that participants' scores would be negative (i.e., participants typically completed at least five lines before failing at the task).

⁸ Three teammates (confederates) were employed for the experiment. Some combination of these three teammates assisted with each participant.

teammate recommendations to follow) while the other teammate was present but did not provide any advice. In the Adaptive Team Environment condition, one teammate was assigned to offer advice to the participant while the other teammate was present but did not offer advice. In the Maladaptive Team Environment condition, the teammate who offered/would offer advice in the Adaptive Team Environment condition was assigned to be present but not offer advice, while the teammate who did not/would not offer advice in the Adaptive Team Environment condition was assigned to offer advice. Henceforth, the teammate who offered advice in the Adaptive Team Environment condition will be referred to as the “good teammate,” and the teammate who offered advice in the Maladaptive Team Environment condition will be referred to as the “bad teammate.”

Experimental Manipulations

Previous research has revealed that one’s perception of his/her teammate’s competency at performing a task is positively correlated with (1) one’s trust in his/her teammate’s ability to help one successfully perform a task and (2) one’s reported task cohesiveness with his/her teammates (see Marcos et al., 2010; Miller et al., under review). Accordingly, prior to beginning the experimental conditions, an attempt was made to manipulate participants’ perceptions of their teammates’ skill levels. Given the positive relationship between perceived competence and trust as well as perceived competence and task cohesion (Marcos et al.; Miller et al.), it was expected that, by manipulating participants’ perceptions of their teammates’ competencies at Tetris®, participants’ trust in their teammates’ abilities to help them successfully play Tetris® as well as participants’ task cohesiveness with their teammates while engaging in Tetris® would be altered. As perceived competence, trust, and task cohesion are associated with

the quality of the team environment (Carron et al., 2002; Dirks, 1999; Marcos et al.) (i.e., whether the team environment is adaptive or maladaptive), it was expected that, by positively influencing participants' perceptions of the good teammate's Tetris® competency, the generation of an adaptive team environment for participants while performing with the good teammate would occur. Similarly, it was expected that, by negatively influencing participants' perceptions of the bad teammate's Tetris® competency, the generation of a maladaptive team environment for participants while performing with the bad teammate would occur.

Perceived competence was manipulated in a three-step process. First, after participants entered the testing area and completed the informed consent and Tetris® expertise paperwork, they were introduced to the good and bad teammates. The good teammate informed participants that he was a much more experienced and, thus, better Tetris® player than the bad teammate, who acknowledged this information. Second, participants watched the good teammate play Tetris® for 5 min and the bad teammate play for 5 min. With the participants watching, the good teammate performed Tetris® to the best of his ability, attempting to optimize the placement of every game piece. Conversely, the bad teammate did not perform to the best of his ability, as he attempted to optimize the placement of only 25% of the game pieces, intentionally misplacing the other 75%. Finally, in the Adaptive Team Environment condition, the good teammate offered advice to the best of his ability for every game piece presented, while, in the Maladaptive Team Environment condition, the bad teammate offered advice to the best of his ability for only 25% of the pieces, intentionally giving non-optimal advice for the other 75%.

As established prior to the experiment, the teammates were comparable in regard to Tetris® ability (both played at the same Tetris® difficulty level), so that they could switch who played the role of the good teammate and who played the role of the bad teammate, thus controlling for differences beyond the accuracy of the advice they were offering. An attempt was also made to control for communication style differences between the teammates in that each teammate offered advice via the same three hand signals. These hand signals were drawing a circle in the air to indicate that participants should rotate game pieces, pointing directly on the screen to where participants should place game pieces, and giving a “thumbs-up” when participants had game pieces in the recommended location. Participants were told that their teammates received the same incentive-based monetary reward (details on the reward system to follow) as the participants (i.e., participants were told, “if you win \$40, then so does your teammate”). Participants were told that, given this reward system, they should decide how much to follow their teammates’ recommendations because, if participants found better places for game pieces than their teammates had recommended, their teammates would benefit from this more optimal placement.

To determine whether the experimental manipulations were effective, participants were asked to fill out answers to a questionnaire about each teammate immediately after playing with that teammate. The Teammate Questionnaire asked participants to utilize a five-point Likert scale (highest scores equal to 5) to respond to one question regarding how competent they believed their teammate to be at Tetris®, a second question concerning how much they trusted their teammate’s abilities to help them successfully play Tetris®, and a third question inquiring about the level of task cohesiveness they felt

with their teammate (see Appendix A for specific questions). This novel and brief questionnaire was employed (as opposed to more traditional and longer questionnaires) because it asked questions about perceived competence, trust, and task cohesiveness specifically related to the cognitive-motor task being performed (Tetris®) and was minimally disruptive to the ecological validity of the experiment (i.e., it did not take a long time to complete and, thus, did not disrupt the flow of the experiment). Further, Miller et al. (under review) observed this questionnaire has good construct validity. In order to try and ensure that participants felt comfortable responding honestly to the questionnaire, they were told that their responses would not be revealed to either teammate.

Cerebral Cortical Dynamics and Attentional Reserve

Psychophysiological recording and signal processing. Scalp EEG was collected from 32 channels of a stretchable EEG cap housing a 64 channel BrainVision atciCAP system (Brain Products, Munich, Germany) labeled in accordance with an extended international 10-20 system (Jasper, 1958). The EEG data were online referenced to the left earlobe, and a common ground was employed at the FPz site. Electrode impedances were maintained below 10 kΩ throughout the experiment and bandpass filters were set at .01-100 Hz with a sampling rate of 1 kHz. The EEG signal was amplified and digitized with a BrainAmp DC amplifier (Brain Products GmbH, Munich, Germany) linked to Brain Vision Recorder software version 1.10 (Brain Products GmbH, Munich, Germany).

Cerebral cortical dynamics: cortical activation (EEG spectral power) and networking (EEG coherence). All EEG data processing was conducted by employing BrainVision Analyzer 2.0 software (BrainProducts GmbH, Munich, Germany). Data

were re-referenced to an averaged ears montage, low-passed filtered at 50 Hz with a 48-dB rolloff employing a zero phase shift Butterworth filter, and spline fit to 250 Hz. Next, the data were visually inspected for marked artifact and then eyeblink artifacts were reduced employing the ICA-based ocular artifact rejection function within the Brain Vision Analyzer software (electrode FP2 served as the VEOG channel). This function searches for an eyeblink template in channel FP2 and then finds ICA-derived components that account for a user specified (70%) amount of variance in the template matched portion of the signal from FP2. These components were removed from the EEG signal, and the signal was reconstructed for further processing. Next, data from each team environment condition were epoched into 1-s sweeps and baseline corrected using the mean of the pre-stimulus interval. Epochs containing amplitudes of more than 75 μV were discarded.

Spectral power was calculated across 1-Hz bins and averaged across the frequency bandwidths theta (3 – 8 Hz), low-alpha (8 – 10 Hz), high-alpha (10 – 13 Hz), beta (13 – 30 Hz), and gamma (30 – 44 Hz). These averages were then natural log transformed prior to statistical analysis. Coherence was defined as $C_{xy}(f)^2$, calculated across 1-Hz bins, and averaged across the frequency bandwidths theta (3 – 8 Hz), alpha (8 – 13 Hz), low-beta (13 – 20 Hz), and high-beta (20 – 30 Hz) between electrode Fz, which overlies the premotor region, and the following electrodes: F3, F4, C3, C4, T3, T4, P3, P4, O1, and O2. Coherence values were subjected to a Fisher z-transformation prior to statistical analysis to approximate a normal distribution.

Attentional reserve (ERPs). To assess participants' attentional reserves available to attend to novel stimuli, task-irrelevant, novel sounds were presented in each Team

Environment condition. Specifically, participants were presented with a set of 30 familiar auditory stimuli randomly selected from a larger collection obtained from the New York State Psychiatric Institute (Fabiani, Kazmerski, Cycowicz, & Friedman, 1996). The stimuli were presented in random order (87–96 dB SPL; interstimulus interval = 6–30 s.) from two speakers positioned 70 cm behind the participants.

