

ABSTRACT

Title of Dissertation: UNDERSTANDING PSYCHOLOGICAL
INFLUENCE ON HUMAN PERFORMANCE:
THE ROLE OF CEREBRAL CORTICAL AND
NEUROMUSCULAR ACTIVATION DURING
MAXIMAL EXERTION KNEE EXTENSIONS

Andrew Anderson Ginsberg, Doctor of
Philosophy), 2023

Dissertation directed by: Professor Bradley D. Hatfield, Ph.D.,
Department of Kinesiology

The dissertation describes a programmatic research effort involving a series of studies (study one, two, three) to address the phenomenon of cognitive strategies facilitating and contributing to enhanced motor performance. Cognitive strategies consist of various mental approaches used before or during the execution of a motor task to improve performance. Psyching, one of the common strategies, typically involves a combination of elements intended to modify arousal and attentional focus to enhance performance. Prior findings within the sport psychology literature have revealed positive effects of psyching on performance, however, the underlying mechanisms of effect are not well understood. To further understand changes in musculoskeletal performance as a result of psyching, the present research used a multidimensional approach (psychological + psychophysiological + kinetic) by employing the measures of electroencephalography (EEG) - cortical activity, electromyography (EMG) -

muscle activity, and isokinetic dynamometry - peak torque during maximal exertion to achieve peak torque of a dynamic knee-extension skeletal muscle action.

In each of the three studies, participants performed the psychomotor task under three different preparatory strategies, a task-related attentional focus strategy identified as psyching (PSY) and for comparative purposes mental arithmetic (MA) and reading comprehension (RC) strategies serving as attentional distractions. For studies one and two, participants were characterized as recreationally trained or untrained. The results of study one provide evidence that task-related attentional focus, compared to distracting attentional strategies, is associated with increased force production. The EEG results of study two provide further evidence suggesting that during preparation for movement, the task-related attentional focus strategy distributed neural resources toward task-related (motor) regions and away from task-unrelated (non-motor) regions. Such a phenomena is consistent with the notion of the alpha (i.e., inhibitory) gating as described by Jensen and Mazaheri (2010). A novel contribution of study one was the experimental manipulation of cognitive strategies (RC, MA, PSY) in order to isolate on the element of task-related attentional focus.

The primary focus of the program of research was study three. Participants were characterized as expert (highly strength-trained athletes) with a training status identified as advanced. An additional comparative “resting” condition was implemented to engage the degree of cortical arousal during the three kicking conditions. Individualized alpha power (IAF) as an index as inhibition was subjected to a 4 Strategy (EO, MA, RC, PSY) x 6 ROI (central, frontal, left temporal, right temporal, parietal, occipital) x 4 Time (-20 to -15 s, -15 to -10 s, -10 to -5 s, and -5 to 0 s relative to knee extension initiation) repeated-measures ANOVA. Integrated EMG (iEMG) was subjected to a 3 Strategy (MA, RC, PSY) x 3 Muscle (rectus femoris (RF), vastus

medialis (VM) and vastus lateralis (VL)) x 2 Time (-1 to 0 s, 0 to +1 s, respectively corresponding to “pre” and “post” initiation of the knee extension) repeated-measures ANOVA. Peak Torque was subjected to a 4 Strategy (BL, MA, RC, PSY) one-way repeated-measure ANOVA. The BL strategy consisted of maximal exertion during an orientation session in the absence of attentional manipulation.

Study three replicated and extended the results of study one and study two suggesting that the use of task-related attentional focus leads to better performance, via the influence of brain and muscle activity. More specifically, enhanced motor performance was achieved via the task-related attentional focus cognitive strategy through heightened localized brain activity. In the evaluation of elite athletes, it appears that motor cortex activation is robustly elevated compared to rest across all three strategies in the motor region. This activation is accompanied by heightened inhibition in non-motor regions as a result of the task-related attentional focus. EMG revealed that the task-related attentional focus strategy was associated with an increase of neuromuscular activation of the quadriceps muscles.

Although beyond the scope of this research, a cascade of events provides a model for explaining the influence of cognitive strategies on maximal skeletal muscle performance. Namely, the focused brain dynamics associated with the task-related attentional focus leads to elevated motor unit recruitment which translates to heightened musculoskeletal performance (peak torque).

The findings of this research program extend the neural efficiency model of human performance and support the gating-by-inhibition phenomenon as a central factor. That is the attentional focus translated to heightened localization of motor activity in the brain resulting in elevated performance.

UNDERSTANDING PSYCHOLOGICAL INFLUENCE ON HUMAN
PERFORMANCE: THE ROLE OF CEREBRAL CORTICAL AND
NEUROMUSCULAR ACTIVATION DURING MAXIMAL EXERTION KNEE
EXTENSION

by

Andrew Anderson Ginsberg

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
2023

Advisory Committee:

Professor Bradley D. Hatfield, Ph.D., Chair

Rodolphe J. Gentili, Ph.D.

Hyuk Oh, Ph.D.

Germano Gallicchio, Ph.D.

Dushanka V. Kleinman, D.D.S, M.Sc.D.

© Copyright by
Andrew Anderson Ginsberg
2023

Acknowledgements

My adviser, Dr. Bradley D. Hatfield, you have served the role of boss, mentor, colleague, and friend over the past decade. Thank you for allowing a graduate student with limited research experience to join your team. I am forever thankful for the many opportunities you have provided me. Dr. Rodolphe Gentili, I am thankful for your career advice and expertise on cerebral cortical dynamics. Dr. Hyuk Oh, thank you for your expert guidance regarding signal processing. Dr. Germano Gallicchio, I would like to express my deepest appreciation for all of your support and the many hours we spent communicating via WhatsApp. Your level of expertise is truly unmatched. Dr. Dushanka Kleinman, thank you for agreeing to serve on this committee, I would be remiss not mentioning that you were my first graduate school professor at UMD. The students, faculty and staff of the Department of Kinesiology I will cherish our friendships and many years working together. To members of the human performance biopsychology laboratory, thank you for being amazing teammates throughout the years, I have learned so much from you all. To the many interns, thank for your efforts with data collection during the three studies. To my parents, mom and dad, thank you for your support and for being role models. To my brother, Rob, thank you for supporting and motivating me. To my wife, Jenica, and children, Abigail and Cameron, thank you for your unwavering support and patience for me during this long journey. This endeavor would not have been possible without you allowing me the opportunity and time to fly back to the east coast to focus on and complete the degree. Without you all, none of this would have been possible.

Table of Contents

Acknowledgements.....	ii
Table of Contents.....	iii
List of Tables.....	iv
List of Figures.....	vi
Chapter 1: General Introduction.....	1
Document Organization.....	1
Introduction.....	2
Aims of Dissertation.....	5
List of Presentations.....	7
References.....	8
Chapter 2: Kinetics, perceived effort, and neurophysiological modulations due to cognitive strategies in a psychomotor task.....	14
Introduction.....	14
Study 1 Methods.....	18
Results.....	25
Discussion.....	28
Study Two Methods.....	29
Results.....	38
General Discussion.....	55
References.....	61
Chapter 3: A Psychophysiological Approach to Understanding Superior Performance in Maximal Muscular Effort.....	69
Introduction.....	69
Methods.....	75
Results.....	95
Discussion.....	117
Self-Report of Technique Used.....	125
References.....	128
Chapter 4: General Discussion.....	141
Overview.....	141
Aims of Dissertation.....	142
Summary of Findings.....	143
Practical Implications.....	147
Limitations and Future Directions.....	148
References.....	149
Appendices.....	153
Bibliography.....	166

List of Tables

Table 2.1. Demographic information of study one participants. Data are represented as mean \pm standard deviation unless otherwise indicated.

Table 2.2. Peak Torque (N*m) as a Function of Cognitive Strategy & Rate of Perceived Effort (PE) on the Knee Extension Task as a Function of Cognitive Strategy. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA). MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching = ^aSignificantly different from PSY. $p < .05$, $**p < .01$, $***p < .001$

Table 2.3. Demographic information of study two participants. Data are represented as mean \pm standard deviation unless otherwise indicated.

Table 2.4. Peak Torque (N*m) as a Function of Cognitive Strategy & Perceived Effort (PE) on the Knee Extension Task as a Function of Cognitive Strategy. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA). MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching ^aSignificantly different from PSY. $p < .05$, $**p < .01$, $***p < .001$

Table 2.5. EEG Lower alpha power (-2 IAF to IAF) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 2.6. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the lower alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 2.7. Upper alpha power (IAF to IAF+2) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy. Note. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 2.8. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the upper alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 3.1. Demographic information of study three participants. Data are represented as mean \pm standard deviation unless otherwise indicated

Table 3.2. Rating Motivation of each Measure as a Function of Attentional Strategy, Rating Attentional of each Measure as a Function of Attentional Strategy, Peak Torque (N*m) as a Function of Attentional Strategy, Rating of Perceived Effort (RPE) on the Physical Task as a Function of Attentional Strategy, Electromyography (iEMG) (0 to +1)s as a Function of Attentional Strategy. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA).

BL = Baseline, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching, MO = Motivation, AF = Attentional Focus, PE = Perceived Effort

^aSignificantly different from PSY. ^bSignificantly different from BL $p < .05$, ** $p < .01$, *** $p < .001$

Table 3.3. EEG Lower alpha power (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 3.4. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the lower alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 3.5. Upper alpha power (IAF to IAF +2) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Table 3.6. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the upper alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

List of Figures

Figure 2.1. The experimental set-up demonstrating a participant engaging in an experimental strategy while seated on the isokinetic dynamometer (Biodex® System 4 Pro).

Figure 2.2. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. *** $p < .001$

Figure 2.3. Perceived effort (PE) on the physical task for each experimental strategy. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. ** $p < .01$

Figure 2.4. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$

Figure 2.5. Perceived effort (PE) on the physical task for each experimental strategy. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. ** $p < .01$, *** $p < .001$

Figure 2.6. Panel A: Lower Alpha Frequency (IAF-2 to IAF) power ($10\log_{10}[V^2]$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T3, FC5, F7), right temporal (T4, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$ Panel B: EEG scalp maps of lower-alpha (IAF-2 to IAF) power ($10\log_{10}[V^2]$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Panel C: EEG scalp maps of statistical values (t scores) comparing lower-alpha (IAF-2 to IAF) power ($10\log_{10}[V^2]$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Figure 2.7. Panel A: Upper Alpha Frequency (IAF to IAF+2) power ($10\log_{10}[V^2]$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T3, FC5, F7), right temporal (T4, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of upper alpha (IAF to IAF+2) power ($10\log_{10}[V^2]$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Panel C: EEG scalp maps of statistical values (t scores) comparing upper-alpha (IAF to IAF+2) power ($10\log_{10}[V^2]$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Figure 3.1. A representation of the study design for the familiarization session (visit I) that is described within the procedures.

Figure 3.2 A representation of the study design for the experimental session (visit II) that is described within the procedures.

Figure 3.3. The experimental set-up demonstrating a participant engaging in an experimental strategy while seated on the isokinetic dynamometer (Biodex® System 4 Pro).

Figure 3.4. Representation of quadriceps rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) EMG activity during the 5 seconds pre movement and 1 second post movement.

Figure 3.5. Motivation to perform the (physical and attentional strategy) task for the different experimental strategies. Higher scores correspond to higher ratings of motivation. BL = Baseline MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.6. Report of level of attentional focus on the cognitive task and physical task (muscular task) for the different experimental strategies. Higher scores correspond to higher ratings of focus. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.7. Perceived effort (PE) on the physical task for each experimental strategy. BL = Baseline, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.8. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.9. Integrated electromyography (iEMG) from (0 to 1)s post knee extension for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.10. Integrated electromyography (iEMG) from (-1 to 0) s pre knee extension for the different experimental strategies. RF = rectus femoris, VM = vastus medialis and VL = vastus lateralis. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.11. Integrated electromyography (iEMG) from (0 to 1) s post knee extension for the different experimental strategies. RF = rectus femoris, VM = vastus medialis and VL = vastus lateralis. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.12. Panel A: Lower Alpha Frequency (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T3, FC5, F7), right temporal (T4, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$ Panel B: EEG scalp maps of lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Panel C: EEG scalp maps of statistical values (t scores) comparing lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Figure 3.13. Panel A: Upper Alpha Frequency (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal

(F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T3, FC5, F7), right temporal (T4, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of upper-alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Panel C: EEG scalp maps of statistical values (t scores) comparing upper-alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

Chapter 1: General Introduction

Document Organization

This document has been organized into Four Chapters. Chapter One introduces concepts and biopsychological measures related to human performance and describes the programmatic research effort involving a series of studies (study one, two, three) to address the phenomenon of cognitive strategies facilitating and contributing to enhanced motor performance. To further understand changes in musculoskeletal performance as a result of psyching, the present research used a multidimensional approach (psychological + psychophysiological + kinetic) by employing the measures of electroencephalography (EEG) - cortical activity, electromyography (EMG) - muscle activity, and isokinetic dynamometry - peak torque during maximal exertion to achieve peak torque of a dynamic knee-extension skeletal muscle action. Chapter Two encompasses study one and study two and expands our knowledge of if experimentally manipulating the preparatory cognitive strategy leads to a shift in the balance between task-related (motor-regions) and task-unrelated (non-motor regions) processes and an increase in performance during a maximal exertion knee extension. Further, whether the adoption task-related attentional focus strategy leads not only to changes in motor performance but also to a different pattern of EEG alpha gating. Chapter Three encompasses study three and expands our understanding of the mechanisms of effect of the task-related attentional focus strategies by examining cortical activity, muscle activity and motor performance during a maximal exertion knee extension. Further, expands our

knowledge of whether or not psychomotor efficiency and alpha gating can help to understand why and if psyching enhances performances of elite athletes. Chapter Four provides an overall summary of the findings from chapters two and three, highlights limitations of the described research and provides suggestions for future research.

Introduction

What does it take to reach an optimal state for skilled motor performance? Throughout the sport psychology literature, cognitive strategies are defined as self-directed mental approaches used before or during motor-skill execution to improve physical performance. These strategies employed by athletes to prepare for competition to reach optimal levels of superior performance Krane and Williams, (2006) include imagery, positive self-talk, preparatory arousal, and attentional focus Shelton and Mahoney, (1978). Further, psyching is described as an athlete-directed cognitive strategy implemented prior or during movement execution using a combination of cognitive strategies intended to modify arousal, attentional focus and confidence with the goal of enhancing psychomotor performance (Brody et al. 2000; Hardy et al. 1996; Perkins et al. 2001; Tod et al. 2003; Tod et al. 2015). Prior findings within the sport psychology literature have shown positive effects for the use of psyching on maximal muscular strength (for a review, see Tod et al. 2015). The impact of mental preparation on behavioral motor performance is well understood, however, the biopsychological literature is limited, and thus inconclusive as to why psyching improves performance.

The primary measures detailed within the dissertation are discussed below. Electroencephalography (EEG) is an approach to measure time-varying fluctuations of voltages using electrodes attached to the scalp and reveals postsynaptic potentials within the pyramidal neurons of the cerebral cortex (Nunez & Srinivasan, 2006). EEG provides excellent temporal resolution to gain insight into the electrical activity in the cerebral cortex. Alpha power is considered the dominant and strongest signal recorded by EEG in the cerebral cortex and can be divided into two components: lower-alpha (8-10 Hz) reflecting general arousal (Klimesch, 1996; Baumeister et al. 2007) and upper-alpha (10-12 Hz) indicative of task-specific attentional processes (Budzynski et al. 2009; Kerrick et al. 2004). Historically, EEG alpha power (8-12 Hz) reflects regional cortical idling Pfurtscheller, (1992) and more recently has been shown to indicate active cortical inhibition (Klimesch et al. 2007; Klimesch, 2012). Alpha power is inversely related to cortical activation, specifically, when there is an increase of alpha power in one region, there is a decrease in cortical activation (Klimesch et al. 2007).

Electromyography (EMG) measures the electrical potential difference of skeletal muscle activity between two electrodes (De Luca, 1997) and is an estimate of neural drive to the muscle (Babault et al. 2002). Surface EMG (sEMG) is a non-invasive approach and is the most common method to record muscle activity in sport studies (De Luca, 1997; Farina et al. 2010). To optimally produce muscle force, two neuromuscular mechanisms are needed, motor neuron recruitment and rate coding (Enoka & Duchateau, 2017). Prior studies have shown that the relationship between EMG and muscle force is proportional to one another (De Luca, 1997; Konrad, 2006).

Further, concentric contractions occur when the muscle is shortened with movement occurring against gravity and external force, whereas eccentric contractions lengthen the involved muscle fibers with gravity and lower the external load. An individual's strength is defined as the maximal force generated by a muscle when measured at a specific speed (Harman et al. 2008). An isokinetic muscular movement is a constant rate of shortening or lengthening of the muscle at a constant speed with force being applied (Pytel & Kamon, 1981). Further, the use of the isokinetic dynamometer has been shown to be the standard measure for muscular force Stark et al. (2011) and a reliable instrument to measure isokinetic force (Alvares et al. 2015). Lastly, several prior studies have indicated that to measure muscle strength during isokinetic movement, peak torque should be used (Simpson et al. 2019).

The psychomotor efficiency hypothesis was introduced by Hatfield and Hillman (2001) as a special case of general neural efficiency to describe the influence of task-related and task-unrelated activity of different biological systems involving neural effort, motor unit recruitment, and energy expenditure on superior motor performance. More specifically, it is suggested that neural activity during high levels of performance is described by a decrease in nonessential input to the essential motor preparatory processes, as displayed by an inhibition of task-unrelated processes across the cerebral cortex while a simultaneous heightening occurs in the cortical regions that are associated with task-related processes resulting in net efficiency (Hatfield et al. 2020).

Further, Jensen and Mazeheri's gating-by-inhibition (2010) model could be useful in describing Hatfield and Hillman's (2001) concept of general neural efficiency as balance between task-related and task-unrelated activity. This model contends that cortical alpha controls regional activity in the cerebral cortex by diverting activation away from regions displaying greater alpha power (increased inhibition) and moves activation towards regions showing lessened alpha power (decreased inhibition). Previous studies have provided evidence for the utility of alpha gating in explaining neural efficiency (Baumeister et al. 2007; Deeny et al. 2009; Del Percio et al. 2009; Hatfield, 2018; Haufler et al. 2000; Kerrick et al. 2004). However, there is no experimental evidence evaluating whether or not the adoption of a more or less efficient cognitive strategy leads not only to changes in motor performance but also to a different pattern of EEG alpha gating.

Aims of Dissertation

Chapter Two encompasses study one and study two of this overall research effort. The aim of study one (described in chapter 2) was to isolate the influence of task-related attentional focus and examine performance during a maximal exertion knee extensions. More specifically, to examine whether or not adopting a task-focused, compared to distracted cognitive strategies, in preparation for motor performance alters the kinetic output.

The aim of study two (described in chapter 2) was to examine the magnitude of cerebral cortical activation during the task-related attentional focus cognitive strategy compared to distraction strategies. Further, to examine if the cortical activation during task-related focus was associated with an elevation in performance

during a knee-extension task. Specifically, if experimentally manipulating the preparatory cognitive strategy leads to a shift in the balance between task-related (motor regions) and task-unrelated (non-motor regions) processes and an increase in performance during a maximal exertion knee extension. For study one and study two, participants were characterized as recreationally trained.

Chapter Three encompasses study three. The aim of study three (described in chapter 3) was to further our understanding of the mechanisms of effect of the task-related attentional focus strategies by examining cortical activity, muscle activity and motor performance during a maximal exertion knee extension. More specifically, what enables elite athletes to efficiently achieve superior motor performance. Further, in this experimental study, whether psychomotor efficiency and alpha-gating can help to understand why and if task-related attentional focus i.e., psyching enhances performances of elite athletes was explored. For study three (chapter three), participants were characterized as elite highly strength-trained athletes based on the requirements set by Swann et al. (2015) i.e., competing at the regional, university, semi-professional or higher level. In each of the three studies, participants performed the motor task under three different preparatory strategies, a task-related attentional focus strategy (PSY) and for comparative purposes mental arithmetic (MA) and reading comprehension (RC) strategies serving as attentional distractions.

Chapter Four provides an overall summary of the findings from chapters two and three, highlights limitations of the described research and provides suggestions for future research. It is the intent of this dissertation, to add to the scholarship on enhanced motor performance specifically through the use of cognitive strategies i.e.,

psyching. Further, the results will add to our understanding of the applicability of the psychomotor efficiency hypothesis Hatfield and Hillman, (2001) and gating-by-inhibition model Jensen & Mazaheri, (2010) in the field of human performance.

List of Presentations

This dissertation includes chapters that will be submitted as manuscripts to the journal of Medicine & Science in Sports & Exercise (MSSE):

Data from this dissertation were included in abstracts presented at the following conferences:

Ginsberg, A.A., Lu, C., Gallicchio, G., Elue, E., Teso, J., Bah, M., Hatfield, B.D. (2019). The effect of mental preparation on brain dynamics and muscular force during maximal voluntary movement. Poster presented at North American Society for the Psychology of Sport and Physical Activity (NASPSPA) Conference, Hyatt Regency Baltimore Inner Harbor, Baltimore MD.

Ginsberg, A.A., Lu, C., Gallicchio, G., Elue, E., Teso, J., Bah, M., Hatfield, B.D. (2019). The Effect of Cognitive Strategies on Brain Dynamics and Muscular Force during Maximal Voluntary Movement. Poster presented at Public Health Research @ Maryland Annual Conference, College Park, MD.

Ginsberg, A.A., Lu, C., Gallicchio, G., Elue, E., Teso, J., Bah, M., Hatfield, B.D. (2018). The Effect of Cognitive Strategies on Brain Dynamics and Muscular Force during Maximal Voluntary Movement. Poster presented at Mid-Atlantic Chapter of The American College of Sports Medicine (MARC ACSM) Annual Meeting, Harrisburg, PA.

Ginsberg, A.A., Lu, C., Elue, E., Bah, M., Hatfield, B.D. (2018). The Effect of Mental Preparation on Voluntary Torque Production and Cortico-Cortical Communication. Poster presented at Public Health Research @ Maryland Annual Conference, College Park, MD.

Ginsberg, A.A., Lu, C., Elue, E., Bah, M., Hatfield, B.D. (2017). The Effect of Mental Preparation on Voluntary Torque Production and Cortico-Cortical Communication. Poster presented at Mid-Atlantic Chapter of The American College of Sports Medicine (MARC ACSM) Annual Meeting, Harrisburg, PA.

Ginsberg, A.A. (2016). The Effect of Mental Preparation on Volitional Muscular Movements. Poster presented at Mid-Atlantic Chapter of The American

College of Sports Medicine (MARC ACSM) Annual Meeting, Harrisburg, PA.

References

- Alvares, J. B. d. A. R., Rodrigues, R., de Azevedo Franke, R., da Silva, B. G. C., Pinto, R. S., Vaz, M. A., & Baroni, B. M. (2015). Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Physical Therapy in Sport, 16*(1), 59-65. <https://doi.org/10.1016/j.ptsp.2014.04.004>
- Babault, N., Pousson, M., Michaut, A., Ballay, Y., & Hoecke, J. (2002). EMG activity and voluntary activation during knee-extensor concentric torque generation. *European Journal of Applied Physiology, 86*(6), 541-547. <https://doi.org/10.1007/s00421-002-0579-3>
- Baumeister, R. F., & Vohs, K. D. (2007). Self-Regulation, ego depletion, and motivation. *Social and Personality Psychology Compass, 1*(1), 115-128. <https://doi.org/10.1111/j.1751-9004.2007.00001.x>
- Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport, 71*(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>
- Budzynski, T. H., Budzynski, H. K., Evans, J. R., & Abarbanel, A. (Eds.). (2009). *Introduction to Quantitative EEG and neurofeedback: Advanced theory and applications*. San Diego, CA: Academic 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(2), 106-116. <https://doi.org/10.3200/JMBR.41.2.106-116>
- Del Percio, C., Babiloni, C., Bertollo, M., Marzano, N., Iacoboni, M., Infarinato, F., ... & Eusebi, F. (2009). Visuo-attentional and sensorimotor alpha rhythms are related to visuo-motor performance in athletes. *Human Brain Mapping*, 30(11), 3527-3540. <https://doi.org/10.1002/hbm.20776>
- De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>
- Enoka, R. M., & Duchateau, J. (2017). Rate coding and the control of muscle force. *Cold Spring Harbor Perspectives in Medicine*, 7(10), a029702. <https://doi.org/10.1101/cshperspect.a029702>
- Farina, D., Holobar, A., Merletti, R., & Enoka, R. M. (2010). Decoding the neural drive to muscles from the surface electromyogram. *Clinical Neurophysiology*, 121(10), 1616-1623. <https://doi.org/10.1016/j.clinph.2009.10.040>
- Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc
- Harman, E., Garhammer, J., & Pandorf, C. (2008). Administration, scoring, and interpretation of selected tests. In T.R. Baechle & R. E Earle (Eds.), *Essentials*

of Strength Training and Conditioning (2nd ed.) (pp. 287-317). Champaign, IL: Human Kinetics.

Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.

Hatfield, B. D. (2018). Brain dynamics and motor behavior: A case for efficiency and refinement for superior performance. *Kinesiology Review*, 7(1), 42-50.

<https://doi.org/10.1123/kr.2017-0056>

Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of Sport Psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>

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(2-3), 131-160. [https://doi.org/10.1016/S0301-0511\(00\)00047-8](https://doi.org/10.1016/S0301-0511(00)00047-8)

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.

<https://doi.org/10.3389/fnhum.2010.00186>

Konrad, P. (2006). The ABC of EMG: A practical introduction to kinesiological In Noraxon INC. USA. (Version 1., Issue March). Noraxon INC. USA.

<http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf>

- Kerick, S. E., Douglass, L. W., & Hatfield, B. D. (2004). Cerebral cortical adaptations associated with visuomotor practice. *Medicine & Science in Sports & Exercise*, 36(1), 118-129.
<http://dx.doi.org/10.1249/01.MSS.0000106176.31784.D4>
- Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology*, 24(1-2), 61-100.
[https://doi.org/10.1016/S0167-8760\(96\)00057-8](https://doi.org/10.1016/S0167-8760(96)00057-8)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88.
<https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.
<https://doi.org/10.1016/j.tics.2012.10.007>
- Krane, V., & Williams, J. M. (2006). Psychological characteristics of peak performance. In J. M. Williams (Ed.), *Applied sport psychology: Personal growth to peak performance* (pp. 207-227). Boston, MA: McGraw-Hill.
- Nunez, P. L., & Srinivasan, R. (2006). *Electric fields of the brain: the neurophysics of EEG* (2nd ed.). New York, NY: Oxford University Press.
- Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259. <https://doi.org/10.1080/104132001753144392>
- Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest.

Electroencephalography and Clinical Neurophysiology, 83(1), 62-69.

[https://doi.org/10.1016/0013-4694\(92\)90133-3](https://doi.org/10.1016/0013-4694(92)90133-3)

Pytel, J. L., & Kamon, E. (1981). Dynamic strength test as a predictor for maximal and acceptable lifting. *Ergonomics*, 24(9), 663-672.

<https://doi.org/10.1080/00140138108924889>

Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of “psyching-up” strategies in weight lifters. *Cognitive Therapy and Research*, 2(3), 275-284.

<https://doi.org/10.1007/BF01185789>

Simpson, D., Ehrensberger, M., Nulty, C., Regan, J., Broderick, P., Blake, C., & Monaghan, K. (2019). Peak torque, rate of torque development and average torque of isometric ankle and elbow contractions show excellent test–retest reliability. *Hong Kong Physiotherapy Journal*, 39(01), 67-76.

<https://doi.org/10.1142/S1013702519500069>

Stark, T., Walker, B., Phillips, J. K., Fejer, R., & Beck, R. (2011). Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: A systematic review: *American Academy of Physical Medicine and Rehabilitation*, 3(5), 472-479. <https://doi.org/10.1016/j.pmrj.2010.10.025>

Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>

Tod, D., Iredale, F., & Gill, N. (2003). ‘Psyching-up’ and muscular force production. *Sports Medicine*, 33(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

Chapter 2: Kinetics, perceived effort, and neurophysiological modulations due to cognitive strategies in a psychomotor task

Introduction

Cognitive strategies are mental approaches used before or during the execution of a motor task to improve performance. They are considered to be a powerful performance tool to enhance behavior to the highest-level during competition (Tod et al. 2003). Further, psyching is a specific cognitive strategy used before or during movement execution aimed to enhance physical performance (Brody et al. 2000; Hardy et al. 1996; Tod et al. 2003) through increased mental and physical activation (Shelton & Mahoney, 1978). According to Pineschi & Di Pietro (2013) the processes of psyching includes standing, initiating abdominal breathing, using self-talk, stimulating imagery, and physical movement. However, the viable use of psyching strategies remains unclear as the mechanisms of these strategies remain unclear (McGuigan et al. 2005; Tod et al. 2015).

Tod et al. (2005) tested the impact of psyching on force production while performing the bench press on a modified isokinetic dynamometer. The authors found that compared to distraction conditions (attention placebo control i.e., estimate of heart rate, distraction control i.e., mental arithmetic), peak force measured after psyching-up was significantly increased. Psychophysiology underpinnings of the phenomenon of psyching have been proposed to help explain the relationship between mental preparation and force production (for a review, see Tod et al. 2015), and it is understood that an unknown combination of factors account for performance (Tod et al. 2003). However, the psychophysiological activity underlying mental

preparation has yet to be determined through quantitative measurement (Tod et al. 2003; Tod & McGuigan, 2006), as most studies have used subject-determined psychological states and performance outcomes rather than examining the cause or process underlying the changes (Jones & Stuth, 1997). At the behavioral level, although the impact of mental preparation on motor performance is well understood, the biopsychological literature is limited, and it is not clear as to why psyching improves performance.

A putative mechanism accounting for the beneficial effect of psyching on motor performance is increased efficiency, defined as the individual's ability to complete a certain work through minimal resources. The psychomotor efficiency model was introduced by Hatfield and Hillman (2001) as a special case of general neural efficiency to describe the influence of task-related (motor) and task-unrelated (non-motor) biological activity on motor performance. Specifically, regarding the neurophysiological activity, the model suggests that a high level of performance is characterized by a decrease in nonessential input to the essential motor preparatory processes, as seen through the inhibition of task-unrelated processes across the cerebral cortex while a simultaneous heightening occurs in the cortical regions that are associated with task-related processes resulting in net efficiency (Hatfield et al. 2020). The net result is that enhanced motor performance is accompanied by a decrease in overall neural effort due to a reduction of task-unrelated activity (Hatfield & Hillman, 2001).

The concept of neural efficiency in motor tasks can be investigated through electroencephalography (EEG), a technique that allows one to examine patterns of

activation in the cerebral cortex (Hatfield et al. 2004; Hatfield & Kerrick, 2007).

Within EEG studies, most interest has been directed towards activity within the alpha frequency (8-12 Hz), initially purported to reflect cortical idling (Pfurtscheller, 1992) and more recently shown to indicate active cortical inhibition (Klimesch et al. 2007; Klimesch, 2012). Further, alpha activity can be divided into two components: lower alpha (8-10 Hz) reflecting general arousal (Klimesch, 1996; Baumeister et al. 2007) and upper alpha (10-12 Hz) indicative of task-specific attentional processes (Budzynski et al. 2009; Kerrick et al. 2004). As suggested by Gallicchio et al (2019), a model that seems particularly useful in describing Hatfield and Hillman's (2001) concept of general neural efficiency as balance between task-related and task-unrelated activity is Jensen and Mazaheri's gating-by-inhibition model (2010). This model contends that cortical alpha controls regional activity in the cerebral cortex by diverting activation away from regions displaying greater alpha power (increased inhibition) and moves activation towards regions showing lessened alpha power (decreased inhibition). While numerous studies have provided observational evidence for the utility of alpha gating in explaining neural efficiency (Baumeister et al. 2007; Deeny et al., 2009; Del Percio et al. 2009; Hatfield, 2018; Haufner et al. 2000; Janelle et al 2000; Kerrick et al. 2004), there is no experimental evidence evaluating whether or not the adoption of a more or less efficient cognitive strategy leads not only to changes in motor performance but also to a different pattern of EEG alpha gating.

To address this knowledge gap, in this experimental study, we manipulated the preparatory cognitive strategy as a means to shift the balance between task-related (motor) regions and task-unrelated (non-motor) regions during performance of a

psychomotor task i.e., maximal concentric isokinetic knee extensions. To do so, we evaluated changes in motor performance and EEG alpha as individuals performed a psychomotor task under three different preparatory strategies, a performance enhancement strategy i.e., psyching (PSY) and two distracting strategies i.e., mental arithmetic (MA) and reading comprehension (RC) and “rest” eyes open (EO) strategy for context. To date, the viable use of psyching strategies remains unclear as the mechanisms of these strategies remain unclear (McGuigan et al. 2005; Tod et al. 2015).

In line with previous studies (for review see Tod et al. 2015), we hypothesized that psyching (PSY) would be associated with improved maximal motor performance as indicated by greater peak torque output compared to distracting attentional strategies such as mental arithmetic and reading comprehension (MA, RC).

Based on the neural efficiency model, we also hypothesized that the adoption of different preparatory strategies would influence the balance between task-related (motor) and task-unrelated (non-motor) cerebral cortical activation observed through regional patterns of EEG alpha. Specifically, we expected that psyching would be associated with a more efficient cortical pattern with greater alpha power in task-unrelated (non-motor) regions and diminished alpha power in task-related (motor) regions compared to distracting conditions. These two hypotheses were evaluated in two experimental studies.

Study 1 Methods

Participants

Twenty-three healthy participants (11 males, 12 females), mean age 21.26 years ($SD = 1.45$, $range = 19 - 25$) were recruited from the student population of the University of Maryland, College Park. All participants reported at least one year of weight training experience ($average = 4.19$ years of training) and were right-handed (laterality quotient $>+40$ on the Edinburgh Handedness Inventory, Oldfield, 1971). Participants were characterized by a mean height of 168.31 cm ($SD = 16.01$, $range = 107.5 - 190.5$) and body weight 81.34 kg ($SD = 11.56$, $range = 62.1 - 109.4$). (see Table 2.1) Participants reported no history of psychiatric, psychological, or neurological disorders, cardiovascular, pulmonary or musculoskeletal conditions that would impact their ability to exercise, no use of illicit drugs, or feeling unable to comply with the study's protocol. All participants were informed that they may cease their participation at any point during the study and that they would be under no obligation to continue until the end. All participants provided their consent before participating in this experiment, which was approved by the university's Institutional Review Board (IRB) and Ethical Committee in accordance with the Helsinki Declaration before data collection was conducted.

