Abstract

Title of dissertation: THE INFLUENCE OF CONSCIOUS CONTROL OF MOVEMENT ON BRAIN PROCESSES AND THE QUALITY OF COGNITIVE-MOTOR PERFORMANCE

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The impact of mental stress on fine motor performance is typically maladaptive. The current research was conducted to investigate the manner by which state anxiety affects performance using a cognitive neuroscience perspective. The basic proposition tested, derived from the Reinvestment Theory and the Psychomotor Efficiency Hypothesis, is that stress introduces neuromotor noise to motor planning processes that translate as excess recruitment of motor units and degrade performance. Electroencephalography (EEG) was employed in Study 1 to assess regional cortical activation and cortico-cortical communication between non-motor associative and motor planning regions during the preparatory period of a dart-throwing task. The task was performed during stress (i.e., social evaluation, monetary incentives, and threat of electrical shock) and a relatively relaxed control condition through a within-subjects design. Regional activation was estimated from bilateral EEG recordings in the frontal, central, temporal, parietal, and occipital regions via spectral analysis to assess low-alpha and high-alpha band power to determine generalized arousal and task-relevant attentional focus, respectively. Cortico-cortical communication was estimated between all bilateral regions and the frontal motor planning area with particular emphasis on the left temporal (T3) to midline frontal (Fz) coherence. Elevated state anxiety was induced and associated with heightened T3-Fz EEG connectivity and synchrony of high-alpha band in the right occipital region. Based on these findings, Study 2 was conducted to determine the psychological processes accounting for the observed elevation in T3-Fz EEG coherence and the quality of muscle action during the throwing task. Specifically, participants employed an internal and an external attentional focus to perform the throwing task while their EEG and electromyography (EMG) were monitored. The use of internal focus, which is consistent with explicit monitoring of movement mechanics, was predicted to result in elevated T3-Fz EEG connectivity. This prediction was supported and, furthermore, the magnitude of connectivity was positively associated with motor unit activity assessed via EMG of four major muscle groups (i.e., flexor carpi ulnaris, extensor carpi radialis, biceps brachii, and triceps brachii). The evidence provided supports the theoretical notion that explicit monitoring promotes inefficient muscle activity, which mediates to impact performance negatively.

THE INFLUENCE OF CONSCIOUS CONTROL OF MOVEMENT ON BRAIN PROCESSES AND THE QUALITY OF COGNITIVE-MOTOR PERFORMANCE

by

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General Introduction

Overview

The program of research reported includes two studies designed to gain insight into the manner by which mental stress impacts the performance of cognitive-motor behavior. The first investigation (Study 1) was conducted to examine the influence of state anxiety on cerebral cortical activity with a specific focus on the cortico-cortical communication between verbal-analytic and motor preparatory processes as measured by electroencephalographic (EEG) coherence. The loci related to these processes are the left temporal and midline frontal, respectively. Specifically, the prediction was that such communication between the left temporal and midline frontal regions is elevated based on the theoretical framework of Masters' reinvestment theory (Masters, 1992; Masters & Maxwell, 2008). This prediction was supported. The significance of the stress-induced elevation is discussed in terms of interference with neuromotor preparatory processes, which translates into alterations in skeletal muscle motor unit recruitment and altered kinematics of movement (i.e., typically undesirable translation). As such, the finding was consistent with the reinvestment theory. The second investigation (Study 2) was conducted as a follow-up to Study 1 to determine the psychological process underlying the observed elevation in EEG coherence between the left temporal and midline frontal regions. This problem was approached by contrasting the magnitude of cortico-cortical communication between the verbal-analytic and motor planning regions while an internal focus on movement-related mechanics is dominant during the preparatory period just prior to the onset of forward extension movement of a dart throwing task, which is assumed to occur during reinvestment, versus an external focus on the target. In this regard, Wulf and colleagues (McNevin, Shea, & Wulf, 2003; Wulf, Höß, & Prinz, 1998; Wulf, McNevin, & Shea, 2001) have discussed extensively the adaptive benefit of an external focus of attention relative to an internal focus during skilled motor behavior. The magnitude of EEG coherence between the regions identified above was, in fact, elevated with the internal focus during the preparatory period and was joined by elevated EEG coherence between the motor preparatory region and several additional regions across the scalp topography. This finding, along with that from Study 1, was interpreted as evidence that mental stress alters brain processes via an internal focus on the details (i.e., analysis) of a movement. The impact of the stress-induced cortical dynamics on movement quality and performance was assessed by measurement of motor unit recruitment through assessment of electromyographic (EMG) of the involved musculature and accuracy in attempting a bull's eye.

Background

Efficiency (i.e., work relative to effort or resources required) has been acknowledged as a fundamental characteristic of superior human performance in both the physiological and psychological domains. Efficient performance is characterized by engagement of essential task-relevant processes achieved by adaptive resource allocation and expenditure of minimal effort within the constraints and demands of a given task by coordinated action of various systems within a human organism. For example, elite distance runners illustrate the phenomenon of running economy by exhibiting a decrement in O_2 consumption (i.e., per unit of body mass) compared to less accomplished runners during treadmill work at absolute submaximal workloads (Daniels, 1985). Furthermore, the emergence of relative economy was also observed in the patterning of skeletal muscle activation in novice rowers as a function of practice such that they exhibited relative stability and consistency in peak forces of the stroking movement after practice with an overall reduction in motor unit activation to produce the same amount of force (Lay, Sparrow, Hughes, & O'Dwyer, 2002).

In this manner, Hatfield and Hillman (2001) theorized that the human brain subscribes to the same principle of economy or efficiency as other biological systems while adapting to environmental challenges over time. According to Fitts and Posner (1967), cognitive-motor skill acquisition progresses from an initial stage of cognitive analysis to an intermediate associative stage, during which less effortful regulation of motor processes is required and, finally, it advances to the autonomous stage. As a result, practice leads to a higher quality of performance due to minimization of non-essential neurocognitive activity and the autonomous stage allows for execution of motor skill with refinement and attenuation of cerebral cortical activity relative to the associative and cognitive stages. The notion of neural efficiency (Haier et al., 1992) is characterized by a reduction in the allocation of central neural resources during challenge. In this regard, performance (i.e., work) is accomplished with a reduction of cortical and subcortical activity that can be described as a form of neural efficiency. In support of this notion, Deeny, Hillman, Janelle, and Hatfield (2003) observed that superior rifle marksmen, who held more competitive experience than a cohort of equally experienced marksmen, exhibited lower levels of cortico-cortical communication between non-motor and motor planning regions of the cerebral cortex during the aiming period just prior to trigger pull. This observation was achieved by measuring EEG coherence (i.e., a refined measure of networking) between the left temporal (T3) region, which is associated with verbal-analytic processing, and the midline frontal (Fz) region, which is associated with volitional motor preparatory processes. The reduction in EEG coherence in those who had more competitive success, compared to marksmen with similar years of shooting experience but less competitive success suggests the attenuation of disruptive neural activity or “neuromotor noise” introduced to the essential motor processes. Deeny et al. suggested that the refined ‘input’ from the left temporal association region (T3) to the motor planning region (Fz) observed in high-level competitors is a contributor to superior motor performance due to the absence of any disruption to the timing and frequency of firing of those motor neurons that are essential to specific motor units required to perform the task. Based on this reasoning and empirical observation, Hatfield and Kerick (2007) offered a conceptual model of the relationship between cortical processes and motor behavior by advancing the notion of psychomotor efficiency such that the reduction of non-essential ‘neuromotor noise’ to the premotor region leads to efficient recruitment of motor units in skeletal muscle in the case of the superior performer. Such action promotes consistency of movement and concordance between intended and actual action of the limbs. In this manner, expert motor behavior or superior performance is accomplished with simplified task-relevant cerebral cortical dynamics in the form of minimal cortical activation and refined cortico-cortical communication. Such a characteristic translates into reduced activation in skeletal muscles within the constraints of the task and the resulting performance in the skilled athlete is often described as graceful, smooth, and fluid.