To derive ERPs time-locked to the stimuli, EEG data were first re-referenced to an averaged ears montage, low-passed filtered at 20 Hz with a 48-dB rolloff employing a zero phase shift Butterworth filter, and spline fit to 250 Hz. Next, marked artifacts and ocular artifacts were removed from the data (see “Cerebral cortical dynamics” subsection for description of ocular artifact removal procedure). ERPs were obtained by extracting the epoch of 200 ms prior to stimulus onset through 800 ms post-stimulus, then baseline corrected with reference to the pre-stimulus interval. Next, each of the 30 trials was visually inspected and any trials containing obvious artifact were excluded from subsequent analysis. The remaining trials were then averaged. Each ERP was based on a minimum of 20 trials. The mean amplitude for each ERP component was calculated using the approach recommended by Handy (2005), which recommends the use of narrow time windows centered around the peaks of the components in the grand average waveform. Accordingly, the time windows used were as follows: N1 = 135–155 ms; P2 = 220–280 ms; novelty-P3 = 295–355 ms; LPP = 530–650 ms for each of the three midline electrodes of interest (Fz, Cz, and Pz). For a pictorial description of the experimental set-up, please see Figure 1.



Fig. 1. The experimental set-up demonstrating a participant engaging in the cognitive-motor task (Tetris®) while receiving recommendations from his teammate, who is seated to his left.

Experimental Protocol

Upon entering the testing preparation room (a room directly outside of the testing laboratory), participants completed informed consent and a Tetris® experience questionnaire (participants' lifetime Tetris® experience ranged from never having played Tetris® to having played up to 50 hrs). After completing the paperwork, the experimental protocol was explained to participants, and participants were introduced to their teammates. Participants were told that they were competing against nineteen other participants in the study. Participants were told that if their Tetris® Score placed them first among all participants, they would receive \$40; if they placed second, they would receive \$25; if they placed third, they would receive \$15.

Next, participants entered the testing laboratory and established their Tetris® difficulty levels while being prepared for EEG recording. Participants then watched each teammate perform Tetris® for 5 min. After watching their teammates perform Tetris®,

participants engaged in each of the three team environment conditions, which were counterbalanced with respect to order. Prior to beginning the Adaptive and Maladaptive Team Environment conditions, participants practiced performing Tetris® with the recommendations of the appropriate teammate (e.g., the good teammate prior to the Adaptive Team Environment condition) for 1.5 min. Participants were given a 3 min break in-between each condition. After the Adaptive and Maladaptive Team Environment conditions, participants completed the Teammate Questionnaire. After completing all conditions, participants were thanked for their time and told them that they would be contacted if they earned any prize money (i.e., if they finished in 1st, 2nd, or 3rd place).

Statistical Analysis

To determine whether the experimental manipulations (i.e., the generation of the Adaptive and Maladaptive Team Environment conditions) were effective, three one-tailed paired sample *t*-tests to compare participants' responses to the questions about their (1) perceived competence of and (2) trust in their teammates, as well as their (3) task cohesiveness with their teammates were conducted. Tetris® score was subjected to a one-way repeated measures ANOVA with Team Environment (Condition) serving as the independent variable. Spectral power averages and coherence values for the aforementioned bandwidths were subjected to separate 3 x 2 x 5 (Condition x Hemisphere x Region) repeated measures ANOVAs. Significant interactions were followed up with one-way ANOVAs applied to each region or hemisphere (depending on which interaction was significant). Mean amplitudes for the aforementioned ERP components were subjected to separate 3 x 3 (Condition x Electrode) repeated measures ANOVAs. Significant interactions were followed by one-way ANOVAs applied to each

electrode. All simple mean effects were followed by Fisher's Least Significant Difference tests. Conventional degrees of freedom are reported through the results, and the Greenhouse–Geisser correction is provided when sphericity was violated. Alpha levels were set to 0.05 for all tests and Cohen's *d* effect sizes are provided where appropriate.

Results

Manipulation Checks

Statistical analyses revealed that participants perceived the Tetris® competence of the good teammate ($M = 4.42$) to be significantly higher than the bad teammate ($M = 2.83$) ($t(11) = 6.92$, $p < 0.001$); participants had significantly more trust in the good teammate's abilities to help them successfully play Tetris® ($M = 4.75$ versus $M = 2.67$, $t(11) = 8.02$, $p < 0.001$); and participants reported significantly more task cohesion with the good teammate ($M = 4.42$ versus $M = 2.58$, $t(11) = 5.7$, $p < 0.001$). These results support that the experimental manipulations were effective in creating the Adaptive and Maladaptive Team Environment conditions.

Cognitive-Motor Task (Tetris®) Performance

Statistical analyses revealed that Condition had a significant effect on participants' Tetris® Scores ($F(2,22) = 7.38$, $p = 0.004$). Post-hoc analyses revealed that participants' Tetris® Scores were significantly higher in the Adaptive Team Environment condition than the Neutral Team Environment ($p = 0.02$, $d = 0.61$) and Maladaptive Team Environment conditions ($p < 0.001$, $d = 0.75$, see Figure 2).

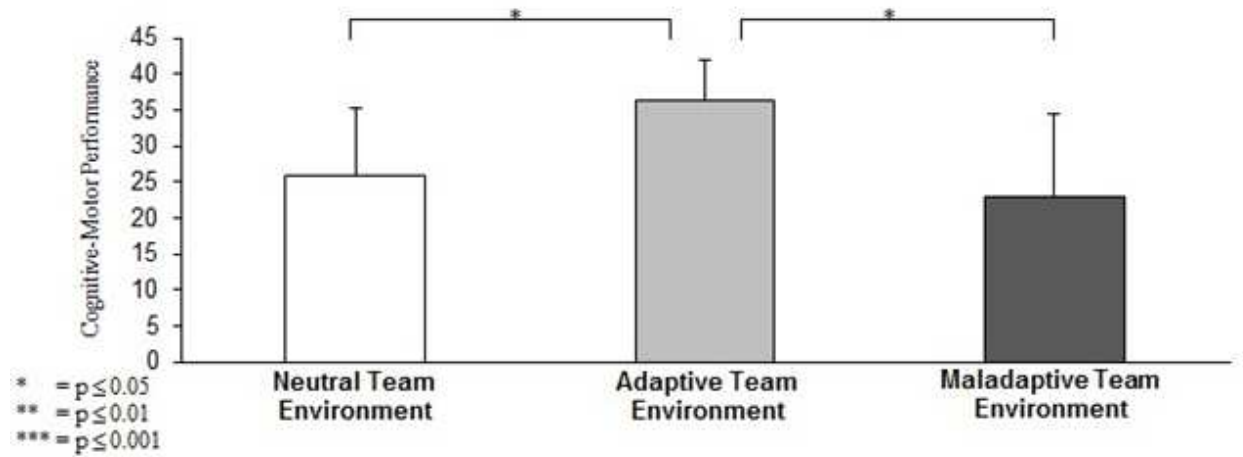


Fig. 2. Cognitive-motor performance.

Psychophysiological (Cerebral Cortical Dynamics and Attentional Reserve) Results

Cerebral cortical activation (EEG spectral power).

Theta. Statistical analyses revealed no significant results for the theta bandwidth.

Low-alpha. Statistical analyses revealed a significant main effect of Condition for low-alpha power $F(2, 22) = 4.99$; $p = 0.016$. Post-hoc analyses revealed that participants' exhibited less low-alpha power in the Adaptive Team Environment condition than the Neutral ($p = 0.019$, $d = 0.52$) and Maladaptive ($p = 0.048$, $d = 0.36$) Team Environment conditions (see Figure 3).