Table 2.1.
Demographic Information of Participants

No. of Participants, N	23
Gender	
Male	11 (47%)
Female	12 (52%)
Age (years)	21.26 ± 1.45
Height (cm)	168.31 ± 16.01
Weight (kg)	81.34 ± 11.56
Strength Training (years)	4.19 ± 1.43

Note. Data are presented as mean ± standard deviation unless otherwise indicated.

Procedures

Knee Extension Task. The knee extension task consisted of extending the right leg by exerting a maximal isokinetic concentric contraction. To minimize muscular effort during the subsequent knee flexion phase, participants were instructed to passively allow their leg to return to the starting position (Marchant & Greig, 2017). Prior to each knee extension, participants completed a 20-second preparatory period during which they were instructed to keep their arms relaxed, hands in their lap, and to remain as motionless as possible and adopt one of three cognitive strategies, described below. To gain familiarity with the force-measuring apparatus, each participant was seated and secured in the chair of the dynamometer to prevent unwanted movements. (see Figure 2.1) Using the right leg, the axis of the dynamometer lever arm was measured and visually aligned at the lateral epicondyle of the knee. The length of the lever arm was adjusted for comfort. The range of movement was standardized to the participant's full range of movement and the experimenter calculated the range of motion for total flexion, total extension, the approximate 90-degree position and the total limb weight, as well as set the angular velocity to 60 degrees/second. Participants were instructed to keep their arms relaxed and hands in their lap during the trial. Following each knee extension, a 120-second

rest period was given during which participants provided their Perceived Effort (PE) using a categorical scale modified from Borg's (1978) perceived exertion scale. All instructions concerning the strategy and the task were given via a recorded auditory statement in order to ensure consistency and to reduce researcher bias. No visual or verbal feedback or encouragement was provided throughout the entirety of the experimental session.



Figure 2.1. The experimental set-up demonstrating a participant engaging in an experimental strategy while seated on the isokinetic dynamometer (Biodex® System 4 Pro).

Visit I (familiarization)

Qualifying participants' body weight (kg) and height (cm) were measured and participants were then familiarized with the apparatus, procedures, psychological scales used in the study and completed a light warm-up consisting of dynamic stretching led by the researchers. Participants completed three submaximal and six maximal effort trials of the knee extension task to gain familiarity with the operation of and the speed at which the isokinetic dynamometer would operate. Upon completion of the familiarization session (visit I), participants were scheduled for the experimental session (visit II) no earlier than 48 hours and no later than 72 hours. Participants were informed prior to the experimental session (visit II) and encouraged to maintain their normal dietary, sleeping patterns and to abstain from strenuous exercises (more intense than normal daily activities) for a minimum of twenty-four hours prior to the experimental session (visit II).

Visit II (experimental testing)

After arriving at the laboratory, the researchers administered the same warm-up protocol and dynamometer calibration as conducted during the familiarization session. Participants then completed three trials of the knee extension task for each of three cognitive strategies (nine trials in total) (cf. Brody et al., 2000). The order of the three cognitive strategies was counterbalanced to avoid carry-over effects and consisted of a mental arithmetic strategy (MA), a reading strategy (RC), and a psyching-up strategy (PSY).

Cognitive Strategies. During the 20-second preparatory period, participants were instructed to perform a mental preparation consistent with one of three cognitive strategies. During the mental arithmetic (MA) strategy, participants were instructed to

silently count backwards by 7 starting with the number 1000 and to verbally report the number they stopped on. Participants were encouraged prior to starting the mental arithmetic (MA) strategy to be as fast and accurate as possible. During the reading comprehension (RC) strategy, participants were instructed to silently read the provided passage and to comprehend the reading in order to answer provided questions. During the psyching (PSY) strategy participants were instructed to focus on their leg muscles, to concentrate and to be prepared as possible for the physical knee extension task. The mental arithmetic and reading comprehension strategies were employed to distract participants from the knee extension task. The prompts to (1) begin the cognitive strategy (“begin”) and, after 20 seconds, to (2) extend the leg (“move”) were given verbally by the experimenter. All instructions concerning the condition and the task were given by a pre-recorded statement (see supplemental material).

Measures

Perceived Effort (PE). Immediately following each trial within each testing strategy, participants reported their level of perceived effort on a categorical scale adapted from Borg’s Rating of Perceived Exertion scale (Borg, 1978). Participants circled with a pencil on the scale the rating they felt best represented their level of effort during the trial defined as how hard they had to drive their leg to lift the “weight” (Moritani et al. 1987). The scale ranged from 6 (corresponding to “no effort at all”) to 20 (corresponding to “maximal effort”).

Kinetics. Using a standardized set-up, peak torque output measurements identified as the highest torque output of the limbs joint as the limb proceeds through a range of motion Morrissey (1987) were obtained using an isokinetic dynamometer (Biodex® System 4 Pro). The isokinetic dynamometer was pre-calibrated to the manufacturer's specifications, separately for each strategy (MA, RC, PSY). The set-up was individually adjusted for unilateral knee extension of the right knee and was held constant for every participant throughout the study.

Data Processing

Kinetics

Using a standardized set-up, the peak torque output measurements were obtained using the Biodex® System 4 Pro Isokinetic Dynamometer (Shirley, NY). Average peak torque output was assessed for each trial.

Perceived Effort (PE)

The Perceived Effort (PE) measures of each participant were recorded and averaged across the three trials for each strategy (MA, RC, PSY).

Statistical Analysis

All statistical analyses were performed using a combination of IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, N.Y., USA), MATLAB (Mathworks, Natick, MA) and RStudio (RStudio, Boston, MA). We conducted a series of repeated-measure rmANOVAs, described below separately for each variable set. The Greenhouse-Geisser correction was applied, and corrected degrees of freedom are reported in the presence of violation of the sphericity assumption. Paired-sample t tests with a False Discovery Rate (FDR) correction with $q = 0.05$ (Benjamini

& Hochber, 1995) to contain Type I error, were employed to further evaluate effects of interest. Measures of effect sizes (partial eta squared η_p^2 and Cohen's d) are also reported when appropriate. Values of 0.02, 0.13, and 0.26 for η_p^2 and of 0.20, 0.50, and 0.80 for d were interpreted as small, medium, and large effects, respectively (Cohen, 1992). All criterion alpha levels were set to 0.05.

Kinetics

To test for differences in maximal skeletal muscle performance of the isokinetic knee extension task peak torque (Tkp) between strategies were subjected to a 3 Strategy (MA, RC, PSY) one-way repeated-measures analysis of variance (rmANOVA).

Perceived Effort (PE)

To assess self-report perceived effort for the knee extension task, (PE) scores were subjected to a 3 Strategy (MA, RC, PSY) one-way repeated-measures analysis of variance (rmANOVA).

Results

Kinetics

The repeated measure ANOVA on Strategy (MA, RC, PSY) revealed a main effect $F(2, 44) = 7.347, p = 0.002, \eta_p^2 = 0.250$. Post-hoc analysis revealed that torque output of the PSY strategy was significantly greater than both the MA strategy ($p < 0.001, d = 0.226$) and RC condition ($p < 0.001, d = 0.183$). (see Figure 2.2) and (see Table 2.2) No significant difference was revealed between MA and RC.

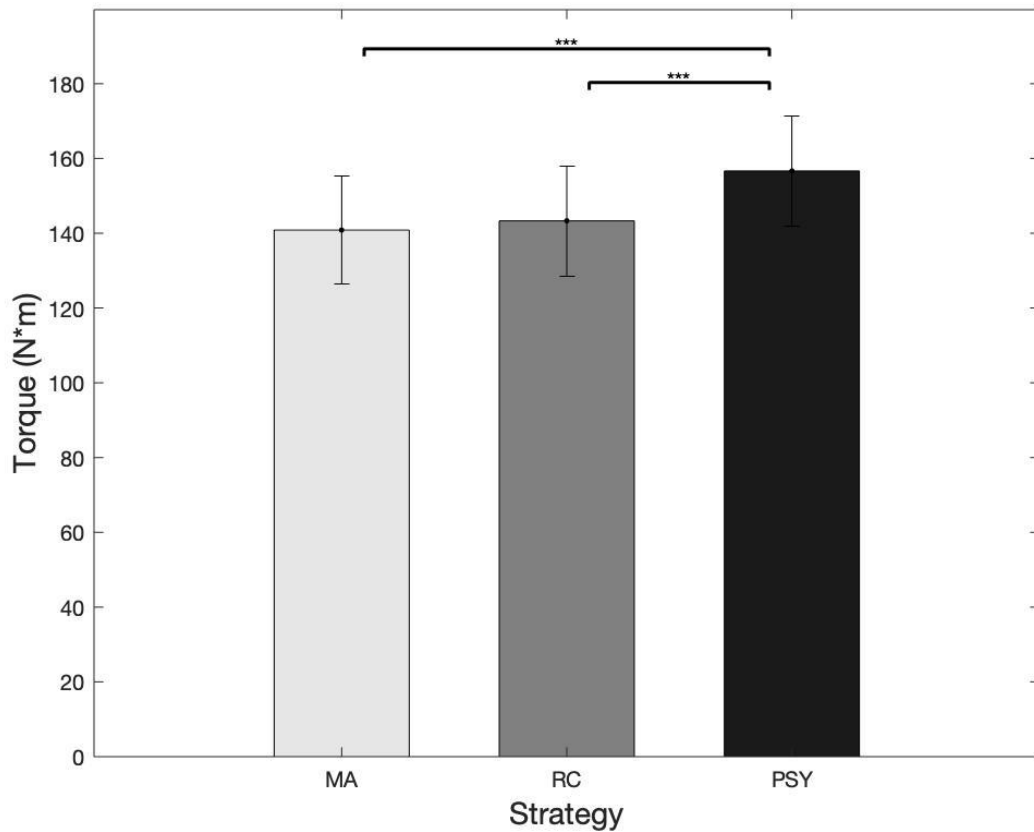


Figure 2.2. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. *** $p < .001$

Table 2.2.

*Peak Torque (N*m) as a Function of Cognitive Strategy & Rate of Perceived Effort (PE) on the Knee Extension Task as a Function of Cognitive Strategy*

	MA	RC	PSY
Peak Torque (N*m)	140.85 ^{a***} (69.25)	143.52 ^{a***} (70.79)	156.64 (70.44)
Perceived Effort (PE)	15.01 ^{a**} (2.89)	15.44 (2.32)	16.50 (2.57)

Note. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA).

MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

^a Significantly different from PSY.

$p < .05$, ** $p < .01$, *** $p < .001$

Perceived Effort (PE)

The repeated measure ANOVA on Strategy (MA, RC, PSY) revealed a main effect $F(3, 42) = 19.624, p < 0.001, \eta_p^2 = 0.584$. Post-hoc analysis revealed that PE was greater for the PSY strategy compared to the MA strategy ($p = 0.005, d = 0.542$) whereas the MA and RC strategies did not significantly differ (see Figure 2.3).

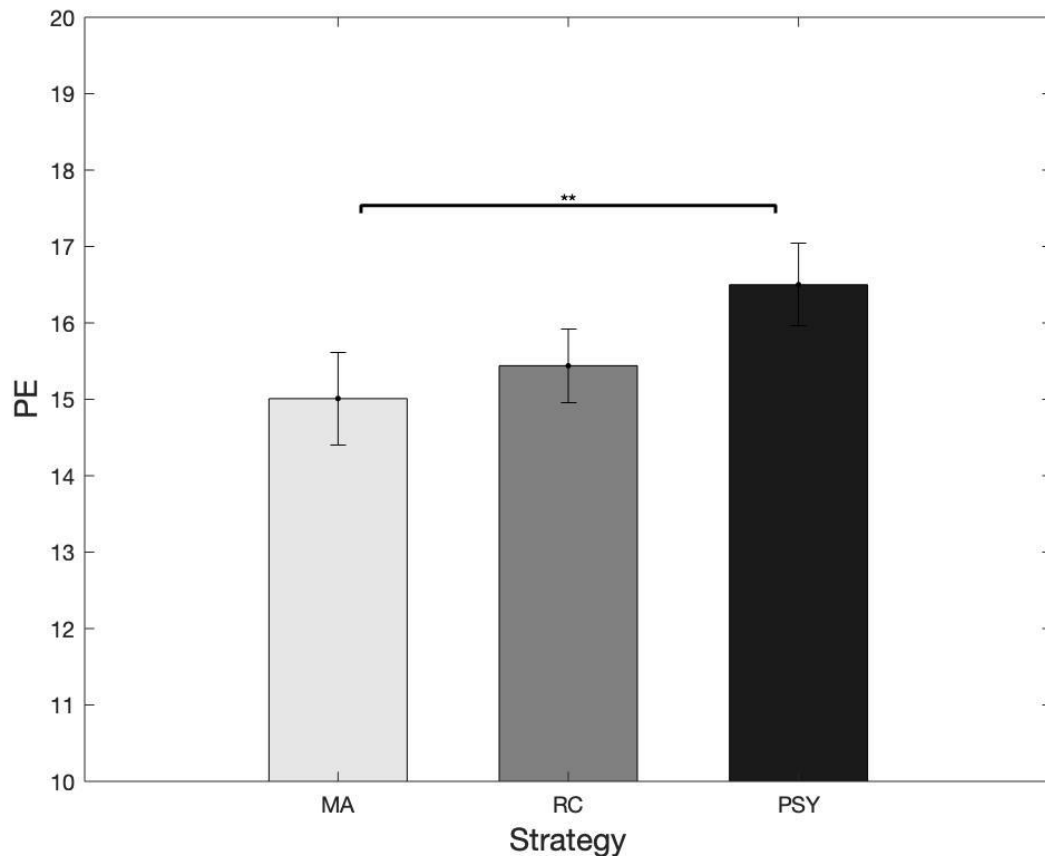


Figure 2.3. Perceived effort (PE) on the physical task for each experimental strategy. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. ** $p < .01$

Discussion

The aim of study one was to isolate the influence of task-related attentional focus i.e., psyching (PSY) and examine performance during maximal exertion knee extensions. More specifically, to examine whether or not adopting a task-focused, compared to distracted cognitive strategies, in preparation for motor performance alters the kinetic output. We hypothesized that task-related attentional focus i.e., psyching (PSY) compared to distracting attentional strategies such as reading comprehension (RC) and mental arithmetic (MA) would be associated with improved maximal motor performance as indicated by greater torque output.

Study one demonstrated and provides evidence that psyching (PSY) strategies compared to distracting (MA, RC) attentional strategies, are associated with increased force production. This finding aligned with our hypothesis and supported positive effects which was consistent with the literature (review Tod et al. 2015) stating that peak torque output was significantly greater for the psyching (PSY) strategy than reading comprehension (RC) and mental arithmetic (MA) strategies. Additionally, we predicted that participants would indicate a greater level of perceived effort (PE) for the psyching (PSY) strategy compared to mental arithmetic (MA) and reading comprehension (RC). The present results are supportive of and consistent with this hypothesis in that participants rated themselves as giving a higher rate of perceived effort (PE) following the task-related attentional focus strategy (PSY) compared to the distracting attentional strategies (RC, MA). Further, the perceived effort (PE) results are in line with Brody (2000) who argued that participants engaged in the psyching (PSY) strategy resulted in a self-report perception of heightened readiness.

These behavioral and subjective metric findings build on the notion that individuals can use certain cognitive strategies i.e., psyching to better mentally prepare for improving ones' motor performance. Certainly these results could be used by athletes to maximize their performance. It is possible that such strategies also could be taught to others (i.e., the person who simply exercises) to maximize their performance outcomes. Thus, the results of study one set the foundation and provide reasoning to further investigate the mental processes underlying mental preparation for maximizing motor and movement performance.

Study Two Methods

Participants

Twenty-four healthy adults (11 females and 13 males) with a mean age 20.66 years ($SD = 1.27$, $range = 19 - 24$), mean height of 170.11 cm ($SD = 8.37$, $range = 151 - 183.5$) and body weight 77.54 kg ($SD = 15.29$, $range = 47 - 109.9$) participated in this study. All participants were right-handed (laterality quotient $>+40$ on the Edinburgh Handedness Inventory, Oldfield, 1971) and reported a minimum of one year of strength training experience ($average = 3.70$ years of training). (see Table 2.3) Participants were recruited from the student population of the University of Maryland, College Park and were excluded if they had a self-reported history of psychiatric disorder, psychological disorders, neurological illness or disorders, cardiovascular, pulmonary or musculoskeletal conditions that would impact their ability to exercise, are using illicit drugs, or if they did not feel they could comply with the study's protocol. During the screening, participants were administered a Background Health History Questionnaire, Physical Activity Readiness Questionnaire

(PAR-Q), and Edinburgh Handedness Inventory (EHI). Participants were paid \$25: \$5 at the completion of the familiarization session (visit I) and \$20 at the completion of the experimental session (visit II). All participants provided their consent before participating in this experiment, which was approved by the university's institutional review board and ethical committee.

Table 2.3.
Demographic Information of Participants

No. of Participants, N	24
Gender	
Male	13 (54%)
Female	11 (46%)
Age (years)	20.66 ± 1.27
Height (cm)	170.11 ± 8.37
Weight (kg)	77.50 ± 15.29
Strength Training (years)	3.70 ± 1.62

Note. Data are presented as mean ± standard deviation unless otherwise indicated.

Procedures

Visit I (familiarization)

After providing informed consent, participants were measured and recorded for body weight (kg) and height (cm). After familiarization with the testing apparatus, procedures and psychological scales used, participants completed a light warm-up consisting of dynamic stretching led by the researchers.

Participants were seated in the dynamometer chair and secured by five straps (lower leg, upper leg, waist, and two across the chest) to prevent movements other than right knee extension. The dynamometer was then calibrated and standardized for participants' range of motion for total flexion and extension of the right leg.

Participants completed three submaximal and six maximal effort trials of the knee extension task to gain familiarity with the operation of and the speed at which

the isokinetic dynamometer would operate. Directly following each trial, a 120-second rest or recovery period was given during which participants provided their Perceived Effort (PE) using a categorical psychological scale modified from Borg's (1978) perceived exertion scale. Upon completion of the familiarization session (visit I), participants were scheduled for the experimental session (visit II) no earlier than 48 hours and no later than 72 hours.

Visit II (experimental testing)

Upon arriving at the laboratory, the researchers used the warm-up protocol as previously used during the familiarization session (visit I). After completing the dynamometer calibration, straps of the dynamometer were loosened and participants were fitted with a stretchable EEG cap. Researchers applied conductive gel to all sites via a blunt-tipped medical syringe. During this visit, baseline EEG measures eyes with closed (EC) and eyes open (EO) were recorded. The experimental protocol consisted of three strategies, presented in counterbalanced order across participants: mental arithmetic (MA), reading comprehension (RC), and psyching (PSY). Each strategy consisted of three trials cued by a 20 second period (nine trials in total) at the end of which participants were instructed to exert maximal voluntary effort.

Knee Extension Task. The physical task consisted of extending the right leg by exerting a maximal isokinetic concentric contraction (knee extension). While seated in the dynamometer chair, participants were instructed to extend their leg immediately after receiving the verbal “move” command, and then to passively return their leg to the starting position after completing the knee extension (i.e., knee flexion phase of the movement). Participants were instructed to keep their arms relaxed,

hands in their lap, and to remain as motionless as possible prior to knee extension during all trials. Each trial consisted of knee extension movement preceded by a 20-second preparatory period during which attention was manipulated. Directly after each trial, a 120-second rest period was given during which participants completed psychological scales of: Perceived Effort (PE). No visual or verbal feedback or encouragement was provided throughout the entirety of the familiarization and experimental session.

Cognitive Strategy. During the preparatory period of the mental arithmetic (MA) strategy, participants were instructed to silently count backwards by 7 starting with the number 1000 and to verbally report the number they stopped on. During the preparatory period of the reading comprehension (RC) strategy, participants were instructed to silently read the provided passage and to comprehend the reading in order to answer provided questions. These two strategies were employed to distract participants from the task (knee extension). During the preparatory period of the psyching (PSY) strategy participants were instructed to focus (i.e., visualize) on their leg muscles, to concentrate and to be prepared as possible for the knee extension. Each 20-second preparatory period began when the experimenter said “begin” and ended when the experimenter said “move”. All instructions concerning the strategy and the task were kept constant across participants by using a pre-recorded statement.

Measures

Kinetics

Using a standardized set-up, peak torque output measurements were obtained using the Biodex® System 4 Pro Isokinetic Dynamometer. The isokinetic

dynamometer was pre-calibrated to the manufacturer's specifications for each strategy. Each participant performed concentric contractions through a range of approximately 90 degrees of knee flexion. The set-up of the force measuring apparatus was individually adjusted for unilateral knee extension of the right knee which was held constant for every participant throughout the study. Additionally, as mentioned previously, participants were instructed to passively return their leg to the starting position during the knee flexion phase of the movement to minimize muscular effort. Each participant was seated and secured by five straps in the chair of the dynamometer (lower leg, upper leg, waist, and two across the chest) to prevent unwanted movements. Using the right leg, the axis of the dynamometer lever arm was measured and visually aligned at the lateral epicondyle of the knee. The length of the lever arm was adjusted for comfort. The range of movement was standardized to the participant's full range of movement and the researchers calculated the range of motion for total flexion, total extension, the approximate 90-degree position and the total limb weight and set the angular velocity to 60 degrees/second. Participants were instructed to keep their arms relaxed and hands in their lap during the research trials. All trials were performed with the right leg. The force characteristic measure consisted of peak torque (T_{kp}) output and was determined from the three trials (trial 1, trial 2, trial 3) of each condition (MA, RC, PSY).

Perceived Effort (PE)

Immediately following each trial within each testing strategy, participants reported their level of perceived effort (PE) on a categorical scale adapted from Borg's Rating of Perceived Exertion scale (Borg, 1978). Participants circled with a

pencil on the scale the rating they felt best represented their level of effort during the trial defined as how hard they had to drive their leg to lift the “weight” (Moritani et al. 1987). The scale ranged from 6 (corresponding to “no effort at all”) to 20 (corresponding to “maximal effort”).

Cortical Activity - Electroencephalography (EEG)

All psychophysiological measures were recorded through BrainVision Recorder 2.0 (Brain Products GmbH, Germany) and BrainAmp standard amplifier with a sampling rate of 1000 Hz (no online filter). The actiCap EEG System with active electrodes, BrainAmp standard amplifier, and BrainVision Analyzer Recorder version 2.0 (Brain Products GmbH, Munich, Germany) were used to record the electroencephalographic (EEG) activity from twenty-seven sites (F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2) in accordance with the international 10-10 system (Chatrian, 1985). Participants were fitted with a stretchable EEG cap. Researchers applied conducting gel to all sites via a blunt-tipped medical syringe.

In addition, four active electrodes were placed at the outer canthus of each eye and below and above the right eye to record horizontal (HEOG) and vertical (VEOG) electrooculogram respectively. The system used a common ground at site AFz, and electrodes were placed on the left and right mastoids to be used for possible offline referencing. Electrode impedances were maintained below 10 k Ω .

Data Processing

Cortical Activity

Processing of the physiological data was conducted using customized MATLAB scripts (MathWorks, Natick, MA) supported by EEGLAB functions (Delorme & Makeig, 2004). The data were bandpass filtered 1-40 Hz (Finite Impulse Response; FIR) with filter order = 2^{12} , as implemented in EEGLAB and epoched from -20.25 to +0.25s relative to the initiation of the leg extension (i.e., 0 s), which was identified by a digital trigger manually entered by the researchers simultaneously to the 'move' command, for each experimental trial of the three conditions (MA, RC, and PSY). For comparative purposes, we also epoched a time window of the same duration for the EO condition by selecting a central time interval within the 2-minute recording (i.e., from 49.75 to 70.25s). Upon visual inspection, bad channels were rejected (across all participants' data, one EEG channel and four EOG channels). No bad trials were identified. Independent Component Analysis (ICA) was applied to minimize non-neural activity (e.g., ocular artifacts) from the data. The channels that were previously discarded and the FCz channel, which was missing for three participants, were then retrieved through spherical interpolation. The data were re-referenced to the average of all EEG channels. Time-frequency decomposition was performed via MultiTaper short-time Fast Fourier Transform (MT st-FFT) over 81 500-ms intervals (50% overlap) with middle points linearly spaced from -20 to 0 seconds (for the trials of the three experimental conditions) and from 50 to 70 seconds (for the EO comparative condition), multiplied by Slepian tapers (Prerau et al. 2017), and zero-padded to reach a duration of 2 s. This procedure generated time-frequency

coefficients with a resolution of 2Hz, but spectral density of 0.50 Hz and 0.25 seconds.

Power (μV^2) was computed as the squared absolute value of the MT st-FFT coefficients in each point of the time-frequency space. Values were then averaged across time in four bins (-20 to -15 s, -15 to -10 s, -10 to -5 s, and -5 to -0 s, with 0 s = ‘move’ command) and across frequency within the alpha band relative to the Individual Alpha Frequency (IAF). Namely, we examined lower alpha band (IAF-2 to IAF) and upper alpha band (IAF to IAF+2). IAF was determined as “center of gravity” for each participant applying the procedure described by Corcoran et al. (2018) to parieto-occipital signals recorded during the eyes-closed resting period. On average IAF was 9.80 Hz ($SD = 0.65$). Power values were log-transformed ($10 \cdot \log_{10}$).

Statistical Analysis

Prior to analysis, all data were averaged across the three trials per each strategy. We conducted a series of repeated-measure rmANOVAs, described below separately for each variable set. The Greenhouse-Geisser correction was applied and corrected degrees of freedom are reported in the presence of violation of the sphericity assumption. Paired-sample t tests with a False Discovery Rate (FDR) correction with $q = 0.05$ (Benjamini & Hochber, 1995) to contain Type I error, were employed to further evaluate effects of interest. Measures of effect sizes (partial eta squared η_p^2 and Cohen’s d) are also reported when appropriate. Values of 0.02, 0.13, and 0.26 for η_p^2 and of 0.20, 0.50, and 0.80 for d were interpreted as small, medium, and large effects, respectively (Cohen, 1992). All criterion alpha levels were set to

0.05. All statistical analyses were performed using a combination of IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, N.Y., USA), MATLAB (Mathworks, Natick, MA) and RStudio (RStudio, Boston, MA).

Kinetics

To test for differences in maximal skeletal muscle performance of the isokinetic knee extension task, peak torque (T_{kp}) between strategies were subjected to a 3 Strategy (MA, RC, PSY) one-way repeated-measures ANOVA).

Perceived Effort (PE)

To assess participants' reported effort of how hard they had to drive, i.e., kick their leg when provided the “move” command were subjected to a 3 Strategy (MA, RC, PSY) repeated-measure ANOVA.

Cortical Activity

To test for differences in cerebral cortical activation among the three strategies during the preparatory period, we conducted region-of-interest (ROI) and channel-based analyses, described in turn below. The ROI analyses involved a 4 Strategy (EO, MA, RC, PSY) x 6 ROI (central, frontal, left temporal, right temporal, parietal, and occipital) x 4 Time (-20 to -15 s, -15 to -10 s, -10 to -5 s, and -5 to 0 s relative to knee extension initiation) repeated-measure ANOVA, separately for the lower and upper alpha frequency bands. Six regions of interest (ROI's) were identified following preliminary topographical analysis to examine functional areas associated with different cognitive processes and to ensure a wide coverage of the cortex: frontal: (F3, Fz, F4), central: (CP1, Cz, CP2), left temporal: (T7, FC5, F7), right temporal: (T8, FC6, F8), parietal: (P3, Pz, P4), occipital: (O1, Oz, O2). Power

was averaged across these specific channels yielding one value for each of the six regions. Preliminary topographical analysis determined that these channel sites were representative of the selected regions.

Channel-based analyses involved a series of paired-sample t-tests between the PSY strategy and each of the other two strategies and control condition (EO, MA, RC) separately for each channel, time bin, and frequency band; the p-values associated with these tests were submitted to the False Discovery Rate correction ($q = 0.05$) to control for multiple comparisons.

Results

Kinetics

The repeated measure ANOVA on Strategy (MA, RC, PSY) revealed a main effect for torque output among MA strategy ($M = 115.56$, $SD = 37.68$), RC strategy ($M = 115.27$, $SD = 36.31$, and PSY strategy ($M = 126.20$, $SD = 42.95$), ($F(2, 46) = 5.378$, $p = 0.008$, $\eta_p^2 = .189$). Post-hoc analysis revealed that torque output of the PSY strategy was significantly greater than the MA strategy ($p < 0.021$, $d = 0.263$) and RC strategy ($p = 0.011$, $d = 0.274$). The MA and RC strategies were undifferentiated and there were no other significant main effects or interactions identified. (see Table 2.4) (see Figure 2.4)

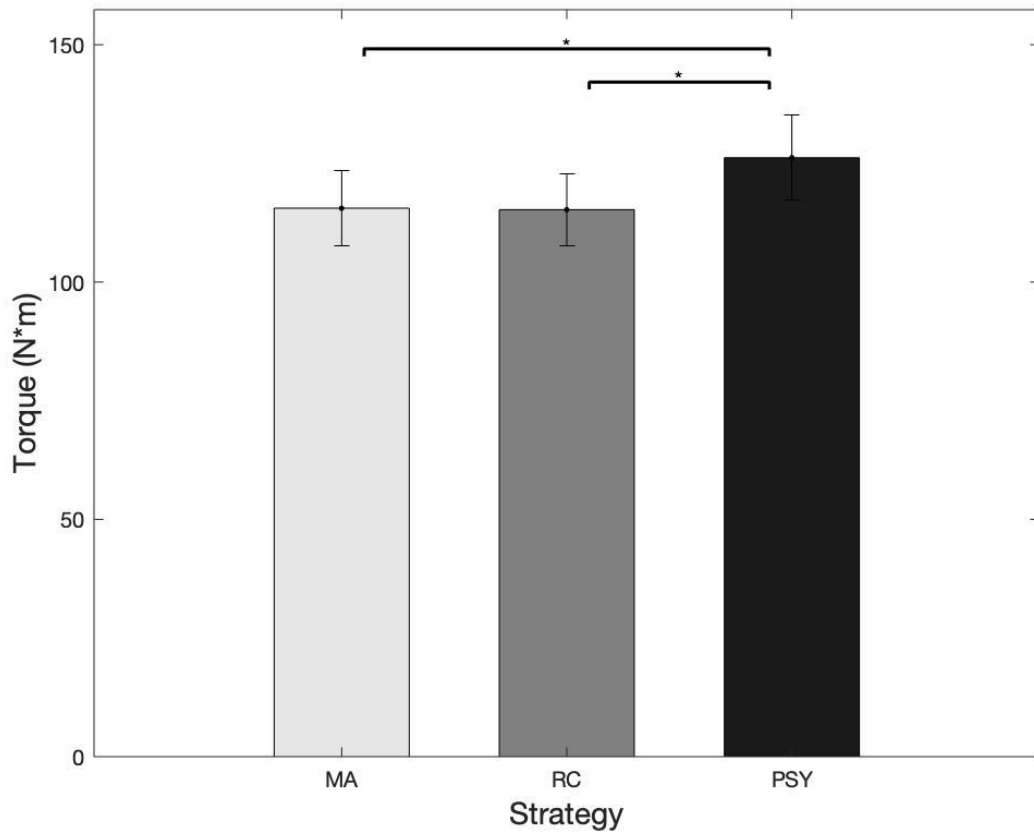


Figure 2.4. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$

Table 2.4.

*Peak Torque (N*m) as a Function of Cognitive Strategy & Perceived Effort (PE) on the Knee Extension Task as a Function of Cognitive Strategy*

	MA	RC	PSY
Peak Torque (N*m)	115.56 ^{a*} (37.68)	115.27 ^{a**} (36.31)	126.20 (42.95)
Perceived Effort (PE)	15.75 ^{a***} (1.48)	16.27 ^{a**} (1.88)	17.18 (1.98)

Note. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA). MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

^a Significantly different from PSY.

$p < .05$, ** $p < .01$, *** $p < .001$

Perceived Effort (PE)

The repeated measure ANOVA on Strategy (MA, RC, PSY) revealed a main effect for rating of perceived effort (PE) on the physical task among MA strategy ($M = 15.75$, $SD = 1.48$), RC strategy ($M = 16.27$, $SD = 1.88$), and PSY strategy ($M = 17.18$, $SD = 1.98$), ($F(2, 46) = 12.603$, $p < 0.001$, $\eta_p^2 = 0.354$). Post-hoc analysis revealed that perceived effort (PE) of the PSY strategy was significantly greater than the distracting strategies MA ($p < 0.001$, $d = 0.818$) and RC ($p = 0.009$, $d = 0.471$) whereas the MA and RC strategies were undifferentiated. There were no other significant main effects or interactions detected. (see Figure 2.5).