Mental Stress and Performance

However, in our daily life, many motor skills such as those evoked when playing musical instruments and engaging in sporting games are often performed in a competitive or socially evaluative context in which performers often experience varying degrees of unpleasant feelings and disturbing physiological responses in addition to or excessive arousal. The phenomenon of state anxiety and “choking” (e.g., as described by Baumeister, 1984) is well known in competitive sport settings and is typically described as degradation in cognitive motor performance relative to the customary quality of performance demonstrated by an individual under non-evaluative conditions. Specifically, degradation of cognitive motor performance under such conditions may result from excessive task-irrelevant thoughts and worries due to elevated state anxiety, which elevates cognitive load and promotes maladaptive attentional processing (e.g., Eysenck, Derakshan, Santos, & Calvo, 2007). According to the psychomotor efficiency hypothesis (Hatfield & Hillman, 2001; Hatfield & Kerick, 2007), it is plausible that the elevated state anxiety observed under the stress of competitions manifests as heightened cerebral cortical activation and non-essential networking (i.e., cortico-cortical communication) to the frontal motor planning areas of the brain. In support of this notion, Hatfield and colleagues (Hatfield et al., 2013) employed head-to-head competition to investigate the effect of such an evaluative environment on cognitive-motor performance and the underlying psychophysiological processes. Participants [Reserve Officers’ Training Corps (ROTC) candidates] were paired to compete against each other during an air-pistol shooting task, in which the participants’ aiming and target shooting accuracy was executed under time constraints and evaluation of a superior officer. Relative to a non-competitive control condition, Hatfield and colleagues observed a modest increase in state anxiety (e.g., as indicated by elevation in cortisol and heart rate) and heightened cortical activity in the form of EEG desynchrony of high-alpha (10-12 Hz) spectral band power accompanied by elevated cortico-cortical communication between the bilateral frontal (i.e., F3 and F4) and the motor planning (i.e., Fz) regions during competition. Although there was no difference in shooting accuracy between the two conditions, participants did exhibit an increase in the variability of aiming trajectory under competition. That is, they were less steady under competition and had to exert more effort to accomplish the same level of accuracy as achieved during the non-competitive control condition. This finding suggests a maladaptation in the quality of aiming under stress and is also consistent with attentional control theory (Eysenck et al., 2007) in that state anxiety impacts the processing efficiency of motor behavior.

The theoretical explanation of the relationship between mental stress and motor performance has traditionally been described as an inverted-U (i.e., a bell-shape curve) or the Yerkes-Dodson law. Accordingly, arousal facilitates performance to a point beyond which further increases in arousal are associated with degraded performance. Derivations of this general proposition have appeared in the literature (e.g., Hanin’s Individual Zones of Optimal Function (IZOF), Hardy’s Catastrophe theory, etc.). However, such conceptual models fail to offer underlying mechanisms to explain the impact of stress or task challenge on performance outcome. Specifically, the impact of stress can be mediated by anxiety and excessive arousal, which can be objectively observed from changes expressed in the central and peripheral nervous systems that translate to visceral organ and musculoskeletal activity. The hypotheses of psychomotor efficiency and reinvestment are two promising perspectives that offer underlying mechanisms to study the relationship between mental stress and neuromotor performance.

As described above, Hatfield and Kerick (2007) elucidated that superior cognitive-motor performance is characterized by decreased input of neuromotor noise to the premotor region such that reduction in non-essential processing would lead to efficient recruitment of motor units in skeletal muscle during motor behavior so that movement of the extremities is executed as planned or desired. It is plausible that elevated state anxiety induced by stress may undermine the characteristics of motor efficiency exhibited in superior performers such that the elevated state anxiety promotes input of non-essential verbal-analytic processing to the motor planning region (i.e., sport psychologists describe this phenomenon as engagement of negative self-talk).

Such a notion is also consistent with a reversion model in motor behavior proposed by the reinvestment theory (Masters, 1992; Masters & Maxwell, 2008), which asserts that self-consciousness about one's movements (i.e., movement self-consciousness) and conscious control of the mechanics of one's movements (i.e., conscious motor processing) induces an explicit monitoring or "dechunking of knowledge" in motor control processes. Such explicit monitoring or "knowledge dechunking," by which the performer engages in overthinking of the details or elements of interactivity of the task, typically diminishes as motor learning progresses. However, the conscious control of movement (or thinking about the detailed mechanics of a movement) under conditions of mental stress represents a reinvestment of these processes in motor behavior, which may lead to further breakdown of skilled performance. In other words, a performer would revert to an earlier stage of skill development under conditions of significant mental stress. In this manner, the degradation of motor performance associated with elevated state anxiety during competitive or social evaluative settings may be caused by retreat from the relatively autonomous stage to the cognitive-analytical stage elucidated by Fitts and Posner (1967) in their human performance theory.

Furthermore, such reinvestment of conscious control in volitional movement has been associated with heightened verbal-analytic processing. Zhu, Poolton, Wilson, Maxwell, and Masters (2011, study 1) observed a positive association between participants' propensity of reinvestment and the magnitude of cortico-cortical communication between the left temporal (T3) and the motor planning (Fz) regions during the preparatory period just prior to golf putting. Specifically, EEG coherence between T3 and Fz in the high-alpha band was significantly greater in novice golfers of high-reinvestment propensity relative to their low-reinvestment cohorts. Such finding suggests that conscious motor control is highly associated with involvement of verbal-analytic processing. Specifically, this finding is consistent with the perspective of psychomotor efficiency, which identifies a step beyond the explanation offered by the reinvestment theory by description of the disruption of motor processes in the brain that result in the alteration of motor unit recruitment in those muscles specific to the intended action (e.g., a throwing movement). In a follow-up study, Zhu et al. (2011, study 2) observed elevated T3-Fz coherence in individuals performing golf putting under conditions of videotaping, which was employed to induce mental stress. Elevation of T3-Fz coherence in the high-alpha band implies heightened communication between the motor planning region (i.e., Fz) and associative functions such as verbal-analytical processing (i.e., as associated with the T3 recording location). However, the increment in T3-Fz coherence cannot be exclusively related to mental stress because an error-prone (i.e., effortful) practice schedule was administrated to the participants, thus making it difficult to disambiguate the cause of the elevation in cortico-cortical communication. Even so, such elevated coupling may be indicative of non-essential input of neuromotor noise to the neural processes mediating motor planning.