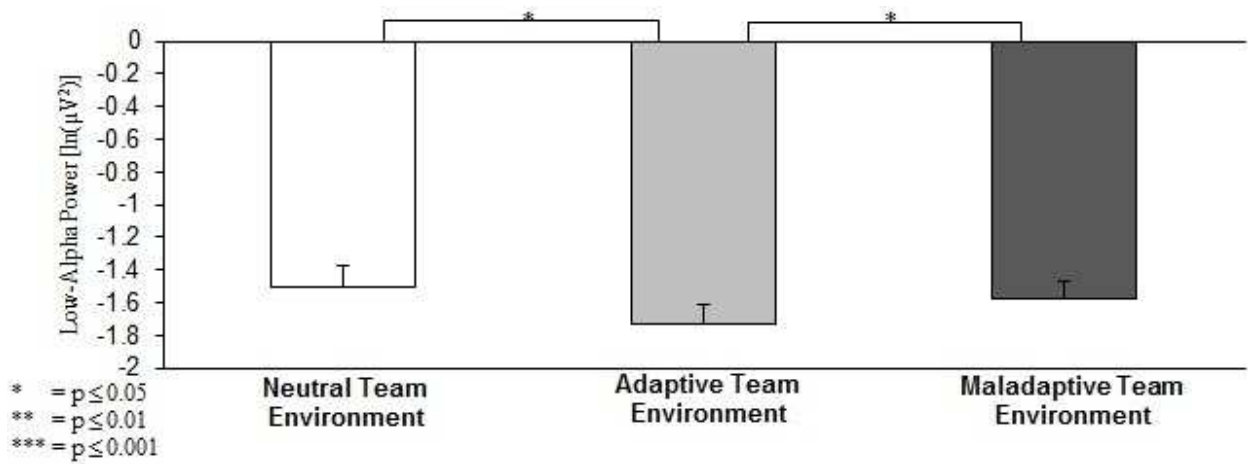


Fig. 3. Low-alpha power averaged across the scalp topography.

High-alpha. Statistical analyses revealed a significant Condition x Hemisphere interaction for high-alpha power ($F(2, 22) = 3.89$; $p = 0.036$). However, post-hoc analyses failed to yield significant results.

Beta. Statistical analyses showed a significant main effect of Condition for the beta bandwidth ($F(2, 22) = 42.68$; $p < 0.001$). This effect revealed an elevation in beta power during the Maladaptive Team Environment condition in comparison to the Neutral and Adaptive Team Environment conditions. However, the main effect was superseded by a significant Condition x Region interaction ($F(3.56, 39.17) = 3.99$; $p = 0.01$; $\epsilon = 0.445$). This interaction revealed that beta power was greater in the Maladaptive Team Environment condition relative to the Neutral Team Environment condition at frontal ($p < 0.001$; $d = 1.61$), central ($p < 0.001$; $d = 1.78$), temporal ($p = 0.001$; $d = 0.83$), parietal ($p < 0.001$; $d = 1.81$), and occipital ($p < 0.001$; $d = 1.38$) regions (see Figure 4A - E). Additionally, beta power was greater in the Maladaptive Team Environment condition than the Adaptive Team Environment condition at frontal ($p < 0.001$; $d = 1.46$), central (p

< 0.001 ; $d = 1.71$), parietal ($p < 0.001$; $d = 1.76$), and occipital ($p < 0.001$; $d = 1.26$) regions (see Figure 4A - E).

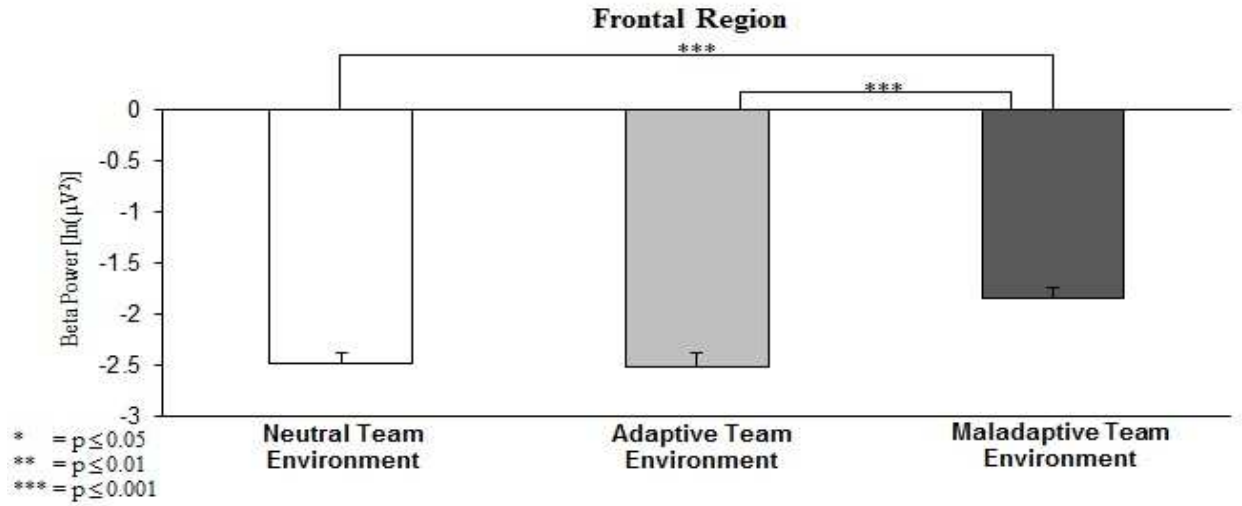


Fig. 4A. Beta power at the frontal region.

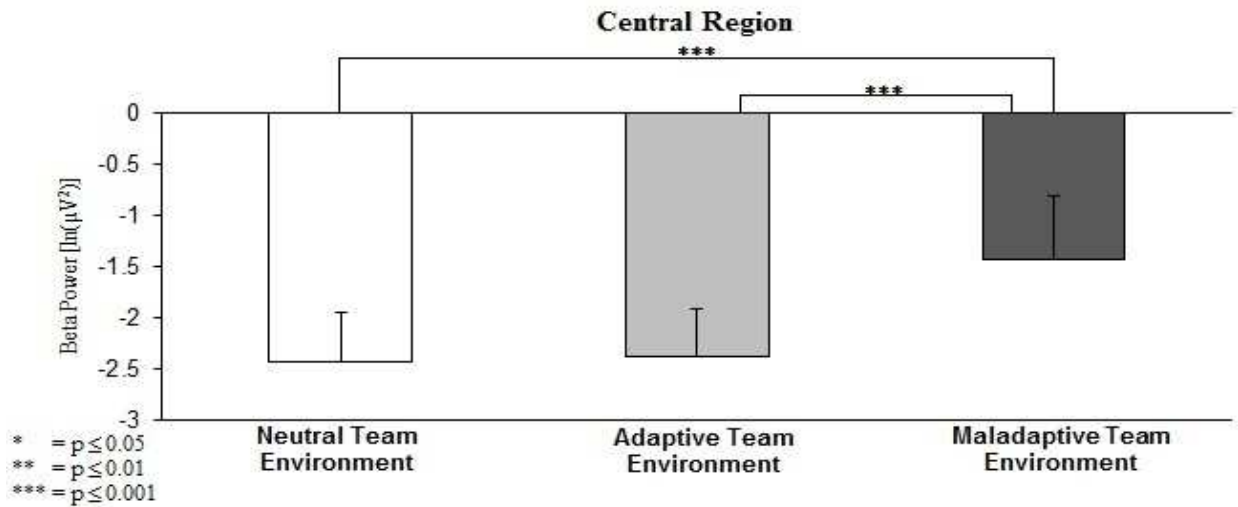


Fig. 4B. Beta power at the central region.