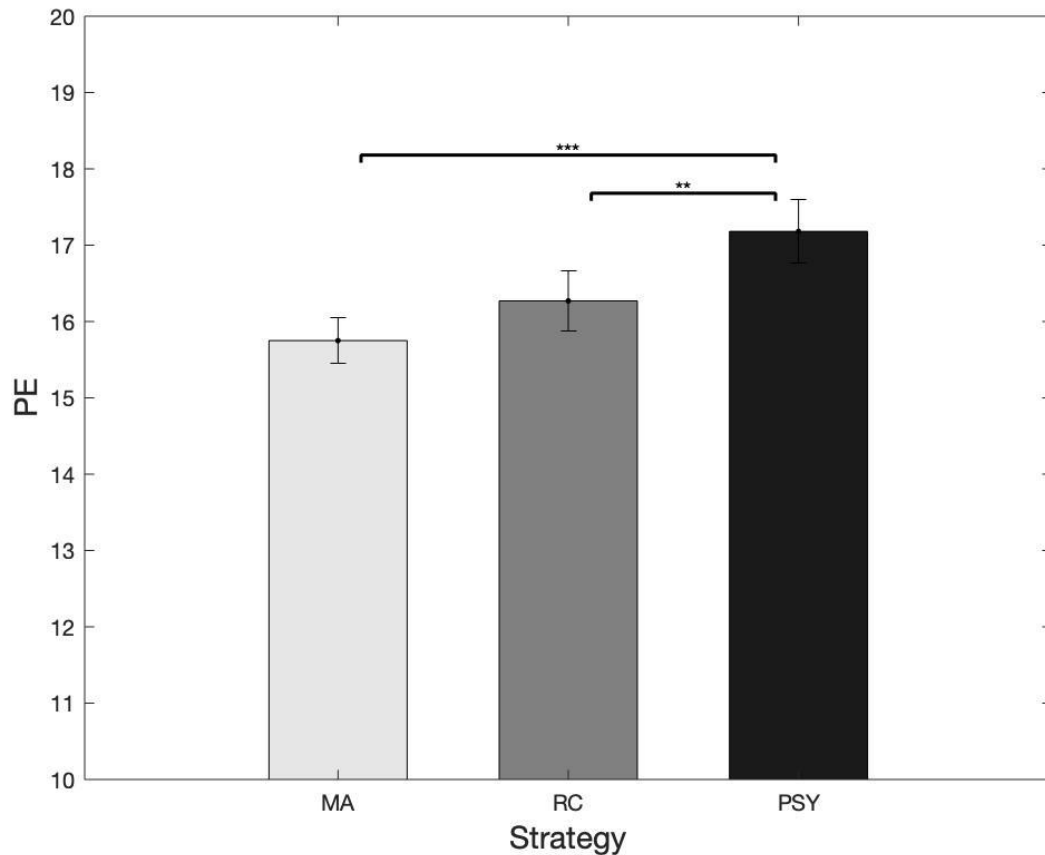


Figure 2.5. Perceived effort (PE) on the physical task for each experimental strategy. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. ** $p < .01$, *** $p < .001$

Cortical Activity

Lower alpha power (IAF -2 to IAF)

The 4 Strategies x 6 ROI x 4 Time repeated-measures ANOVA revealed a main effect for Strategy, $F(2.149, 49.416) = 4.506, p = 0.014, \eta_p^2 = .164$, a main effect for ROI, $F(3.058, 70.327) = 39.079, p < .001, \eta_p^2 = .630$, a marginal main effect for Time, $F(3, 69) = 2.670, p = .054, \eta_p^2 = .104$, a Strategy x ROI interaction, $F(5.926, 136.304) = 4.592, p < .001, \eta_p^2 = .166$, a ROI x Time interaction, $F(8.337, 191.742) = 2.348, p = .018, \eta_p^2 = .093$, and a Strategy x ROI x Time interaction, $F(45, 1035) = 1.512, p = .017, \eta_p^2 = .062$. Mean values are reported in (see Table 2.5.). In line with

our hypotheses and analytic strategy, we focused on the Strategy x ROI interaction by collapsing across the Time factor and conducting FDR-corrected post-hoc paired-sample t-tests between strategy pairs (see Figure 2.6.). These tests revealed that lower-alpha power was significantly lower in two experimental strategies (RC and PSY) compared to the control EO strategy across all ROIs. FDR-corrected channel-based analyses (see Table 2.6.) confirmed that lower-alpha power diminished from the EO control to the PSY strategy across numerous channels. In addition, it revealed a focal spatial effect whereby PSY showed diminished lower-alpha power compared to MA in central and centro-parietal channels in the five seconds before initiating the knee extension. This trend was also observed when comparing PSY with RC, although it was not below the statistical threshold.

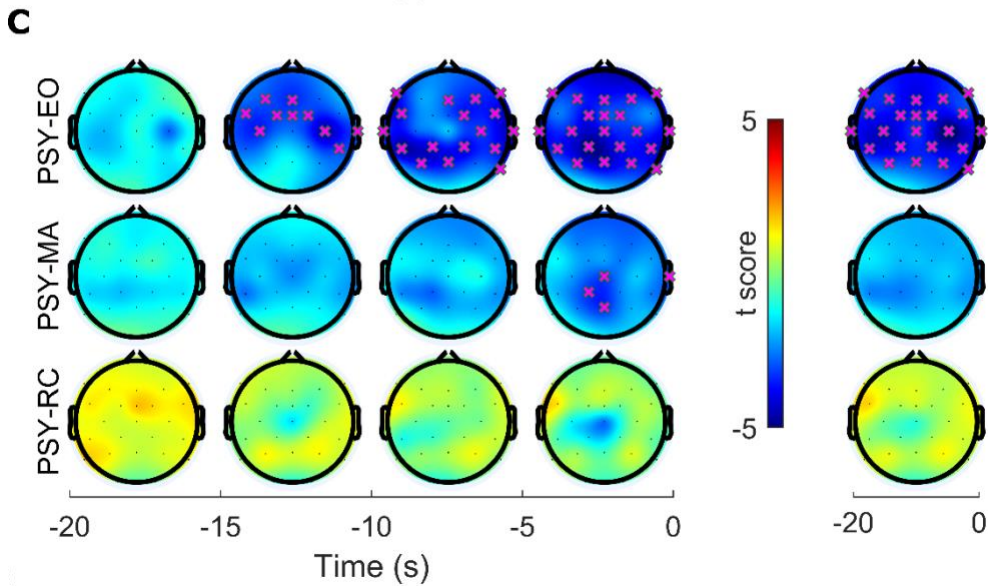
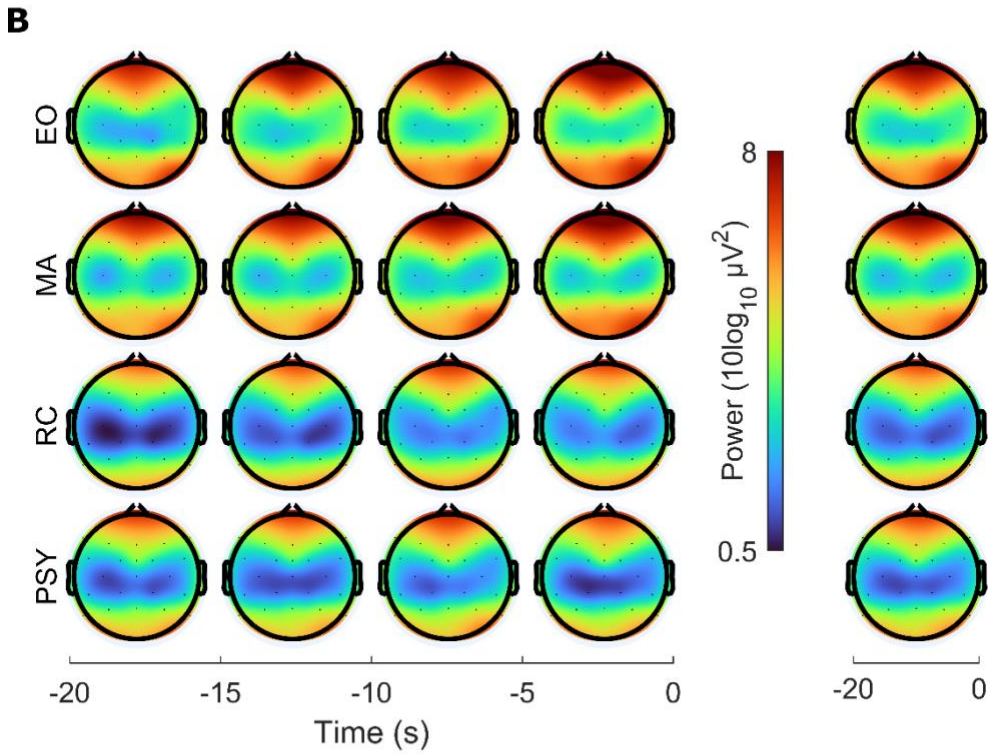
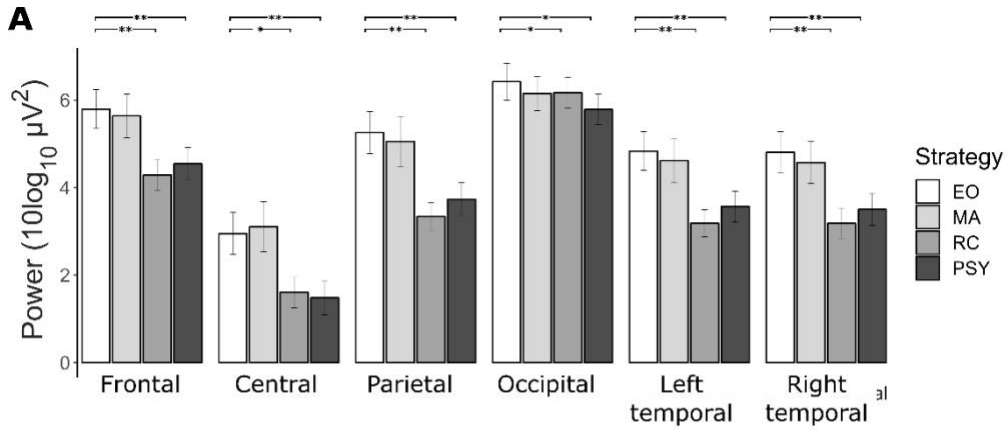


Figure 2.6

Panel A: Lower Alpha Frequency (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T7, FC5, F7), right temporal (T8, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Panel C: EEG scalp maps of statistical values (t scores) comparing lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Table 2.5. Lower alpha power (-2 IAF to IAF) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy

Note. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Time	EO	MA	RC	PSY
frontal	-20 to -15 s	5.28 (4.51)	5.37 (4.87)	3.89 (3.38)	4.52 (3.47)
	-15 to -10 s	5.83 (4.40)	5.47 (5.24)	4.26 (3.65)	4.33 (3.53)
	-10 to -5 s	5.85 (4.23)	5.66 (4.74)	4.61 (3.85)	4.75 (4.06)
	-5 to 0 s	6.22 (4.45)	6.06 (4.94)	4.40 (3.33)	4.57 (3.82)
central	-20 to -15 s	2.38 (4.64)	3.12 (5.75)	1.09 (3.09)	1.57 (3.51)
	-15 to -10 s	2.95 (4.98)	3.01 (5.93)	1.50 (3.94)	1.38 (3.77)
	-10 to -5 s	3.15 (4.55)	2.97 (5.34)	1.89 (3.63)	1.75 (4.13)
	-5 to 0 s	3.32 (4.87)	3.33 (5.53)	1.97 (3.33)	1.23 (3.87)
parietal	-20 to -15 s	4.80 (4.69)	4.91 (5.80)	3.13 (2.96)	3.76 (3.62)
	-15 to -10 s	4.93 (5.00)	4.87 (5.92)	3.23 (3.29)	3.77 (3.64)
	-10 to -5 s	5.54 (4.85)	5.01 (5.42)	3.55 (3.29)	3.88 (4.23)

	-5 to 0 s	5.77 (4.61)	5.44 (5.55)	3.45 (2.88)	3.54 (3.90)
occipital	-20 to -15 s	6.38 (4.30)	5.98 (4.00)	6.01 (3.41)	5.85 (3.31)
	-15 to -10 s	6.47 (3.92)	5.96 (3.96)	6.16 (3.52)	5.68 (3.30)
	-10 to -5 s	6.27 (4.22)	6.10 (3.61)	6.33 (3.53)	5.78 (3.91)
	-5 to 0 s	6.57 (4.29)	6.57 (4.02)	6.19 (3.27)	5.82 (3.38)
left temporal	-20 to -15 s	4.24 (4.45)	4.42 (5.01)	2.92 (2.80)	3.48 (3.34)
	-15 to -10 s	4.80 (4.50)	4.56 (5.20)	3.09 (3.45)	3.33 (3.42)
	-10 to -5 s	5.03 (4.17)	4.64 (4.88)	3.43 (3.22)	3.79 (3.66)
	-5 to 0 s	5.28 (4.29)	4.86 (5.14)	3.31 (2.84)	3.69 (3.50)
right temporal	-20 to -15 s	4.24 (4.87)	4.68 (4.85)	3.18 (3.34)	3.89 (3.52)
	-15 to -10 s	4.82 (4.65)	4.55 (4.95)	3.08 (3.58)	3.40 (3.47)
	-10 to -5 s	5.19 (4.64)	4.43 (4.58)	3.16 (3.32)	3.45 (3.90)
	-5 to 0 s	4.99 (4.27)	4.65 (4.65)	3.34 (3.31)	3.28 (3.60)

Table 2.6. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the lower alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Comparison	p_{FDR}	d
Frontal	EO > RC	.005	0.836
	EO > PS	.007	0.753
Central	EO > RC	.015	0.651
	EO > PS	.007	0.771
Parietal	EO > RC	.006	0.805
	EO > PS	.007	0.718
Left temporal	EO > RC	.005	0.846
	EO > PS	.007	0.728
Right temporal	EO > RC	.003	0.976
	EO > PS	.007	0.728

Upper alpha power (IAF to IAF +2)

The 4 Strategy x 6 ROI x 4 Time repeated measures ANOVA revealed a main effect for Strategy, $F(3,69) = 5.830, p = .001, \eta_p^2 = .202$, a main effect for ROI, $F(3.094, 71.157) = 26.227, p < .001, \eta_p^2 = .533$, a Strategy x ROI interaction, $F(6.557, 150.811) = 4.691, p < .001, \eta_p^2 = .169$, a Region x Time interaction, $F(7.828, 180.045) = 2.216, p = .029, \eta_p^2 = .088$, and a Strategy x Region x Time interaction, $(F(45, 1035) = 1.381, p = .050, \eta_p^2 = .057$. Mean values are reported in (see Table 2.7)

In line with our hypotheses and analytic approach, we focused on the Strategy x ROI interaction by collapsing across the Time factor and conducting FDR-corrected post-hoc paired-sample t-tests between strategy pairs (see Figure 2.7). These tests revealed that upper alpha power diminished from EO to the experimental strategies (especially RC) across all ROIs except the occipital. Further, results indicated that the two distracting strategies, MA and RC, were qualitatively different, with the latter showing smaller values than the former for most ROIs. The PSY strategy showed less upper-alpha power than the MA strategy, exclusively for the central ROI. FDR-corrected channel-based analyses (see Table 2.8) indicated that upper-alpha power diminished from the EO control to the PSY strategy across selected centro-parietal and right temporal channels. These analyses also revealed a focal pattern whereby upper-alpha power was lower for PSY than MA (and marginally for RC) for one left centro-parietal channel.

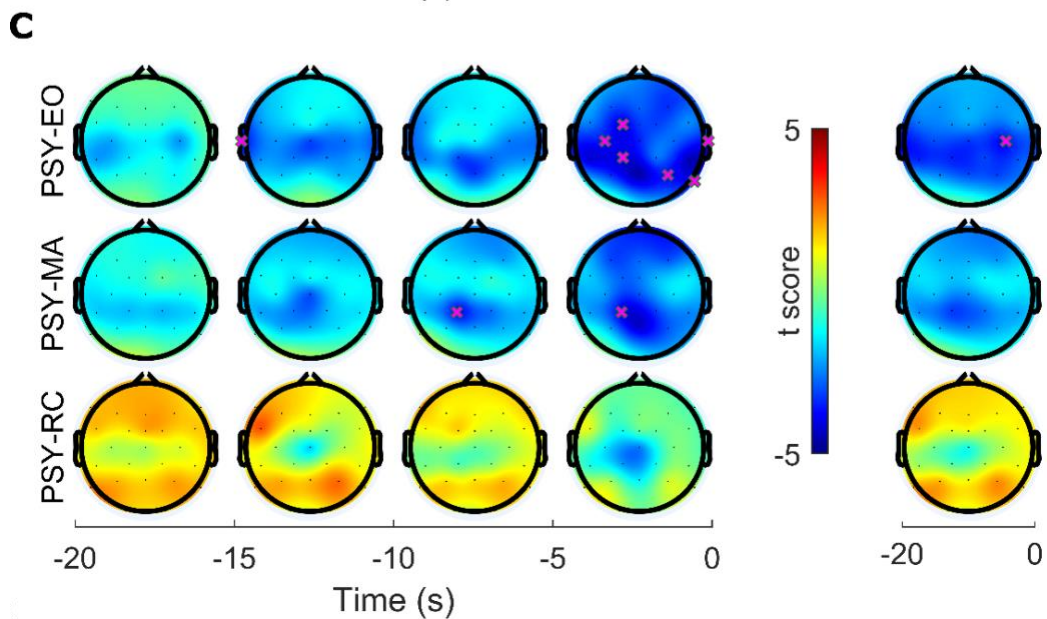
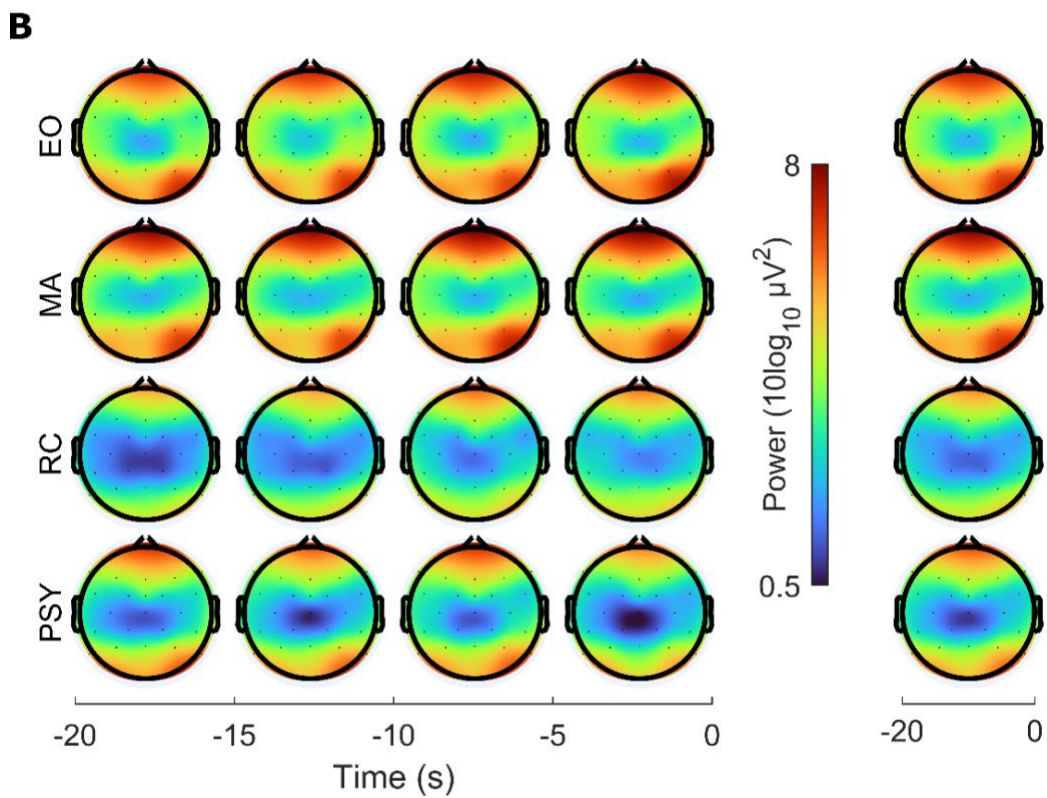
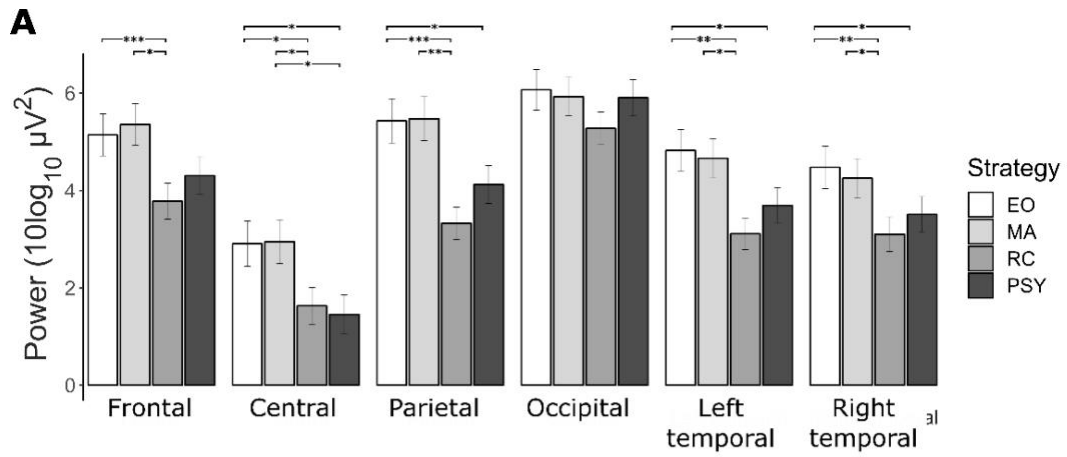


Figure 2.7.

Panel A: Upper Alpha Frequency (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T7, FC5, F7), right temporal (T8, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of upper alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Panel C: EEG scalp maps of statistical values (t scores) comparing upper-alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Table 2.7. Upper alpha power (IAF to IAF+2) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy
 Note. Data are presented as mean \pm standard deviation, unless otherwise indicated.
 EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Time	EO	MA	RC	PSY
frontal	-20 to -15 s	4.93 (4.11)	5.30 (4.01)	3.39 (3.49)	4.53 (3.92)
	-15 to -10 s	4.98 (4.35)	5.25 (4.45)	3.67 (3.62)	4.25 (3.84)
	-10 to -5 s	5.22 (4.34)	5.43 (4.18)	4.09 (3.92)	4.57 (4.09)
	-5 to 0 s	5.44 (4.34)	5.47 (4.20)	3.98 (3.67)	3.87 (3.53)
central	-20 to -15 s	2.63 (4.54)	3.02 (4.53)	1.12 (3.50)	1.64 (3.93)
	-15 to -10 s	3.17 (4.58)	2.90 (4.76)	1.48 (3.69)	1.43 (3.95)
	-10 to -5 s	2.94 (4.57)	3.01 (4.27)	1.88 (3.96)	1.74 (4.25)
	-5 to 0 s	2.90 (4.78)	2.86 (4.39)	2.04 (3.77)	1.01 (3.87)
parietal	-20 to -15 s	5.14 (4.40)	5.43 (4.56)	2.91 (3.12)	4.24 (3.96)
	-15 to -10 s	5.36 (4.78)	5.41 (4.66)	3.13 (3.14)	4.15 (3.84)

	-10 to -5 s	5.49 (4.63)	5.59 (4.44)	3.57 (3.58)	4.48 (4.10)
	-5 to 0 s	5.73 (4.27)	5.48 (4.31)	3.70 (3.25)	3.63 (3.63)
occipital	-20 to -15 s	6.28 (4.25)	5.85 (3.90)	5.16 (3.33)	6.20 (3.55)
	-15 to -10 s	5.83 (4.25)	5.58 (3.92)	5.25 (3.41)	5.94 (3.86)
	-10 to -5 s	5.94 (4.20)	6.03 (3.77)	5.32 (3.47)	5.94 (4.09)
	-5 to 0 s	6.24 (3.93)	6.25 (4.18)	5.39 (3.11)	5.54 (3.38)
left temporal	-20 to -15 s	4.47 (4.47)	4.73 (3.94)	2.92 (3.03)	3.83 (3.78)
	-15 to -10 s	5.04 (4.10)	4.70 (4.27)	2.85 (3.28)	3.62 (3.57)
	-10 to -5 s	5.02 (4.52)	4.63 (3.90)	3.44 (3.47)	3.89 (3.87)
	-5 to 0 s	4.78 (4.07)	4.60 (4.02)	3.23 (3.19)	3.44 (3.34)
right temporal	-20 to -15 s	4.24 (4.45)	4.43 (3.96)	3.11 (3.58)	4.01 (3.94)
	-15 to -10 s	4.52 (4.33)	4.12 (4.17)	2.92 (3.42)	3.28 (3.50)
	-10 to -5 s	4.59 (4.60)	4.29 (3.95)	3.05 (3.57)	3.61 (3.75)

-5 to 0 s 4.56 (4.10) 4.19 (3.81) 3.34 (3.59) 3.14 (3.45)

Table 2.8. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the upper alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Comparison	p_{FDR}	d
Frontal	EO > RC	.005	0.814
	MA > RC	.016	0.652
Central	EO > RC	.010	0.714
	EO > PS	.010	0.72
	MA > RC	.018	0.626
	MA > PS	.021	0.591
Parietal	EO > RC	< .001	1.072
	EO > PS	.016	0.652
	MA > RC	.009	0.751
Left temporal	EO > RC	.001	0.996
	EO > PS	.020	0.602
	MA > RC	.017	0.638
Right temporal	EO > RC	.002	0.919
	EO > PS	.033	0.544
	MA > RC	.019	0.615

General Discussion

To date, there is no experimental evidence evaluating whether or not the adoption of a more or less efficient cognitive strategy leads not only to changes in motor performance but also to a different pattern of EEG alpha gating. Thus, we investigated changes in motor performance and EEG alpha as individuals performed a psychomotor task. Specifically, and based on our knowledge, we conducted the first study to experimentally manipulate cognitive strategies (RC, MA, PSY) in order to isolate on the element of task-related attentional focus. Our findings provide support that task-related attentional focus strategies i.e., psyching strategies compared to distracting attentional strategies, leads to better performance and an increase in activation with the motor region. The implications for our findings are discussed below.

Based upon the findings of study one, study two attempted a replication of these results, and was further expanded by incorporating the measure of electroencephalography (EEG). The aim of study two was to examine the magnitude of cerebral cortical activation during the task-related attentional focus cognitive strategy compared to distraction strategies. Further, to examine if the cortical activation during task-related focus was associated with an elevation in performance a maximal exertion knee extension task. Specifically, if experimentally manipulating the preparatory cognitive strategy leads to a shift in the balance between task-related (motor-regions) and task-unrelated (non-motor regions) processes and an increase in performance during a maximal exertion knee extension. The biopsychological literature is currently unclear as to why psyching may assist with performance improvements because no consistent explanation has garnered vast support.

Therefore, investigating the variables underlying the mental preparation force production relationship may broaden the understanding of how psyching may contribute to improved performance, i.e., increased force production (Tod et al. 2003).

Based on the neural efficiency model, we expected to see that psyching (PSY) would be associated with a change in alpha pattern compared with the different experimental strategies of mental arithmetic (MA) and reading comprehension (RC) as indicated by EEG alpha. Further, we expected that psyching (PSY) would be associated with enhanced performance as indicated by increased torque output and that participants would report a greater level of perceived effort (PE) for the psyching (PSY) strategy compared to mental arithmetic (MA) and reading comprehension (RC).

As was expected and aligned with the results of study one, the results from study two related to behavioral performance confirmed that participants were able to enhance performance when using mental preparation by focusing and getting as prepared as possible (PSY) on the given task. Further, aligned with our hypothesis and supported by results of study one, torque output was significantly greater for the psyching (PSY) strategy compared to distracting strategies. More specifically, torque output of the knee extension task revealed that when engaged in the psyching (PSY) strategy, participants performed significantly better than both distracting mental arithmetic (MA) and reading comprehension (RC) strategies. These results suggest that in the case of a maximal effort knee extension, the use of psyching (PSY) of recreationally trained participants leads to better performance which is demonstrated

by an increase in torque output. The results of this study extend previous work exemplifying that the use of psyching enhances performance (See Tod et. al. 2015). Further and in support of our previous findings (see study one) and in agreement with our hypothesis, participants' subjective rating of perceived effort (PE) was greater for psyching (PSY) than both mental arithmetic (MA) and reading comprehension (RC) strategies.

Pertaining to EEG, results revealed that regardless of strategy used prior to initiating the maximal effort knee extension task, alpha activity was displayed across the different regions of the cortex with a distinct focal pattern revealing central activation surrounded by inhibition: power was lowest over the central regions. It should be noted that the functional meaning of (alpha I), i.e., lower alpha (8-10 Hz) is that of reflecting general arousal (Klimesch, 1999; Baumeister et al. 2007).

Compared to the control eyes-open (EO) rest strategy, low-alpha power was significantly lower than RC and PSY strategies for all regions of the cortex. Based on proposed active cortical inhibition (Klimesch et al. 2007; Klimesch, 2012), in line with the gating-by-inhibition hypothesis (Jensen & Mazaheri, 2010) and as we predicted, the topographical pattern suggests that during preparation for movement, resources were directed away from unrelated (non-motor) regions (highest inhibition) and directed towards related (motor) regions (lowest inhibition) i.e., central.

A more spatially localized movement related alpha gating appears to be stronger for psyching (PSY) compared to reading comprehension (RC) and mental arithmetic (MA) which suggests that psyching evoked a more efficient redistribution of resources towards sensorimotor processing. Furthermore, for the study of

recreationally trained participants, it appears that the heightening of movement related regions is more important than the inhibition of movement unrelated regions. Additionally, in central and central-parietal channels (task-related), the psyching (PSY) strategy displayed diminished lower-alpha power compared to the mental arithmetic (MA) strategy.

Further, tests indicated that upper-alpha power was reduced from the control EO strategy to the varying experimental strategies (RC, MA, PSY). It should be noted that the functional meaning (alpha II), i.e., upper alpha (10-12 Hz) is indicative of task-specific attentional processes (Kerrick et al. 2004). Unlike for lower-alpha power, upper-alpha power revealed that MA and RC were different with RC being lower for the majority of the regions. Aligned with our hypothesis, a focal pattern emerged with the PSY strategy displaying activation within the central region surrounded by inhibition: lowest power in the central region. Further analysis revealed a focal pattern whereby upper-alpha power was lower for PSY than MA (and marginally for RC). In agreement with the motor homunculus representation of the right leg (Penfield & Rasmussen 1950) central activation for upper-alpha psyching (PSY) strategy showed greater activation for one left centro-parietal channel.

An argument can be made that during the preparation period prior to enhanced performance (PSY strategy), a suppression occurs in the cortical regions of task-unrelated (non-motor) processes and a release from inhibition occurs in the cortical regions that are associated with task-relevant (motor) processes which is aligned with what was noted by (Hatfield & Hillman, 2001). Results are supported by the sport

literature showing that neural efficiency is accompanied by greater alpha in temporal and occipital regions (task-unrelated) and lower alpha in the central region (task-related) (Babiloni et al. 2008, Cooke et al. 2014, Kerick et al. 2001). Further, supportive results are the findings of Gallicchio et al. (2016) who revealed an inhibition of task-irrelevant regions and activation of task-relevant regions during a golf putting task. It is conceivable that we can speculate and infer a link with the EEG alpha results to psychomotor efficiency, i.e., enhanced motor performance during the psyching (PSY) strategy was achieved with a more focused or localized brain activity. This finding speaks to the importance of developing additional specific attentional strategies to be utilized in motor performance preparation.

In light of our findings, the possible interpretations of our data are also limited which could be addressed in future research. Limitations in the present study may include the small number of trials performed using each strategy due to the possible increase in physical and mental fatigue when executing a maximal effort task. The interpretation of our results is also limited by the lack of a “do-nothing” strategy whereby participants are provided no verbal instructions prior to the leg extension.

Future Research and Implications

Future research efforts might consider using a multi-measure electroencephalography (EEG) and electromyography (EMG) investigation to better understand the psychophysiological model of mental preparation during maximal volitional effort. A cascade of events utilizing such measures could help to further understand the psychophysiological underpinnings of psyching. Namely, the focused brain dynamics associated with the task-related attentional focus leads to elevated

motor unit recruitment which translates to heightened musculoskeletal performance (peak torque).

Additionally, from a design perspective, participants could be required to complete a manipulation check questionnaire prior to and after the task related to motivation to perform the task. This modification of method could help to ensure that participants are fully engaged, adhered to directions satisfactorily, and were motivated prior to performing both the physical task of knee extension and the cognitive strategies of mental arithmetic (MA), reading comprehension (RC) and psyching (PSY).

From an applied perspective, this study is of great importance for practitioners, sport psychologists, and athletic coaches. From a methodological point of view, future studies could utilize more advanced EEG equipment or other neuroimaging techniques in a non-laboratory setting to investigate the impact of mental preparation prior to voluntary movements. It is worth considering that participants self-identified as recreational athletes and thus extending this work by evaluating highly strength-trained athletes should be of great importance for further understanding of elite human performance.

References

- Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology*, 586(1), 131-139
<https://doi.org/10.1113/jphysiol.2007.141630>
- Baumeister, R. F., & Vohs, K. D. (2007). Self-Regulation, ego depletion, and motivation. *Social and Personality Psychology Compass*, 1(1), 115-128.
<https://doi.org/10.1111/j.1751-9004.2007.00001.x>
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: series B (Methodological)*, 57(1), 289-300.
<https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>
- Borg, G. (1978). Subjective effort in relation to physical performance and working capacity. In H. L. Pick (Ed), *Psychology: From research to practice* (pp. 338-361). New York: Plenum.
- Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>
- Budzynski, T. H., Budzynski, H. K., Evans, J. R., & Abarbanel, A. (Eds.). (2009). *Introduction to Quantitative EEG and neurofeedback: Advanced theory and applications*. San Diego, CA: Academic Press.
<https://doi.org/10.1080/00029238.1985.11080163>

- Chatrjian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activities. *American Journal of EEG technology*, 25(2), 83-92.
- Cohen, J. (1992). A Power Primer. *Psychological Bulletin*, 112 (1), 155–159
<https://psycnet.apa.org/doi/10.1037/0033-2909.112.1.155>
- Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, 51(4), 374-384.
<https://doi.org/10.1111/psyp.12182>
- Corcoran, A. W., Alday, P. M., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2018). Toward a reliable, automated method of individual alpha frequency (IAF) quantification. *Psychophysiology*, 55(7), e13064.
<https://doi.org/10.1111/psyp.13064>
- 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(2), 106-116. <https://doi.org/10.3200/JMBR.41.2.106-116>
- Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9-21.
<https://doi.org/10.1016/j.jneumeth.2003.10.009>

- Del Percio, C., Babiloni, C., Bertollo, M., Marzano, N., Iacoboni, M., Infarinato, F., ... & Eusebi, F. (2009). Visuo-attentional and sensorimotor alpha rhythms are related to visuo-motor performance in athletes. *Human Brain mapping, 30*(11), 3527-3540. <https://doi.org/10.1002/hbm.20776>
- Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., & Hoedlmoser, K. (2016). Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting. *International Journal of Psychophysiology, 109*, 92-99. <https://doi.org/10.1016/j.ijpsycho.2016.09.004>
- Gallicchio, G., & Ring, C. (2019). Don't look, don't think, just do it! Toward an understanding of alpha gating in a discrete aiming task. *Psychophysiology, 56*(3), e13298. <https://doi.org/10.1111/psyp.13298>
- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D., Haufler, A. J., Hung, T.-M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal of Clinical Neurophysiology, 21*(3), 144-156. <https://doi.org/10.1097/00004691-200405000-00003>
- 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.84-110). Hoboken, NJ: John Wiley & Sons.
- Hatfield, B. D. (2018). Brain dynamics and motor behavior: A case for efficiency and refinement for superior performance. *Kinesiology Review*, 7(1), 42-50.
<https://doi.org/10.1123/kr.2017-0056>
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of sport psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- 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(2-3), 131-160. [https://doi.org/10.1016/S0301-0511\(00\)00047-8](https://doi.org/10.1016/S0301-0511(00)00047-8)
- Janelle, C. M., & Hatfield, B. D. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology. *Military Psychology*, 20(S1), S39-S69.
<https://doi.org/10.1080/08995600701804798>
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.
<https://doi.org/10.3389/fnhum.2010.00186>
- Jones, L., & Stuth, G. (1997). The uses of mental imagery in athletics: An overview. *Applied and Preventive Psychology*, 6(2), 101-115.
[https://doi.org/10.1016/S0962-1849\(05\)80016-2](https://doi.org/10.1016/S0962-1849(05)80016-2)

- Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology*, 58(3), 263-277. [https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)
- Kerick, S. E., Douglass, L. W., & Hatfield, B. D. (2004). Cerebral cortical adaptations associated with visuomotor practice. *Medicine & Science in Sports & Exercise*, 36(1), 118-129. <http://dx.doi.org/10.1249/01.MSS.0000106176.31784.D4>
- Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology*, 24(1-2), 61-100. [https://doi.org/10.1016/S0167-8760\(96\)00057-8](https://doi.org/10.1016/S0167-8760(96)00057-8)
- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews*, 29(2-3), 169-195. [https://doi.org/10.1016/S0165-0173\(98\)00056-3](https://doi.org/10.1016/S0165-0173(98)00056-3)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88. <https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617. <https://doi.org/10.1016/j.tics.2012.10.007>
- Marchant, D. C., & Greig, M. (2017). Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic

knee extensions. *Human Movement Science*, 52, 67-73.