The Present Program of Research

Importantly, more research exclusively focusing on the effect of mental stress on neuromotor performance is needed, which was a primary purpose of the dissertation. In addition, Zhu et al. (2011) confined their examination of EEG coherence to T3-Fz and T4-Fz electrode pairings to assess EEG coherence; there is a need to examine a more extensive topography to examine non-motor to motor communication more globally under stress.

The purpose of this dissertation entailing two studies is to add knowledge in the area of sport psychology. Specifically, the major concept to be tested in the proposed dissertation is that reinvestment of conscious control (i.e., non-essential verbal-analytic processing on one's movements or on the mechanics of one's movements) in motor behavior can disrupt the efficiency of brain and skeletal muscle activity. Such conscious control in motor behavior is expected to degrade performance outcome and processes. As such, Study 1 employed a neurocognitive perspective to study reinvestment theory along with the psychomotor efficiency hypothesis of cortical dynamics and neuromotor performance to explain stress-induced alterations in motor performance. Study 2 employed a manipulation of one specific element, the focus of attention, to determine the psychological processes underlying reinvestment theory and its translational effect on the quality of musculo-skeletal activity and performance during motor behavior.

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Elevated State Anxiety Alters Cerebral Cortical Dynamics and Degrades Precision Cognitive-Motor Performance

Introduction

An occurrence of inferior performance is an unwanted outcome for anyone in any context. For example, the phenomenon of choking has been observed in diverse situations such as those involving public speaking or sports and games, and investigations of underlying mechanisms have become prevalent in the sport and exercise sciences (e.g., Baumeister, 1984; Baumeister & Showers, 1986; Beilock & Carr, 2001; Beilock & Gray, 2007). Understanding the causes of inferior performance is an important issue for anyone whose desire is the pursuit of optimal performance.

Anxiety is considered to be one of the major attributes underlying inferior performance due to its impact on human performance that manifests in many ways. Often, individuals report heightened state anxiety associated with elevated arousal experienced by symptoms such as increased respiration and heart rate during competitive or stressful settings. Moreover, they typically experience unpleasant cognitive elaborations and feelings such as worry and nervousness along with performance degradation (e.g., Nibbeling, Oudejans, & Daanen, 2012; Nibbeling, Oudejans, Ubink, & Daanen, 2014) due to limited capacity of working memory and compromised efficiency of attentional control (Eysenck, Derakshan, Santos, & Calvo, 2007). In line with the notion of compromised processing effectiveness and efficiency, it appears that elevated state anxiety, induced by competitive or social evaluative contexts, alters the efficiency of salient neurophysiological processes, which has been observed in well-trained or skilled individuals responding to numerous challenges ranging from standardized tests to cognitive-motor tasks (e.g., Haier, Siegel, MacLachlan, Soderling, Lottenberg, & Buchsbaum, 1992; Hatfield & Hillman, 2001).

Germane to sport performance, many studies have examined the relationship between cerebral cortical dynamics and psychomotor performance (see Hatfield, Haufler, Hung, & Spalding, 2004, for a review). These studies have clearly indicated that a reduction in electroencephalographic (EEG) coherence reflects refinement of cortico-cortical communication in neural processes, especially during motor learning (Hatfield et al., 2004; Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). More specifically, EEG coherence serves as an index of the magnitude of cortico-cortical communication between two regions of the brain. A classic study by Busk and Galbraith (1975) revealed that practice of a visuomotor task was associated with a significant decrease in cortico-cortical coupling as learning progressed. A similar finding was obtained in two cross-sectional comparison studies of cerebral cortical activity during the aiming period of a target shooting task in expert and novice marksmen. Deeny, Haufler, Saffer and Hatfield (2009) and Del Percio et al. (2011) observed lower coherence between the frontal cerebral cortical region and a number of other regions across the scalp topography, where the EEG is recorded, prior to the trigger pull in experts relative to that observed between these brain regions in novices. Specifically, the observed reduction in coherence was manifested in the low-alpha (8-10 Hz) and high-alpha (10-12 Hz) frequency ranges and correlated with a reduction in the magnitude of event-related synchronization of spectral power in the same frequency range. In a similar vein, Deeny, Hillman, Janelle, and Hatfield (2003) observed that rifle marksmen with superior competitive performance histories exhibited lower levels of EEG coherence (i.e., refined networking), specifically between the left temporal (T3) and the midline frontal (Fz) regions, during the aiming period of target shooting compared to marksmen who held similar years of shooting experience, but relatively poor performance during competition. Deeny et al. (2003) suggested that the refined ’input’ from the left temporal association region (i.e., T3) to the motor planning region (i.e., Fz) is an influential contributor to superior performance due to a reduction of ‘neuromotor noise.’ Collectively, the results of these studies suggest that increased efficiency in the neural systems mediating motor behavior leads to enhancement of performance. With practice, human motor behavior is able to advance from a cognitive-analytical stage to a relatively autonomous stage (Fitts & Posner, 1967) and the improved quality of performance may be due, in part, to the refinement of communication between critical brain regions.

Presence of significant ‘neuromotor noise’ may explain the deteriorating effect of anxiety on motor performance. It is plausible that the refinement of cortico-cortical communication observed in experts as a result of practice can be degraded by mental stress. Specifically, an elevation in EEG low- and high-alpha coherence may indicate a loss of efficiency in neurophysiological processing and lead to performance degradation because of a maladaptive alteration of neuronal activity in the motor planning region. Although Zhu, Poolton, Wilson, Maxwell and Masters (2011, study 2) observed elevated T3-Fz coherence in individuals performing golf putting under the evaluative pressure condition of videotaping, such a finding was confounded with the study design, which was implemented with an effortful practice schedule, and it is difficult to determine unambiguously if the mental stress induced from the videotaping was the exclusive cause for the elevated T3-Fz coherence. In other words, any one of 1) the error-prone (i.e., effortful) practice schedule, which was employed to induce explicit motor learning, 2) the stress induced by the videotaping, or 3) a combination of effortful practice and mental stress could have accounted for the observed increment in T3-Fz coherence. Even so, the observed elevation of T3-Fz coherence in the high-alpha band supports the position that inferior performance may result from elevated communication between the motor planning region (e.g., Fz) and those involved with associative functioning (e.g, T3) such as verbal-analytical processing. Such elevated coupling may be indicative of non-essential input to the workspace mediating motor planning and such activity could lead to a sudden degradation in the quality of motor performance in light of the alteration of critical preparatory processes during motor planning. In light of the study design employed by Zhu et al. (2011) there is a need for a singular focus on the relationship between mental stress, brain dynamics and motor performance and the employment of a robust mental stressor.