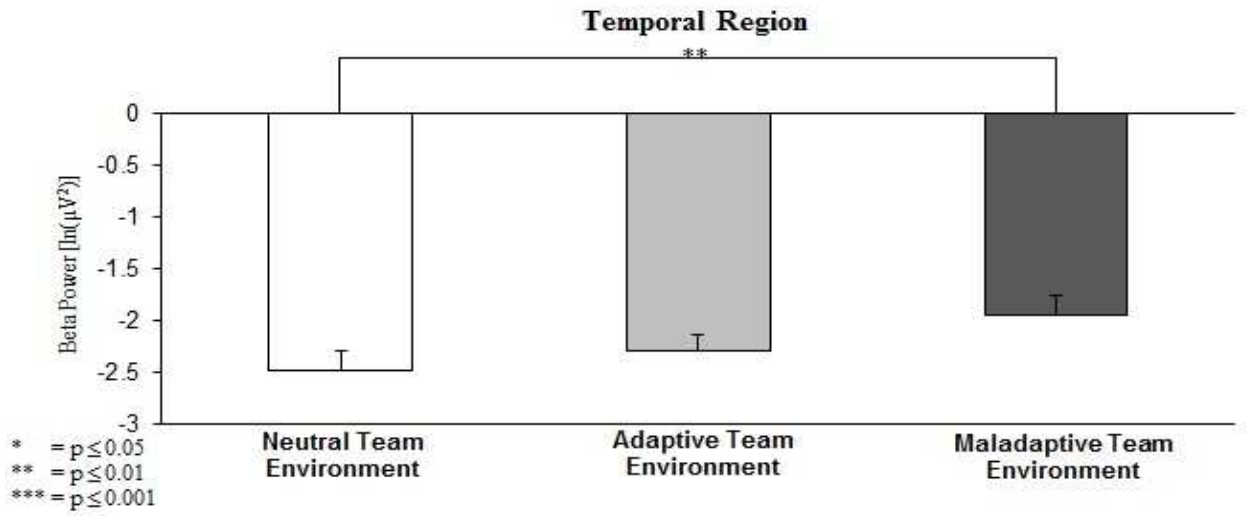


Fig. 4C. Beta power at the temporal region.

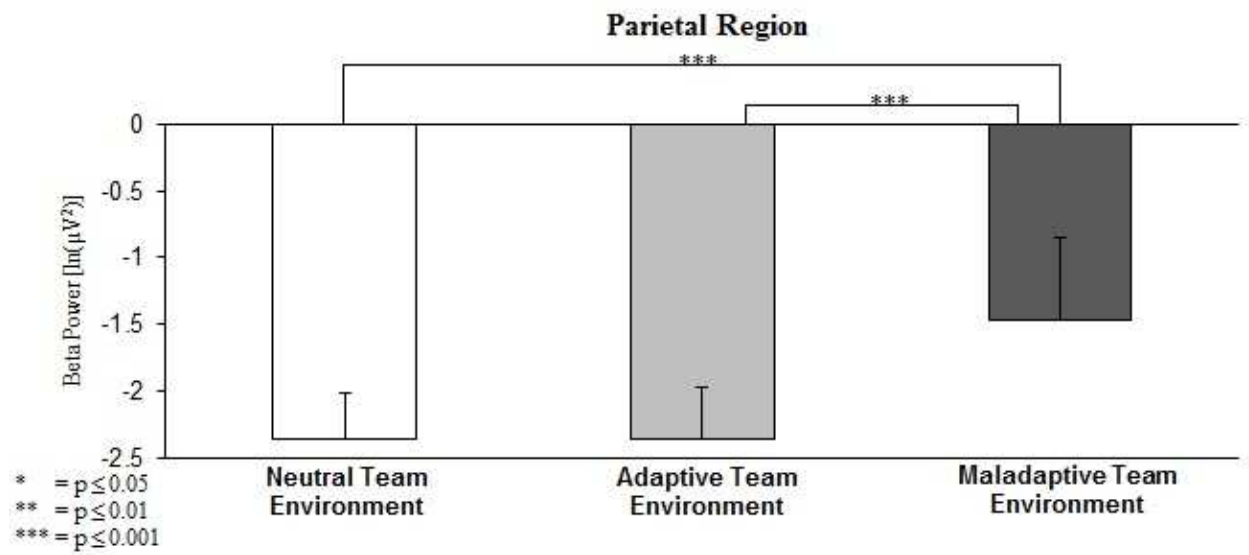


Fig. 4D. Beta power at the parietal region.

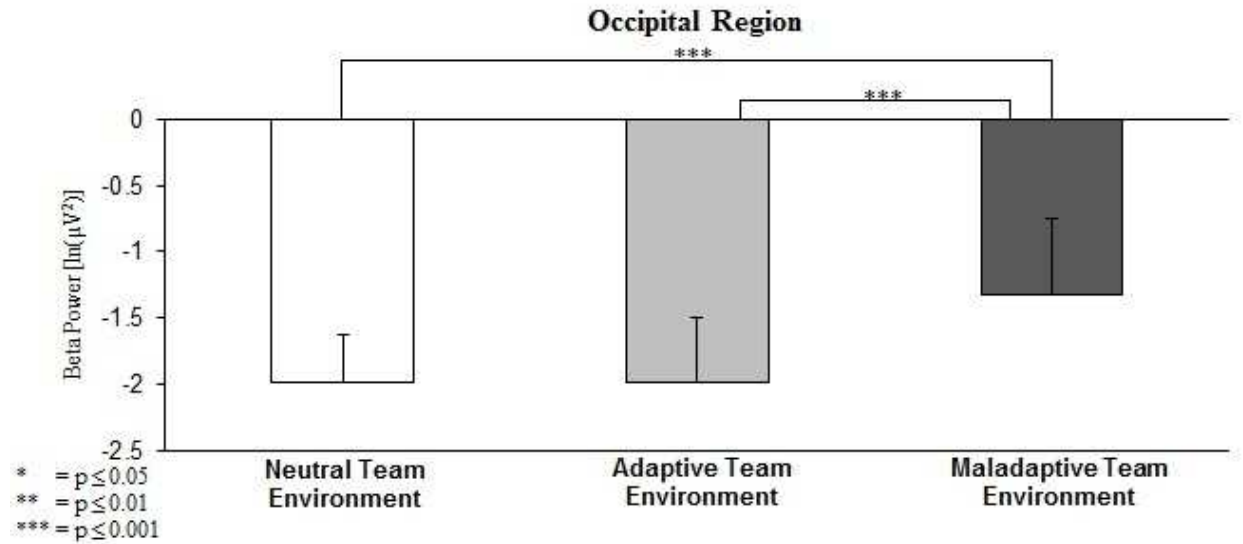


Fig. 4E. Beta power at the occipital region.

Gamma. Statistical analyses revealed no significant results for the gamma bandwidth.

Cerebral cortical networking (EEG coherence). Statistical analyses revealed no significant results for any of the bandwidths.

Attentional reserve (ERPs). Figure 5 illustrates the grand average ERPs recorded from the midline electrodes of interest (Fz, Cz, and Pz) for each experimental condition. The N1, P2, novelty-P3, and LPP components are denoted at the electrode at which each respective component is maximal in amplitude when averaged across experimental condition.

N1. Statistical analyses revealed no significant results for the N1 component.

P2. Statistical analyses revealed no significant results for the P2 component.

Novelty-P3. Statistical analyses revealed a significant main effect of Condition for the novelty-P3 component ($F(2, 22) = 9.35$; $p = 0.001$). Post-hoc analyses revealed that participants exhibited attenuated novelty-P3 amplitudes during the Maladaptive Team

Environment condition relative to the Neutral Team Environment ($p < 0.001$, $d = 1.03$) and Adaptive Team Environment ($p = 0.002$, $d = 0.81$) conditions (see Figure 6).

LPP. Statistical analyses revealed a significant Condition x Electrode interaction for the LPP component ($F(2, 22) = 3.53$; $p = 0.014$). However, one-way ANOVAs at each of the midline electrodes of interest failed to yield significant results.