<https://doi.org/10.1016/j.humov.2017.01.007>

McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences*, 23(7), 687-692. <https://doi.org/10.1080/02640410400021401>

Moritani, T., & Muro, M. (1987). Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *European Journal of Applied Physiology and Occupational Physiology*, 56, 260-265.

<https://doi.org/10.1007/BF00690890>

Morrissey, M. C. (1987). The relationship between peak torque and work of the quadriceps and hamstrings after meniscectomy. *Journal of Orthopaedic & Sports Physical Therapy*, 8(8), 405-408.

<https://www.jospt.org/doi/10.2519/jospt.1987.8.8.405>

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)

Penfield, W., & Rasmussen, T. (1950). The cerebral cortex of man; a clinical study of localization of function.

Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest.

Electroencephalography and Clinical Neurophysiology, 83(1), 62-69.

[https://doi.org/10.1016/0013-4694\(92\)90133-3](https://doi.org/10.1016/0013-4694(92)90133-3)

- Pineschi, G., & Di Pietro, A. (2013). Anxiety management through psychophysiological techniques: Relaxation and psyching-up in sport. *Journal of Sport Psychology in Action*, 4(3), 181-190.
<https://doi.org/10.1080/21520704.2013.820247>
- Prerau, M. J., Brown, R. E., Bianchi, M. T., Ellenbogen, J. M., & Purdon, P. L. (2017). Sleep neurophysiological dynamics through the lens of multitaper spectral analysis. *Physiology*, 32(1), 60-92.
<https://doi.org/10.1152/physiol.00062.2015>
- Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of “psyching-up” strategies in weight lifters. *Cognitive Therapy and Research*, 2(3), 275-284.
<https://doi.org/10.1007/BF01185789>
- Tod, D., Iredale, F., & Gill, N. (2003). ‘Psyching-up’ and muscular force production. *Sports Medicine*, 33(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>
- Tod, D. A., Iredale, K. F., McGuigan, M. R., Strange, D. E. O., & Gill, N. (2005). "Psyching-up" enhances force production during the bench press exercise. *Journal of Strength and Conditioning Research*, 19(3), 599-603. Retrieved from <https://search.proquest.com/docview/213066537?accountid=14696>
- Tod, D., & McGuigan, M. (2006). The efficacy of psyching-up on strength performance. In B.T. Selkirk (Ed.), *Focus on Exercise and Health Research* (pp. 163-179). New York, NY: Nova Science Publishers, Inc.

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

Chapter 3: A Psychophysiological Approach to Understanding Superior Performance in Maximal Muscular Effort

Introduction

To achieve optimal sport performance, athletes benefit from physical preparation such as a warm-up; however, to get the edge on their competition, sport research has shown that prior to performance most athletes also engage in some type of mental preparation (McGowan et al. 2015; Tod et al. 2003; Tod et al. 2015). Throughout the sporting world, athletes employ a range of mental preparation strategies including imagery, positive self-talk, preparatory arousal, and attentional focus Shelton and Mahoney (1978) to prepare for competition to reach optimal levels of superior performance Krane and Williams (2006) resulting in spectators often mesmerized by great feats of superior human performance outcomes. Such mental preparation strategies come in many different forms and are often described as the cognitive, emotional, and behavioral strategies used to reach an ideal performance state involving an optimal psychological state and outcome of peak performance (Gould et al. 2009; Tenenbaum et al. 1995).

Arousal is a state of preparedness and includes an array of emotional energy, physical energy, neural activity, and associated physiological activity (Campos et al. 2004). Further, preparatory arousal is a technique that involves actively getting pumped up emotionally with the determination to increase one's arousal level Perkins et al. (2001) and was suggested to be the most effective strategy shown to enhance support and indicated by an earlier review conducted by (Tod et al. 2003). Depending on the nature of the sport or cognitive-motor challenge, the alteration of the level of

arousal of the performer will differ according to the demands of the task, with low arousal for tasks requiring fine motor control and reduced strength and high arousal for tasks demanding gross motor control and greater amounts of strength (Oxendine, 1970; Pineschi & Di Pietro, 2013). Consequently, athletes' ability to produce maximal skeletal performance can be critical for success in sports such as karate, track and field, swimming, rugby, gymnastics, powerlifting, weightlifting and football.

Further, arguments can be made that the most important factor contributing to high levels of performance is attention to the right things at the right time (Janelle & Hatfield, 2008). Attentional focus is described as an individual using conscious effort to focus their attention by incorporating direct thoughts with the intent to perform a motor skill (Benz et al. 2016). Throughout the literature, the concept of attentional focus is subdivided into two types of focus: internal focus and external focus (Wulf & Prinz, 2001). However, this is beyond the scope of this research project as we did not provide instructions or manipulate internal vs. externally focusing.

Psyching, is defined as an athlete-directed cognitive strategy implemented prior or during movement execution using a combination of cognitive strategies intended to modify arousal, attentional focus and confidence meant to enhance psychomotor performance (Brody et al. 2000; Hardy et al. 1996; Perkins et al. 2001; Tod et al. 2003; Tod et al. 2015). Prior findings within the sport psychology literature have shown positive effects for the use of psyching on maximal muscular strength (Caudill & Weinberg, 1983; Elko & Ostrow, 1992; Gould et al. 1980; Lee, 1990; Shelton & Mahoney, 1978; Theodorakis et al. 2000; Tod et al. 2005; Tynes & McFatter, 1987; Weinberg et al. 1980; Whelan et al. 1990; Wilkes & Summers 1984).

Further, when instructed to give maximal effort while performing a movement, individuals must concentrate all of their cognitive resources required for the task and limit external distractions which could be revealed by alterations in the central nervous system (Weiss et al. 1995). However, the psychobiological underpinnings of the benefits of psyching remain unclear (McGuigan et al. 2005; Tod et al. 2015) although literature has shown that conscious cognitive approaches are essential for effective performance preparation (Arvinen-Barrow et al. 2007; Herman et al. 2012; McGowan et al. 2015).

A seminal model, the psychomotor efficiency hypothesis was introduced by Hatfield and Hillman (2001) as a special case of general efficiency of different biological systems involving neural effort, motor unit recruitment, and energy expenditure on superior motor performance. More specifically, regarding neurophysiological activity, the model suggests that high levels of performance described by a decrease in nonessential input to the essential motor preparatory processes, as displayed by an inhibition of task-unrelated processes across the cerebral cortex while a simultaneous heightening occurs in the cortical regions that are associated with task-related processes resulting in net efficiency (Hatfield et al. 2020). Further, enhanced performance will be supported by a decrease in overall neural effort due to a reduction of task-unrelated activity (Hatfield & Hillman, 2001).

Investigating efficiency during motor performance can be achieved via electroencephalography (EEG), a technique that enables researchers to assess cerebral cortical patterns of activation (Hatfield et al. 2004; Hatfield & Kerick, 2007). Further, many prior investigations have focused on alpha frequency (8-12 Hz) which has been

revealed to suggest active cortical inhibition (Klimesch et al. 2007; Klimesch, 2012). An understanding of the positive effect of cognitive strategies on performance is improved efficiency described as an athlete's ability to reach superior performance with minimal resources. Specifically, increased cortical activation in motor regions (increased efficiency of the distribution of neural resources) of the cerebral cortex would promote heightened recruitment of motor units leading to enhancements of the primary movers, resulting in performance (elevated force production). Grounded within and expanding on the general neural efficiency hypothesis Hatfield and Hillman (2001), a model that further describes the balance between task-related and task-unrelated activity is the gating-by-inhibition model (Jensen & Mazaheri, 2010). This model suggests that cortical alpha controls regional activity in the cerebral cortex by diverting activation away from regions exhibiting greater alpha power i.e., increased inhibition and moves activation towards cortical regions displaying diminished alpha power i.e., release of inhibition. Prior research focusing on alpha oscillations and elite athletes has characterized superior performance as a decrease in alpha power in central regions (Babiloni et al. 2008; Cook et al. 2014, Gallicchio et al. 2016; Gallicchio et al. 2017) and an increase in alpha power in temporal and occipital regions (Hatfield et al. 1984; Gallicchio et al. 2016; Kerick et al. 2001).

Complimentary, to the measure of alpha oscillations, the electrical activity generated by muscle fibers can be measured from electromyographic (EMG) (Fridlund & Cacioppo, 1986) and is an estimation of neural drive to the muscle (Babault et al. 2002) with surface EMG (sEMG) being the most common method to record muscle activity in sport studies (De Luca, 1997; Farina et al. 2010). To

optimally produce muscle force, two neuromuscular mechanisms are needed, motor neuron recruitment and rate coding (Enoka et al. 2017). The force generating ability of a muscle is dependent on many variables including: muscle mass, muscle fiber type and activation of the selected muscle (Pincivero et al. 2003). Prior studies have shown that the relationship between EMG and muscle force is proportional to one another (De Luca, 1997; Konrad, 2006).

Building on the phenomenon from our previous research (see Chapter 2) showing task-related attentional focus (psyching) to be beneficial to performance, the aim of this study was to further our understanding of the mechanisms of effect of the task-related attentional focus strategies by examining cortical activity, muscle activity and motor performance during a maximal exertion knee extension. What distinguishes that elite athlete from their teammates and competitors. More specifically, what enables elite athletes to efficiently achieve superior motor performance. Further, in this experimental study, whether the psychomotor efficiency and alpha gating can help to understand why and if psyching enhances performances of elite athletes was explored. We utilized the research processes from Chapter 2 by manipulating the preparatory cognitive strategies of elite athletes as a means to shift the balance between task-related (motor) and task-unrelated (non-motor) regions during performance of maximal concentric isokinetic knee extensions.

Psychophysiological (psychological + physiological + kinetic) measures were examined for the entirety of the study. To date, most research related to elite athletes has focused primarily on precision sports and submaximal effort tasks when examining electroencephalography (EEG) and electromyography (EMG) activity.

Thus, to investigate the cognitive state of elite athlete human performance, we employed a multidimensional approach to identify the psychophysiological underpinnings of psyching across the multiple biological systems involved including skeletal motor performance, neuromuscular activation and cerebral cortical activation utilizing: peak torque of isokinetic concentric knee extension, electromyography (EMG), and electroencephalography (EEG).

Based on the findings of Chapter Two and in line with previous literature (Tod et al. 2015), we hypothesized that psyching (PSY) compared to distracting attentional strategies mental arithmetic (MA) and reading comprehension (RC) would be related with improved maximal motor performance as indicated by greater torque output.

Expanding the results of our prior work (see Chapter 2) and grounded within the psychomotor efficiency hypothesis and gating-by-inhibition model, we predicted that during superior performance, the use of task-related attentional focus (i.e., psyching (PSY) would distribute neural resources displaying a regional pattern of EEG alpha with reduced alpha power in the task-related (motor) regions and greater alpha power in task-unrelated (non-motor) regions.

Additionally, and contingent on support of the above listed hypothesis we hypothesized that psyching (PSY) would be associated with increased neuromuscular activity as indicated by mean surface integrated electromyography (iEMG) activity of the quadriceps muscles i.e. rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) compared to distracting attentional strategies (MA, RC).

Additionally, several measures of subjective rating were used prior and after the execution of the knee extension as manipulation checks. We hypothesized that prior to the task, ratings of motivation (MO) to perform to the best of one's ability on the mental task would not differ between attentional strategies (PSY, RC, MA). Prior to the task, ratings of motivation (MO) to perform to the best of one's ability on the physical task (knee extension) would not differ between attentional strategies (PSY, RC, MA). Perceived effort (PE) during the physical task (knee extension) would be greater for the task-related attentional focus strategy (PSY) compared to distracting attentional strategies (RC, MA). Ratings of attentional focus (AF) on the physical task (knee extension) during the preparatory period of mental preparation (PSY) would be greater compared to the distracting attentional strategies (RC, MA). Lastly, ratings of attentional focus (AF) on the mental task during the preparatory period would not differ between attentional strategies (PSY, RC, MA).

Methods

Participants

Fifteen healthy participants (age: $M = 20.26$ years, $SD = 1.03$, $range = 19 - 22$) were recruited from the student population of the University of Maryland, College Park. All participants reported a minimum of one year of strength training experience ($M = 7.40$ years of training). (see Table 3.1) Participants training status was identified as "advanced" (corresponding to a highly trained athlete) through the National Strength and Conditioning (NSCA) classification system for resistance training. This classification was based on participants' current training program, years of experience, training frequency per week, and the physical training stress and

technique experience (Harman et al. 2008). Further, participants were characterized as expert (highly trained) athletes based on the requirements set by Swann et al. (2015) i.e., competing at the regional, university, semi professional or higher level. Participants were characterized by a mean height of 188.19 cm ($SD = 5.37$, $range = 179.5 - 198.2$) and mean body weight of 116.20 kg ($SD = 22.31$, $range = 71.0 - 143.3$). Additionally, all participants were right-handed (laterality quotient $>+40$ on the Edinburgh Handedness Inventory; Oldfield, 1971), right-leg dominant, based on preferences when kicking a ball through a goal post Wyatt and Edwards (1981), stepping up onto a step, and recovering from a small perturbation from the back (Hoffman et al. 1998). Participants reported no history of psychiatric, psychological, or neurological disorders, or cardiovascular, pulmonary or musculoskeletal conditions that would impact the ability to exercise, no use of illicit drugs, or feeling unable to comply with the study's protocol. All participants were informed that they may cease their participation at any point during the study and that they would be under no obligation to continue until the end. Each participant was compensated with \$25 for their participation: \$5 at the completion of the familiarization session (visit I) and \$20 at the completion of the experimental session (visit II). All participants provided their consent before participating in this experiment, which was approved by the university's Institutional Review Board and Ethical Committee, in accordance with the Helsinki Declaration (IRBNET Package: 1235039-2) before data collection was conducted.

Table 3.1.
Demographic Information of Participants

No. of Participants, N	15
Gender	
Male	15 (100%)
Female	0 (0%)
Age, years	20.26 ± 1.03
Height (cm)	188.19 ± 5.37
Weight (kg)	116.20 ± 22.31
Frequency (week)	4 ± 0
Training	High
Strength Training (years)	7.4 ± 1.12

Note. Data are presented as mean ± standard deviation unless otherwise indicated.

Study Design

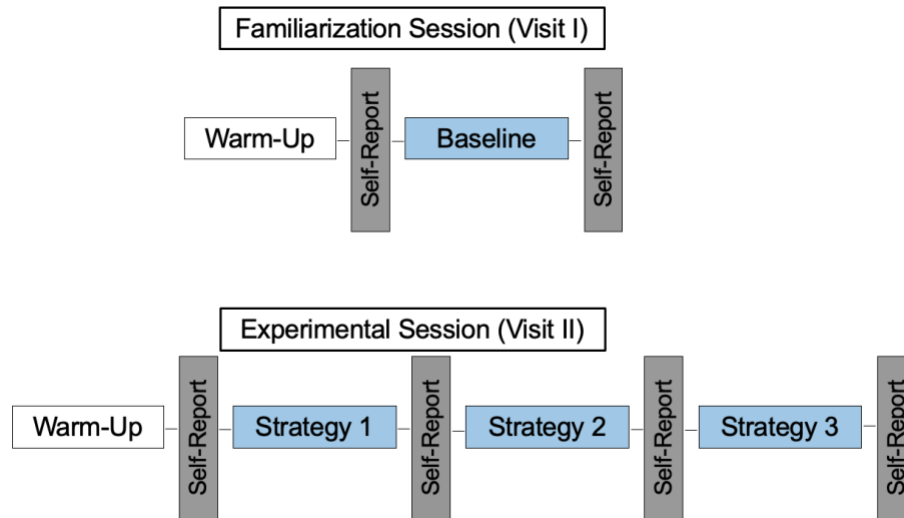


Figure 3.1. A representation of the study design for the familiarization session (visit I) that is described within the procedures.

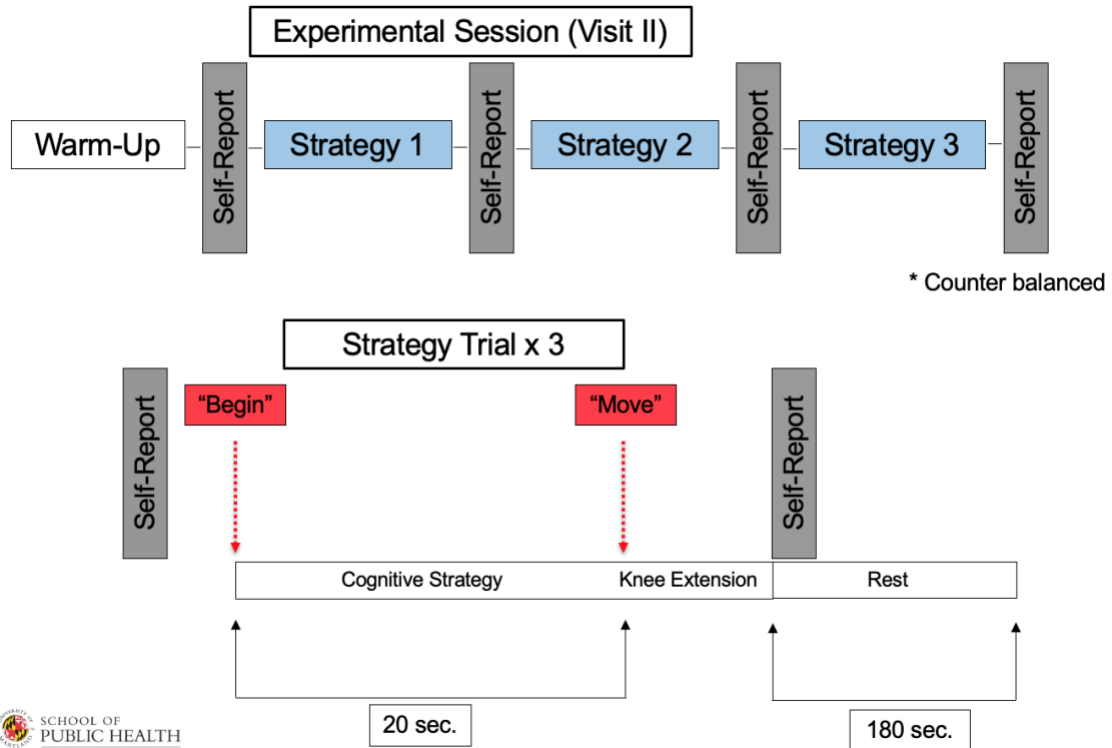


Figure 3.2 A representation of the study design for the experimental session (visit II) that is described within the procedures.

Procedures

Knee Extension Task

The task consisted of performing isokinetic concentric maximal contractions of the right leg quadriceps through a range of approximately 90 degrees of knee extension (i.e., similar to a single-leg extension exercise) from the seated position. Participants were instructed to passively return their leg to the starting position during the knee flexion phase of the movement to minimize muscular effort outside the extension phase. Each contraction was preceded by a 20-second preparatory period. Participants were instructed to keep their arms relaxed and hands in their lap to ensure that no additional forces contributed to performance measures Cannon et al. (2007) and to keep their eyes open and remain as motionless as possible prior to the knee

extension during all trials. Participants were instructed and reminded to exert maximal effort on the knee extension task for each contraction (trial). No performance feedback (e.g., participants were blinded to the torque values they were generating) was provided because of prior studies indicating effects on isokinetic torque Campenella et al. (2000) or verbal feedback or encouragement due to the effect on force production (Marchant & Greig, 2017). Directly after each maximal effort trial, a 180-second rest period was given to minimize fatigue Abeln et al. (2013); Calatayud et al. (2016) as prior literature has suggested at least 60 seconds of rest to recover when completing a standard isokinetic strength test Parcell et al. (2002) or between trial rest periods recommended to be three minutes in length Nuzzo et al. (2019) for full recovery.

For each recording session (visit I and visit II) the preparation for the task followed the following protocol. In accordance with the manufacturers' guidelines, each participant was seated and secured by five straps on the chair of the dynamometer (lower leg, upper leg, waist, and two across the chest) to prevent unwanted movements other than right knee extension. (see Figure 3.3) The dynamometer orientation was set to 90 degrees, the dynamometer tilt was set to 0 degrees, the seat orientation was set to 90 degrees, and the seat back tilt was set to 70 - 85 degrees. Next the dynamometer was calibrated by using the right leg, the axis of the dynamometer lever arm was measured and visually aligned at the lateral epicondyle of the knee. The length of the lever arm was adjusted for participant comfort. The range of movement was standardized to the participant's full range of movement and the researcher(s) calculated the range of motion for total flexion, total

extension, the approximate 90 degree position and the total limb weight and the angular velocity was set to 180 degrees/second (submaximal) and 60 degrees/second (maximal) as isokinetic testing of quadriceps strength typically use an angular velocity of and 60 degrees/second (Dauty et al. 2018; Van Dyk et al. 2016).



Figure 3.3. The experimental set-up demonstrating a participant engaging in an experimental strategy while seated on the isokinetic dynamometer (Biodex® System 4 Pro).

Visit I (familiarization and baseline)

Interested individuals were asked to schedule a one-hour block for a familiarization and screening session at our lab at The University of Maryland, College Park, School of Public Health. During the screening, participants were administered a Background Health History Questionnaire, Physical Activity Readiness Questionnaire (PAR-Q), and Edinburgh Handedness Inventory. After providing informed consent, participants' descriptive characteristics were recorded. Measurements of head circumference andinion-nasion distance were recorded to provide the researchers with the correct EEG cap size and for appropriate placement on the participant's scalp during the experimental session (visit II). Prior research has suggested to complete at least a minimum of one familiarization session prior to experimental testing Maffiuletti et al. (2016) in order to maximize reliability.

During this session, participants completed a light warm-up consisting of dynamic stretching conducted by the researchers adopting a protocol validated in previous studies by our group (See Chapter 2.). Then, participants completed five trials of submaximal and four trials of maximal isokinetic concentric knee extensions while their peak torque output was recorded. (see Figure 3.1) The last three maximal trials were averaged to obtain a baseline measure of peak torque output. The baseline was identified as "BL" and the trial # was identified as "01". Participant naming conventions are: "MPBDX_ID#_Condition_Trial#". Therefore, the first participant was identified as "MPBDX_01_BL_01" for baseline, trial one data. Maximum effort was taken by the researchers to ensure the comfort and safety of all research participants.

Upon completion of the familiarization session (visit I), participants were scheduled for the experimental session (visit II) which occurred no less than 48 hours later. Participants were instructed to schedule a three-hour block for the completion of the experimental session (visit II). Participants were informed prior to the experimental session (visit II) and encouraged to maintain normal dietary, sleeping patterns and to abstain from non-planned strenuous exercises for a minimum of twenty-four hours prior to the experimental session (visit II). To control the influence of external factors, the experimental session was administered by the same researchers in the same laboratory, within The University of Maryland, College Park, School of Public Health.

Visit II (experimental testing)

Participants were identified using the same ID# used during the familiarization session (visit I). Participants completed the same light warm-up protocol used for visit I. During this period, the researcher(s) entered the necessary data on the laboratory computers required to perform the experimental session. Then each participant was seated on the isokinetic dynamometer and instrumented for the psychophysiological recording described below. Researchers applied conducting gel to all EEG sites via a blunt-tipped medical syringe. Researchers prepared the skin and applied six flat-electrodes (SEMG) to the quadriceps muscle of the right leg. Participants' skin was dry-shaved and cleaned with an alcohol swab prior to electrode placement. Additionally, researchers attached to the ankle pad of the dynamometer the inertial data MTw IMU (XSENS, The Netherlands) sensor however, due to technical difficulties it was later determined that this device was unable to be utilized

with data analysis for a few participants. Prior to performance of the leg extension task, EEG activity was recorded for two resting periods, one with eyes closed (EC) and the other with eyes open (EO). The former was used to identify the individual alpha frequency, whereas the latter was used as a control condition for the experimental EEG recordings.

Then, participants completed three trials of the knee extension task for each of three attentional strategies (nine trials in total), as conducted by Brody et al. (2000). The order of the three cognitive strategies was counterbalanced to avoid carry-over effects. (see Figure 3.2) The attentional strategy instructions (see below) were written to be simple and appropriate to the task performed by participants. In total, researchers and participants spent approximately four hours of in-person contact time (familiarization and experimental sessions).

Cognitive Strategies

Participants were instructed to adopt a mental preparation consistent with one of three cognitive strategies – mental arithmetic (MA), reading comprehension (RC), or psyching (PSY) – for the 20 seconds before performing the maximal exertion knee extension task. The reading comprehension (RC) and mental arithmetic (MA) strategies were employed to distract participants from the physical task (knee extension). The attentional strategies were manipulated by the researchers by providing participants with different pre-recorded verbal instructions and tasks to perform during the 20 - second time interval prior to movement. The experimenter gave verbal prompts for the participant to “begin” the mental task and, 20 seconds later, to end it and “move” the leg to perform the physical task. All instructions

followed pre-recorded statements, which are reported in the supplemental material, to ensure consistency and to reduce experimenter bias.

To evaluate the compliance to the instructions of the distracting attentional strategy (RC) at the completion of each trial within the (RC) strategy, participants were asked, how many paragraphs were in the reading following trial one, how many words were in the reading after trial two, and how many paragraphs were in the reading following trial three. These compliance questions were used to ensure that participants were engaged for the duration of 20 seconds.

During the mental arithmetic (MA) strategy, participants were instructed to silently count backwards by 7 starting with the number 1000 and to verbally report the number they stopped on. Participants were encouraged prior to mental arithmetic to be as fast and accurate as possible and to remain engaged in the task for the full duration of the 20 seconds.

During the reading comprehension (RC) strategy, participants were instructed to silently read the provided passage (avg. 85 words) and to comprehend the reading in order to answer provided questions. Participants were engaged in the distraction conditions (MA, RC) as evident by verbal responses at the completion of each trial.

During the psyching (PSY) strategy, participants were instructed to focus on their leg muscles, to concentrate and be as prepared as possible for the physical knee extension task by getting themselves “psyched-up”.

Measures

Psychological variables

Motivation (MO). Prior to each trial of the knee extension task, participants reported how motivated they were to engage in the mental task (i.e., cognitive strategy) and to perform the subsequent physical task (i.e., knee extension) on a custom-built 100 mm Visual Analog Scale (VAS). Participants marked the scale with a pencil on the line at the location they felt best represented their current motivation state. The scale ranged from 0 (corresponding to “very low” to 100 (corresponding to “very high”). The ends of the line represented the opposite extremes of the same variable.

Attentional Focus (AF). Immediately following each trial (i.e., during the 180-second resting period between consecutive trials), participants were instructed to report the level of attentional focus put in the physical task (i.e., knee extension) and in the mental task (i.e., cognitive strategy) that they had just completed. Participants marked a 100-mm Visual Analog Scale (VAS) at the location they felt best represented their level of attentional focus ranging from 0 (corresponding to “completely distracted”) to 100 (corresponding to “very focused”).

Perceived Effort (PE). Immediately following each trial within each testing strategy, participants reported their level of perceived effort on a categorical scale adapted from Borg’s Rate of Perceived Exertion scale (Borg, 1978) that they had just completed. Participants circled with a pencil on the scale the rating they felt best represented their level of effort during the trial defined as how hard they had to drive

their leg to lift the “weight” (Moritani et al. 1987). The scale ranged from 6 (corresponding to “no effort at all”) to 20 (corresponding to “maximal effort”).

Kinetics

Peak torque output during the knee extension task was measured using an isokinetic dynamometer (Biodex® System 4 Pro). Additionally, the Biodex Isokinetic Dynamometer has been established to be a reliable instrument to measure isokinetic force (Alvares et al. 2015). The isokinetic dynamometer was pre-calibrated to the manufacturer's specifications, separately for each strategy (MA, RC, PSY). The set-up was individually adjusted for unilateral knee extension of the right knee and was held constant for every participant throughout the study.

Psychophysiological Recordings

All psychophysiological measures were recorded through BrainVision Recorder 2.0 (Brain Products GmbH, Germany) with a sampling rate of 1000 Hz.

Muscle Activity - Electromyography (EMG). The BrainVision Recorder software version 2.0 (Brain Products GmbH, Munich, Germany) was used to record surface electromyography (SEMG) activity of the right agonist muscle, quadriceps rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) which are primarily responsible for the extension of the leg, during movement (knee extension). Because of the deep location of the vastus intermedius (VI), sampling of this portion of the quadriceps (QF) was not measured due to methodical limitations. The electrode preparation and placement followed the Surface Electromyography for the Non-Invasive Assessment of Muscle (SENIAM) for Surface Electromyography (SEMG) (Hermens et al. 2000). To ensure quality sensor-skin contact and obtain quality

SEMG recordings, the researchers prepared the participants' skin by dry-shaving the quadriceps to remove hair over the electrode locations. The skin was then cleaned with an alcohol swab and researchers allowed the alcohol to dry before electrode placement. Researchers applied conducting gel to all six electrode sites via a blunt-tipped medical syringe.

While seated in the dynamometer chair, the participant was placed in the starting position to allow the researchers to determine the proper electrode location (anatomical landmarks) for each muscle. The inter electrode distance (center to center distance) of the recommended sensor location was 2 cm. The electrode orientation (position between) the two monopolar surface electrodes was parallel to the muscle fibers. The researchers used double sided rings to fixate the electrodes to the skin, and wires were taped to skin to prevent them from swinging. Researchers marked the location of two monopolar surface electrodes (RF) in accordance with SENIAM group recommendations. The mark was placed at 50% on the line from the anterior spina iliac superior to the superior portion of the right patella. The two monopolar surface electrodes (VL) were marked at 2/3 on the line from the anterior spina iliac superior to the lateral side of the right patella in accordance with SENIAM group recommendations. Additionally, two monopolar surface electrodes (VM) were marked and placed at 80% between the locations of the anterior spina iliaca superior and in a front location of the anterior border of the right leg medial ligament in accordance with SENIAM group recommendations.

After marking all locations, researchers verified the proper locations and attached all electrodes. The dynamometer set-up of the study precludes the ability to

measure the antagonist muscles during movement. To avoid inter-experimenter variations, the same researchers prepared and applied the electrodes for all participants. Moreover, it is worth noting that the main statistical analyses will be conducted within-participants, and, therefore, unintended montage differences across participants will have none-to-minimal impact on the findings. The common reference and ground will be the same used for EEG as was conducted by (de Morree et al. 2012). The extension of the knee will be used to indicate the initiation of movement and knee flexion will indicate the end of extension.

Cortical Activity - Electroencephalography (EEG). The actiCap EEG System with active electrodes, BrainAmp standard amplifier, and BrainVision Analyzer Recorder version 2.0 (Brain Products GmbH, Munich, Germany) were used to record the electroencephalographic (EEG) activity from 29 sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, C3, Cz, C4, T7, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2) in accordance with the international 10 - 10 system (Chatrian, 1985). Participants were fitted with a stretchable EEG cap. Researchers applied conducting gel to all sites via a blunt-tipped medical syringe. The electrocardiogram (ECG) was recorded from one active electrode placed below the left clavicle (unipolar configuration). One active electrode was placed at the outer canthus of the right eye to measure horizontal electrooculogram (HEOG) and one active electrode was placed just below the right eye over the orbicularis oculi muscle to measure vertical electrooculogram (VEOG). The system used a common ground at site AFz, and electrodes were placed on the left and right mastoids to be used for possible offline referencing. The EEG was recorded at a sampling rate of 1000 Hz (no

online filter) and electrode impedances were maintained below 10 k Ω .

Data Processing

Processing of the physiological data was conducted using customized MATLAB scripts (MathWorks, Natick, MA) supported by EEGLAB functions (Delorme & Makeig, 2004).

Muscle Activity

Muscle activity data recorded in mV were bandpass filtered 20-450 Hz (Finite Impulse Response, filter order = 2^{12}). The monopolar surface channels of the rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) were converted to bipolar single-differential signals. The signals were then full-wave rectified (i.e., absolute value). Visual inspection determined that the vastus lateralis (VL) would be used to detect kick initiation which was determined by the most significant EMG changes. The signals were epoched from (-5 to +1) s in one second bins relative to the initiation of the knee extension (i.e., 0 s = initiation of knee extension as detected through a voltage-change algorithm applied to the RMS EMG time series). Root-mean-squared (RMS) was computed on 20-ms moving windows to estimate the envelope of the signal. Finally, the RMS envelope was integrated over time for each of 1-s contiguous windows by computing the area under the curve in the time points corresponding to each bin to provide an estimate of motor unit activation in the unit of time.

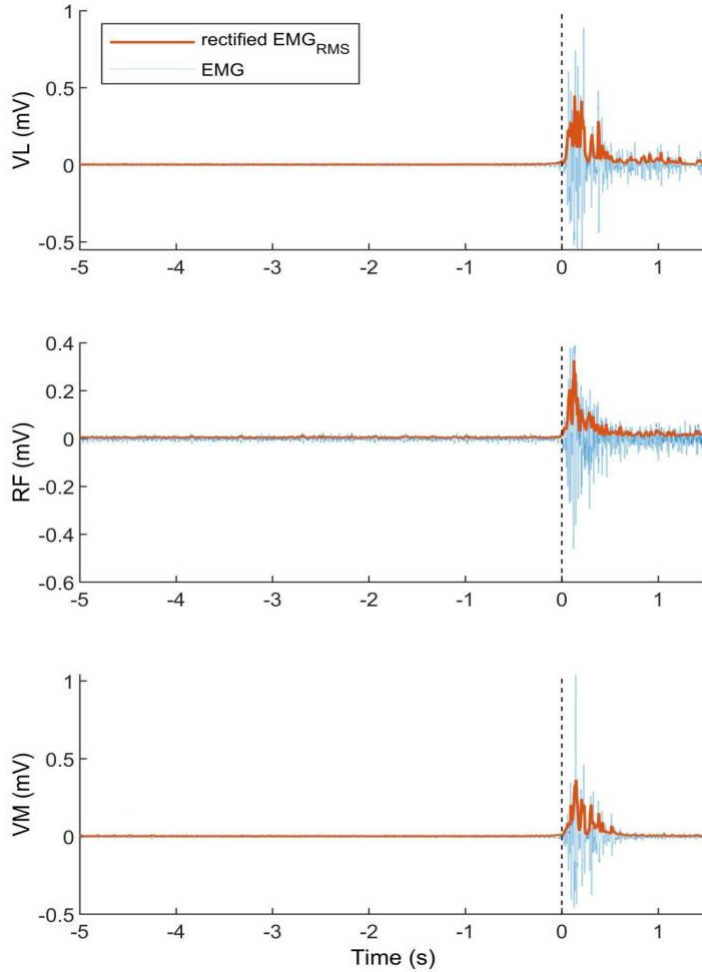


Figure 3.4. Representation of quadriceps rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) EMG activity during the 5 seconds pre movement and 1 second post movement.