In addition to the measure of EEG coherence, EEG spectral power can also be used to yield informative metrics of cerebral cortical activity under stress. Broadband EEG alpha power (8-13 Hz) is considered to be the ‘idling frequency’ in the frequency spectrum and it reflects the state of cerebral cortical activation (Adrian & Matthews, 1934). Elevations or synchrony of post-synaptic neuronal activity as reflected in this band are commonly interpreted as relaxation or a reduction in cortical activation, whereas reductions in power or relative desynchrony are typically interpreted as increased activation (Pfurtscheller, 1992; Pfurtscheller, Stancák & Neuper, 1996). Furthermore, Pfurtscheller and colleagues (Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller et al., 1996) advocate for consideration of such specificity in EEG alpha power (i.e., low-alpha and high-alpha) to capture diverse neuro-cognitive processes. For example, relative synchronization or elevation of low-alpha power (8-10 Hz), in contrast to a reference condition, indexes a reduction in general cortical arousal while relative synchronization of high-alpha frequencies (10-13 Hz) indexes a decrease in task-relevant information processing (Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller et al., 1996). In this manner, the examination of changes in EEG spectral power in both the low- and high-alpha frequency bands can be informative about underlying elements of cognitive-motor processes and provide greater insight regarding contrasts between novices and experts (see Hatfield et al., 2004; Hatfield & Kerick, 2007 for reviews; Del Percio et al., 2009; Del Percio et al., 2011) and help our understanding of the conditions leading to elevated state anxiety. In this regard, Hatfield et al. (2013) observed desynchrony of high-alpha power during a competitive shooting match compared to a control condition (i.e., shooting alone in the absence of social comparison), which suggests a loss of focused attention on the task during the stress of competition. This alteration in electrocortical activity observed during competition was associated with a loss of steadiness and fluency in the aiming trajectory that may have resulted from alterations in relevant neuronal activity critically related to the skeletal muscle activity associated with the shooting position and pistol hold by the upper extremities. It has also been observed that expert rifle shooters exhibit synchrony of low- and high-alpha power compared to novices (see Hatfield et al., 2004; Hatfield & Kerick, 2007 for reviews), but mental stress may evoke a reversion in experts to desynchrony. In this manner, experts or experienced performers would become less relaxed and attentive and more like novices in the expression of cortical dynamics such as elevated cortico-cortical communication between the non-motor and motor planning regions and heightened cortical activation associated with task-irrelevant information processing.

As such, the present study was designed to manipulate mental stress and examine cerebral cortico-cortical communication between critical brain regions of interest, as well as regional cortical activity, while examining the quality of motor performance as participants performed a dart-throwing task for accuracy. The purpose of such an experimental approach was to provide an insight into the influence of mental stress on motor behavior. Therefore, compared to a non-stress condition, a relative increase in state anxiety under stress was predicted, which would be manifested as an elevation of high-alpha EEG coherence between sites T3 and Fz.

Accompanied with such a finding, a decrease in the low-alpha spectral power was predicted globally across all regions of the cerebral cortex, indicative of a heightened level of general cortical arousal under stress. Moreover, an increase in the high-alpha spectral power in the left hemisphere was predicted which would indicate a reduction in focused attention (i.e., distraction) and an increase in task-irrelevant information processing such as verbal-analytical processing (Hatfield, Landers & Ray, 1984). It was predicted that there would be no change in the high-alpha power in the right hemisphere because of requisite and adaptive engagement of visuo-spatial processing for the task-relevant demands of dart throwing. The changes in EEG coherence and spectral power were expected to occur at any or all time epochs during the preparatory period of dart throws. Lastly, the expected changes in cortical dynamics under mental stress were predicted to translate to degraded performance.

Therefore, the testing hypotheses were:

(1) Compared to a non-stress condition, there will be a relative increase in state anxiety under stress.

(2) Compared to a non-stress condition, there will be an elevation of high-alpha EEG coherence between sites T3 and Fz under stress.

(3) Compared to a non-stress condition, there will be a decrease in the low-alpha spectral power across all regions of the cerebral cortex under stress.

(4) Compared to a non-stress condition, there will be an increase in the high-alpha spectral power in the left hemisphere but no change in the right hemisphere under stress.

(5) Compared to a non-stress condition, there will be a decrease in performance accuracy under stress.

(6) Compared to a non-stress condition, there will be an increase in performance variability under stress.

Methods

Participants

Twenty-one healthy male college students ranging in age from 20 to 25 years (mean age 21.75±1.83 years) and inexperienced with the dart-throwing task were recruited to participate in the study from a Taiwanese University. All participants were right-hand dominant, as determined via procedures developed by Chapman and Chapman (1987), and were ipsilateral-eye dominant. Participants reported: (a) no history of neurological, cardiovascular, or other major disorders; (b) no history of psychiatric disorders; (c) no current use of medications; and (d) no hospitalizations or experience of general anesthesia within the last 12 months. In addition, all participants reported refraining from alcohol, caffeine, and nicotine for at least 24 hours before psychophysiological testing began. Participants provided informed consent on a form approved by the Institutional Review Board (IRB).

Task

Participants were required to perform 60 dart throws that were grouped into six blocks, consisting of ten dart throws each, under standardized task conditions. Performance accuracy was quantified as the total score of 60 shots (maximum possible score was 600 points). The horizontal distance to the dartboard (i.e., from the participant's feet that were evenly positioned) was 2.37 m positioned with the center of the target at a standard height of 1.74 m. The dartboard consisted of 10 concentric rings and a shot breaking the innermost ring (a bull's-eye) was scored as a 10 and a shot placed outside of the outermost ring (a miss) was scored as a 0.

Psychological Measures

Anxiety was measured by the Competitive State Anxiety Inventory 2 (CSAI-2), which was first developed by Martens, Vealey, and Burton (1990) and conceptualized as a multi-dimensional measurement for state anxiety prior to competition. Three subscales of CSAI-2, which assess cognitive anxiety, somatic anxiety, and self-confidence, evaluate and differentiate these dimensions of state anxiety independently.

A translated version of the CSAI-2 based on the Form E of the original CSAI-2 was used in this study in consideration of the native language of the participants. The translated version includes six items for cognitive anxiety subscale (Cronbach's alpha = .81), six items for somatic anxiety subscale (Cronbach's alpha = .88), and nine items for state self-confidence subscale (Cronbach's alpha = .93). Compared to the original CSAI-2, which consists of nine items for each subscale, fewer items were included in the translated version of cognitive and somatic anxiety subscales based on a confirmatory factor analysis. Each item of the CSAI-2 ranges from a low of 1 to a high of 4.

In order to determine the relative standing for the current sample in contrast to the norms obtained from the original CSAI-2, the mean and standard deviation for each subscale of the CSAI-2 were further transformed by multiplying by nine in light of the original item numbers for each subscale (i.e., nine items for each subscale of the original CSAI-2). In doing so, one is able to interpret the current results of CSAI-2 while relating the current sample to the norms of the general population.

Psychophysiological Recording

Scalp electroencephalographic data were collected using tin electrodes housed within a stretchable lycra cap, (Electrode-Cap Instrumentation, Inc.). Data were recorded from 28 sites (FP1, FP2, F3, F4, Fz, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, T3, T4, T5, T6, PC1, PC2, PC5, PC6, POz, Pz, P3, P4, O1, and O2) referenced to linked mastoids, and labeled in accordance with the modified International 10-20 system (Jasper, 1958). Specifically, only 11 scalp sites were chosen for further analysis to test our hypotheses because they were examined in previous related studies (e.g., Deeny et al., 2003; Hatfield et al., 2004). At all sites of interest, impedances were maintained below 10 kΩ. The ground electrode was located at the frontal pole (Fpz). Vertical and horizontal electro-oculograms (VEOG and HEOG, respectively) were recorded with bipolar configurations of 10-mm Grass cup tin electrodes (model E5GH). VEOG was recorded via sensors that located superior and inferior to the right eye and HEOG was recorded via sensors that were placed at the left and right orbital canthi.