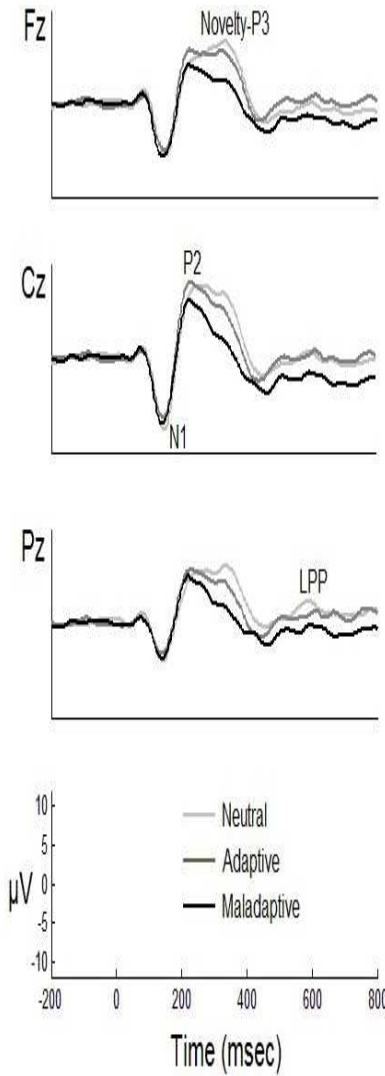


Fig. 5. Grand-average ERPs time-locked to task-irrelevant, novel auditory stimuli and recorded from the midline electrodes of interest.

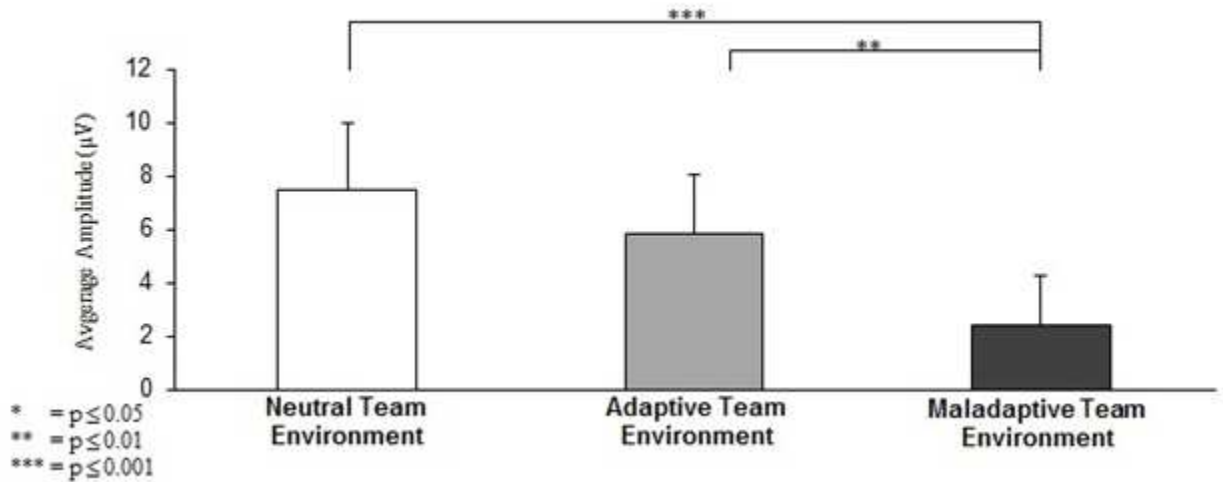


Fig. 6. Mean amplitudes of the novelty-P3 averaged across the midline electrodes of interest.

Discussion

As predicted, participants performing in the Adaptive Team Environment condition exhibited superior performance on the cognitive-motor task relative to when these same participants engaged in the Neutral and Maladaptive Team Environment conditions, which were undifferentiated. This outcome replicates that observed by Miller et al. (under review).

As expected, participants performing in the Maladaptive Team Environment condition exhibited less efficient cerebral cortical activation than while engaging in the Neutral and Adaptive Team Environment conditions, which were undifferentiated. Specifically, participants performing in the Maladaptive Team Environment condition demonstrated an elevation in beta frequency bandwidth power, which is indicative of increased task-related cerebral cortical activation, across the scalp topography concomitant with equal task performance in comparison to the Neutral Team Environment condition (Ray & Cole, 1985). Similarly, participants engaging in the

Maladaptive Team Environment condition exhibited an elevation in beta power across the scalp topography concomitant with poorer task performance relative to the Adaptive Team Environment condition. No significant differences in the theta, high-alpha, or gamma bandwidths, all of which are also indicative of task-related cortical activation, were observed between the team environment conditions.

Cerebral cortical activation represented by elevated theta and gamma power is associated increased task-related sensory encoding and processing, respectively, and cortical activation indicated by reduced high-alpha power is linked with decreased task-related cortical idling (Onton, Delorme, Makeig, 2005; Pfurtscheller & Lopes da Silva, 1999; Raghavachari et al., 2001; von Stein & Sarnthein, 2000). Conversely, cerebral cortical activation indicated by elevated beta power is associated with increased task-related high-order cognitive processing (Miller, 2007). As significant changes in cerebral cortical activation between team environments were indicated exclusively by beta power, it follows that cortical activation changed as a function of the high-order cognitive processing demanded in each team environment. Specifically, in the Maladaptive Team Environment condition participants' cerebral cortices were inefficiently activated due to excessive high-order cognitive processing relative to the Neutral and Adaptive Team Environment conditions.

The exclusive results for the beta frequency bandwidth are reasonable given that high-order cognitive processing likely increased in the Maladaptive Team Environment condition relative to the Neutral and Adaptive Team Environment conditions. Specifically, while performing in the Maladaptive Team Environment, participants likely engaged in rumination trying to reconcile the poor advice being given by the bad

teammates with the participants' notions on how to perform the task. Conversely, it is not surprising that significant results were not observed for the theta and gamma bandwidths given that the sensory encoding and processing demands imposed by the task (the rate at which participants were asked to manage Tetris® game pieces) were held constant throughout the experiment (participants engaged at the same task difficulty level in each team environment condition). Similarly, the lack of significant results for the high-alpha bandwidth is reasonable considering that task demands throughout the experiment were so great that little, if any, cortical idling could occur in any of the team environments (i.e., there was a floor effect for high-alpha power).

An unexpected but intriguing spectral power result was the observation that low-alpha power was significantly reduced in the Adaptive Team Environment condition in comparison to the Neutral and Maladaptive Team Environment conditions. Reductions in low-alpha power are indicative of increases in general arousal (Pfurtscheller & Lopes da Silva, 1999). Thus, participants exhibited significantly greater arousal during the Adaptive Team Environment condition relative to the Neutral and Maladaptive Team Environment conditions. This outcome could have occurred because participants' may have believed that their best opportunity to win the monetary award was while performing with the advice of the good teammate in the Adaptive Team Environment, thus increasing their arousal during this environment. As increased arousal is sometimes associated with enhanced task performance (Yerkes & Dodson, 1908), and participants demonstrated superior cognitive-motor task performance in the Adaptive Team Environment, it is possible that participants' increased states of arousal may have facilitated their performances.

Contrary to expectations, no differences in the efficiency of cerebral cortical networking (EEG coherence) with the premotor region were observed between team environment conditions. This outcome indicates that the magnitude of cerebral cortical communication with the premotor region was similar in each team environment (Nunez & Srinivasan, 2005). However, it is possible that the quality of the information communicated to the premotor region differed among the team environments. Specifically, it is plausible that the quality of the information communicated to the premotor region was better in the Adaptive Team Environment condition, wherein participants were processing information from a good teammate and exhibiting superior task performances.

In sum with regard to cognitive-motor task performance and cerebral cortical dynamics, participants exhibited superior task performances in the Adaptive Team Environment condition, possibly facilitated by more optimal states of arousal, relative to the Neutral and Maladaptive Team Environment conditions. Participants demonstrated inefficient cortical dynamics in the Maladaptive Team Environment condition in comparison to the Neutral and Adaptive Team Environment conditions. Specifically, in the Maladaptive Team Environment, participants demonstrated excessive cortical activation across the scalp topography due to disproportionate high-order cognitive processing demands. Thus, relative to the Neutral Team Environment, the maintenance of performance in the Maladaptive Team Environment came at a neural metabolic cost, while the enhanced performance in the Adaptive Team Environment came without an additional neural cost.