Cortical Activity

The data were bandpass filtered 1-40 Hz (Finite Impulse Response (FIR) filter, order = 2^{12}) as implemented in EEGLAB and epoched from -20.25 to +0.25 s relative to the initiation of the knee extension (i.e., 0 s), which was identified by the burst of EMG activity. We visually inspected the signals to identify noisy epochs (i.e., showing gross artifacts) and bad channels (i.e., showing electrical noise).

Following visual inspection, no epoch, channels, or trials were rejected. Independent Component Analysis (ICA) was run through the “runica” infomax algorithm on

concatenated trials for each participant. Components associated with non-neural activity (i.e., eye movements, blinks, cardiac artifact) were rejected. The selection was informed on visual inspection of temporal data series, spectral power, and scalp topography of each component as well as on the output of the ICLabel algorithm (Pion-Tonachini et al. 2019). The signals were thoroughly checked to ensure that significant artifacts (e.g., eye-blinks, motor artifact) were excluded from subsequent analyses. The data was re-referenced to the average of all EEG channels.

Time-frequency decomposition was performed via MultiTaper short-time Fast Fourier Transform (MT st-FFT) over 0.5 second time windows (50% overlap) with middle points linearly spaced from -20 to 0 seconds for the preparatory conditions (with 0 s defined as the initiation of knee extension) and 50 to 70 seconds for the 2-min baseline condition. Each window was multiplied by Slepian tapers Prerau et al. (2017) and then zero-padded to reach a duration of 2 seconds. Finally, the Fourier coefficients were computed in the time-frequency plane with a temporal precision of 0.25 seconds and a spectral precision of 0.50 Hz.

Individualized Alpha Power. Power (μV^2) was computed as the squared absolute value of the (MT st-FFT) coefficient in each point of the time-frequency plane. Values were averaged across time to yield a measure for each of four 5-second time intervals (i.e., -20 to -15 s, -15 to -10 s, -10 to -5 s, and -5 to 0 s, with 0 s = initiation of knee extension) and across frequency to yield a measure in lower alpha (IAF-2 to IAF) and upper alpha (IAF to IAF+2) bands. Individual Alpha Frequency (IAF) was determined as the “center of gravity” for each participant applying the procedure described by Corcoran et al. (2018) to eyes-closed resting EEG baseline

parieto-occipital (O1, Oz, O2, Pz) channels recorded prior to experimental task. On average IAF was 10.46 Hz ($SD = 0.56$). Power values were finally log-transformed ($10 \cdot \log_{10}$).

Statistical Analysis

All statistical analyses were performed using a combination of IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, N.Y., USA), MATLAB (Mathworks, Natick, MA) and RStudio (RStudio, Boston, MA). We conducted a series of repeated-measure rmANOVAs, described below separately for each variable set. The Greenhouse-Geisser correction was applied and corrected degrees of freedom are reported in the presence of violation of the sphericity assumption. Paired-sample t tests with a False Discovery Rate (FDR) correction with $q = 0.05$ (Benjamini & Hochber, 1995) to contain Type I error, were employed to further evaluate effects of interest. Measures of effect sizes (partial eta squared η_p^2 and Cohen's d) are also reported when appropriate. Values of 0.02, 0.13, and 0.26 for η_p^2 and of 0.20, 0.50, and 0.80 for d were interpreted as small, medium, and large effects, respectively (Cohen, 1992). All criterion alpha levels were set to 0.05. All values were averaged across strategies to generate a single score for each of the strategies.

Psychological Variables

A series of repeated-measure rmANOVAs were conducted to assess participants' motivation (MO), attentional focus (AF), and perceived effort (PE) when engaging in the mental task and during the physical task. Motivation (MO) to engage in the mental task and the physical task were assessed, respectively, through a 3 Strategy (MA, RC, PSY) ANOVA and through a 4 Strategy (EO, MA, RC, PSY) ANOVA. Attentional focus (AF) during the mental task and in the physical task were

each assessed through a 3 Strategy (MA, RC, PSY) ANOVA. Perceived effort (PE) on the physical task was assessed through a 4 Strategy (EO, MA, RC, PSY) ANOVA.

Kinetics

To test for differences in maximal skeletal muscle performance of the isokinetic knee extension task peak torque (T_{kp}) between strategies were subjected to a 4 Strategy (BL, MA, RC, PSY) one-way repeated-measure (rmANOVA). The force characteristic measures consisted of peak torque (T_{kp}) output and was determined from the average of the trials (trial 1, trial 2, trial 3) of each strategy (MA, RC, PSY).

Muscle Activity

To assess for differences in muscular activation among the three strategies, the iEMG values were subjected to a 3 Strategy (MA, RC, PSY) x 3 Muscle (rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL)) x 2 Time (-1 to 0 s, 0 to +1 s, respectively corresponding to “pre” and “post” initiation of the knee extension) repeated-measures ANOVA.

Cortical Activity

To test for differences in cerebral cortical activation among the four strategies during the preparatory period, we conducted region-of-interest (ROI) and channel-based analyses, described below. The ROI analyses involved a 4 Strategy (EO, MA, RC, PSY) x 6 ROI (central, frontal, left temporal, right temporal, parietal, occipital) x 4 Time (-20 to -15 s, -15 to -10 s, -10 to -5 s, and -5 to 0 s relative to knee extension initiation) repeated-measure rmANOVA, separately for the lower and upper alpha frequency bands. ROIs were identified following preliminary topographical analysis to examine functional areas associated with different cognitive processes and ensure a

wide coverage of the cortex by averaging power across channels (frontal: F3, Fz, F4; central: CP1, Cz, CP2; left temporal: T7, FC5, F7; right temporal: T8, FC6, F8; parietal: P3, Pz, P4; occipital: O1, Oz, O2). Channel-based analyses involved a series of paired-sample t-tests between the PSY strategy and each of the other three strategies (EO, MA, RC) separately for each channel, time bin, and frequency band; the p-values associated with these tests were submitted to the False Discovery Rate correction ($q = 0.05$) to control for multiple comparisons.

Results

Manipulation Checks

Psychological Variables

Mean values and standard deviations for motivation (MO), attentional focus (AF), and perceived effort (PE) are reported in (see Table 3.2). The ANOVAs revealed no differences in the motivation to engage in the mental task across the three strategies (MA, RC, PSY), $F(2, 28) = 0.157, p = 0.855, \eta_p^2 = 0.011$, or in the motivation to engage in the physical task across the eyes-open control condition and the three strategies (EO, MA, RC, PSY), $F(1.711, 23.953) = 0.364, p = 0.779, \eta_p^2 = 0.025$.

No differences were revealed in the attentional focus allocated to mental task across the three strategies (MA, RC, PSY), $F(2, 28) = 0.503, p = 0.610, \eta_p^2 = 0.035$. However, a difference emerged for the attentional focus dedicated to the physical task across the three strategies (MA, RC, PSY), $F(1.453, 20.346) = 35.209, p < 0.001, \eta_p^2 = 0.716$. Post hoc analysis revealed that attentional focus on the physical task was

greater following the PSY strategy than following the MA ($p < 0.001$, $d = 2.076$) or the RC ($p < 0.001$, $d = 2.064$) strategy; instead, the MA and RC strategies were undifferentiated.

Perceived effort in the physical task differed across the four strategies (EO, MA, RC, PSY), $F(3, 42) = 19.624$, $p < 0.001$, $\eta_p^2 = 0.584$. Post-hoc analysis revealed that perceived effort was greater in the PSY strategy than the MA ($p = 0.003$, $d = 0.509$), RC ($p = 0.009$, $d = 0.336$), and EO control condition ($p = 0.002$, $d = 0.317$). In addition, perceived effort was greater in the EO control condition than in the MA ($p = 0.003$, $d = 0.509$), and RC ($p = 0.009$, $d = 0.336$) strategies. (see Table 3.2).

Table 3.2.

*Rating Motivation of each Measure as a Function of Attentional Strategy, Rating Attentional of each Measure as a Function of Attentional Strategy, Peak Torque (N*m) as a Function of Attentional Strategy, Rating of Perceived Effort (PE) on the Physical Task as a Function of Attentional Strategy, Electromyography (iEMG) (0 to +1)s as a Function of Attentional Strategy*

	BL	MA	RC	PSY
(MO) Cognitive	-	90.88 (7.58)	90.55 (9.50)	91.66 (8.56)
(MO) Physical	92.11 (6.66)	92.88 (5.58)	91.55 (8.29)	93.11 (4.95)
(AF) Cognitive	-	91.55 (8.32)	90.88 (6.23)	92.55 (5.97)
(AF) Physical	-	52.55 ^{a***} (27.29)	54.11 ^{a***} (26.36)	93.77 (6.59)
Peak Torque (N*m)	180.43 ^{a**} (39.35)	180.15 ^{a***} (36.85)	174.56 ^{a***} (34.87)	206.31 (40.41)
Perceived Effort (PE)	17.64 (2.28)	16.40 ^{a*** b**} (2.58)	16.80 ^{a*** b**} (2.69)	18.31 ^{b**} (1.93)
EMG (0 to 1)s	-	0.16 ^{a*} (0.10)	0.16 ^{a**} (0.10)	0.20 (0.12)

Note. Data are represented as Mean (SD) with the results from the one-way repeated-measures analysis of variance (rmANOVA).

BL = Baseline, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching, MO = Motivation, AF = Attentional Focus, PE = Perceived Effort

^a Significantly different from PSY.

^b Significantly different from BL

p < .05, **p < .01, ***p < .001

Motivation (MO)

Mental Task. The one-way ANOVA on Strategy (MA, RC, PSY) did not reveal differences for the motivation to perform the mental task among MA ($M =$

90.88, $SD = 7.58$), RC ($M = 90.55$, $SD = 9.50$), and, PSY ($M = 91.66$, $SD = 8.56$), ($F(2, 28) = 0.157$, $p = 0.855$, $\eta_p^2 = 0.011$).

Physical Task. The one-way ANOVA on Strategy (BL, MA, RC, PSY) did not reveal differences for the motivation to perform the physical task among BL ($M = 92.11$, $SD = 6.66$), MA ($M = 92.88$, $SD = 5.58$), RC ($M = 91.55$, $SD = 8.29$), and PSY ($M = 93.11$, $SD = 4.95$), $F(1.711, 23.953) = 0.364$, $p = 0.779$, $\eta_p^2 = 0.025$. (see

Figure 3.5)

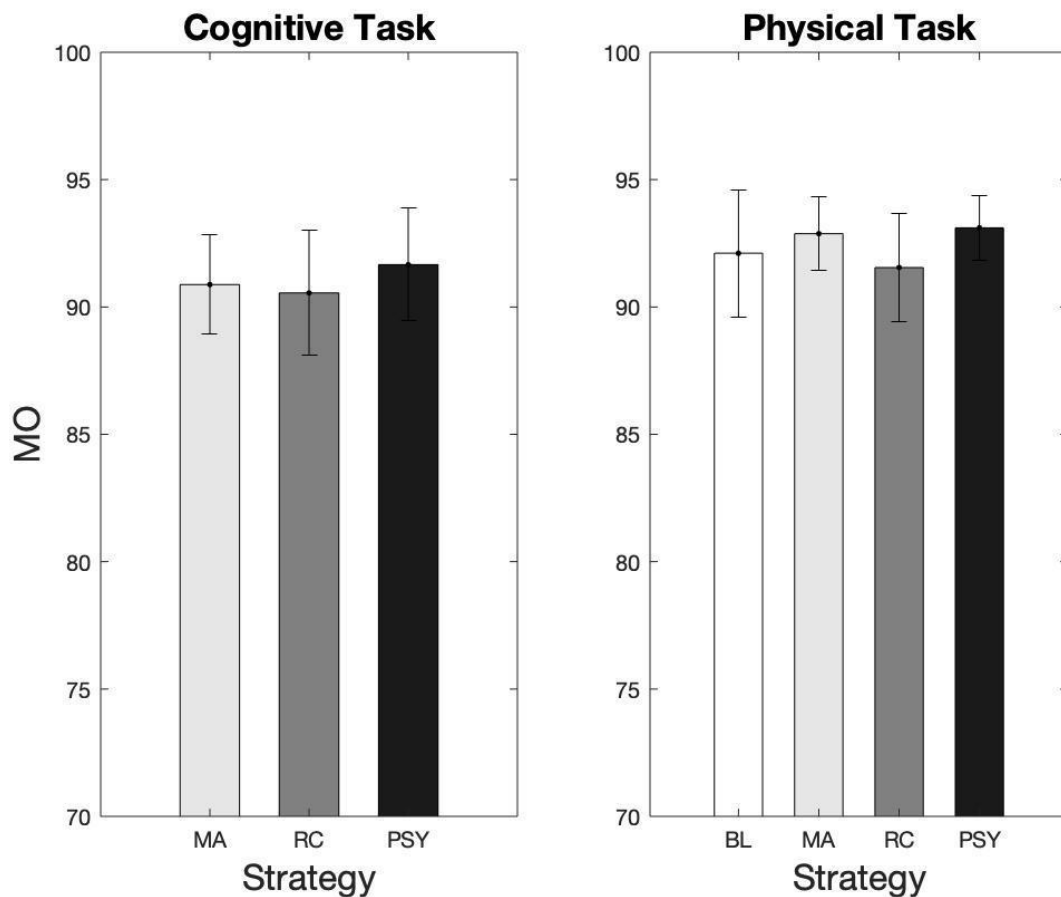


Figure 3.5. Motivation to perform the (physical and attentional strategy) task for the different experimental strategies. Higher scores correspond to higher ratings of motivation. BL = Baseline MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Attentional Focus (AF)

Cognitive Task. The one-way ANOVA on Strategy (MA, RC, PSY) did not reveal differences for attentional focus on the mental task among MA strategy ($M = 91.55$, $SD = 8.32$), RC strategy ($M = 90.88$, $SD = 6.23$), and PSY strategy ($M = 92.55$, $SD = 5.97$), ($F(2, 28) = 0.503$, $p = 0.610$, $\eta_p^2 = 0.035$).

Physical Task. The one-way ANOVA on Strategy (MA, RC, PSY) revealed a main effect for attentional focus on the physical task among MA strategy ($M = 52.55$, $SD = 27.29$), RC strategy ($M = 54.11$, $SD = 26.36$), and PSY strategy ($M = 93.77$, $SD = 6.59$), ($F(1.453, 20.346) = 35.209$, $p < 0.001$, $\eta_p^2 = 0.716$).

Post hoc analysis revealed that attentional focus on the physical task for the PSY strategy was significantly greater than both the MA strategy ($p < 0.001$, $d = 2.076$) and RC strategy ($p < 0.001$, $d = 2.064$). Results revealed that the MA and RC strategies were undifferentiated. (see Figure 3.6)

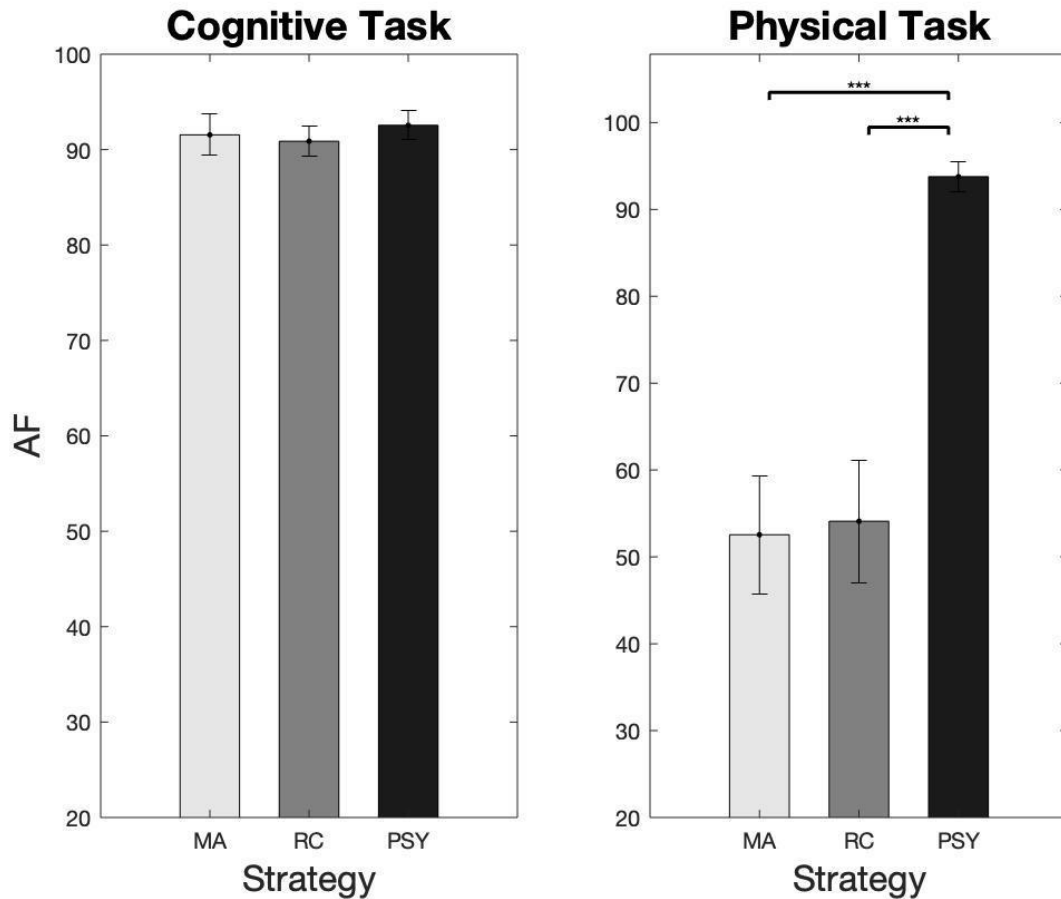


Figure 3.6. Report of level of attentional focus on the cognitive task and physical task (muscular task) for the different experimental strategies. Higher scores correspond to higher ratings of focus. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Perceived Effort (PE)

The one-way ANOVA on Strategy (BL, MA, RC, PSY) revealed a main effect for rating of perceived effort on the physical task among the three conditions among BL condition ($M = 17.64$, $SD = 2.28$), MA condition ($M = 16.40$, $SD = 2.58$), RC condition ($M = 16.80$, $SD = 2.69$), and PSY condition ($M = 18.31$, $SD = 1.93$), ($F(3, 42) = 19.624$, $p < 0.001$, $\eta_p^2 = 0.584$). Post-hoc analysis revealed that PE of the BL strategy was significantly greater than the distracting strategies MA ($p = 0.003$, d

= 0.509), RC ($p = 0.009$, $d = 0.336$), and was significantly less than the PSY strategy ($p = 0.002$, $d = 0.317$). Additionally, it was determined that the PSY strategy was significantly greater than both distracting strategies MA ($p < 0.001$, $d = 0.838$) and RC ($p < 0.001$, $d = 0.645$). (see Figure 3.7)

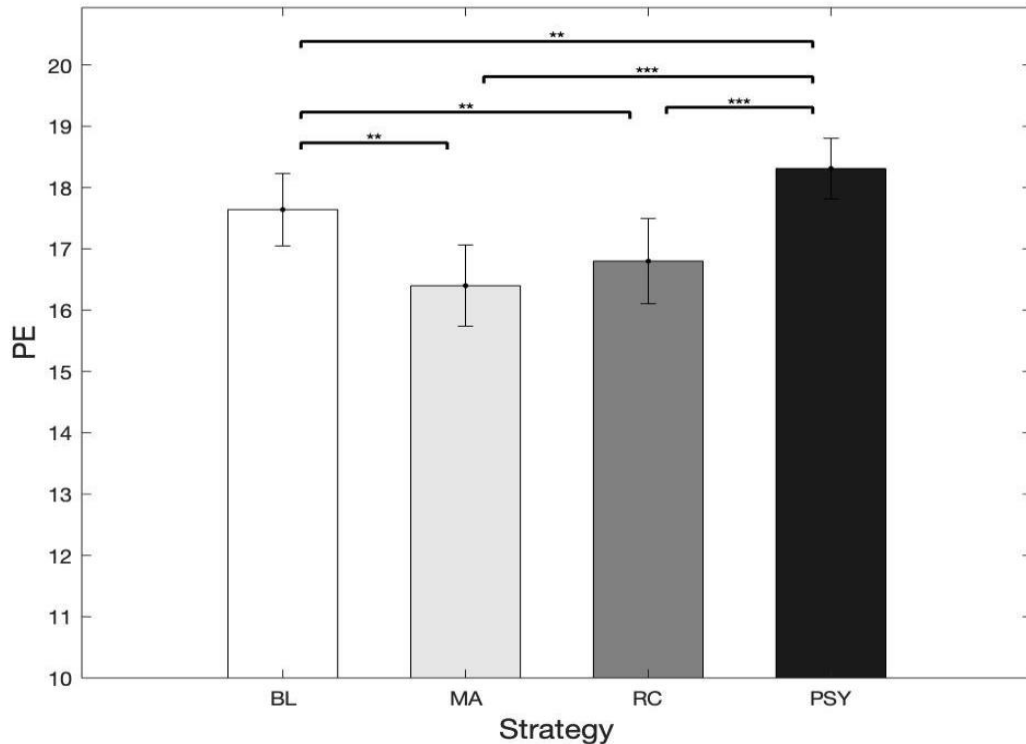


Figure 3.7. Perceived effort (PE) on the physical task for each experimental strategy. BL = Baseline, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Kinetics

The one-way ANOVA on Strategies (BL, MA, RC, PSY) revealed a main effect for torque output among BL strategy ($M = 180.43$, $SD = 39.35$), MA strategy ($M = 180.15$, $SD = 36.85$), RC strategy ($M = 174.56$, $SD = 34.87$), and PSY strategy ($M = 206.31$, $SD = 40.41$), ($F(2.071, 28.99) = 8.567$, $p = 0.001$, $\eta_p^2 = .380$). Post-hoc analysis further revealed a larger torque for the PSY strategy compared to BL strategy

($p = 0.004$, $d = 0.648$), MA strategy ($p < 0.001$, $d = 0.676$) and RC strategy ($p < 0.001$, $d = 0.841$). (see Figure 3.8)

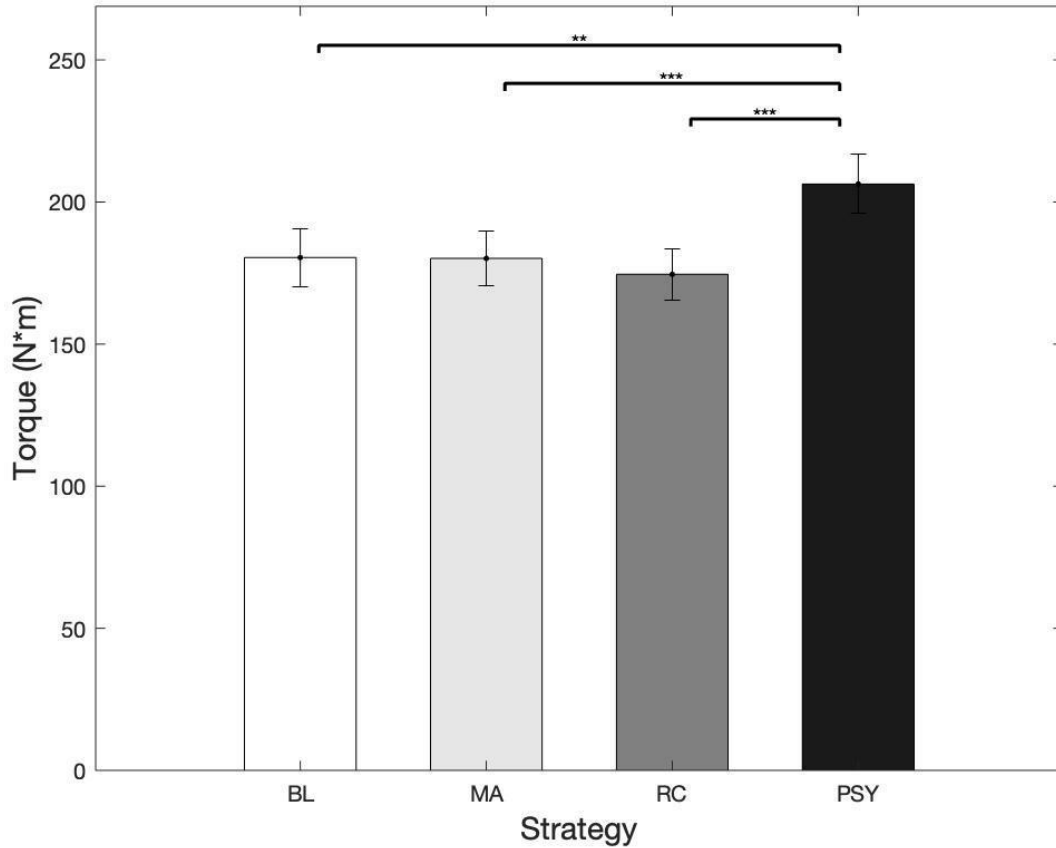


Figure 3.8. Behavioral performance (peak torque) for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Muscle Activity

To assess muscle activity, a 3 Strategy (MA, RC, PSY) x 3 Muscle (rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) x 2 Time (-1 to 0 s, 0 to +1 s) repeated measures ANOVA was conducted.

The repeated measure ANOVA on Strategy (MA, RC, PSY) from (-1 to +1) s revealed a main effect iEMG ($F(2, 28) = 7.520$, $p = 0.002$, $\eta_p^2 = .349$). Post-hoc

analysis revealed that iEMG of the PSY strategy exhibited greater iEMG compared to both the MA strategy (PSY > MA, $p = 0.012$, $d = 0.1736$) and RC strategy (PSY > RC, $p = 0.004$, $d = 0.1930$).

The repeated measure ANOVA on time revealed that iEMG between (-1 to 0 and 0 to +1) s was significantly greater during (0 to +1) s i.e. “post” compared to (-1 to 0) s i.e. “pre” ($F(1, 14) = 51.34$, $p < 0.001$, $\eta_p^2 = .786$). Post-hoc analysis revealed that iEMG of the PSY strategy exhibited greater iEMG compared to both the MA strategy (PSY > MA, $p = 0.012$, $d = 0.1736$) and RC strategy (PSY > RC, $p = 0.004$, $d = 0.1930$).

However, the main effect was superseded by a significant Strategy x Time interaction ($F(2, 28) = 7.646$, $p = 0.002$, $\eta_p^2 = .353$). Post-hoc analysis revealed that iEMG at (0 to +1) s, i.e. “post” was significantly greater among the PSY strategy ($M = 0.208$, $SD = 0.121$) compared to the MA strategy ($M = 0.167$, $SD = 0.107$), RC strategy ($M = 0.163$, $SD = 0.101$); (PSY > MA, $p = 0.014$, $d = 0.3589$; PSY > RC, $p = 0.002$, $d = 0.4037$). (see Figure 3.9), (see Figure 3.10), (see Figure 3.11)

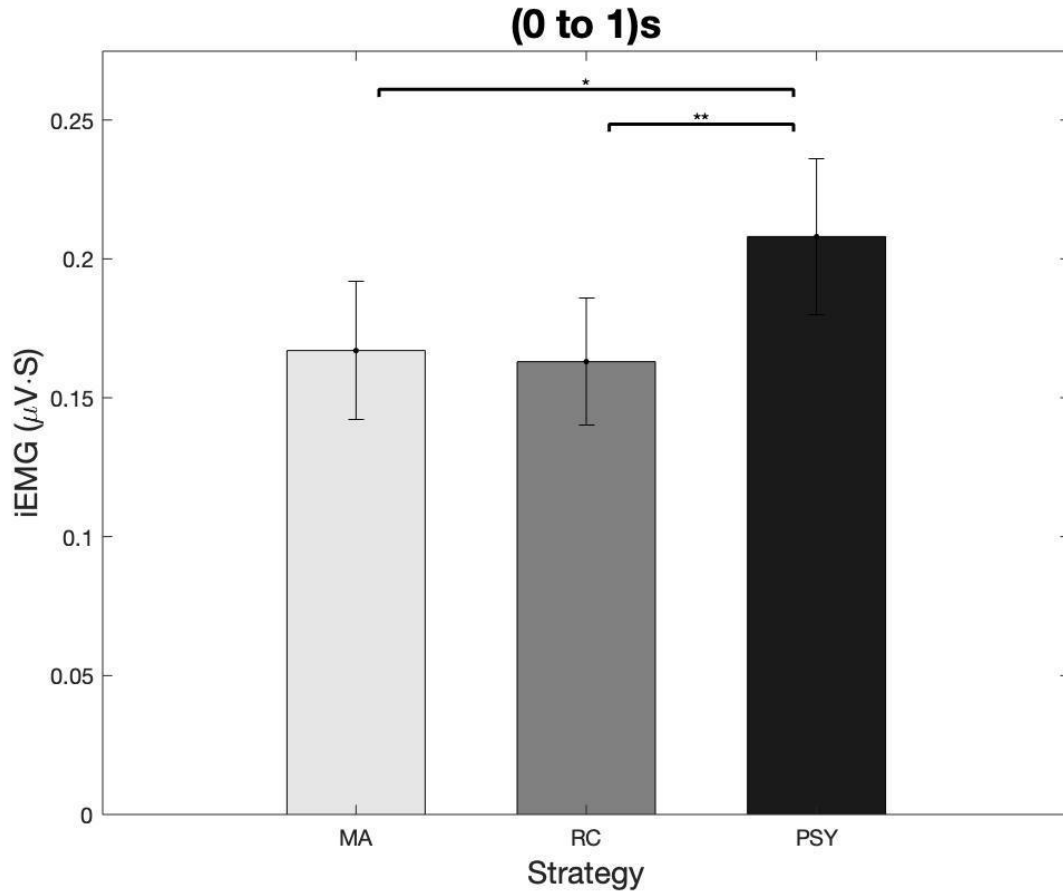


Figure 3.9. Integrated electromyography (iEMG) from (0 to 1)s post knee extension for the different experimental strategies. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

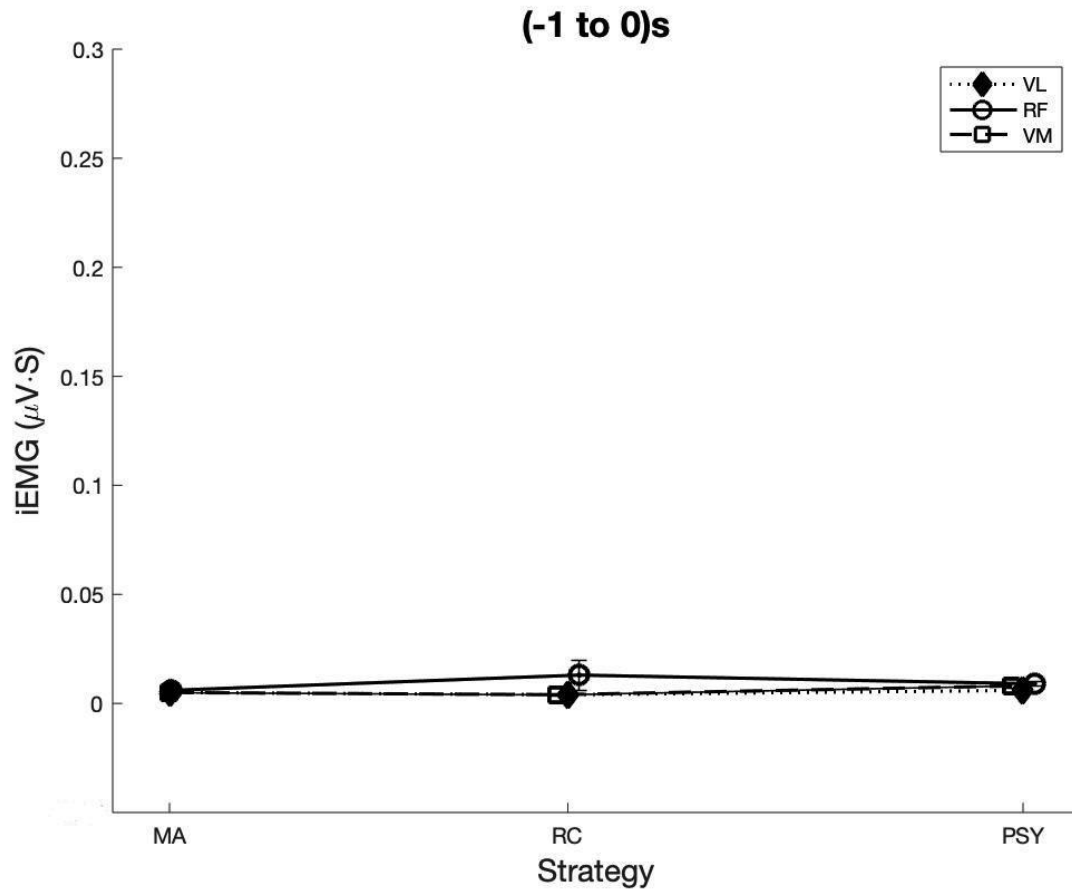


Figure 3.10. Integrated electromyography (iEMG) from (-1 to 0) s pre knee extension for the different experimental strategies. RF = rectus femoris, VM = vastus medialis and VL = vastus lateralis. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

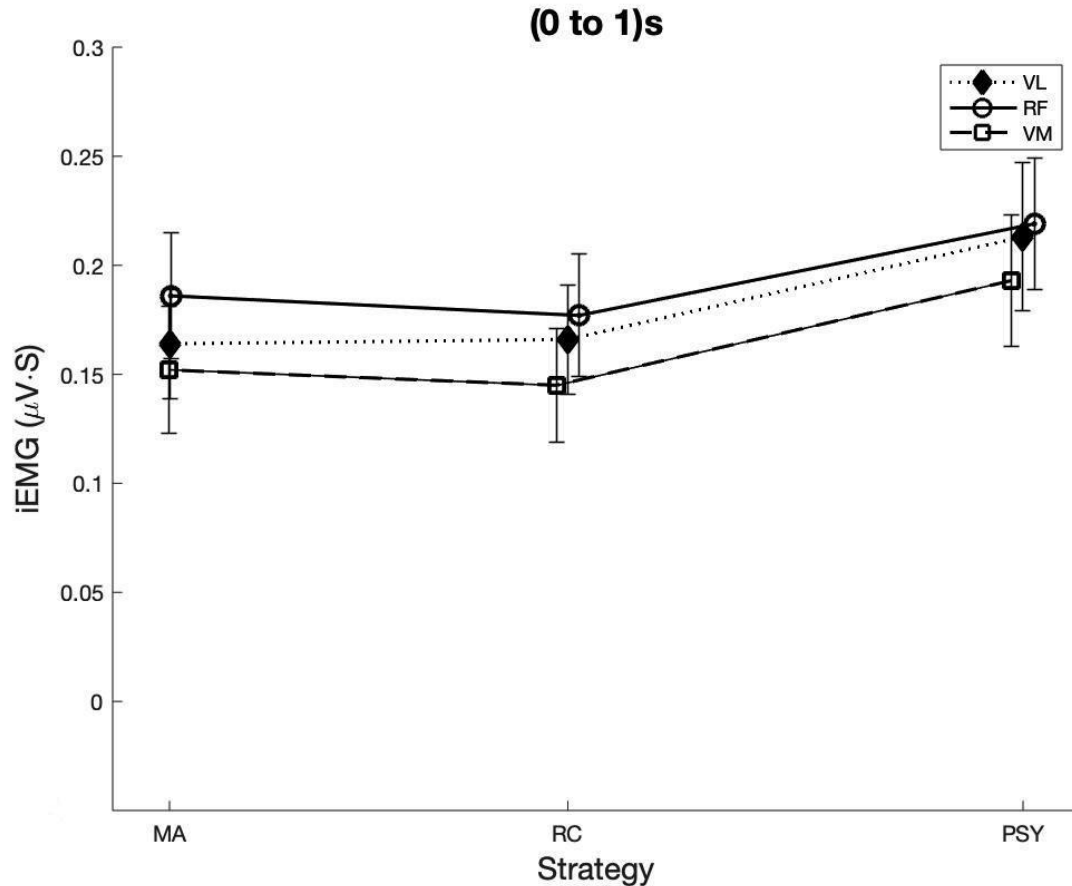


Figure 3.11. Integrated electromyography (iEMG) from (0 to 1) s post knee extension for the different experimental strategies. RF = rectus femoris, VM = vastus medialis and VL = vastus lateralis. MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Cortical Activity

Lower alpha power (IAF -2 to IAF)

The 4 Strategy x 6 ROI x 4 Time repeated-measure ANOVA revealed a main effect for Strategy, $F(3, 42) = 12.941, p < 0.001, \eta_p^2 = .480$, a main effect for ROI, $F(2.800, 37.197) = 14.693, p < 0.001, \eta_p^2 = .517$, a Strategy x ROI interaction, $F(15, 210) = 2.058, p = .013, \eta_p^2 = .128$, and a ROI x Time interaction, $F(15, 210) = 0.742, p = .047, \eta_p^2 = .110$. Mean values are reported in (see Table 3.3). In line with

our hypotheses and analytic strategy, we focused on the Strategy x ROI interaction by collapsing across the Time factor and conducting FDR-corrected post-hoc paired-sample t-tests between strategy pairs (see Figure 3.12). These tests revealed that lower-alpha power was significantly lower in the experimental strategies (MA, RC, and PSY) compared to the control EO strategy across all ROIs. FDR-corrected channel-based analyses (see Table 3.4) confirmed that lower-alpha power diminished from the EO control to the PSY strategy across numerous channels.