In addition, a pair of bipolar sensors was placed on the right extensor indicis muscle, which mainly controls the extension movement of index finger, in order to measure electromyographic (EMG) activity. The action of the index finger was used to indicate the throwing movement of a dart release, and a visually monitored burst of the EMG is indicative of the time point of the throwing movement. The burst of the EMG signal was therefore used to serve as an event marker. Each event marker was verified by a manual trigger, which was done by one of the experimenters when a dart release from the participant's hand was observed.

All signals were collected using Neuroscan Synamps 1, linked to Neuroscan 4.0 acquisition/edit software on a PC running Windows XP operating system. Bandpass filters were set at 1-100 Hz with a 60-Hz notch filter and the sampling rate was set to 500 Hz.

Procedures

The study entailed two phases consisting of (1) phase 1: practice of the task and (2) phase 2: EEG assessment during performance of the task under conditions of stress and non-stress. During the practice phase all participants were trained for a period of three months on every other day during the week (i.e., 3 or 4 days a week) and each session consisted of 100 dart throws for accuracy. Participants were instructed to hold the dart for a minimum period of 2-s prior to each throw with the arm in a flexed position and in a vertical orientation with the dart close to the shoulder. Failure to execute the stationary hold period resulted in deletion of that trial until all 100 trials were properly completed on the training day. The purpose of the practice phase was to assist participants to achieve a stable level of performance so that the effect of mental stress on the quality of motor behavior could be assessed during phase 2 with a minimal variability (e.g., standard deviation of scores was equal to or less than 2 for three consecutive practice sessions) of performance.

Participants were asked to refrain from consuming alcohol and caffeine on the day of testing. After arriving at the laboratory, participants were informed of the procedures of the study and asked to provide written consent. Participants were then fitted with the EEG cap and Omni-prep conducting gel was applied to all sites of interest via a blunt-tipped medical syringe. Additionally, EOG and EMG sensors were attached as described above. When impedances reached the specified levels, participants were individually tested in a sound-attenuated room where equipment for the dart-throwing task was installed.

Prior to the beginning of either of the testing conditions, participants warmed up for several minutes at their discretion and made 20 throws for record. The mean of those 20 throws served as an individualized baseline performance. Participants completed the CSAI-2 before the initiation of the 60 trials in each condition and a seated 10-min break was given between conditions.

A combination of pressure or stress manipulations employed in previous studies in experimental settings has been shown to be effective in the elicitation of state anxiety (e.g., Cooke, Kavussanu, McIntyre, & Ring, 2010; Mesagno, Harvery, & Janelle, 2011; 2012). Therefore, the same approach was employed in the present study to induce state anxiety and maximize the situational effect on the dart-throwing performance during the stress testing condition of phase 2.

The order of the testing conditions of phase 2 was randomized via drawing. Therefore, it resulted in placing six participants in one order (i.e., the stress condition was conducted before the non-stress) and 15 in the other order (i.e., stress condition was conducted after the non-stress). The participant was informed of the testing order prior to beginning of the conditions on the testing day.

Stress condition. To achieve an elevation in state anxiety during the Stress condition, relative to that experienced in the Non-stress condition, videotaping and performance-contingency incentives were employed. Specifically, a digital video camera was positioned approximately 45 degrees to the left side of the participant to record their dart throwing movement. Participants were told that their movement would be analyzed after the completion of the testing. In addition, monetary reward and threat of electric shock were employed as performance-contingency reward and punishment so that participants would maintain their motivation to achieve a challenging standard. Participants were told that failures to meet the standard would result in an electric shock at the termination of the condition, which was never employed.

The standard of performance during the Stress condition for participants to receive the incentive and avoid shock was based on the performance achieved in the period prior to the Stress condition. When Stress occurred after Non-stress, the performance standard was based on the average score achieved during the last 20 throws during Non-stress. On the other hand, when Stress occurred first in the order, the performance standard was based on the individualized baseline performance achieved during the warm-up period. The standard of performance varied after completion of every 20 trials. By updating the standard of performance every 20 throws, each participant was provided a dynamic and challenging goal to perform well. Monetary reward, if warranted, was granted after completion of 10 throws if the standard was exceeded. The amount awarded was $3 for a successful block of 10 trials thus resulting in a limit of $18 if the standard was exceeded for each of the six evaluation sets and no deduction was made due to poor throws.

Non-stress condition. This condition was identical to the Stress condition except that there was no stress induction (i.e., no videotaping and performance-contingency incentives). However, the participants were reminded and instructed to *do their best* while performing the dart-throwing task.

EEG Signal Processing

EEG data reduction and computation were performed using the Compumedics-Neuroscan Scan 4.3 analysis program (Neuroscan, Inc., Charlotte, NC, USA). First, ocular artifact reduction via a regression-correction algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986) was applied to the continuous records of the EEG activity. The EEG of the last two seconds prior to the throw was segmented into four periods, 0.5-s each, for further analysis. The 0.5-s epochs were baseline corrected using the average of the interval. Epochs were further examined to exclude those whose amplitude exceed ± 100 µV or contain movement-related artifacts. Segmented data were subjected to fast Fourier transformation (FFT) using a Hamming window tapered 10% and averaged across 60 trials for the low-alpha (8-10 Hz) and high-alpha (10-12 Hz) frequency bands. In doing so, four consecutive epochs during the aiming period for each condition were yielded and all power values were then natural log (ln) transformed prior to statistical analyses.

EEG coherence was computed using the coherence transformation function of Compumedics-Neuroscan Scan 4.3 analysis program (Neuroscan, Inc., Charlotte, NC, USA) on the electrode pairs of interest. The midline frontal electrode site (Fz) located in the premotor region is the common site of interest to pair with the 10 following recording sites in the five cortical regions: the bilateral frontal (F3 and F4), temporal (T3 and T4), central (C3 and C4), parietal (P3 and P4), and occipital (O1 and O2). The procedure of obtaining the coherence estimates is referred to as complex correlation and can be described by the following formula:

$$Coh(f) = \frac{\left|\sum_{i=1}^{N} F_1(f) \cdot F_2^*(f)\right|^2}{\sum_{i=1}^{N} \left|F_1(f)\right|^2 \cdot \sum_{i=1}^{N} \left|F_1(f)\right|^2}$$

where *Coh (f)* is a coherence function, *f* is frequency, *N* is a number of EEG realizations involved in averaging, $F_1(f)$ and $F_2(f)$ are Fast Fourier Transforms (FFT) of EEG signal in two different channels, and * symbol denotes complex conjugation.

The mean of the computed coherence values for each of the four time periods were then subjected to a Fisher z-transformation prior to statistical analysis to ensure a normal distribution.

Statistical Analysis

The factor Order (Order 1 consisted of Non-stress prior to Stress, n = 15; Order 2 consisted of Stress prior to Non-stress, n = 6) was included in all ANOVAs. A series of 2 x 2 (Order x Condition) ANOVAs with Order as a between-subject factor and Condition as a within-subject factor was employed to evaluate the effect of treatment on somatic anxiety, cognitive anxiety, and self-confidence measured via CSAI-2, as well as dart throwing performance accuracy and performance variability (i.e., standard deviation of 60 dart throw scores) separately.