As expected, the decrease in the efficiency of cerebral cortical dynamics while performing in the Maladaptive Team Environment condition was accompanied by a consumption of attentional resources (reduction in attentional reserve), as indexed by ERPs to task-irrelevant, novel auditory stimuli, during this team environment condition relative to the Neutral and Adaptive Team Environment conditions. Specifically, the amplitude of the novelty-P3 ERP component was significantly attenuated during the Maladaptive Team Environment in comparison to the Neutral and Adaptive Team Environments. Conversely, the N1, P2, and LPP components did not significantly differ between the team environments. This result is not surprising given that the novelty-P3 has been observed to be exceptionally effective at indexing attentional reserve (Miller et al., 2011; Rietschel, *dissertation*; Ullsperger et al., 2001).

The observation that attentional reserve is diminished in the Maladaptive Team Environment relative to the Neutral and Adaptive Team Environments is in accord with Miller et al. (under review)'s results. Miller et al. observed that the efficiency of attentional resource allocation, which is positively related to attentional reserve (Wickens et al., 1983), was reduced in a maladaptive team environment relative to neutral and adaptive team environments. Miller et al. also observed that cognitive workload, which is inversely related to attentional reserve (Wickens et al.), was increased in a maladaptive team environment in comparison to neutral and adaptive team environments.

To summarize, participants exhibited decreased efficiency of cerebral cortical dynamics during the Maladaptive Team Environment condition relative to the Neutral and Adaptive Team Environment conditions. These inefficient cortical dynamics during the Maladaptive Team Environment were accompanied by reductions in attentional

reserve in comparison to the Neutral and Adaptive Team Environments. Participants exhibited superior cognitive-motor task performance, possibly facilitated by more optimal states of arousal, in the Adaptive Team Environment relative to the Neutral and Maladaptive Team Environments. Thus, the results suggest that, relative to neutral team environments, maintaining performance in maladaptive team environments comes at the expense of neural and attentional resources, while adaptive team environments enhance performance without an additional cost to neural and attentional resources.

Cerebral cortical dynamics and attentional reserve have been observed to have strong impacts on the performances of individuals challenged with tasks in non-team environments (Beilock et al., 2002; Deeny et al., 2003; Haufler et al., 2000; Smith & Chamberlin, 1992; Strayer et al., 2003). However, individuals frequently perform in team environments of variable quality. Yet, the impact of team environments on cerebral cortical dynamics and attentional reserve has not been investigated. The present study addressed this shortcoming in the literature and revealed that a maladaptive team environment negatively impacted cerebral cortical dynamics and attentional reserve relative to neutral and adaptive team environments. Additionally, an adaptive team environment was associated with superior task performance, possibly due to the optimization of state of arousal, in comparison to neutral and maladaptive team environments. These results are in accord with Miller et al. (under review)'s observations that neurocognitive processes, as measured by secondary task performance and a questionnaire, are less efficient in a maladaptive team environment while performance is superior in an adaptive team environment. The present study provides neurobiological evidence to support Miller et al.'s conclusion that maladaptive team environments cause

neurocognitive inefficiency and provides insight into the neurophysiological processes underlying the changes in neurocognitive functioning as well as task performance observed by Miller et al. Like Miller et al.'s observations, the present results are particularly informative in that they shed light upon neurocognitive mechanisms underlying the frequently reported positive correlation between group cohesion and task performance (for a review of this relationship, see Carron et al., 2002). Despite the robustness of the cohesion-performance relationship, the neurocognitive mechanisms mediating it are not well-understood (see Cox, 2011). Taken together, the results of Miller et al. and the present study suggest that cerebral cortical dynamics and attentional resources mediate the cohesion-performance relationship. To directly address this possibility, future research could involve conducting a mediation analysis (Barron & Kenny, 1986) of a larger data set collected from a paradigm similar to Miller et al.'s and the present study's.

As with Miller et al. (under review)'s results, the present study revealed that high levels of perceived competence of and trust in one's teammates, as well as task cohesiveness with one's teammates, constituted an adaptive team environment. Thus, the reasons these factors are adaptive are worthy of discussion. Miller et al. suggested that one reason perceived competence and trust are beneficial to team environment may be that they encourage a form of "cognitive outsourcing." Specifically, Miller et al. suggested that

...a team member is likely to outsource certain aspects of a task to his/her teammates if s/he perceives his/her teammates as being competent and trusts his/her teammates to perform well in these areas. Such outsourcing enables a team member to

reallocate his/her attention to other elements of the task, consequently improving his/her performance. (p. 19)

The present results provide insight as to which aspects of a task are outsourced and to which aspects of a task a team member is able to reallocate his/her neural resources. Specifically, as the present study observed that high-order cognitive processing demands were lessened in an adaptive team environment, it is likely that aspects of a task requiring high-order cognitive processing are outsourced in such an environment. Using Tetris®, the cognitive-motor task employed by both Miller et al. and the present study, as an example task, in an adaptive team environment a team member probably outsources the high-order cognitive processes of mentally rotating game pieces and deciding where to place game pieces to his/her teammate.

As the present study observed no changes associated with the magnitude of sensory and motor processes between team environments, it is likely that a team member is able to devote more neural resources to the quality of these processes during an adaptive team environment relative to a maladaptive team environment. Continuing with Tetris® as an example task, while performing in an adaptive team environment, a team member is probably able to devote more neural resources to the early sensory processing of game pieces as well as the motor execution necessary to optimize the placement of the game pieces in comparison to a maladaptive team environment.

In a team environment in which team members perceive one another as being competent and trustworthy, team members are likely to experience increased task cohesion (Marcos et al., 2010). Miller et al. noted that increases in task cohesion are associated with increases in motivation, which can enhance performance (Bray &

Whaley, 2001). The present study observed that individuals performing in an adaptive team environment, wherein greater levels of task-cohesion were reported, exhibited higher levels of arousal, which also can enhance performance (Yerkes & Dodson, 1908). Correspondingly, prior work has reported that increased arousal due to task cohesion enhances performance (Greene, 1989).

Like Miller et al. (under review), the present study illustrates the importance of generating adaptive team environments wherein team members perceive one another as being competent and trustworthy and work cohesively. Fortunately, a large number of studies have examined methods by which to generate adaptive team environments (see Gorman, Cooke, & Amazeen, 2010; Salas, Cooke, & Rosen, 2008; Wheelan, 2009). Miller et al.'s and the present study's results underscore the importance of this research and indicate that means to augment perceived competence, trust, and task cohesiveness should receive special consideration. If future research continues to provide insight into neurocognitive processes influenced by team environment, human performance in a number of settings may be improved and costly performance failures averted.

Appendices

Appendix A. Teammate Questionnaire

How good did you think your teammate was at Tetris®?

1 = extremely poor

2 = below average

3 = average

4 = above average

5 = excellent

How much trust did you put in your teammate's ability to help you successfully play Tetris® (i.e., how much were you able to rely on your teammate)?

1 = none

2 = very little

3 = a moderate amount

4 = a good amount

5 = a great amount

Please rate how much you agree with the following statement: "In regards to playing Tetris®, my teammate and I had good cohesion (i.e., we had good chemistry)"

1 = Strongly Disagree

2 = Disagree

3 = Undecided

4 = Agree

5 = Strongly Agree

References

- Allison, B. Z., & Polich, J. (2008). Workload assessment of computer gaming using a single-stimulus event-related potential paradigm. *Biological Psychology*, 77, 277 – 283.
- Baron, R. M., & Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: conceptual, strategic and statistical considerations. *Journal of Personality and Social Psychology*, 51, 1173 – 1182.
- Başar-Eroglu, C., Strüber, D., Schiirmann, M., & Stadler, M., & Başar, E. (1996). Gamma-band responses in the brain: a short review of psychophysiological correlates and functional significance. *International Journal of Psychophysiology*, 24, 101 - 112.
- Bauer, L., Goldstein, R., & Stern, J. (1987). Effects of information processing demands on physiological response patterns. *Human Factors*, 29, 213 - 234.
- Beilock, S. L., Wierenga, S. A., & Carr, T. H. (2002). Expertise, attention, and memory in sensorimotor skill execution: impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55, 1211 - 1240.
- Bell, M. A., & Fox, N. A. (1996). Crawling experience is related to changes in cortical organization during infancy: evidence from EEG coherence. *Developmental Psychobiology*, 29, 7, 551 - 561.
- Bray, C. D., & Whaley, D. E. (2001). Team cohesion, effort, and objective individual performance of high school basketball players. *The Sport Psychologist*, 15, 260 – 275.