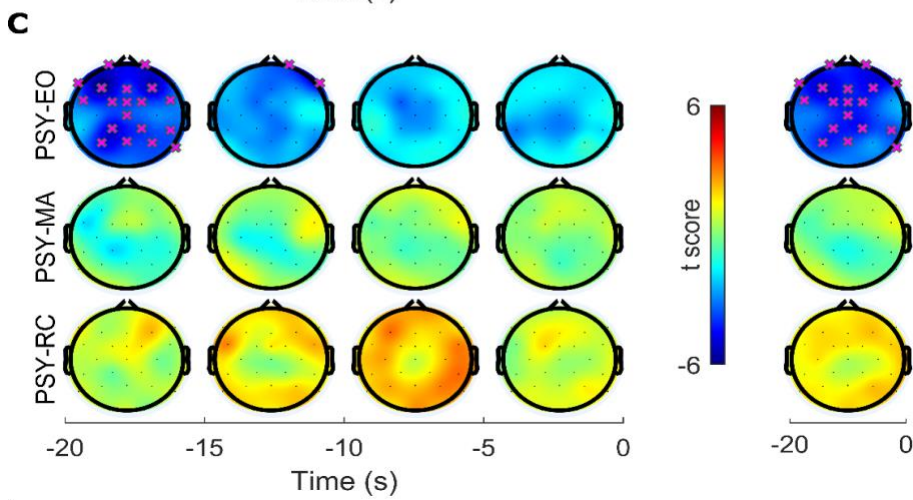
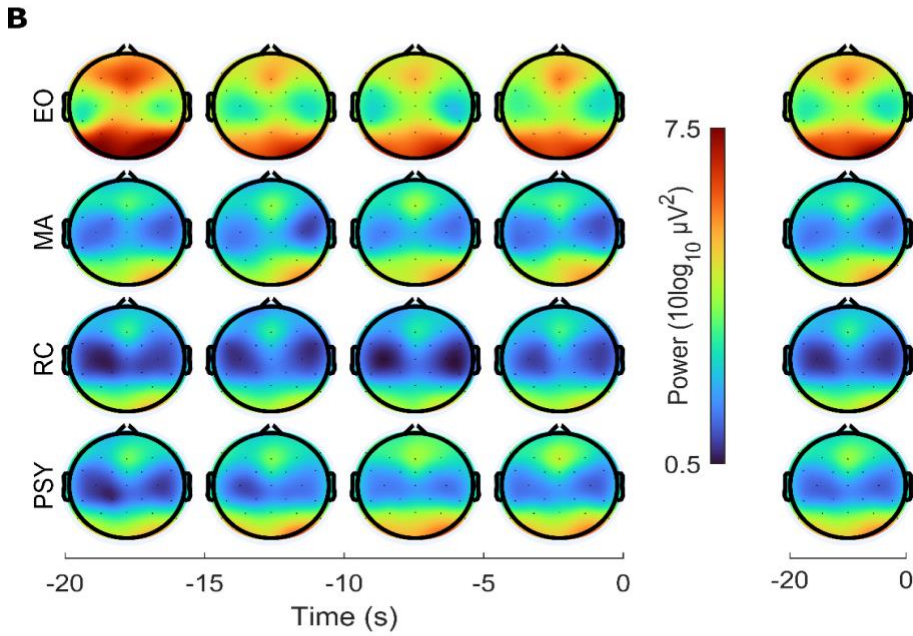
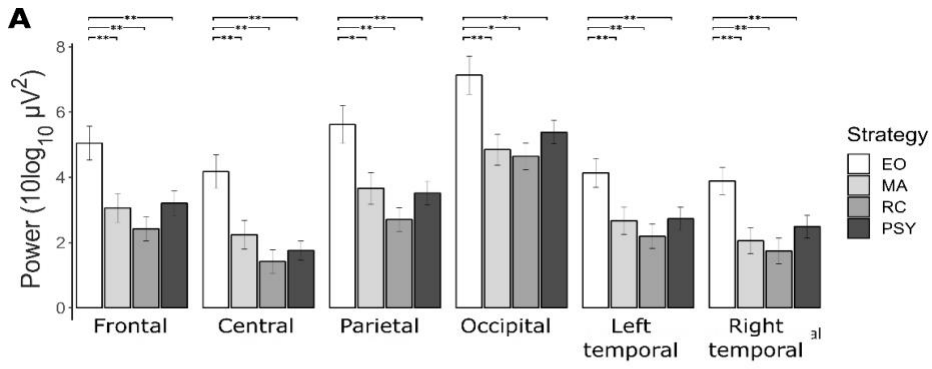


Figure 3.12.

Panel A: Lower Alpha Frequency (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T7, FC5, F7), right temporal (T8, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher's least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Panel C: EEG scalp maps of statistical values (t scores) comparing lower-alpha (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Table 3.3. EEG Lower alpha power (IAF-2 to IAF) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy

Note. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Time	EO	MA	RC	PSY
frontal	-20 to -15 s	6.00 (3.56)	2.97 (3.49)	2.42 (2.97)	2.84 (2.88)
	-15 to -10 s	4.71 (4.03)	3.00 (3.53)	2.30 (3.28)	3.04 (2.92)
	-10 to -5 s	4.61 (4.29)	3.20 (3.31)	2.37 (2.98)	3.45 (3.20)
	-5 to 0 s	4.88 (4.39)	3.08 (3.63)	2.60 (2.77)	3.50 (3.08)
central	-20 to -15 s	4.82 (4.09)	2.08 (3.40)	1.12 (2.71)	1.32 (2.04)
	-15 to -10 s	3.76 (4.21)	2.29 (3.45)	1.53 (3.00)	1.64 (2.15)

	-10 to -5 s	4.08 (4.11)	2.40 (3.62)	1.38 (2.74)	2.07 (2.47)
	-5 to 0 s	4.03 (3.77)	2.19 (3.46)	1.64 (2.82)	2.00 (2.46)
parietal	-20 to -15 s	6.47 (4.50)	3.42 (3.80)	2.79 (2.80)	2.94 (2.53)
	-15 to -10 s	5.22 (4.41)	3.47 (3.74)	2.62 (2.96)	3.39 (2.75)
	-10 to -5 s	5.38 (4.63)	3.99 (3.98)	2.58 (2.74)	4.00 (3.23)
	-5 to 0 s	5.40 (4.70)	3.79 (3.78)	2.84 (2.84)	3.73 (3.06)
occipital	-20 to -15 s	8.08 (4.85)	4.79 (3.25)	4.83 (3.31)	4.97 (2.72)
	-15 to -10 s	6.79 (3.93)	4.86 (4.14)	4.56 (3.38)	5.50 (2.81)
	-10 to -5 s	6.81 (4.35)	4.89 (3.87)	4.49 (3.14)	5.62 (3.14)
	-5 to 0 s	6.84 (5.18)	4.87 (3.80)	4.70 (3.17)	5.43 (2.73)
left temporal	-20 to -15 s	4.44 (3.29)	2.67 (3.14)	2.17 (3.14)	2.56 (2.75)
	-15 to -10 s	4.24 (3.67)	2.62 (3.52)	2.11 (3.00)	2.92 (2.95)
	-10 to -5 s	3.87 (3.69)	2.78 (3.33)	2.04 (2.84)	2.83 (2.79)
	-5 to 0 s	3.99 (3.49)	2.61 (3.46)	2.45 (2.77)	2.61 (2.77)
right temporal	-20 to -15 s	4.62 (3.55)	2.12 (3.17)	2.01 (3.04)	2.33 (2.72)
	-15 to -10 s	4.00 (2.91)	1.98 (3.09)	1.68 (3.34)	2.55 (3.11)
	-10 to -5 s	3.56 (3.31)	2.18 (3.23)	1.58 (3.15)	2.74 (2.65)
	-5 to 0 s	3.37 (3.53)	1.94 (2.98)	1.71 (2.85)	2.34 (2.68)

Table 3.4. Results of the FDR-corrected post-hoc t-tests (p -values and Cohen's d) conducted to examine strategy differences between strategies across regions for the lower alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Comparison	p_{FDR}	d
Frontal	EO > MA	.002	1.173
	EO > RC	.002	1.416
	EO > PSY	.002	1.317
Central	EO > MA	.004	1.034
	EO > RC	.002	1.254
	EO > PSY	.002	1.202
Parietal	EO > MA	.013	0.845
	EO > RC	.002	1.161
	EO > PSY	.007	0.931
Occipital	EO > MA	.003	1.074
	EO > RC	.014	0.824
	EO > PSY	.021	0.765
Left temporal	EO > MA	.002	1.162
	EO > RC	.002	1.199
	EO > PSY	.004	1.017
Right temporal	EO > MA	.002	1.187

EO > RC	.002	1.32
EO > PSY	.006	0.947

Upper alpha power (IAF to IAF +2)

The 4 Strategy x 6 ROI x 4 Time repeated-measure ANOVA revealed a main effect for Strategy, $F(3, 42) = 18.873, p < 0.001, \eta_p^2 = .574$, a main effect for ROI, $F(2.665, 37.312) = 14.008, p < 0.001, \eta_p^2 = .500$, and a Strategy x ROI interaction, $F(15, 210) = 5.555, p < .001, \eta_p^2 = .200$. Mean values are reported in (see Table 3.5). In line with our hypotheses and analytic strategy, we focused on the Strategy x ROI interaction by collapsing across the Time factor and conducting FDR-corrected post-hoc paired-sample t-tests between strategy pairs (see Figure 3.13). These tests revealed that, similarly for lower-alpha power, upper-alpha power was significantly lower in the experimental strategies (MA, RC, and PSY) compared to the control EO strategies across all ROIs. In addition, upper-alpha power was significantly greater for PSY than RC across all ROIs except for the central and left temporal. FDR-corrected channel-based analyses (see Table 3.6) indicated that the PSY strategy showed significantly lower upper-alpha power than the EO control strategy across numerous channels. Furthermore, these analyses also revealed a focal spatial trend whereby upper-alpha power was greater for PSY than RC in the channels surrounding, but not within, the central region.

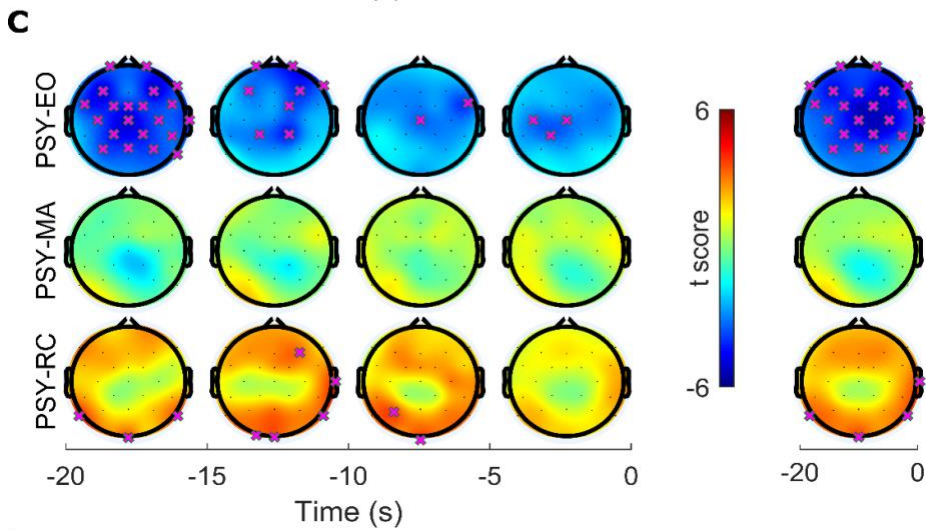
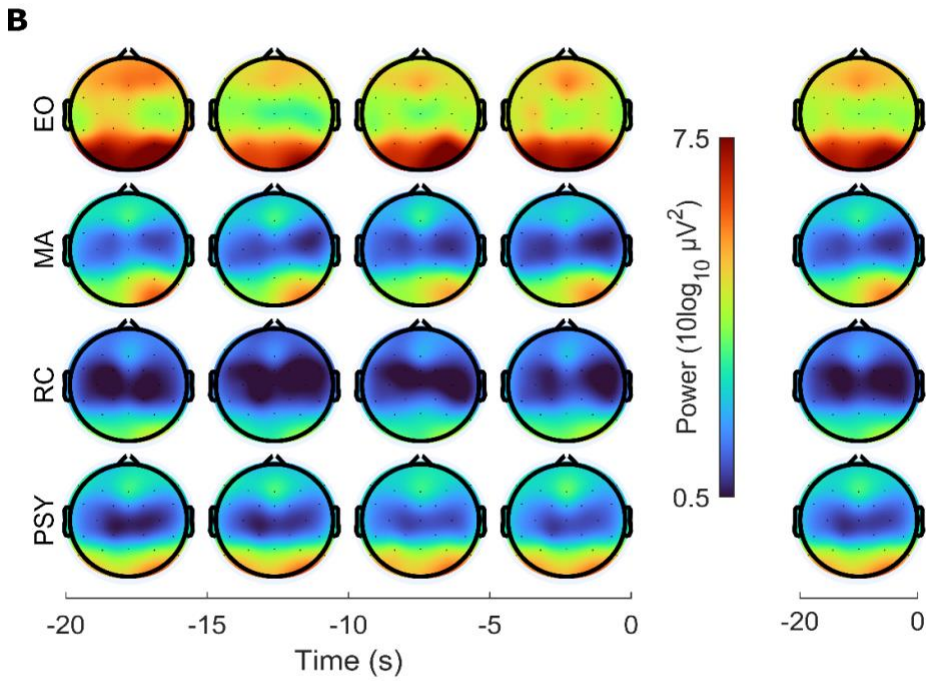
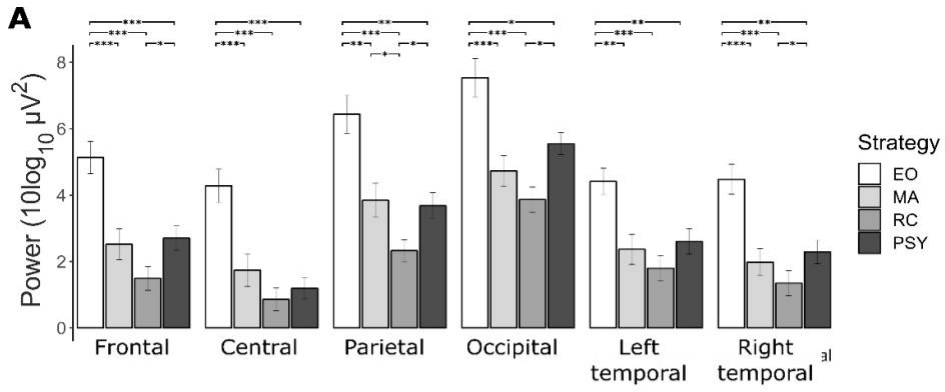


Figure 3.13

Note.

Panel A: Upper Alpha Frequency (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension. Six regions of interest (ROIs) were identified: frontal (F3, Fz, F4), central (CP1, Cz, CP2), left temporal (T7, FC5, F7), right temporal (T8, FC6, F8), parietal (P3, Pz, P4), and occipital (O1, Oz, O2). Fisher’s least-squared difference (LSD) post-hoc pairwise comparisons with a Benjamini-Hochberg correction (false discovery rate = 0.05) were employed to evaluate effects of interest. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching. Error bars are indicative of standard error. * $p < .05$, ** $p < .01$, *** $p < .001$

Panel B: EEG scalp maps of upper-alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) of the 20 s prior to knee extension initiation. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Panel C: EEG scalp maps of statistical values (t scores) comparing upper-alpha (IAF to IAF+2) power ($10\log_{10}\mu V^2$) during PSY with the values during EO, MA, and RC in the 20 s prior to knee extension initiation. Negative t scores indicate that PSY was lower, and positive values indicate that PSY was greater, than the other strategy. The symbol \times indicates that the t score was associated with $p < .05$ (with FDR multiple-comparison correction). This analysis was conducted for exploratory purposes only. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching.

Table 3.5. *Upper alpha power (IAF to IAF +2) power ($10\log_{10}\mu V^2$) mean (standard deviation) averaged in five time bins, separately for each region and strategy. Data are presented as mean \pm standard deviation, unless otherwise indicated. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching*

ROI	Time	EO	MA	RC	PSY
frontal	-20 to -15 s	5.64 (3.68)	2.71 (3.77)	1.59 (2.80)	2.62 (2.80)
	-15 to -10 s	4.79 (3.38)	2.61 (3.72)	1.20 (2.94)	2.72 (2.82)
	-10 to -5 s	4.95 (4.19)	2.41 (3.60)	1.51 (3.00)	2.66 (3.08)
	-5 to 0 s	5.16 (4.07)	2.34 (3.65)	1.68 (2.61)	2.81 (2.99)
central	-20 to -15 s	4.86 (3.96)	2.05 (3.95)	0.65 (2.77)	0.91 (2.32)
	-15 to -10 s	3.88 (4.12)	1.69 (4.01)	0.62 (2.81)	1.10 (2.31)

	-10 to -5 s	4.18 (4.04)	1.65 (3.97)	1.05 (2.70)	1.46 (2.71)
	-5 to 0 s	4.21 (3.73)	1.58 (3.76)	1.13 (2.78)	1.30 (2.52)
parietal	-20 to -15 s	6.93 (4.51)	3.97 (4.18)	2.36 (2.51)	3.34 (2.75)
	-15 to -10 s	5.87 (4.13)	3.65 (3.98)	2.09 (2.69)	3.66 (3.15)
	-10 to -5 s	6.53 (4.83)	3.87 (4.21)	2.33 (2.65)	4.01 (3.40)
	-5 to 0 s	6.43 (4.63)	3.90 (3.88)	2.52 (2.56)	3.71 (3.19)
occipital	-20 to -15 s	8.23 (4.99)	4.94 (3.73)	4.16 (3.15)	5.43 (2.43)
	-15 to -10 s	6.94 (4.23)	4.79 (4.11)	3.54 (2.99)	5.65 (2.59)
	-10 to -5 s	7.44 (4.02)	4.44 (3.62)	3.71 (2.81)	5.46 (2.55)
	-5 to 0 s	7.55 (4.95)	4.74 (3.37)	4.06 (2.97)	5.66 (2.80)
left temporal	-20 to -15 s	4.65 (3.17)	2.71 (3.47)	1.74 (3.28)	2.62 (2.90)
	-15 to -10 s	4.11 (3.06)	2.45 (3.75)	1.60 (3.14)	2.65 (3.30)
	-10 to -5 s	4.38 (3.26)	2.05 (3.55)	1.78 (3.05)	2.44 (3.05)
	-5 to 0 s	4.53 (3.09)	2.28 (3.59)	2.08 (2.82)	2.71 (2.95)
right temporal	-20 to -15 s	4.99 (3.70)	2.36 (3.48)	1.63 (3.09)	2.30 (2.72)
	-15 to -10 s	4.42 (3.31)	1.93 (3.05)	1.20 (3.18)	2.23 (3.28)
	-10 to -5 s	4.45 (3.61)	1.99 (3.27)	1.36 (3.02)	2.35 (2.66)
	-5 to 0 s	4.06 (3.59)	1.65 (3.04)	1.22 (2.73)	2.29 (2.37)

Table 3.6. Results of the FDR-corrected post-hoc t-tests (p-values and Cohen’s d) conducted to examine strategy differences between strategies across regions for the upper alpha band. Only significant post-hoc results are reported. EO = Eyes Open, MA = Mental Arithmetic, RC = Reading Comprehension, PSY = Psyching

ROI	Comparison	<i>p</i>_{FDR}	<i>d</i>
Frontal	EO > MA	< .001	1.566
	EO > RC	< .001	2.387
	EO > PSY	< .001	1.275
	PSY > RC	.023	0.73
Central	EO > MA	< .001	1.221
	EO > RC	< .001	1.755
	EO > PSY	< .001	1.235
Parietal	EO > MA	.002	1.13
	EO > RC	< .001	1.764
	EO > PSY	.006	0.937
	MA > RC	.040	0.645
	PSY > RC	.033	0.677
Occipital	EO > MA	< .001	1.508
	EO > RC	< .001	1.371
	EO > PSY	.020	0.755
	PSY > RC	.013	0.821

Left temporal	EO > MA	.002	1.092
	EO > RC	< .001	1.342
	EO > PSY	.007	0.912
Right temporal	EO > MA	< .001	1.612
	EO > RC	< .001	1.881
	EO > PSY	.002	1.072
	PSY > RC	.011	0.851

Discussion

The aim of study three was to further our understanding of the mechanisms of effect of the task-related attentional focus strategies by examining cortical activity, muscle activity and motor performance during a maximal exertion knee extension. More specifically, what enables elite athletes to efficiently achieve superior motor performance. Further, in this experimental study, whether psychomotor efficiency and alpha gating can help to understand why and if psyching enhances performances of elite athletes was explored. In this experimental study, we manipulated the preparatory cognitive strategy as a means to shift the balance between task-related (motor) and task-unrelated (non-motor) regions during performance of a psychomotor task.

To further understand changes in musculoskeletal performance as a result of psyching, we employed a multidimensional approach (psychological + psychophysiological + kinetic) to identify the psychophysiological underpinnings of

task-related attentional focus (psyching) across the multiple biological systems. By employing the measures of electroencephalography (EEG) - cortical activity, electromyography (EMG) - muscle activity, and isokinetic dynamometry - peak torque during maximal exertion to achieve peak torque of a dynamic knee-extension skeletal muscle action. To our knowledge, this is the first study to investigate task-related attentional focus i.e., psyching on superior human performance using a multidimensional approach to better understand the influence of elite athletes' (i.e., highly trained) use of cognitive strategies (PSY) on behavioral / kinetic (i.e., torque output) muscular (i.e., EMG) and cortical (i.e., EEG) activity during a maximal effort isokinetic knee extension task.

We hypothesized that during superior performance, the utilization of the psyching (PSY) strategy would distribute neural resources displaying a regional pattern of EEG alpha with reduced alpha power in the task-related (motor) regions and greater alpha power in task-unrelated (non-motor) regions. Regarding EEG alpha, overall the present findings pertaining to EEG alpha further support the findings from chapter 2. Tests revealed a topographical pattern that alpha power was significantly lower in the experimental strategies (MA, RC, and PSY) compared to the control EO strategies across all regions. For upper-alpha power, the psyching (PSY) strategy displayed greater power than the reading comprehension (RC) strategy for all regions except central and temporal regions. Further, results revealed greater power during the psyching (PSY) strategy compared to the reading comprehension (RC) strategy in channels surrounding but not within the central region. This may be interpreted as a

distribution of neural resources away from the frontal, parietal, occipital, right temporal regions towards the central (task-related) region.

In agreement with the results of chapter two, a more spatially localized movement related alpha gate, appears to be stronger for psyching (PSY) compared to reading comprehension (RC) and mental arithmetic (MA). For highly trained athletes, there appears to be a more intense gate for psyching (PSY) compared to distracting strategies which is reflected by the stronger inhibition of task-unrelated (non-motor) regions. For distracting strategies of mental arithmetic (MA) and reading comprehension (RC), results reveal a weaker gate in which more mental resources are allocated to task-unrelated regions of the maximal exertion knee extension task. In the evaluation of elite athletes, it appears that activation is optimal across all three strategies in task-related (motor) regions with the primary difference being in the task-unrelated (non-motor) regions. Therefore, for highly trained athletes, it is more about blocking out the distractions.

Furthermore, this regional pattern supports the gating-by-inhibition hypothesis (Jensen & Mazaheri, 2010), in which resources were directed away from (frontal, parietal, occipital, right temporal) i.e., highest inhibition regions and towards the (central) region i.e., lowest inhibition. One can speculate that for the highly trained athlete, regardless of strategy used there was an optimal distribution of resources to the regions of relevance with the most efficient redistribution being observed with the use of the psyching (PSY) strategy. Results are supportive of prior sport literature focusing on alpha oscillations in that elite athletes superior performance has been characterized as a decrease in alpha power in central regions

Babiloni et al. (2008); Cooke et al. (2014); Gallicchio et al. (2016); Gallicchio et al. (2017) and an increase in alpha power in temporal and occipital regions (Gallicchio et al. 2016; Kerick et al. 2001). Further, the use of task-related attentional focus i.e., psyching (PSY) is supported by the psychomotor efficiency hypothesis Hatfield and Hillman (2001) and gating-by-inhibition model Jensen and Mazaheri (2010) in that cortical alpha activity was diverted away from task-unrelated (non-motor) regions and towards task-related (motor) regions.

Contingent on the above mentioned psychophysiological measure, we expected that mental preparation (PSY) will be associated with increased neuromuscular activity as indicated by mean surface integrated electromyography (iEMG) activity of the quadriceps muscles. As predicted and indicated by the results, prior to movement i.e., leg extension (-1 to 0) seconds there was no difference between strategies for (iEMG) activity of the quadriceps muscles. This indicated that participants did not begin to activate muscles prior to the beginning of the physical action. However, as predicted from (0 to +1) seconds of the movement action (iEMG) of the PSY strategy was significantly greater than both distractor strategies (MA, RC). It is important to note that not all studies have shown beneficial effects of muscle activity from the use of psyching and our results are in contradiction to Brody et al. (2000) who found a lack of significant findings of EMG between similar strategies. Utilizing a similar study design, the authors examined the effects of psyching on neuromuscular performance and motor unit activation of the upper extremity using highly strength-trained participants completing a maximal isometric elbow flexion task. The authors hypothesized that during the use of the psyching

strategy, an increase in motor unit activation in the agonist muscle and a decrease in motor unit activation of the antagonist muscle would occur compared to distraction strategies. Results revealed that self-report measures of perceived effort, muscle activity (EMG) and maximal force were not different across strategies. Additionally, self-report measures of perceived arousal and attentional focus were higher after completing the psyching-up strategy than for the reading aloud and mental arithmetic strategies. The main finding was that psyching leads to an enhanced level of readiness for performance compared to distraction. The authors suggest that these differences could be attributed to the constraints of the task used maximal isometric elbow flexion opposed to maximal isokinetic leg extension or prior experience of participants on the apparatus.

As it relates to behavioral performance, we predicted that task-related attentional focus, psyching (PSY) compared to distracting attentional strategies (MA, RC) will be associated with improved maximal motor performance as indicated by greater torque output. In support of our previous findings (see study one and study two) and in support of our hypothesis, performance was influenced by the use of the psyching (PSY) strategy compared to when employing the distracting strategies of mental arithmetic and reading comprehension (MA, RC) as indicated by greater torque output. Furthermore, the study extends previous work illustrating the beneficial effect of the use of psyching, (Biddle, 1985; Caudill & Weinberg, 1983; Elko & Ostrow, 1992; Gould et al. 1980; Lee, 1990; Shelton & Mahoney, 1978; Theodorakis et al. 2000; Tod et al. 2005; Tynes & McFatter, 1987; Weinberg et al. 1980; Whelan et al. 1990; Wilkes & Summers, 1984).

To expand the work of our prior studies (See Chapter 2.), several manipulation checks were utilized with the following results expected. To ensure that participants were engaged to the task, adhered to directions satisfactorily, and were motivated prior to performing both the physical task of knee extension and the mental task of mental arithmetic (MA), reading comprehension (RC) and psyching (PSY), level of motivation was measured. We predicted that prior to the task, ratings of motivation (MO) to perform to the best of one's ability on the mental task (attentional strategy) will not differ between strategies (MA, RC, PSY). Furthermore, prior to the task, ratings of motivation (MO) to perform to the best of one's ability on the physical task (knee extension) will not differ between attentional strategies (MA, RC, PSY). As predicted, participants' motivation to perform to the best of their ability on the mental task (attentional strategy) and the physical task (knee extension) did not differ between strategies used indicating that regardless of strategy used, participants reported similar motivational states. These results are encouraging in that enhanced motivation to perform a task may lead to superior physical performance by increasing the attentional effort used by individuals during a task (Sarter et al. 2006).

Further, we hypothesized that attentional focus (AF) on the physical task (knee extension) for the PSY strategy will be greater compared to distracting strategies (MA, RC) and attentional focus (AF) on the mental task (attentional strategy) will not differ between strategies (MA, RC, PSY). Aligned with our a priori hypothesis, participants' attentional focus (AF) on the physical task was enhanced by using psyching and disrupted when employing the two distracting conditions. Prior

studies have shown that maximum force production can be attributed to an individual's level of focus of attention (Halperin et al. 2017).

For the last psychological variable measured, we predicted that perceived effort (PE) during the physical task (knee extension) will be greater for the (PSY) strategy compared to (RC, MA) strategies. Compared to the BL control strategy performed, perceived effort (PE) in the physical task increased when using psyching (PSY) and decreased when adopting either distracting strategy mental arithmetic (MA) and reading comprehension (RC). These results could be interpreted that the use of psyching enhanced the highly trained athletes' perception effort, whereas the distracting strategies lead to a feeling of lessened effort on the physical task.

It is of importance to note that participants were characterized as expert (highly trained) athletes based on the requirements set by Swann et al. (2015) i.e., competing at the regional, university, semi professional or higher level. Additionally, upon completion of the study, these highly strength-trained athletes were asked to provide a verbal open ended response (see supplemental material) describing the cognitive strategy / technique used during the 20 second preparatory period of the PSY condition. All participants reported some sort of variety or combination of task-related attentional focus and preparatory arousal which is in support of the use of different cognitive strategies outlined by (Tod et al. 2015). It is feasible that given the participants play different positions, each participant uses a variety of cognitive strategies to improve and enhance their performance outcome prior to executing a task. The protocol employed in this study extended the work and findings of chapter 2.

Limitations and Future Research

The results of the study should be interpreted in light of several methodological limitations. Due to the nature of psychophysiological and human subjects research, we were limited to access and participants availability, thus future studies that replicate and extend this research might benefit from a larger cohort of participants. Additionally, we provided participants with attentional distractions prior to lifting i.e., leg extension; however, participants know they will be performing a maximal lift during all three strategies. It might be that during the 20 second period, participants actually begin to prepare thus the lack of significant findings for lower alpha power. Further, although classified as highly trained i.e., elite in their chosen sport, the participants did not have prior experience with the instrumentation i.e., testing apparatus. Selecting a task with greater familiarity or weightoom experience could provide further insights into the influence of psyching on performance. Another major limitation and advancement that is needed is being able to move beyond the laboratory to study human performance, particular brain dynamics during real world sporting scenarios. Furthermore, it should be acknowledged that electroencephalography (EEG) is limited in what the instrument can tell us about the brain. Additionally, the set-up of the torque measuring apparatus limited the ability to record (iEMG) of the antagonist muscles involved. An additional psychophysiological measure to detect the emotional state of the participant i.e., heart rate variability (HRV) could be used as a complementary assessment. Finally, an additional methodological change could be to incorporate a competitive context to

evaluate how this added variable is associated with the performance of the participants.

Future studies may want to investigate the impact of a training study to further test the influence of psyching on performance. Using self-selected mental preparation strategies may allow participants to feel more “natural” prior to the movement task.