In order to examine cortico-cortical communication beyond a replication of the finding by Zhu et al. (2011), high-alpha EEG coherence between the Fz and the homologous electrode sites within a cortical region (e.g., T3-Fz and T4-Fz) was subjected to a series of 2 x 2 x 2 x 4 (Order x Condition x Hemisphere x Time) ANOVAs for the five brain regions separately. In the same manner, a series of 2 x 2 x 2 x 4 (Order x Condition x Hemisphere x Time) with repeated measures on all factors were conducted to evaluate the effect of anxiety on the low- and high-alpha spectral power averages. The criterion alpha level was set to $p < .01$ with Bonferroni correction.

Conventional degrees of freedom were reported throughout and the Greenhouse-Geisser correction (ε) was provided when sphericity was violated. Furthermore, the probabilities reported for each effect were based on the corrected degrees of freedom. Partial eta squares (η_p^2), the percentage of variance that is explained by the treatment effects, were presented as a measure of effect size with significant ANOVA effects. Tukey's HSD method was employed to determine the significance for post-hoc comparisons of means. In addition, Cohen's measure of effect size (*d)* was provided to indicate the standardized difference between two conditional means. An alpha level of $p \leq .05$ was adopted in all other analyses except for those used for the high-alpha EEG coherence as well as low- and high-alpha bandwidths of EEG spectral power averages.

Results

State Anxiety Manipulation

ANOVA revealed a significant main effect of Condition for the raw scores of somatic anxiety (F (1, 19) = 11.87, MSE = 0.07, p = .003, η_p^2 = .39, d = 0.56) and self-confidence (F (1, 19) = 19.59, MSE = 0.07, p < .001, η_p^2 = .51, d = 1.03). Examination of the means revealed that greater somatic anxiety and less self-confidence was observed in the Stress condition.

However, ANOVA revealed an Order x Condition interaction for the raw score of cognitive anxiety (F (1, 19) = 6.46, MSE = 0.08, p = .02, η_p^2 = .25.). Post hoc analysis indicated that greater cognitive anxiety was found in the Stress condition (M = 1.91, SD = 0.62) compared to the Non-stress condition (M = 1.35, SD = 0.35) in Order 2, while no difference was observed between conditions in Order 1 although the mean in the Stress condition was higher than that in the Non-stress condition.

For further clarification, Table 1 presents the transformed subscale mean scores and standard deviations for the translated CSAI-2 for conditional contrasts within either order. In addition, according to the norms of the original CSAI-2 for male college students, percentile ratings for the transformed subscale mean scores and standard deviations of the CSAI-2 are reported in Table 2, which aids in the interpretation of the magnitude of change between the non-stress and stress conditions within either order. It appears that participants assigned in the Order 1 exhibited greater cognitive and somatic anxiety during both conditions than those in the Order 2.

Performance

ANOVA revealed a significant main effect of Condition for the dart throw total score (*F* (1, 19) = 5.84, *MSE* = 0.09, *p* = .026, η_p^2 = .24, *d* = 0.51). Examination of the means revealed that performance was lower during the Stress condition, compared to the Non-stress condition.

A significant Order x Condition interaction was revealed for performance variability (*F* (1, 19) = 6.87, *MSE* = 0.06, *p* = .017, η_p^2 = .27). Post hoc analysis revealed that greater performance variability was observed in the Stress condition (*M* = 2.02, *SD* = 0.42) compared to that in the Non-stress condition (*M* = 1.68, *SD* = 0.39) for the Order 1, while no difference was observed between the conditions for the Order 2. Descriptive results for dart-throwing performance accuracy and performance variability are presented in Table 1 for conditional contrasts within each order.

Table 1

Descriptive Results for Transformed Subscale Scores of Chinese CSAI-2 and Dart-throwing Performance Accuracy and Performance Variability in Non-stress and Stress Conditions for Order 1 and Order 2.

	Order 1		**Order 2**	
	Non-stress	**Stress**	**Non-stress**	**Stress**
Measure	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***
Cognitive anxiety*^{2}	**20.88 (5.76)**	**21.60 (6.84)**	**12.15 (3.15)**	**17.19 (5.58)**
Somatic anxiety*^{1,2}	**13.59 (5.04)**	**17.37 (6.93)**	**9.72 (1.17)**	**11.52 (3.15)**
Self-confidence*^{1,2}	**23.13 (2.97)**	**19.26 (3.87)**	**21.87 (2.70)**	**18.54 (5.22)**
Dart throw total score*^{1,2}	**489.80 (27.05)**	**472.12 (36.01)**	**495.0 (22.18)**	**482.76 (41.64)**
Dart throw score SD*^{1}	**1.68 (0.39)**	**2.02 (0.42)**	**1.76 (0.30)**	**1.66 (0.31)**

***^{1} Indicate significantly difference between Non-stress and Stress conditions in Order 1 (*p* < .05); *^{2}, Order 2.**

Table 2

Percentile of three subscales of translated CSAI-2 for current study

	Order 1		**Order 2**	
	Non-stress	**Stress**	**Non-stress**	**Stress**
Measure	***Percentile***	***Percentile***	***Percentile***	***Percentile***
Cognitive anxiety	**68**	**75**	**12**	**40**
Somatic anxiety	**27**	**49**	**5**	**16**
Self-confidence	**39**	**17**	**34**	**17**

NOTE. According to the norms of the original CSAI-2, the mean of standard total score and standard deviation of three subscales for male college students (N = 158) are as follows: Cognitive anxiety, M = 17.68, SD = 4.84; Somatic anxiety, M = 17.68, SD = 4.86; Self-confidence, M = 25.37, SD = 5.15. Accordingly, percentile rank for the three subscales of the CSAI-2 is provided in this table.

Electrophysiological Measures

High-alpha (10-12 Hz) coherence. The 4-way ANOVA, which was used to examine the regional specificity of interest, revealed a significant Condition x Hemisphere x Time interaction (F (3, 57) = 5.2, MSE = 0.03, p = .008, ε = .74, η_p^2 = .22) between the midfrontal and temporal regions regardless of order. No other significant effects involving Condition were observed in the frontal, central, parietal, and occipital regions. Post hoc comparisons revealed the T3-Fz high-alpha coherence during the third time interval (-1.0 s ~ -0.5 s) in the Stress condition was greater than its counterpart in the Non-stress condition (see Figure 1).