- Brookings, J. B., Wilson, G. F., & Swain, C. R. (1996). Psychophysiological changes in workload during simulated air traffic control. *Biological Psychology*, 42, 361 – 377.
- Busk, J., & Galbraith, G.C. (1975). EEG correlates of visuo-motor practice in man. *Electroencephalography and Clinical Neurophysiology*, 38, 415 - 422.
- Carron, A. V., Colman, M. M., Wheeler, J. (2002). Cohesion and performance in sport: a meta-analysis. *Journal of Sport and Exercise Psychology*, 24, 168 – 188.
- Carron, A. V., Widmeyer, W. N., Brawley, L. R. (1985). The development of an instrument to assess cohesion in sports teams: The Group Environment Questionnaire. *Journal of Sport Psychology*, 7, 244 – 266.
- Chronbach, L. J. & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, 52, 281 – 302.
- Cox, R. H. (2011). *Sport Psychology*. New York, NY: McGraw-Hill.
- Davidson, R.J. (1984). Affect, cognition, and hemispheric specialization. In C. E. Izard, J. Kagain & R. Zajonc (Eds.). *Emotion, Cognition and Behavior*. New York: Cambridge University Press.
- Deeny, S. P., Haufler, A. J., Saffer, M., & Hatfield, B. D. (2009). Electroencephalographic coherence during visuomotor performance: a comparison of cortico-cortical communication in experts and novices. *Journal of Motor Behavior*, 41, 106 – 116.
- Deeny, S. P., Hillman, C. H., Janelle, C., & Hatfield, B. D. (2003). Cortico-cortical communication and superior performance in skilled marksmen: an EEG coherence analysis. *Journal of Sport and Exercise Psychology*, 25, 188 - 204.

- Del Percio, C., Babiloni, C., Marzano, N., Iacoboni, M., Infarinato, F., Vecchio, F., Eusebi, F. (2009). “Neural efficiency” of athletes’ brain for upright standing: a high resolution EEG study. *Brain Research Bulletin*, 79, 193 - 200.
- Del Percio, C., Rossini, P. M., Marzano, N., Iacoboni, M., Infarinato, F., Vecchio, ... Eusebi, F. (2008). Is there a “neural efficiency” in athletes? a high resolution EEG study. *NeuroImage*, 42, 1544 - 1553.
- Dirks, K. T. (1999). The effects of interpersonal trust on work group performance. *Journal of Applied Psychology*, 84, 445–455.
- Fabiani, M., Kazmerski, V. A., Cycowicz, Y. M., Friedman, D. (1996). Naming norms for brief environmental sounds: effects of age and dementia. *Psychophysiology*, 33, 462 – 475.
- Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47, 381 – 391.
- Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: an event-related brain potential (ERP) sign of the brain’s evaluation of novelty. *Neuroscience Biobehavioral Reviews*, 25, 355 – 373.
- Gevins, A. S. & Smith, M. E. (2008). EEG in Neuroergonomics. In Parasuraman, R. & M. Rizzo (Eds.) *Neuroergonomics: The Brain at Work*. New York, NY: Oxford University Press.
- 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, 374 – 385.

- Goodale, M. A. & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*, 15, 20 - 25.
- Gorman, J. C., Cooke, N. J., Amazeen, P. G. (2010). Training adaptive teams. *Human Factors*, 52, 295 – 307.
- Grabner, R. H., Fink, A., Stipacek, C., Neuper, C. & Neubauer, A. C. (2004). Intelligence and working memory systems: evidence of neural efficiency in alpha band ERD. *Cognitive Brain Research*, 20, 212 - 225.
- Greene, C. N. (1989). Cohesion and productivity in work. *Small Group Behavior*, 20, 70 – 86.
- Handy, T. C. (2005). *Event-related Potentials: A Methods Handbook*. Cambridge, MA: MIT Press.
- Hart, S. G. (2006). NASA-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, 904 – 908. Santa Monica, CA.
- Hart, S. G. & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.) *Human Mental Workload*. Amsterdam: North Holland Press.
- Hatfield, B. D. & Hillman, C. H. (2001). The psychophysiology of sport. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of research on sport psychology* (2nd ed., pp. 362 - 386). New York: John Wiley.
- Hatfield, B. D. & Kerick, S. E. (2007). The psychology of superior sport performance: A cognitive and affective neuroscience perspective. In G. Tenenbaum & R. C.

- Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed., pp.84 – 107). Hoboken, NJ: John Wiley & Sons, Inc.
- Hatfield, B. D., Landers, D. M., & Ray, W. J. (1984). Cognitive processes during self-paced motor performance: an electroencephalographic profile of skilled marksmen. *Journal of Sport Psychology*, 6, 42 - 59.
- 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 shooters. *Biological Psychology*, 53, 131 – 160.
- Hillman, C. H., Apparies, R. J., Janelle, C. M., & Hatfield, B. D. (2000). An electrocortical comparison of executed and rejected shots in skilled marksmen. *Biological Psychology*, 52, 71 – 83.
- Hillyard, S. A. & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Review of Psychology*, 34, 33 – 61.
- Hillyard, S. A., Hink, R. F., Schwent, V. L., Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, 182, 177 - 180.
- Isreal, J., Chesney, G., Wickens, C., & Donchin, E. (1980). P300 and tracking difficulty: evidence for multiple resources in dual-task performance. *Psychophysiology*, 17, 259 – 273.
- Isreal, J., Wickens, C., Chesney, G., & Donchin, E. (1980). The event-related potential as an index of display monitoring workload. *Human Factors*, 22, 211 – 224.

- Jasper, H. H. (1958). The ten-twenty electrode system of the international system federation. *Electroencephalography and Clinical Neurophysiology*, 10, 371 – 375.
- Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs. New Jersey: Prentice-Hall.
- Karatekin, C., Couperus, J. W., & Marcus, D. J. (2004). Attention allocation in the dual-task paradigm as measured through behavioral and psychophysiological responses. *Psychophysiology*, 41, 175 – 185.
- Kane, M. J., Conway, A. R. A., Miura, T. K., & Colflesh, G. J. H. (2007). Working memory, attention control, and the N-back task: a cautionary tale of construct validity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33, 615 - 622.
- Kerick, S. E., Hatfield, B. D., & Allender, L. E. (2007). Event-related cortical dynamics of soldiers during shooting as a function of varied task demand. *Aviation, Space, and Environmental Medicine*, 78, B153 - B164.
- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research*, 29, 169 - 195.
- Kramer, A. F., Wickens, C. D., Donchin, E. (1985). Processing of stimulus properties: evidence for dual task integrality. *Journal of Experimental Psychology: Human Perception and Performance*, 11, 393 - 408.
- Kramer, A. F., Sirevaag, E., & Braune, R. (1987). A psychophysiological assessment of operator workload during simulated flight missions. *Human Factors*, 29, 145 - 160.
- Kramer, A. F., Trejo, L. J., & Humphrey, D. (1995). Assessment of mental workload with task-irrelevant auditory probes. *Biological Psychology*, 40, 83 - 100.