Self-Report of Technique Used

PSY Strategy – Participant Self-Report Description of Technique Used

(20 sec period prior to movement)

Participant_01

“I thought about people close to me getting abused (an antagonistic character yelling at me and yelling at them (being helpless). This got me pumped up. I also thought and visualized about when we run out of the tunnel, that feeling of an adrenaline rush.”
(Preparatory Arousal)

Participant_02

“I just focused on performing the task as quickly and fast as hard as possible. I was focused on the motion of getting ready to perform the kick.”*(Task-Related Focus)*

Participant_03

“I was focused on visualizing the leg extension and getting ready to perform it fast and hard. As we say in football, trying to be fast and violent. Doing my best to see the activity or movement before it was performed.” *(Task-Related Focus)*

Participant_04

“I was thinking about soccer players, visualizing how powerfully they kick the ball using this motion. Just visualizing me performing the kicking motion. I was also thinking about running out onto the field from the tunnel. Which gets me pumped up.” *(Preparatory Arousal, Task-Related Focus)*

Participant_05

“Not having to focus on anything else except for getting ready to kick. Getting ready and visualizing to flex my leg muscles so they are ready to go. This makes it easier when performing the movement. Just getting as ready to go.” *(Task-Related Focus)*

Participant_06

“I was just clearing my head from everything except for visualizing the movement. Trying to take in as much air as possible to be able to explode my leg. So that I would

be able to be prepared and get as much explosion as possible with the leg movement.”
(*Task-Related Focus*)

Participant _07

“Just thinking about the task. Thinking about what I needed to do, how to do it as in the movement. Just thinking about getting ready to move as quickly as possible and moving my leg as hard as possible.” (*Task-Related Focus*)

Participant _08

“I tried to just do it. I just tried my best. I focused on the motion of kicking, similar to kicking a football. I tried to focus all of my attention on that so that I could do my best, get those muscles firing.” (*Task-Related Focus*)

Participant _09

“I was just thinking and focusing about pre-game stuff that I use to get mad and pumped-up before football games. So like teams I do not like, like rivalries like Penn State. Just trying to get as pumped up as possible to be as ready as possible to perform the task when told on command.” (*Preparatory Arousal, Task-Related Focus*)

Participant _10

“I just basically picked a spot on the white board and focused on it so I could get ready to perform the kick with my muscles. I told myself, I am going to try and break the machine when told to kick. So when told to kick I just tried my best.” (*Task-Related Focus*)

Participant _11

“I was thinking about anything I could to get me mad and focused. I tried to get mad and fired up as possible to focus on my muscles so I could kick.” (*Preparatory Arousal, Task-Related Focus*)

Participant _12

“I just kept telling myself kick, kick, kick, kick. So I could remember and be prepared to kick as hard as I possibly could. Just try to focus and zero in on the motion of kicking.” (*Task-Related Focus*)

Participant _13

“I was thinking about contracting my leg muscles. Just kicking like I normally do. Just thinking about kicking as hard as possible, so when told to kick, I could do it my best.” (*Task-Related Focus*)

Participant _14

“During the 20-second period before kicking, I was thinking about how I was going to contract my leg, thinking about the act before it actually happened, focusing all of my attention on that act. Using my own mind to kind of insight a little bit of anxiety about it, trying to get my heart rate to increase, get that adrenaline pumping a little bit. Similar to what I do before games.” (*Preparatory Arousal, Task-Related Focus*)

Participant _15

“Staring on a specific crack on the white board in front of me. Really locking in all of my attention of getting ready to kick, being prepared to perform the kicking motion as best as I could.” (*Task-Related Focus*)

References

- Abeln, V., Harig, A., Knicker, A., Vogt, T., & Schneider, S. (2013). Brain-imaging during an isometric leg extension task at graded intensities. *Frontiers in Physiology, 4*, 296. <https://doi.org/10.3389/fphys.2013.00296>
- Alvares, J. B. D. A. R., Rodrigues, R., de Azevedo Franke, R., da Silva, B. G. C., Pinto, R. S., Vaz, M. A., & Baroni, B. M. (2015). Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Physical Therapy in Sport, 16*(1), 59-65. <https://doi.org/10.1016/j.ptsp.2014.04.004>
- Arvinen-Barrow, M., Weigand, D. A., Thomas, S., Hemmings, B., & Walley, M. (2007). Elite and novice athletes' imagery use in open and closed sports. *Journal of Applied Sport Psychology, 19*(1), 93-104. <https://doi.org/10.1080/10413200601102912>
- Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology, 586*(1), 131-139. <https://doi.org/10.1113/jphysiol.2007.141630>
- Babault, N., Pousson, M., Michaut, A., Ballay, Y., & Hoecke, J. (2002). EMG activity and voluntary activation during knee-extensor concentric torque generation. *European Journal of Applied Physiology, 86*(6), 541-547. <https://doi.org/10.1007/s00421-002-0579-3>
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal*

Statistical Society: series B (Methodological), 57(1), 289-300.

<https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>

Benz, A., Winkelmann, N., Porter, J., & Nimphius, S. (2016). Coaching instructions and cues for enhancing sprint performance. *Strength & Conditioning Journal*, 38(1), 1-11. <https://doi.org/10.1519/SSC.0000000000000185>

Biddle, S. J. (1985). Mental preparation, mental practice and strength tasks: a need for clarification. *Journal of Sports Sciences*, 3(1), 67-74.

<https://doi.org/10.1080/02640418508729733>

Borg, G. (1978). Subjective effort in relation to physical performance and working capacity. In H. L. Pick (Ed), *Psychology: From research to practice* (pp. 338-361). New York: Plenum.

Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>

Calatayud, J., Vinstrup, J., Jakobsen, M. D., Sundstrup, E., Brandt, M., Jay, K., . . .

Andersen, L. L. (2016). Importance of mind-muscle connection during progressive resistance training. *European Journal of Applied Physiology*, 116(3), 527-533. <https://doi.org/10.1007/s00421-015-3305-7>

Campanella, B., Mattacola, C. G., & Kimura, I. F. (2000). Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. *Isokinetics and Exercise Science*, 8, 1-6.

<https://doi.org/10.3233/IES-2000-0033>

- Campos, J. J., Frankel, C. B., & Camras, L. (2004). On the nature of emotion regulation. *Child Development, 75*(2), 377-394.
<https://doi.org/10.1111/j.1467-8624.2004.00681.x>
- Cannon, J., Kay, D., Tarpinning, K. M., & Marino, F. E. (2007). Comparative effects of resistance training on peak isometric torque, muscle hypertrophy, voluntary activation and surface EMG between young and elderly women. *Clinical Physiology and Functional Imaging, 27*(2), 91-100.
<https://doi.org/10.1111/j.1475-097X.2007.00719.x>
- Caudill, D., Weinberg, R., & Jackson, A. (1983). Psyching-up and track athletes: A preliminary investigation. *Journal of Sport Psychology, 5*(2), 231-235.
Retrieved from <https://psycnet.apa.org/record/1984-08135-001>
- Chatrjian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activities. *American Journal of EEG technology, 25*(2), 83-92.
<https://doi.org/10.1080/00029238.1985.11080163>
- Cohen, J. (1992). A Power Primer. *Psychological Bulletin, 112* (1), 155–159
<https://psycnet.apa.org/doi/10.1037/0033-2909.112.1.155>
- Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology, 51*(4), 374-384.
<https://doi.org/10.1111/psyp.12182>

- Corcoran, A. W., Alday, P. M., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2018). Toward a reliable, automated method of individual alpha frequency (IAF) quantification. *Psychophysiology*, *55*(7), e13064. <https://doi.org/10.1111/psyp.13064>
- Dauty, M., Menu, P., & Fouasson-Chailloux, A. (2018). Cutoffs of isokinetic strength ratio and hamstring strain prediction in professional soccer players. *Scandinavian Journal of Medicine and Science in Sports*, *28*(1), 276-281. <https://doi.org/10.1111/sms.12890>
- Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9-21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- de Morree, H. M., Klein, C., & Marcora, S. M. (2012). Perception of effort reflects central motor command during movement execution. *Psychophysiology*, *49*(9), 1242-1253. <https://doi.org/10.1111/j.1469-8986.2012.01399.x>
- De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, *13*(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>
- Elko, K., & Ostrow, A. C. (1992). The effects of three mental preparation strategies on strength performance of young and older adults. *Journal of Sport Behavior*, *15*(1), 34. Retrieved from <https://psycnet.apa.org/>
- Enoka, R. M., & Duchateau, J. (2017). Rate coding and the control of muscle force. *Cold Spring Harbor Perspectives in Medicine*, *7*(10), a029702. <https://doi.org/10.1101/cshperspect.a029702>

- Farina, D., Holobar, A., Merletti, R., & Enoka, R. M. (2010). Decoding the neural drive to muscles from the surface electromyogram. *Clinical Neurophysiology*, *121*(10), 1616-1623.
<https://doi.org/10.1016/j.clinph.2009.10.040>
- Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567-589. <https://doi.org/10.1111/j.1469-8986.1986.tb00676.x>
- Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., & Hoedlmoser, K. (2016). Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting. *International Journal of Psychophysiology*, *109*, 92-99. <https://doi.org/10.1016/j.ijpsycho.2016.09.004>
- Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology*, *6*(1), 89.
<https://doi.org/10.1037/spy0000077>
- Gould, D., Flett, M. R., & Bean, E. (2009). Mental preparation for training and competition. In B.W. Brewer (Ed.), *Handbook of sports medicine and science: Sport Psychology* (pp. 53-63). West Sussex, UK: Wiley-Blackwell.
<https://doi.org/10.1002/9781444303650.ch6>
- Gould, D., Weinberg, R., & Jackson, A. (1980). Mental preparation strategies, cognitions, and strength performance. *Journal of Sport and Exercise Psychology*, *2*(4), 329-339. <https://doi.org/10.1123/jsp.2.4.329>

- Halperin, I., Chapman, D. W., Martin, D. T., & Abbiss, C. (2017). The effects of attentional focus instructions on punching velocity and impact forces among trained combat athletes. *Journal of Sports Sciences*, 35(5), 500-507.
<https://doi.org/10.1080/02640414.2016.1175651>
- Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc.
- Harman, E., Garhammer, J., & Pandorf, C. (2000). Administration, scoring, and interpretation of selected tests. In T.R. Baechle & R. E Earle (Eds.), *Essentials of Strength Training and Conditioning* (2nd ed.) (pp. 287-317). Champaign, IL: Human Kinetics.
- 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 and Exercise Psychology*, 6(1), 42-59.
<https://doi.org/10.1123/jsp.6.1.42>
- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblaus, & C. M. Janelle (Eds.), *Handbook of research on sport psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D., Haufler, A. J., Hung, T.-M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal*

of Clinical Neurophysiology, 21(3), 144-156.

<https://doi.org/10.1097/00004691-200405000-00003>

- 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.84-110). Hoboken, NJ: John Wiley & Sons.
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of Sport Psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- Herman, K., Barton, C., Malliaras, P., & Morrissey, D. (2012). The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Medicine*, 10(1), 75. <https://doi.org/10.1186/1741-7015-10-75>
- Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, 10(5), 361-374. [https://doi.org/10.1016/S1050-6411\(00\)00027-4](https://doi.org/10.1016/S1050-6411(00)00027-4)
- Hoffman, M., Schrader, J., Applegate, T., & Koceja, D. (1998). Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *Journal of Athletic Training*, 33(4), 319. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1320581/>
- Janelle, C. M., & Hatfield, B. D. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology.

Military Psychology, 20(S1), S39-S69.

<https://doi.org/10.1080/08995600701804798>

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.

<https://doi.org/10.3389/fnhum.2010.00186>

Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology*, 58(3), 263-277.

[https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88.

<https://doi.org/10.1016/j.brainresrev.2006.06.003>

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.

<https://doi.org/10.1016/j.tics.2012.10.007>

Konrad, P. (2006). The ABC of EMG: A practical introduction to kinesiological In Noraxon INC. USA. (Version 1., Issue March). Noraxon INC. USA.

<http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf>

Krane, V., & Williams, J. M. (2006). Psychological characteristics of peak performance. In J. M. Williams (Ed.), *Applied sport psychology: Personal growth to peak performance* (pp. 207-227). Boston, MA: McGraw-Hill.

- Lee, C. (1990). Psyching up for a muscular endurance task: Effects of image content on performance and mood state. *Journal of Sport and Exercise Psychology*, *12*(1), 66-73. <https://doi.org/10.1123/jsep.12.1.66>
- Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, *116*(6), 1091-1116. <https://doi.org/10.1007/s00421-016-3346-6>
- Marchant, D. C., & Greig, M. (2017). Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic knee extensions. *Human Movement Science*, *52*, 67-73. <https://doi.org/10.1016/j.humov.2017.01.007>
- McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Medicine*, *45*(11), 1523-1546. <https://doi.org/10.1007/s40279-015-0376-x>
- McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences*, *23*(7), 687-692. <https://doi.org/10.1080/02640410400021401>
- Moritani, T., & Muro, M. (1987). Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *European Journal of Applied Physiology and Occupational Physiology*, *56*, 260-265. <https://doi.org/10.1007/BF00690890>
- Nuzzo, J. L., Taylor, J. L., & Gandevia, S. C. (2019). CORP: assessments of upper- and lower-limb muscle strength and voluntary activation in humans. *Journal*

of Applied Physiology, 126(3), 513-543.

<https://doi.org/10.1152/jappphysiol.00569.2018>

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)

Oxendine, J. B. (1970). Emotional arousal and motor performance. *Quest*, 13(1), 23-32. <https://doi.org/10.1080/00336297.1970.10519673>

Parcell, A. C., Sawyer, R. D., Tricoli, V. A., & Chinevere, T. D. (2002). Minimum rest period for strength recovery during a common isokinetic testing protocol. *Medicine and Science in Sports and Exercise*, 34(6), 1018-1022. <https://doi.org/10.1097/00005768-200206000-00018>

Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259. <https://doi.org/10.1080/104132001753144392>

Pincivero, D. M., Coelho, A. J., Campy, R. M., Salfetnikov, Y., & Suter, E. (2003). Knee extensor torque and quadriceps femoris EMG during perceptually-guided isometric contractions. *Journal of Electromyography and Kinesiology*, 13(2), 159-167. [https://doi.org/10.1016/S1050-6411\(02\)00096-2](https://doi.org/10.1016/S1050-6411(02)00096-2)

Pineschi, G., & Di Pietro, A. (2013). Anxiety management through psychophysiological techniques: Relaxation and psyching-up in sport. *Journal of Sport Psychology in Action*, 4(3), 181-190. <https://doi.org/10.1080/21520704.2013.820247>

- Pion-Tonachini, L., Kreutz-Delgado, K., & Makeig, S. (2019). ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. *NeuroImage*, *198*, 181-197.
<https://doi.org/10.1016/j.neuroimage.2019.05.026>
- Prerau, M. J., Brown, R. E., Bianchi, M. T., Ellenbogen, J. M., & Purdon, P. L. (2017). Sleep neurophysiological dynamics through the lens of multitaper spectral analysis. *Physiology*, *32*(1), 60-92.
<https://doi.org/10.1152/physiol.00062.2015>
- Sarter, M., Gehring, W. J., & Kozak, R. (2006). More attention must be paid: the neurobiology of attentional effort. *Brain research reviews*, *51*(2), 145-160.
<https://doi.org/10.1016/j.brainresrev.2005.11.002>
- Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of “psyching-up” strategies in weight lifters. *Cognitive Therapy and Research*, *2*(3), 275-284.
<https://doi.org/10.1007/BF01185789>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, *16*, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Tenenbaum, G., Bar-Eli, M., Hoffman, J. R., Jablonovski, R., Sade, S., & Shitrit, D. (1995). The effect of cognitive and somatic psyching-up techniques on isokinetic leg strength performance. *The Journal of Strength & Conditioning Research*, *9*(1), 3-7. Retrieved from https://journals.lww.com/nsca-jscr/Abstract/1995/02000/The_Effect_of_Cognitive_and_Somatic_Psyching_up.1.aspx

- Theodorakis, Y., Weinberg, R., Natsis, P., Douma, I., & Kazakas, P. (2000). The effects of motivational versus instructional self-talk on improving motor performance. *The Sport Psychologist, 14*(3), 253-271.
<https://doi.org/10.1123/tsp.14.3.253>
- Tod, D., Iredale, F., & Gill, N. (2003). 'Psyching-up' and muscular force production. *Sports Medicine, 33*(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>
- Tod, D. A., Iredale, K. F., McGuigan, M. R., Strange, D. E. O., & Gill, N. (2005). "Psyching-up" enhances force production during the bench press exercise. *Journal of Strength and Conditioning Research, 19*(3), 599-603. Retrieved from <https://search.proquest.com/docview/213066537?accountid=14696>
- Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine, 45*(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>
- Tynes, L. L., & McFatter, R. M. (1987). The efficacy of "psyching" strategies on a weight-lifting task. *Cognitive Therapy and Research, 11*(3), 327-336.
<https://doi.org/10.1007/BF01186283>
- Van Dyk, N., Bahr, R., Whiteley, R., Tol, J. L., Kumar, B. D., Hamilton, B., ... & Witvrouw, E. (2016). Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *The American Journal of Sports Medicine, 44*(7), 1789-1795.
<https://doi.org/10.1177/0363546516632526>

- Weinberg, R. S., Gould, D., & Jackson, A. (1980). Cognition and motor performance: Effect of psyching-up strategies on three motor tasks. *Cognitive Therapy and Research*, 4(2), 239-245. Retrieved from <https://link.springer.com/content/pdf/10.1007/BF01173655.pdf>
- Weiss, T., Sust, M., Beyer, L., Hansen, E., Rost, R., & Schmalz, T. (1995). Theta power decreases in preparation for voluntary isometric contractions performed with maximal subjective effort. *Neuroscience Letters*, 193(3), 153-156. [https://doi.org/10.1016/0304-3940\(95\)11688-S](https://doi.org/10.1016/0304-3940(95)11688-S)
- Whelan, J. P., Epkins, C. C., & Meyers, A. W. (1990). Arousal interventions for athletic performance: Influence of mental preparation and competitive experience. *Anxiety Research*, 2(4), 293-307. <https://doi.org/10.1080/08917779008248735>
- Wilkes, R. L., & Summers, J. J. (1984). Cognitions, mediating variables, and strength performance. *Journal of Sport Psychology*, 6(3), 351-359. <https://doi.org/10.1123/jsp.6.3.351>
- Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, 8(4), 648-660. <https://doi.org/10.3758/BF03196201>
- Wyatt, M. P., & Edwards, A. M. (1981). Comparison of quadriceps and hamstring torque values during isokinetic exercise. *Journal of Orthopaedic & Sports Physical Therapy*, 3(2), 48-56. <https://doi.org/10.2519/jospt.1981.3.2.48>

Chapter 4: General Discussion

Overview

The overarching aim of the dissertation was to use a programmatic research effort involving a series of studies (study one, two, three) to address the phenomenon of task-related attentional focus cognitive strategies i.e., psyching facilitating and contributing to enhanced motor performance. To further understand changes in musculoskeletal performance as a result of psyching, the present research used a multidimensional approach (psychological + psychophysiological + kinetic) by employing the measures of electroencephalography (EEG) - cortical activity, electromyography (EMG) - muscle activity, and isokinetic dynamometry - peak torque during maximal exertion to achieve peak torque of a dynamic knee-extension skeletal muscle action. Further, in each of the three studies, participants performed the psychomotor task under three different preparatory strategies, a task-related attentional focus strategy and for comparative purposes mental arithmetic (MA) and reading comprehension (RC) strategies serving as attentional distractions.

Cognitive strategies consist of various mental approaches used before or during the execution of a motor task to improve performance. Psyching, one of the common strategies, typically involves a combination of elements intended to modify arousal and attentional focus to enhance psychomotor performance (Brody et al. 2000; Hardy et al. 1996; Perkins et al. 2001; Tod et al. 2003; Tod et al. 2015). We had noted from the previous literature that the viable use of psyching strategies

needed to be explored further, as the mechanisms of these strategies remain unclear (McGuigan et al. 2005; Tod et al. 2015).

Aims of Dissertation

The aim of study one (described in chapter 2) was to isolate the influence of task-related attentional focus and examine performance during a maximal exertion knee extensions. The aim of study two (described in chapter 2) The aim of study two was to examine the magnitude of cerebral cortical activation during the task-related cognitive strategy compared to distraction strategies. Further, to examine if the cortical activation during task-related focus was associated with an elevation in performance a leg extension. Specifically, if experimentally manipulating the preparatory cognitive strategy leads to a shift in the balance between task-related (motor-regions) and task-unrelated (non-motor regions) processes and an increase in performance during a maximal exertion knee extension. For studies one and two (chapter two), participants were characterized as non-athletes having at least one year of weight training experience, whereas, for study three (chapter three), participants were characterized as elite highly-trained athletes based on the requirements set by Swann et al. (2015), for example, competing at the regional, university, semi-professional or higher level. Further, the participants of study three's training status was identified as "advanced" (corresponding to a highly trained athlete) through the National Strength and Conditioning (NSCA) classification system for resistance training. The aim of study three (described in chapter 3) was to further our understanding of the mechanisms of effect of the task-related focus strategies by examining cortical activity, muscle activity and motor performance during a maximal

exertion knee extension. More specifically, what enables elite athletes to efficiently achieve superior motor performance. Further, in this experimental study, whether psychomotor efficiency and alpha gating can help to understand why and if psyching enhances performances of elite athletes was explored. The present chapter provides an overall summary of the findings from chapters two and three, highlights limitations of the described research and provides suggestions for future research.

Summary of Findings

Hatfield and Hillman (2001) introduced the psychomotor efficiency model as a special case of general neural efficiency to describe the influence of task-related and task-unrelated biological activity on motor performance. Relating to neurophysiological activity, the model suggests that superior performance is characterized by a decrease in nonessential input to the essential motor preparatory processes, as seen through the inhibition of task-unrelated processes across the cerebral cortex while a simultaneous heightening occurs in the cortical regions that are associated with task-relevant processes resulting in net efficiency (Hatfield et al. 2020). As suggested by Gallicchio et al. (2017), a model that seems particularly useful in describing Hatfield and Hillman's (2001) concept of general neural efficiency as balance between task-related and task-unrelated activity is Jensen and Mazaheri's gating-by-inhibition (2010). This model contends that cortical alpha controls regional activity in the cerebral cortex by diverting activation away from regions displaying greater alpha power (increased inhibition) and moves activation toward regions showing lessened alpha power (decreased inhibition). The findings of this study extend the Hatfield and Hillman model by providing empirical evidence

that the adoption of a more efficient cognitive strategy leads to changes in performance and to a different pattern of alpha gating.

Although beyond the scope of this research, a cascade of events can provide a model for understanding the influence of cognitive strategies on maximal skeletal muscle performance. For maximal skeletal muscle performance, both neural activation and force generating components will be necessary with upper motor neurons beginning in the cerebellum and brainstem and lower motor neurons originating in the spinal cord contributing to a motor pathway leading to the stimulation of skeletal muscle and enhanced movement performance. Specifically, increased cortical activation in motor preparatory regions of the cerebral cortex could promote heightened recruitment of motor units leading to enhancements of the primary movers resulting in elevated force production. It is unclear from the present studies, but it is reasonable to assume that the distribution of neural resources observed in the cerebral cortical activity during the use of a psyching strategy would translate to efficiency of motor unit recruitment leading to superior performance.

The findings of behavioral performance (peak torque) for study one, study two, and study three confirmed that participants were able optimally to perform when using mental preparation by focusing and getting as prepared as possible (PSY) on the given task. More specifically, results suggest that in the case of a maximal effort leg extension, torque output of the leg extension task revealed that when engaged in the psyching strategy, participants performed significantly better than both distracting strategies. Importantly, in study three results revealed that not only did psyching enhance performance, but data suggests that compared to the day one baseline

measure, distracting strategies appeared to lead to poorer performance. In future work with athletes, caution should be used in implementing distracting strategies that might not be helpful for enhanced performance. Overall, results support previous behavioral studies revealing the beneficial use of psyching (for a review, see Tod et al. 2015).

Topographical EEG analysis of study two revealed alpha activity was displayed across the different regions of the cortex with a distinct focal pattern revealing central activation surrounded by inhibition. Based on proposed active cortical inhibition (Klimesch et al. 2007; Klimesch, 2012) and in line with the gating-by-inhibition hypothesis Jensen & Mazaheri, (2010), the topographical pattern suggests that during preparation for movement, resources were directed away from unrelated regions (highest inhibition) and directed towards related regions (lowest inhibition) i.e., central. A more spatially localized movement related alpha gating appears to be stronger for psyching (PSY) compared to RC and MA which suggests that psyching evoked a more efficient redistribution of resources towards sensorimotor processing. Furthermore, for the study of non-trained participants, it appears that the heightening of movement related regions is more important than the inhibition of movement unrelated regions.

Topographical EEG analysis of study three indicated overall the present findings pertaining to EEG alpha support the findings from study two. Results revealed greater power during the PSY strategy compared to the RC strategy in channels surrounding but not within the central region. In agreement with the study of non-trained participants, a more spatially localized movement related alpha gate, appears to be stronger for psyching (PSY) compared to RC and MA. For highly-

trained athletes, there appears to be a more intense gate for psyching (PSY) compared to distracting strategies which is reflected by the stronger inhibition of task-irrelevant regions. For distracting strategies of mental arithmetic (MA) and reading comprehension (RC), results reveal a weaker gate in which more mental resources are allocated to task-irrelevant regions. The results suggest that activation is optimal across all three strategies in task-relevant regions with the primary difference being in the task-unrelated regions. It appears that there is a ceiling effect for central alpha of the elite athletes in that additional activation did not benefit performance. For highly-trained athletes, it is more about blocking out the distractions. This finding also appears to align with the self-report of the elite athletes as can be seen from the statements, “not having to focus on anything else except for getting ready to kick”, or “just thinking about the task. Thinking about what I needed to do”, or “I was thinking about how I was going to contract my leg, thinking about the act before it actually happened, focusing all of my attention on that act”. Thus, in the study of elite highly-trained athletes, inhibition of movement-unrelated regions appears to be of greater importance than the heightening of movement-related regions as seen with non-trained participants. Results are supported by the sport literature showing that neural efficiency is accompanied by greater alpha in temporal and occipital regions (task-unrelated) and lower alpha in the central region (task-related) (Babiloni et al. 2008; Cooke et al. 2014; Kerick et al. 2001).

In addition, results also revealed that muscle activity (iEMG) of the PSY strategy was significantly greater than both distractor strategies (MA, RC). This finding was expected as the psyching strategy also had the greatest torque produced.

Additionally, with enhanced performance, greater demand will be placed on the muscle thus recruiting additional motor units and altering the firing rates (De Luca, 1985). For professionals such as coaches, trainers and therapists working with athletes to enhance performance, the specificity of verbal instructions is of great importance as even a slight alteration in wording can lead to enhanced performance. This finding was revealed from a study conducted by Sahaly et al. (2003) who showed that when instructed to produce their most explosive contraction compared to produce maximal force as hard and fast as possible, participants developed greater EMG activity and greater rate of force.

Practical Implications

As the assessment and measurement of athlete performance in sport becomes increasingly important, understanding the role of psyching could be instrumental in instructing athletes and others engaged in physical activities as to what cognitive activities to utilize to maximize their performance. It is of great importance for practitioners, sport psychologists, and coaches to be mindful of physical and mental differences of specific task demands. The physical demands of a task, technical precision, and duration will demand different requirements from the performer (Taylor, 1995). Therefore, it is critical to understand that individuals will vary in regard to psychological needs and how they respond to different strategies of enhancing performance (Jones, 1993).

Limitations and Future Directions

The results presented within this dissertation should be interpreted in light of several methodological limitations. A major limitation and advancement that is needed is being able to move beyond the laboratory to study human performance, particularly brain dynamics during real world sporting scenarios. From a methodological point of view, future studies could utilize more advanced EEG equipment or other neuroimaging techniques in a non-laboratory setting to investigate the impact of mental preparation prior to voluntary movements. Evaluating the involvement of frequency bands other than alpha such as theta (4-6 Hz) could provide further insights into performance as frontal theta (4-6 Hz) has been found to be positively related to effortful attentional function and decision making. Future studies may want to investigate the impact of a training study to further test the influence of psyching on performance. Importantly, the findings of this dissertation program extend the neural efficiency model of human performance and support the gating-by-inhibition phenomenon as a central factor. That is the attentional focus translated to heightened localization of motor activity in the brain resulting in elevated performance.

References

- Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology*, 586(1), 131-139
<https://doi.org/10.1113/jphysiol.2007.141630>
- Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>
- Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, 51(4), 374-384.
<https://doi.org/10.1111/psyp.12182>
- De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>
- Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology*, 6(1), 89.
<https://doi.org/10.1037/spy0000077>
- Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc.

- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of sport psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186. <https://doi.org/10.3389/fnhum.2010.00186>
- Jones, G. (1993). The role of performance profiling in cognitive behavioral interventions in sport. *The Sport Psychologist*, 7(2), 160-172. <https://doi.org/10.1123/tsp.7.2.160>
- Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology*, 58(3), 263-277. [https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88. <https://doi.org/10.1016/j.brainresrev.2006.06.003>

- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.
<https://doi.org/10.1016/j.tics.2012.10.007>
- McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences*, 23(7), 687-692. <https://doi.org/10.1080/02640410400021401>
- Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259. <https://doi.org/10.1080/104132001753144392>
- Sahaly, R., Vandewalle, H., Driss, T., & Monod, H. (2003). Surface electromyograms of agonist and antagonist muscles during force development of maximal isometric exercises—effects of instruction. *European Journal of Applied Physiology*, 89, 79-84. <https://doi.org/10.1007/s00421-002-0762-6>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Taylor, J. (1995). A conceptual model for integrating athletes' needs and sport demands in the development of competitive mental preparation strategies. *The Sport Psychologist*, 9(3), 339-357. <https://doi.org/10.1123/tsp.9.3.339>
- Tod, D., Iredale, F., & Gill, N. (2003). 'Psyching-up' and muscular force production. *Sports Medicine*, 33(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

**If
you
answered**

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

- If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
 - take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, **te**ll your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT _____
or GUARDIAN (for participants under the age of majority)

WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



Appendix D - Reading Comprehension Passages

Reading # 1

Manatees are known as "gentle giants" and are purely herbivorous. Manatees eat vast amounts of aquatic plants. A manatee may eat as much as 15 percent of its body weight per day.

Manatees are slow moving animals. They are even slower to reproduce. Females become mature after five to nine years and have calves every two to five years. Young Manatees nurse under water and stay with their mothers for about two years.

- 1) What do manatees primarily eat?
 - a. Fish
 - b. Krill
 - c. Aquatic Plants
 - d. Shrimp

- 2) How often do manatees have calves?
 - a. Twice a year
 - b. Every year
 - c. Every other year
 - d. Every two to five years

Reading #2

Fried dough has been made all around the world. Dutch settlers who brought apple and cream pies, cookies and cobbler to the New World also introduced doughnuts. Their doughnuts were called olykoeks, or oily cakes – sweet dough balls fried in pork fat. Early doughnuts were often filled with apples, prunes or raisins. The name “doughnut” may refer to the nuts put in the middle of the dough ball to prevent an uncooked center or possibly to “dough knots” – another popular shape for the olykoeks. Today, “doughnut” and “donut” are used interchangeably.

- 1) Who brought doughnuts to America?
 - a. Dutch settlers
 - b. English settlers
 - c. French settlers
 - d. Spanish settlers

- 2) Doughnuts were often filled with:
 - a. Jelly or Jam
 - b. Pudding
 - c. Apples, prunes or raisins
 - d. Berries

Reading #3

Blue is a universal color of water and the sky. In Greece, people believe that wearing blue gives you protection against evil. People who believe this wear a blue necklace or bracelet. Blue like green is another calming color and it has been found that people sleep better in blue rooms. However, some people suggest that unlike red, blue makes people eat less. So, if you are thinking of losing weight blue plates can help you to do this as we seem to eat less when eating from them.

- 1) What color is believed to make people eat more?
 - a. Blue
 - b. Green
 - c. Yellow
 - d. Red

- 2) According to the passage, what do people wear to protect them against evil?
 - a. Hat
 - b. Necklace or Bracelet
 - c. Shawl
 - d. Brooch

Reading #4

Hurricanes are large tropical storms that develop in the oceans of the world. Hurricanes gather heat and energy from the warm ocean water. The heat from these warm currents increases the power of the hurricane. Hurricanes that remain over warm water usually get bigger and stronger, but they weaken once they get over land. Hurricanes are storms that are given names, and a new list of names is created each year. The first hurricane name starts with the letter A, like Ashley, and the names move through the alphabet as more hurricanes form.

During the official hurricane season, which lasts from June 1 to November 30, these large storms sometimes hit coastal areas of the United States. As these hurricanes approach, there is rain and strong winds. Meteorologists, scientists who study the weather, watch these storms very carefully

1. A hurricane would be most likely to hit the United States in what month?
 - a. January
 - b. August
 - c. March
 - d. December

2. Hurricanes gather heat and energy from?
 - a. Cold ocean water
 - b. Warm ocean water
 - c. Cold air temperature
 - d. Hot air temperature

Appendix E - Recorded Instructional Conditions

Psyching (PSY) Strategy

“You will be given a 20-second rest interval before each trial in this condition and during this time interval I would like you to focus intently on the task at hand. In essence, focus on contracting your leg muscles needed for the movements you are going to perform, and concentrate all your attention on those muscles by getting mad, aroused and pumped up. Think of absolutely nothing but exploding as hard and quick as possible and being as prepared as possible for a maximal performance. The 20-second preparation period will begin when the experimenter says “begin” and will end when the experimenter says “move”. When the experimenter says “move” you will make an all-out muscular effort by exploding as quickly as possible, pushing your leg up. Once you feel you’ve reached your max you will then relax”.

Reading Comprehension (RC) Strategy

“You will be given a 20-second interval before each trial in this condition, and during this time readings will be given to you on a clipboard held by the tester. I would like you to read the given passage as accurately as possible thinking of absolutely nothing except reading the passage, and all the while working to comprehend what the reading is explaining. After the kick, you will be asked two questions based on the reading, which you will answer by circling the correct statement listed with several options on the sheet in front of you. With each trial, there will be a different passage which you will approach with the instructions mentioned above. You will begin to read when the experimenter says “begin”. You will stop when the experimenter says “move”. When the experimenter says “move” you will make an all-out muscular effort by exploding as quickly as possible, pushing your leg up. Once you feel you’ve reached your max, you will then relax”.