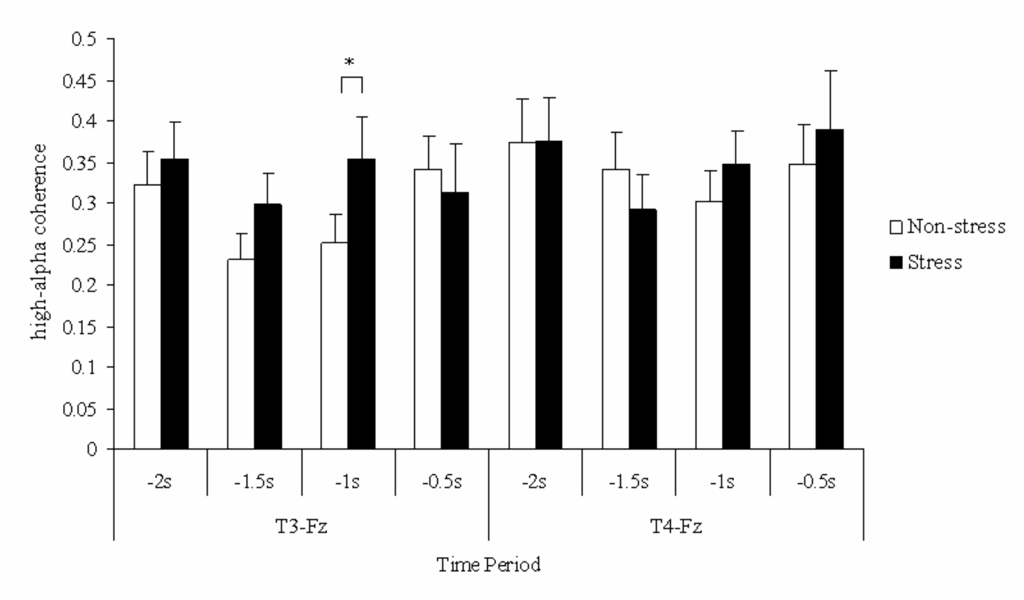

Figure 1. Condition x Hemisphere x Time interaction on high-alpha coherence at T3-Fz and T4-Fz with contrast focuses on Condition as well as on Time within a condition. * indicates a significant difference ($p < .05$).

Low-alpha (8-10 Hz) power. The 4-way ANOVA did not reveal any main effect or interaction involving Condition in any region.

High-alpha (10-12 Hz) power. The 4-way ANOVA revealed a significant Condition x Hemisphere x Time interaction (F (3, 57) = 4.26, MSE = 0.01, p = .009, η_p^2 = .18) in the occipital region regardless of order. Post hoc comparisons revealed high-alpha power in the right hemisphere during the first time interval (-2.0 s ~ -1.5 s) of the Stress condition was greater than that observed during the Non-stress condition (see Figure 2). No significant effects involving Condition were observed in the frontal, central, temporal, and parietal regions.

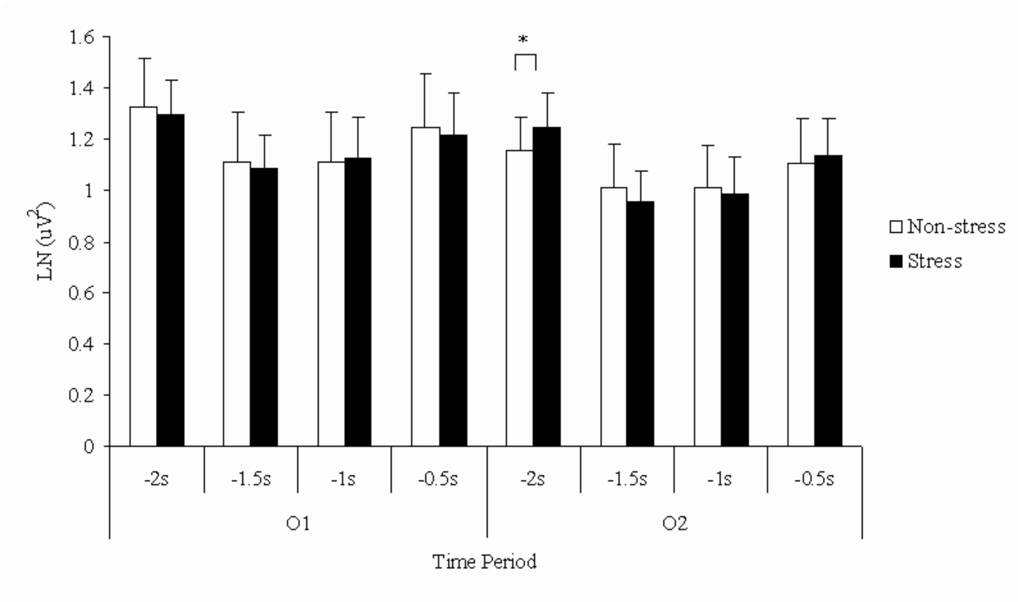

Figure 2. Condition x Hemisphere x Time interaction on high-alpha power for left and right hemispheres in the occipital region with contrast focuses on Condition as well as on Time within a condition. * indicates a significant difference (p < .05).

Discussion

Overview

The tested hypotheses were supported or disputed as follows:

(1) Compared to a non-stress condition, a relative increase in state anxiety under stress was partially supported. Specifically, somatic anxiety increased and self-confidence decreased regardless the order. Cognitive anxiety increased in the Order 2, during which the Stress condition was administered prior to the Non-Stress condition, but not in the Order 1.

(2) Compared to a non-stress condition, an elevation of high-alpha EEG coherence between sites T3 and Fz under stress was supported.

(3) Compared to a non-stress condition, a decrease in the low-alpha spectral power across all regions of the cerebral cortex under stress was not supported. No difference in the low-alpha spectral power was revealed across all regions between the two conditions.

(4) Compared to a non-stress condition, an increase in the high-alpha spectral power in the left hemisphere but no change in the right hemisphere under stress was not supported. An increase in the high-alpha power was revealed in the right occipital region under stress at the first time interval (-2.0 s ~ -1.5 s).

(5) Compared to a non-stress condition, a decrease in performance accuracy under stress was supported.

(6) Compared to a non-stress condition, an increase in performance variability under stress was partially supported. Performance variability increased under the stress condition in the Order 2 but not in the Order 1.

The effect of mental stress in this study degraded the quality of cognitive-motor performance along with a highly specific alteration in cerebral cortical dynamics. The regional specificity of the elevation in EEG coherence between the left temporal and motor planning region strongly suggests that the observed increase in state anxiety was associated with explicit analysis of motor behavior during the preparatory period just prior to release of the throw. Such a finding is relevant to our understanding of the manner by which mental stress can impact the quality of performance and is consistent with a number of theoretical perspectives including reinvestment (Masters, 1992; Masters & Maxwell, 2008), psychomotor efficiency (Hatfield & Hillman, 2001; Hatfield & Kerick, 2007), and human performance theory (Fitts & Posner, 1967). Namely, it appears that the anxious performer reverts to an earlier learned stage of motor behavior; one that is less adaptive due to an elevation in neuromotor noise during motor planning. The neuromotor noise, owing to the rise in non-essential communication from the left hemispheric region to the motor planning region, likely alters the pattern and timing of central motor unit recruitment that translates to alterations in skeletal muscle activity. In addition, the observed elevation in high-alpha power under mental stress suggest a reduction in visual attention or focus on the target further adding to the mechanisms explaining the decline in performance (i.e., accuracy of the throw). In this manner, the study predictions were supported with the exception of the expected desynchrony in low-alpha power. The absence of any difference between the attentional conditions indicates equivalence in general arousal and engagement, which allows for comparability and underscores the usefulness of assessment of both low- and high-alpha power.

General Discussion

As expected, participants reported a moderate increase in somatic anxiety accompanied with a decrease in self-confidence during stress. However, the elevation in cognitive anxiety under mental stress was also revealed, but the magnitude of elevation attained statistical significance only when the stress condition was administered prior to the non-stress condition (i.e., Order 2). Even so, participants performed worse under stress as they exhibited a decline in performance accuracy of the dart-throwing task regardless of the order of conditions.