- Laughlin, S. B. & Sejnowski, T. J. (2003). Communication in neuronal networks. *Science*, 301, 1879 - 1874.
- Maclin, E. L., Mathewson, K. E., Low, K. A., Boot, W. R., Kramer, A. F., Fabiani, M., & Gratton, G. (2011). Learning to multitask: effects of video game practice on electrophysiological indices of attention and resource allocation. *Psychophysiology*, 48, 1173 – 1183.
- Makeig, S., Delorme, A., Westerfield, M., Jung, T. P., Townsend, J., Courchesne, E., & Sejnowski, T. J. (2004). Electroencephalographic brain dynamics following manually responded visual targets. *PLOS Biology*, 2, 747 – 762.
- Marcos, F. M. L., Miguel, P. A. S., Oliva, D. S., & Calvo, T. G. (2010). Interactive effects of team cohesion on perceived efficacy in semi-professional sport. *Journal of Sports Science and Medicine*, 9, 320 – 325.
- Miller, R. (2007). Theory of the normal waking EEG: from single neurones to waveforms in the alpha, beta, and gamma frequency ranges. *International Journal of Psychophysiology*, 64, 18 – 23.
- Miller, M. W., Groman, L. J., Rietschel, J. C., McDonald, C. G., Iso-Ahola, S. E., & Hatfield, B. D. (under review). The effects of team environment on attentional resource allocation and cognitive workload. *Sport, Exercise, and Performance Psychology*.
- 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, 75 – 78.

- Mizuki, Y., Takii, O., Tanaka, T., Tanaka, M., Inanaga, K. (1982). Periodic appearance of frontal midline theta activity during performance of a sensory-motor task. *Psychiatry and Clinical Neurosciences*, 36, 375 - 384.
- Navon, D. & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review*, 86, 214 – 253.
- Nunez, P. L. & Srinivasan, N. (2005). *Electric Fields of the Brain*. New York: Oxford University Press.
- Onton, J., Delorme, A., Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage* 27, 341 - 356.
- Papanicolaou, A. & Johnstone, J. (1984). Probe evoked potentials: theory, method and applications. *International Journal of Neuroscience*, 24, 107 - 131.
- Parasuraman, R. & Beatty, J. (1980). Brain events underlying detection of weak sensory signals. *Science*, 210, 80 - 83.
- Peters, J., Suchan, B., Zhang, Y., & Daum, I. (2005). Visuo-verbal interactions in working memory: evidence from event-related potentials. *Cognitive Brain Research*, 25, 406 - 415.
- Pfurtscheller, G. & Lopes da Silva, F. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical Neurophysiology*, 110, 1842 – 1857.
- Pfurtscheller, G., Stancak, A., Neuper, C. (1996). Event-related synchronization (ERS) in the alpha band— an electrophysiological correlate of cortical idling: a review. *International Journal of Psychophysiology*, 31, 77 – 87.

- Piantoni, G., Kline, K. A., Eagleman, D. M. (2010). Beta oscillations correlate with the probability of perceiving rivalrous visual stimuli. *Journal of Vision*, 10, 13, 18, 1 - 11.
- Picton, T. W. & Hillyard, S. A. (1974). Human auditory evoked potentials II: effects of attention. *Electroencephalography and Clinical Neurophysiology*, 36, 191 - 199.
- Raghavachari, S., Kahana, M. J., Rizzuto, D. S., Caplan, J. B., Kirschen, M. P., Bourgeois, B., Madsen, J. R., & Lisman, J. E. (2001). Gating of human theta oscillations by a working memory task. *Journal of Neuroscience*, 21, 3175 – 3183.
- Ray, W. J. & Cole, H. W. (1985). EEG alpha reflects attentional demands, and beta reflects emotional and cognitive processes. *Science*, 228, 750 – 752.
- Rebert, C. S., Low, D. W., & Larsen, F. (1984). Differential hemispheric activation during complex visuomotor performance: alpha trends and theta. *Biological Psychology*, 19, 159 – 168.
- Rekers, Y., Haun, D. B. M., & Tomasello, M. (2011). Children, but not chimpanzees, prefer to collaborate. *Current Biology*, 21, 1756 – 1758.
- Rietschel, J. C. (2011). Psychophysiological investigation of attentional processes during motor learning. (*Doctoral Dissertation*). Retrieved from the Digital Repository at the University of Maryland.
- 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, 127 – 133.

- Rubio, S., Diaz, E., Martin, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: a comparison of SWAT, NASA-TLX, and workload profile methods. *Applied Psychology*, 53, 61 – 86.
- Ruchkin, D. S., Johnson, Jr., R., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology*, 25, 339 - 353.
- Salas, E., Cooke, N. J., & Rosen, M. A. (2008). On teams, teamwork, and team performance: discoveries and developments. *Human Factors*, 50, 540 – 547.
- 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. *European Journal of Neuroscience*, 25, 587 - 593.
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to P300 ERP. *Psychophysiology*, 23, 695 – 703.
- Shanker, T., & Richtel, M. (2011, January 16). In new military, data overload can be deadly. *The New York Times*.
- Singer, W. (1993). Synchronization of cortical activity and its putative role in information processing. *Annual Review of Physiology*, 55, 349 - 374.
- Sirevaag, E. J., Kramer, A. F., Coles, M. G. H., & Donchin, E. (1989). Resource reciprocity: an event-related brain potential analysis. *Acta Psychologica*, 70, 77 – 97.

Sirevaag, E., Kramer, A., Wickens, C., Reisweber, M., Strayer, D., & Grenell, J. (1993).

Assessment of pilot performance and workload in rotary wing helicopters.

Ergonomics, 9, 1121 - 1140.

Smith, M. D., & Chamberlin, C. J. (1992). Effect of adding cognitively

demanding tasks on soccer skill performance. *Perceptual and Motor*

Skills, 75, 955 - 961.

Sporns, O., Tononi, G., & Kötter, R. (2005). The human connectome: a structural

description of the human brain. *PLoS Computational Biology*, 1, 245 – 251.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency

positive waves evoked by unpredictable auditory stimuli. *Electroencephalography*

and Clinical Neurophysiology, 38, 387 – 401.

Sterman, M. B., & Mann, C. A. (1995). Concepts and applications of EEG analysis in

aviation performance evaluation. *Biological Psychology*, 40, 115 - 130.

Stevens, R. H., Galloway, T., Berka, C., & Sprang, M. (2009). Neurophysiologic

collaboration patterns during team problem solving. *Proceedings of the Human*

Factors and Ergonomics Society's 53rd Annual Meeting, San Antonio, TX.

Strayer, D. L., Drews, F. A., Johnston, W. A. (2003). Cell phone-induced failures

of visual attention during simulated driving. *Journal Experimental*

Psychology: Applied, 9, 23 - 32.

Strayer, D. L., Watson, J. M., & Drews, F. A. (2011). Cognitive distraction while

multitasking in the automobile. In B. Ross (Ed.). *The Psychology of Learning and*

Motivation. Burlington, VT: Academic Press.

- Troche, S. J., Houlihan, M. E., Stelmack, R. M., & Rammsayer, T. H. (2009). Mental ability, P300, and mismatch negativity: analysis of frequency and duration discrimination. *Intelligence*, 37, 365 – 373.
- Ullsperger, P., Freude, G., Erdmann, U. (2001). Auditory probe sensitivity to mental workload changes—an event-related potential study. *International Journal of Psychophysiology* 40, 201 - 209.
- von Stein, A., & Sarnthein, J. (2000). Different frequencies for different scales of cortical integration: from local gamma to long range alpha:theta synchronization. *International Journal of Psychophysiology*, 38, 301 - 313.
- Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In: R. Parasuraman and M. Mouloua. (Eds). *Automation and human performance: Theory and applications*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Wheelan, S. A. (2009). *Creating Effective Teams: A Guide for Members and Leaders*. Thousand Oaks, CA: Sage.
- Wickens, C. D., Isreal, J. B., & Donchin, E. (1977). The event-related cortical potential as an index of task workload. *Proceedings of the Human Factors Society*. Santa Monica, CA: Human Factors Society.
- Wickens, C. D., Kramer, A., Vanasse, L., & Donchin, E. (1983). Performance of concurrent tasks: a psychophysiological analysis of the reciprocity of information-processing resources. *Science*, 221, 1080 - 1082.

Wilson, G. & McCloskey, K. (1988). Using probe evoked potentials to determine information processing demands. *Proceedings of the Human Factors Society*. Santa Monica, CA: Human Factors Society.

Yerkes, R. M. & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, 18, 459 – 482.