Mental Arithmetic (MA) Strategy

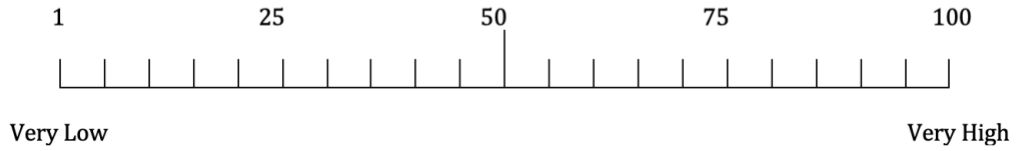
“You will be given a 20-second interval before each trial in this condition and during this interval I would like you to count backwards, quickly but in your head, without speaking aloud. Count backwards by sevens (7's) starting with the number 1000. For example, 1000, 993, 986, 979...and so on. Following the 20-second interval, you will be asked the number you reached for each trial, and it will be recorded. At the start of the second and third 20-second intervals, you will continue at a number provided by the experimenter. For example, if you are provided with the number 872, you will begin to count backwards by sevens (7's) beginning with 872. You will begin counting backwards when the experimenter says “Begin”. You will stop when the experimenter says “move”. When the experimenter says “move”, you will make an all-out muscular effort by exploding as quickly as possible pushing your leg up. Once you feel you've reached your max, you will then relax”.

Appendix F - Motivation Scale (MO)

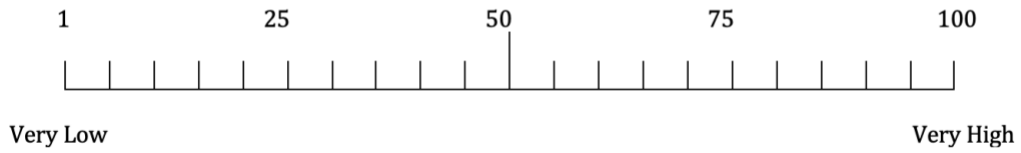
Rate of Motivation Scale (VAS)

Participant #	Condition	Date

A. How motivated are you to perform to the best of your ability during the mental/cognitive tasks (PSY/MA/RC)?



B. How motivated are you to perform to the best of your ability during the physical task (leg extension)?

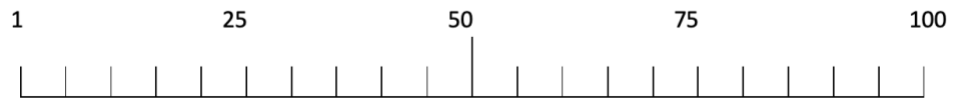


Appendix G - Rate of Attentional Focus (AF)

Rate of Attentional Focus Scale (VAS)

Participant #	Condition	Date
---------------	-----------	------

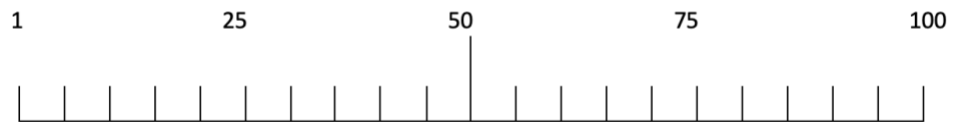
A. During the 20 second period, how focused were you on the task of the attentional condition (PSY/MA/RC)?



Completely Distracted

Very Focused

B. During the 20 second period, how focused were you on the physical task (leg extension)?



Completely Distracted

Very Focused

Appendix H - Rate of Perceived Effort (RPE)

Rate of Perceived Effort Scale (RPE)

Participant #	Condition	Date
---------------	-----------	------

PERCEIVED EFFORT

6	No Effort at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard (Heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal effort

Bibliography

Chapter One

- Alvares, J. B. d. A. R., Rodrigues, R., de Azevedo Franke, R., da Silva, B. G. C., Pinto, R. S., Vaz, M. A., & Baroni, B. M. (2015). Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Physical Therapy in Sport, 16*(1), 59-65. <https://doi.org/10.1016/j.ptsp.2014.04.004>
- Babault, N., Pousson, M., Michaut, A., Ballay, Y., & Hoecke, J. (2002). EMG activity and voluntary activation during knee-extensor concentric torque generation. *European Journal of Applied Physiology, 86*(6), 541-547. <https://doi.org/10.1007/s00421-002-0579-3>
- Baumeister, R. F., & Vohs, K. D. (2007). Self-Regulation, ego depletion, and motivation. *Social and Personality Psychology Compass, 1*(1), 115-128. <https://doi.org/10.1111/j.1751-9004.2007.00001.x>
- Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport, 71*(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>
- Budzynski, T. H., Budzynski, H. K., Evans, J. R., & Abarbanel, A. (Eds.). (2009). *Introduction to Quantitative EEG and neurofeedback: Advanced theory and applications*. San Diego, CA: Academic 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(2), 106-116. <https://doi.org/10.3200/JMBR.41.2.106-116>

Del Percio, C., Babiloni, C., Bertollo, M., Marzano, N., Iacoboni, M., Infarinato, F., ... & Eusebi, F. (2009). Visuo-attentional and sensorimotor alpha rhythms are related to visuo-motor performance in athletes. *Human Brain Mapping*, 30(11), 3527-3540. <https://doi.org/10.1002/hbm.20776>

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>

Enoka, R. M., & Duchateau, J. (2017). Rate coding and the control of muscle force. *Cold Spring Harbor Perspectives in Medicine*, 7(10), a029702. <https://doi.org/10.1101/cshperspect.a029702>

Farina, D., Holobar, A., Merletti, R., & Enoka, R. M. (2010). Decoding the neural drive to muscles from the surface electromyogram. *Clinical Neurophysiology*, 121(10), 1616-1623. <https://doi.org/10.1016/j.clinph.2009.10.040>

Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc

Harman, E., Garhammer, J., & Pandorf, C. (2008). Administration, scoring, and interpretation of selected tests. In T.R. Baechle & R. E Earle (Eds.), *Essentials of Strength Training and Conditioning* (2nd ed.) (pp. 287-317). Champaign, IL: Human Kinetics.

- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblaus, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D. (2018). Brain dynamics and motor behavior: A case for efficiency and refinement for superior performance. *Kinesiology Review*, 7(1), 42-50.
<https://doi.org/10.1123/kr.2017-0056>
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of Sport Psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- 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(2-3), 131-160. [https://doi.org/10.1016/S0301-0511\(00\)00047-8](https://doi.org/10.1016/S0301-0511(00)00047-8)
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.
<https://doi.org/10.3389/fnhum.2010.00186>
- Konrad, P. (2006). The ABC of EMG: A practical introduction to kinesiological In Noraxon INC. USA. (Version 1., Issue March). Noraxon INC. USA.
<http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf>
- Kerick, S. E., Douglass, L. W., & Hatfield, B. D. (2004). Cerebral cortical adaptations associated with visuomotor practice. *Medicine & Science in*

Sports & Exercise, 36(1), 118-129.

<http://dx.doi.org/10.1249/01.MSS.0000106176.31784.D4>

Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology*, 24(1-2), 61-100.

[https://doi.org/10.1016/S0167-8760\(96\)00057-8](https://doi.org/10.1016/S0167-8760(96)00057-8)

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88.

<https://doi.org/10.1016/j.brainresrev.2006.06.003>

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.

<https://doi.org/10.1016/j.tics.2012.10.007>

Krane, V., & Williams, J. M. (2006). Psychological characteristics of peak performance. In J. M. Williams (Ed.), *Applied sport psychology: Personal growth to peak performance* (pp. 207-227). Boston, MA: McGraw-Hill.

Nunez, P. L., & Srinivasan, R. (2006). *Electric fields of the brain: the neurophysics of EEG* (2nd ed.). New York, NY: Oxford University Press.

Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259.

<https://doi.org/10.1080/104132001753144392>

Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest.

Electroencephalography and Clinical Neurophysiology, 83(1), 62-69.

[https://doi.org/10.1016/0013-4694\(92\)90133-3](https://doi.org/10.1016/0013-4694(92)90133-3)

- Pytel, J. L., & Kamon, E. (1981). Dynamic strength test as a predictor for maximal and acceptable lifting. *Ergonomics*, 24(9), 663-672.
<https://doi.org/10.1080/00140138108924889>
- Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of “psyching-up” strategies in weight lifters. *Cognitive Therapy and Research*, 2(3), 275-284.
<https://doi.org/10.1007/BF01185789>
- Simpson, D., Ehrensberger, M., Nulty, C., Regan, J., Broderick, P., Blake, C., & Monaghan, K. (2019). Peak torque, rate of torque development and average torque of isometric ankle and elbow contractions show excellent test–retest reliability. *Hong Kong Physiotherapy Journal*, 39(01), 67-76.
<https://doi.org/10.1142/S1013702519500069>
- Stark, T., Walker, B., Phillips, J. K., Fejer, R., & Beck, R. (2011). Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: A systematic review: *American Academy of Physical Medicine and Rehabilitation*, 3(5), 472-479. <https://doi.org/10.1016/j.pmrj.2010.10.025>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Tod, D., Iredale, F., & Gill, N. (2003). ‘Psyching-up’ and muscular force production. *Sports Medicine*, 33(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

Chapter Two

Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology*, 586(1), 131-139

<https://doi.org/10.1113/jphysiol.2007.141630>

Baumeister, R. F., & Vohs, K. D. (2007). Self-Regulation, ego depletion, and motivation. *Social and Personality Psychology Compass*, 1(1), 115-128.

<https://doi.org/10.1111/j.1751-9004.2007.00001.x>

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: series B (Methodological)*, 57(1), 289-300.

<https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>

Borg, G. (1978). Subjective effort in relation to physical performance and working capacity. In H. L. Pick (Ed), *Psychology: From research to practice* (pp. 338-361). New York: Plenum.

Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>

- Budzynski, T. H., Budzynski, H. K., Evans, J. R., & Abarbanel, A. (Eds.). (2009). *Introduction to Quantitative EEG and neurofeedback: Advanced theory and applications*. San Diego, CA: Academic Press.
<https://doi.org/10.1080/00029238.1985.11080163>
- Chatrjian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activities. *American Journal of EEG technology*, 25(2), 83-92.
- Cohen, J. (1992). A Power Primer. *Psychological Bulletin*, 112 (1), 155–159
<https://psycnet.apa.org/doi/10.1037/0033-2909.112.1.155>
- Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, 51(4), 374-384.
<https://doi.org/10.1111/psyp.12182>
- Corcoran, A. W., Alday, P. M., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2018). Toward a reliable, automated method of individual alpha frequency (IAF) quantification. *Psychophysiology*, 55(7), e13064.
<https://doi.org/10.1111/psyp.13064>
- 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(2), 106-116. <https://doi.org/10.3200/JMBR.41.2.106-116>

- Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9-21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- Del Percio, C., Babiloni, C., Bertollo, M., Marzano, N., Iacoboni, M., Infarinato, F., ... & Eusebi, F. (2009). Visuo-attentional and sensorimotor alpha rhythms are related to visuo-motor performance in athletes. *Human Brain mapping*, *30*(11), 3527-3540. <https://doi.org/10.1002/hbm.20776>
- Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., & Hoedlmoser, K. (2016). Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting. *International Journal of Psychophysiology*, *109*, 92-99. <https://doi.org/10.1016/j.ijpsycho.2016.09.004>
- Gallicchio, G., & Ring, C. (2019). Don't look, don't think, just do it! Toward an understanding of alpha gating in a discrete aiming task. *Psychophysiology*, *56*(3), e13298. <https://doi.org/10.1111/psyp.13298>
- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D., Haufler, A. J., Hung, T.-M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal*

of Clinical Neurophysiology, 21(3), 144-156.

<https://doi.org/10.1097/00004691-200405000-00003>

- 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.84-110). Hoboken, NJ: John Wiley & Sons.
- Hatfield, B. D. (2018). Brain dynamics and motor behavior: A case for efficiency and refinement for superior performance. *Kinesiology Review*, 7(1), 42-50.
<https://doi.org/10.1123/kr.2017-0056>
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of sport psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- 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(2-3), 131-160. [https://doi.org/10.1016/S0301-0511\(00\)00047-8](https://doi.org/10.1016/S0301-0511(00)00047-8)
- Janelle, C. M., & Hatfield, B. D. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology. *Military Psychology*, 20(S1), S39-S69.
<https://doi.org/10.1080/08995600701804798>
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.
<https://doi.org/10.3389/fnhum.2010.00186>

- Jones, L., & Stuth, G. (1997). The uses of mental imagery in athletics: An overview. *Applied and Preventive Psychology, 6*(2), 101-115.
[https://doi.org/10.1016/S0962-1849\(05\)80016-2](https://doi.org/10.1016/S0962-1849(05)80016-2)
- Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology, 58*(3), 263-277. [https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)
- Kerick, S. E., Douglass, L. W., & Hatfield, B. D. (2004). Cerebral cortical adaptations associated with visuomotor practice. *Medicine & Science in Sports & Exercise, 36*(1), 118-129.
<http://dx.doi.org/10.1249/01.MSS.0000106176.31784.D4>
- Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology, 24*(1-2), 61-100.
[https://doi.org/10.1016/S0167-8760\(96\)00057-8](https://doi.org/10.1016/S0167-8760(96)00057-8)
- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews, 29*(2-3), 169-195. [https://doi.org/10.1016/S0165-0173\(98\)00056-3](https://doi.org/10.1016/S0165-0173(98)00056-3)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews, 53*(1), 63-88.
<https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences, 16*(12), 606-617.
<https://doi.org/10.1016/j.tics.2012.10.007>

- Marchant, D. C., & Greig, M. (2017). Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic knee extensions. *Human Movement Science, 52*, 67-73.
<https://doi.org/10.1016/j.humov.2017.01.007>
- McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences, 23*(7), 687-692. <https://doi.org/10.1080/02640410400021401>
- Moritani, T., & Muro, M. (1987). Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *European Journal of Applied Physiology and Occupational Physiology, 56*, 260-265.
<https://doi.org/10.1007/BF00690890>
- Morrissey, M. C. (1987). The relationship between peak torque and work of the quadriceps and hamstrings after meniscectomy. *Journal of Orthopaedic & Sports Physical Therapy, 8*(8), 405-408.
<https://www.jospt.org/doi/10.2519/jospt.1987.8.8.405>
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*(1), 97-113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- Penfield, W., & Rasmussen, T. (1950). The cerebral cortex of man; a clinical study of localization of function.
- Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest.

Electroencephalography and Clinical Neurophysiology, 83(1), 62-69.

[https://doi.org/10.1016/0013-4694\(92\)90133-3](https://doi.org/10.1016/0013-4694(92)90133-3)

Pineschi, G., & Di Pietro, A. (2013). Anxiety management through psychophysiological techniques: Relaxation and psyching-up in sport. *Journal of Sport Psychology in Action*, 4(3), 181-190.

<https://doi.org/10.1080/21520704.2013.820247>

Prerau, M. J., Brown, R. E., Bianchi, M. T., Ellenbogen, J. M., & Purdon, P. L.

(2017). Sleep neurophysiological dynamics through the lens of multitaper spectral analysis. *Physiology*, 32(1), 60-92.

<https://doi.org/10.1152/physiol.00062.2015>

Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of "psyching-up" strategies in weight lifters. *Cognitive Therapy and Research*, 2(3), 275-284.

<https://doi.org/10.1007/BF01185789>

Tod, D., Iredale, F., & Gill, N. (2003). 'Psyching-up' and muscular force production.

Sports Medicine, 33(1), 47-58. [https://doi.org/10.2165/00007256-](https://doi.org/10.2165/00007256-200333010-00004)

[200333010-00004](https://doi.org/10.2165/00007256-200333010-00004)

Tod, D. A., Iredale, K. F., McGuigan, M. R., Strange, D. E. O., & Gill, N. (2005). "

Psyching-up" enhances force production during the bench press exercise.

Journal of Strength and Conditioning Research, 19(3), 599-603. Retrieved

from <https://search.proquest.com/docview/213066537?accountid=14696>

Tod, D., & McGuigan, M. (2006). The efficacy of psyching-up on strength

performance. In B.T. Selkirk (Ed.), *Focus on Exercise and Health Research*

(pp. 163-179). New York, NY: Nova Science Publishers, Inc.

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

Chapter Three

Abeln, V., Harig, A., Knicker, A., Vogt, T., & Schneider, S. (2013). Brain-imaging during an isometric leg extension task at graded intensities. *Frontiers in Physiology*, 4, 296. <https://doi.org/10.3389/fphys.2013.00296>

Alvares, J. B. D. A. R., Rodrigues, R., de Azevedo Franke, R., da Silva, B. G. C., Pinto, R. S., Vaz, M. A., & Baroni, B. M. (2015). Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Physical Therapy in Sport*, 16(1), 59-65. <https://doi.org/10.1016/j.ptsp.2014.04.004>

Arvinen-Barrow, M., Weigand, D. A., Thomas, S., Hemmings, B., & Walley, M. (2007). Elite and novice athletes' imagery use in open and closed sports. *Journal of Applied Sport Psychology*, 19(1), 93-104. <https://doi.org/10.1080/10413200601102912>

Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology*, 586(1), 131-139. <https://doi.org/10.1113/jphysiol.2007.141630>

Babault, N., Pousson, M., Michaut, A., Ballay, Y., & Hoecke, J. (2002). EMG activity and voluntary activation during knee-extensor concentric torque

generation. *European Journal of Applied Physiology*, 86(6), 541-547.

<https://doi.org/10.1007/s00421-002-0579-3>

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: series B (Methodological)*, 57(1), 289-300.

<https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>

Benz, A., Winkelmann, N., Porter, J., & Nimphius, S. (2016). Coaching instructions and cues for enhancing sprint performance. *Strength & Conditioning Journal*, 38(1), 1-11. <https://doi.org/10.1519/SSC.0000000000000185>

Biddle, S. J. (1985). Mental preparation, mental practice and strength tasks: a need for clarification. *Journal of Sports Sciences*, 3(1), 67-74.

<https://doi.org/10.1080/02640418508729733>

Borg, G. (1978). Subjective effort in relation to physical performance and working capacity. In H. L. Pick (Ed), *Psychology: From research to practice* (pp. 338-361). New York: Plenum.

Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000).

The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>

Calatayud, J., Vinstrup, J., Jakobsen, M. D., Sundstrup, E., Brandt, M., Jay, K., . . .

Andersen, L. L. (2016). Importance of mind-muscle connection during progressive resistance training. *European Journal of Applied Physiology*, 116(3), 527-533. <https://doi.org/10.1007/s00421-015-3305-7>

- Campenella, B., Mattacola, C. G., & Kimura, I. F. (2000). Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. *Isokinetics and Exercise Science*, 8, 1-6.
<https://doi.org/10.3233/IES-2000-0033>
- Campos, J. J., Frankel, C. B., & Camras, L. (2004). On the nature of emotion regulation. *Child Development*, 75(2), 377-394.
<https://doi.org/10.1111/j.1467-8624.2004.00681.x>
- Cannon, J., Kay, D., Tarpenning, K. M., & Marino, F. E. (2007). Comparative effects of resistance training on peak isometric torque, muscle hypertrophy, voluntary activation and surface EMG between young and elderly women. *Clinical Physiology and Functional Imaging*, 27(2), 91-100.
<https://doi.org/10.1111/j.1475-097X.2007.00719.x>
- Caudill, D., Weinberg, R., & Jackson, A. (1983). Psyching-up and track athletes: A preliminary investigation. *Journal of Sport Psychology*, 5(2), 231-235.
Retrieved from <https://psycnet.apa.org/record/1984-08135-001>
- Chatrjian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activities. *American Journal of EEG technology*, 25(2), 83-92.
<https://doi.org/10.1080/00029238.1985.11080163>
- Cohen, J. (1992). A Power Primer. *Psychological Bulletin*, 112 (1), 155–159
<https://psycnet.apa.org/doi/10.1037/0033-2909.112.1.155>
- Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor

skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, 51(4), 374-384.

<https://doi.org/10.1111/psyp.12182>

Corcoran, A. W., Alday, P. M., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2018). Toward a reliable, automated method of individual alpha frequency (IAF) quantification. *Psychophysiology*, 55(7), e13064.

<https://doi.org/10.1111/psyp.13064>

Dauty, M., Menu, P., & Fouasson-Chailloux, A. (2018). Cutoffs of isokinetic strength ratio and hamstring strain prediction in professional soccer players. *Scandinavian Journal of Medicine and Science in Sports*, 28(1), 276-281.

<https://doi.org/10.1111/sms.12890>

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9-21.

<https://doi.org/10.1016/j.jneumeth.2003.10.009>

de Morree, H. M., Klein, C., & Marcora, S. M. (2012). Perception of effort reflects central motor command during movement execution. *Psychophysiology*, 49(9), 1242-1253. <https://doi.org/10.1111/j.1469-8986.2012.01399.x>

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>

Elko, K., & Ostrow, A. C. (1992). The effects of three mental preparation strategies on strength performance of young and older adults. *Journal of Sport Behavior*, 15(1), 34. Retrieved from <https://psycnet.apa.org/>

- Enoka, R. M., & Duchateau, J. (2017). Rate coding and the control of muscle force. *Cold Spring Harbor Perspectives in Medicine*, 7(10), a029702. <https://doi.org/10.1101/cshperspect.a029702>
- Farina, D., Holobar, A., Merletti, R., & Enoka, R. M. (2010). Decoding the neural drive to muscles from the surface electromyogram. *Clinical Neurophysiology*, 121(10), 1616-1623. <https://doi.org/10.1016/j.clinph.2009.10.040>
- Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, 23(5), 567-589. <https://doi.org/10.1111/j.1469-8986.1986.tb00676.x>
- Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., & Hoedlmoser, K. (2016). Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting. *International Journal of Psychophysiology*, 109, 92-99. <https://doi.org/10.1016/j.ijpsycho.2016.09.004>
- Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology*, 6(1), 89. <https://doi.org/10.1037/spy0000077>
- Gould, D., Flett, M. R., & Bean, E. (2009). Mental preparation for training and competition. In B.W. Brewer (Ed.), *Handbook of sports medicine and science: Sport Psychology* (pp. 53-63). West Sussex, UK: Wiley-Blackwell. <https://doi.org/10.1002/9781444303650.ch6>

- Gould, D., Weinberg, R., & Jackson, A. (1980). Mental preparation strategies, cognitions, and strength performance. *Journal of Sport and Exercise Psychology*, 2(4), 329-339. <https://doi.org/10.1123/jsp.2.4.329>
- Halperin, I., Chapman, D. W., Martin, D. T., & Abbiss, C. (2017). The effects of attentional focus instructions on punching velocity and impact forces among trained combat athletes. *Journal of Sports Sciences*, 35(5), 500-507. <https://doi.org/10.1080/02640414.2016.1175651>
- Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc.
- Harman, E., Garhammer, J., & Pandorf, C. (2000). Administration, scoring, and interpretation of selected tests. In T.R. Baechle & R. E Earle (Eds.), *Essentials of Strength Training and Conditioning* (2nd ed.) (pp. 287-317). Champaign, IL: Human Kinetics.
- 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 and Exercise Psychology*, 6(1), 42-59. <https://doi.org/10.1123/jsp.6.1.42>
- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of research on sport psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.

- Hatfield, B. D., Haufler, A. J., Hung, T.-M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal of Clinical Neurophysiology*, *21*(3), 144-156.
<https://doi.org/10.1097/00004691-200405000-00003>
- 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.84-110). Hoboken, NJ: John Wiley & Sons.
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of Sport Psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- Herman, K., Barton, C., Malliaras, P., & Morrissey, D. (2012). The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Medicine*, *10*(1), 75. <https://doi.org/10.1186/1741-7015-10-75>
- Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*(5), 361-374.
[https://doi.org/10.1016/S1050-6411\(00\)00027-4](https://doi.org/10.1016/S1050-6411(00)00027-4)
- Hoffman, M., Schrader, J., Applegate, T., & Koceja, D. (1998). Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *Journal of Athletic Training*, *33*(4), 319. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1320581/>

- Janelle, C. M., & Hatfield, B. D. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology. *Military Psychology, 20*(S1), S39-S69.
<https://doi.org/10.1080/08995600701804798>
- Jasper, H. H. (1958). The ten twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience, 4*, 186.
<https://doi.org/10.3389/fnhum.2010.00186>
- Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology, 58*(3), 263-277. [https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews, 53*(1), 63-88.
<https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences, 16*(12), 606-617.
<https://doi.org/10.1016/j.tics.2012.10.007>
- Konrad, P. (2006). The ABC of EMG: A practical introduction to kinesiological In Noraxon INC. USA. (Version 1., Issue March). Noraxon INC. USA.
<http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf>

- Krane, V., & Williams, J. M. (2006). Psychological characteristics of peak performance. In J. M. Williams (Ed.), *Applied sport psychology: Personal growth to peak performance* (pp. 207-227). Boston, MA: McGraw-Hill.
- Lee, C. (1990). Psyching up for a muscular endurance task: Effects of image content on performance and mood state. *Journal of Sport and Exercise Psychology*, *12*(1), 66-73. <https://doi.org/10.1123/jsep.12.1.66>
- Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, *116*(6), 1091-1116. <https://doi.org/10.1007/s00421-016-3346-6>
- Marchant, D. C., & Greig, M. (2017). Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic knee extensions. *Human Movement Science*, *52*, 67-73. <https://doi.org/10.1016/j.humov.2017.01.007>
- McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Medicine*, *45*(11), 1523-1546. <https://doi.org/10.1007/s40279-015-0376-x>
- McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences*, *23*(7), 687-692. <https://doi.org/10.1080/02640410400021401>
- Moritani, T., & Muro, M. (1987). Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *European Journal of*

Applied Physiology and Occupational Physiology, 56, 260-265.

<https://doi.org/10.1007/BF00690890>

Nuzzo, J. L., Taylor, J. L., & Gandevia, S. C. (2019). CORP: assessments of upper- and lower-limb muscle strength and voluntary activation in humans. *Journal of Applied Physiology*, 126(3), 513-543.

<https://doi.org/10.1152/jappphysiol.00569.2018>

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113. [https://doi.org/10.1016/0028-](https://doi.org/10.1016/0028-3932(71)90067-4)

[3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)

Oxendine, J. B. (1970). Emotional arousal and motor performance. *Quest*, 13(1), 23-32. <https://doi.org/10.1080/00336297.1970.10519673>

Parcell, A. C., Sawyer, R. D., Tricoli, V. A., & Chinevere, T. D. (2002). Minimum rest period for strength recovery during a common isokinetic testing protocol. *Medicine and Science in Sports and Exercise*, 34(6), 1018-1022.

<https://doi.org/10.1097/00005768-200206000-00018>

Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259. <https://doi.org/10.1080/104132001753144392>

Pincivero, D. M., Coelho, A. J., Campy, R. M., Salfetnikov, Y., & Suter, E. (2003). Knee extensor torque and quadriceps femoris EMG during perceptually-guided isometric contractions. *Journal of Electromyography and Kinesiology*, 13(2), 159-167. [https://doi.org/10.1016/S1050-6411\(02\)00096-2](https://doi.org/10.1016/S1050-6411(02)00096-2)

- Pineschi, G., & Di Pietro, A. (2013). Anxiety management through psychophysiological techniques: Relaxation and psyching-up in sport. *Journal of Sport Psychology in Action*, 4(3), 181-190.
<https://doi.org/10.1080/21520704.2013.820247>
- Pion-Tonachini, L., Kreutz-Delgado, K., & Makeig, S. (2019). ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. *NeuroImage*, 198, 181-197.
<https://doi.org/10.1016/j.neuroimage.2019.05.026>
- Prerau, M. J., Brown, R. E., Bianchi, M. T., Ellenbogen, J. M., & Purdon, P. L. (2017). Sleep neurophysiological dynamics through the lens of multitaper spectral analysis. *Physiology*, 32(1), 60-92.
<https://doi.org/10.1152/physiol.00062.2015>
- Sarter, M., Gehring, W. J., & Kozak, R. (2006). More attention must be paid: the neurobiology of attentional effort. *Brain research reviews*, 51(2), 145-160.
<https://doi.org/10.1016/j.brainresrev.2005.11.002>
- Shelton, T. O., & Mahoney, M. J. (1978). The content and effect of “psyching-up” strategies in weight lifters. *Cognitive Therapy and Research*, 2(3), 275-284.
<https://doi.org/10.1007/BF01185789>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Tenenbaum, G., Bar-Eli, M., Hoffman, J. R., Jablonovski, R., Sade, S., & Shitrit, D. (1995). The effect of cognitive and somatic psyching-up techniques on

isokinetic leg strength performance. *The Journal of Strength & Conditioning Research*, 9(1), 3-7. Retrieved from https://journals.lww.com/nsca-jscr/Abstract/1995/02000/The_Effect_of_Cognitive_and_Somatic_Psyching_up.1.aspx

Theodorakis, Y., Weinberg, R., Natsis, P., Douma, I., & Kazakas, P. (2000). The effects of motivational versus instructional self-talk on improving motor performance. *The Sport Psychologist*, 14(3), 253-271.
<https://doi.org/10.1123/tsp.14.3.253>

Tod, D., Iredale, F., & Gill, N. (2003). 'Psyching-up' and muscular force production. *Sports Medicine*, 33(1), 47-58. <https://doi.org/10.2165/00007256-200333010-00004>

Tod, D. A., Iredale, K. F., McGuigan, M. R., Strange, D. E. O., & Gill, N. (2005). "Psyching-up" enhances force production during the bench press exercise. *Journal of Strength and Conditioning Research*, 19(3), 599-603. Retrieved from <https://search.proquest.com/docview/213066537?accountid=14696>

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>

Tynes, L. L., & McFatter, R. M. (1987). The efficacy of "psyching" strategies on a weight-lifting task. *Cognitive Therapy and Research*, 11(3), 327-336.
<https://doi.org/10.1007/BF01186283>

Van Dyk, N., Bahr, R., Whiteley, R., Tol, J. L., Kumar, B. D., Hamilton, B., ... & Witvrouw, E. (2016). Hamstring and quadriceps isokinetic strength deficits

are weak risk factors for hamstring strain injuries: a 4-year cohort study. *The American Journal of Sports Medicine*, 44(7), 1789-1795.

<https://doi.org/10.1177/0363546516632526>

Weinberg, R. S., Gould, D., & Jackson, A. (1980). Cognition and motor performance: Effect of psyching-up strategies on three motor tasks. *Cognitive Therapy and Research*, 4(2), 239-245. Retrieved from

<https://link.springer.com/content/pdf/10.1007/BF01173655.pdf>

Weiss, T., Sust, M., Beyer, L., Hansen, E., Rost, R., & Schmalz, T. (1995). Theta power decreases in preparation for voluntary isometric contractions performed with maximal subjective effort. *Neuroscience Letters*, 193(3), 153-156.

[https://doi.org/10.1016/0304-3940\(95\)11688-S](https://doi.org/10.1016/0304-3940(95)11688-S)

Whelan, J. P., Epkins, C. C., & Meyers, A. W. (1990). Arousal interventions for athletic performance: Influence of mental preparation and competitive experience. *Anxiety Research*, 2(4), 293-307.

<https://doi.org/10.1080/08917779008248735>

Wilkes, R. L., & Summers, J. J. (1984). Cognitions, mediating variables, and strength performance. *Journal of Sport Psychology*, 6(3), 351-359.

<https://doi.org/10.1123/jsp.6.3.351>

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, 8(4), 648-660.

<https://doi.org/10.3758/BF03196201>

Wyatt, M. P., & Edwards, A. M. (1981). Comparison of quadriceps and hamstring torque values during isokinetic exercise. *Journal of Orthopaedic & Sports Physical Therapy*, 3(2), 48-56. <https://doi.org/10.2519/jospt.1981.3.2.48>

Chapter Four

Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., ... & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *The Journal of Physiology*, 586(1), 131-139
<https://doi.org/10.1113/jphysiol.2007.141630>

Brody, E. B., Hatfield, B. D., Spalding, T. W., Frazer, M. B., & Caherty, F. J. (2000). The effect of a psyching strategy on neuromuscular activation and force production in strength-trained men. *Research Quarterly for Exercise and Sport*, 71(2), 162-170. <https://doi.org/10.1080/02701367.2000.10608894>

Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, 51(4), 374-384.
<https://doi.org/10.1111/psyp.12182>

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163. <https://doi.org/10.1123/jab.13.2.135>

Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology*, 6(1), 89.
<https://doi.org/10.1037/spy0000077>

- Hardy, L., Jones, J. G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Hoboken, NJ: John Wiley & Sons Inc.
- Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Research on Sport Psychology* (2nd ed.), (pp. 362-386). New York, NY: John Wiley & Sons.
- Hatfield, B. D., Jaquess, K. J., Lo, L. C., & Oh, H. (2020). The cognitive and affective neuroscience of superior athletic performance. *Handbook of sport psychology*, 487-512. <https://doi.org/10.1002/9781119568124.ch23>
- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186. <https://doi.org/10.3389/fnhum.2010.00186>
- Jones, G. (1993). The role of performance profiling in cognitive behavioral interventions in sport. *The Sport Psychologist*, 7(2), 160-172. <https://doi.org/10.1123/tsp.7.2.160>
- Kerick, S. E., McDowell, K., Hung, T. M., Santa Maria, D. L., Spalding, T. W., & Hatfield, B. D. (2001). The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. *Biological Psychology*, 58(3), 263-277. [https://doi.org/10.1016/S0301-0511\(01\)00116-8](https://doi.org/10.1016/S0301-0511(01)00116-8)

- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, 53(1), 63-88.
<https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.
<https://doi.org/10.1016/j.tics.2012.10.007>
- McGuigan, M. R., Ghiagiarelli, J., & Tod, D. (2005). Maximal strength and cortisol responses to psyching-up during the squat exercise. *Journal of Sports Sciences*, 23(7), 687-692. <https://doi.org/10.1080/02640410400021401>
- Perkins, D., Wilson, G. V., & Kerr, J. H. (2001). The effects of elevated arousal and mood on maximal strength performance in athletes. *Journal of Applied Sport Psychology*, 13(3), 239-259. <https://doi.org/10.1080/104132001753144392>
- Sahaly, R., Vandewalle, H., Driss, T., & Monod, H. (2003). Surface electromyograms of agonist and antagonist muscles during force development of maximal isometric exercises—effects of instruction. *European Journal of Applied Physiology*, 89, 79-84. <https://doi.org/10.1007/s00421-002-0762-6>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Taylor, J. (1995). A conceptual model for integrating athletes' needs and sport demands in the development of competitive mental preparation strategies. *The Sport Psychologist*, 9(3), 339-357. <https://doi.org/10.1123/tsp.9.3.339>

Tod, D., Iredale, F., & Gill, N. (2003). 'Psyching-up' and muscular force production. *Sports Medicine*, 33(1), 47-58. [https://doi.org/10.2165/00007256-](https://doi.org/10.2165/00007256-200333010-00004)

[200333010-00004](https://doi.org/10.2165/00007256-200333010-00004)

Tod, D., Edwards, C., McGuigan, M., & Lovell, G. (2015). A systematic review of the effect of cognitive strategies on strength performance. *Sports Medicine*, 45(11), 1589-1602. <https://doi.org/10.1007/s40279-015-0356-1>