Beyond the self-reported psychological changes, the degradation of motor performance during mental stress was accompanied by significant cerebral cortical changes in functional coupling and regional activation. Consistent with the expectation, an increase in high-alpha EEG coherence was observed between the left temporal (T3) and the mid-frontal (Fz) regions prior to throwing darts under stress. Such a finding suggests that participants' motor planning processing was impaired by excessive neuromotor noise. Specifically, such excessive cortico-cortical communication between the verbal-analytical and the motor planning regions may indicate a reinvestment of conscious control in motor planning. According to Masters and Maxwell (2008), a reinvestment refers to a propensity for conscious control in order to manipulate the mechanics of a movement. When a gradual or systematic increment in task difficulty is employed during practice, such training results in an effortless and implicit form of learning, during which a reinvestment of conscious control is unlikely to occur. In other words, an effortless and implicit approach to learning facilitates an autonomous stage of motor learning and performance is executed in an optimal manner with minimal neuromotor noise. When performance degrades under stress, it is likely that a reversion process occurs from the autonomous stage to the cognitive-analytical stage in motor behavior. In the present study the reversion process occurred during the third .5-second time interval prior to movement initiation. Our result not only supports such a notion but also suggests that a short-termed alteration is sufficient to disrupt motor behavior during the critical aiming period.

In contrast to our prediction, in which participants were expected to exhibit an increase in low-alpha power during stress, while we found that the participants actually exhibited similar levels of cortical activation across conditions. This finding suggests that participants exerted a comparable level of general arousal with equal effort and engagement across both conditions. According to Pfurtscheller and Lopes da Silva (1999), low-alpha power is indicative of a general arousal level in cerebral cortical activation in response to task demands and widespread across the scalp topography. Our finding implies that participants devoted themselves to both conditions in a similar manner regarding mental effort.

In addition, the result of hemispheric change in high-alpha power is not consistent with the expectation: participants exhibited an increase in high-alpha power in the right occipital region under stress at the first time interval (-2.0 s ~ -1.5 s). This finding suggests that a reduction in task-specific engagement such as visual-spatial processing occurred at least 1.5 seconds or even earlier prior to movement initiation under stress. Activation in the occipital region is primarily visual-related and visual processing has been suggested to modulate networks in attention and emotion (Vuilleumier & Driver, 2007). Anxiety has been characterized as a slow re-orienting process of disengagement from threat stimuli, which are typically task-irrelevant cues (Fox, Russo, Bowles, & Dutton, 2001). In accordance with the notion of attentional bias to threat, it appears that stress evokes a decrement in task-relevant information processing that occurs because of a shortage of neural resources. In this manner, it is plausible that the failure of task-specific engagement in visual-spatial processing consequently noted earlier in the aiming period (i.e., the first time interval), as revealed by the elevation in high-alpha power, led to the maladaptive alteration in cortico-cortical communication during motor planning (i.e., during the third time interval).

Although the order of conditions impacted the participants' perception of mental stress, as reflected by cognitive anxiety and performance variability, it had no effect on performance accuracy or cerebral cortical dynamics including EEG coherence and spectral power. Specifically, performance degradation was related to the alteration in cerebral cortical dynamics induced by mental stress regardless of order even though the magnitude of self-reported psychological change was relative small for the majority of participants (i.e., the 15 participants randomly assigned to the Order 1). Importantly, the results revealed that the psychophysiological measures of EEG coherence and power are sensitive to capture transient changes attributed to performance degradation under stress. In addition, the magnitude of cortico-cortical communication between the non-motor (i.e., left temporal) and motor (i.e., mid-frontal) regions was particularly low during the non-stress condition and the performance was superior relative to that observed during the stress condition. As such, it appears that any rise in activation in the left temporal region may lead to degraded performance.

In summary, the present study successfully manipulated state anxiety, which significantly impacted cerebral cortical dynamics (i.e., elevated cortico-cortical communication as well as an elevation in regional cortical activation), which was associated with degradation in performance of a precision aiming task. Specifically, the finding of elevated cortico-cortical communication between the left temporal and mid-frontal regions under stress offers a possible explanation for the decline in performance. The examination of brain dynamics during the time period leading to movement initiation further expands the scope of research addressing the impact of state anxiety on cognitive-motor performance.

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The Influence of Attentional Focus on Brain Dynamics, Musculoskeletal Activity, and Neuromotor Performance

Introduction

Overview

Sport is a social/evaluative situation and such a situation often increases the cognitive demand on the performer, whose perceptual processing load and alterations in physical and mental state lead to volatility in neuromotor performance. Zhu et al (2001) and the previous study (Study 1) have revealed that mental stress is manifested as elevated T3-Fz high-alpha (11-13 Hz) coherence and degraded neuromotor performance. Specifically, the elevated T3-Fz EEG coherence indicates heightened neuromotor noise and supports a notion that mental stress results in a reversion from an adaptive stage of motor behavior to one of reinvestment involving conscious control in movement during motor planning. This phenomenon was supported by the finding reported in the previously investigation (Study 1).

To further understand the neurocognitive processes underlying the influence of mental stress on neuromotor performance, the current study focused on the nature of the attentional processes underlying the observed changes in cerebral cortical dynamics, associated musculoskeletal activity, along with the performance outcomes such as accuracy and variability of a dart-throwing task. Specifically, the performer's focus of attention was manipulated to induce a state of conscious control during motor planning. It is plausible that such an internal focus of attention, as proposed by Wulf, Höß, and Prinz (1998), underlies the elevation of T3-Fz EEG coherence observed in Lo (2015, Study 1) and by others (e.g., Zhu et al, 2011). Sport psychologists often refer to negative self-talk and excessive focus on the details of motor behavior as critical elements that explain the problem of "choking" (Baumeister, 1984; Baumeister & Showers, 1986; Beilock & Carr, 2001; Beilock & Gary, 2007). This is a pervasive notion in the field and it would be helpful to further understand this notion. Study 1 revealed a significant elevation in cortico-cortical communication between the left temporo-parietal and motor planning regions (i.e., T3-Fz coherence), but there was no direct evidence as to the nature of the psychological processes underlying that observation. It is reasonable to infer that the processes were verbal-analytic in nature in light of functional neuroanatomical organization of the cerebral cortex, but this is a necessary but insufficient line of evidence to have confidence in the psychological processes. As such, the current study was designed to manipulate the focus of attention (i.e., an internal versus an external focus) to examine any differences in cerebral cortico-cortical communication between the motor planning and non-motor regions of the brain. An observation of elevated communication during internal focus, in combination with the results of Study 1 that revealed heighted coherence during stress, would allow for an inferential strategy to deduce the psychological processes associated with performance anxiety. Such an observation would provide further evidence for construct validation of the presence of reinvestment during cognitive-motor performance under stress. In addition, simultaneous assessment of motor unit activity via electromyography (EMG) of the upper extremity during a precision-aiming throwing task would enable determination of the impact of elevated cortico-cortical communication on the quality (i.e., efficiency) of muscle action.

Attentional processes in cognitive-motor performance under social evaluations

A performer's attentional processes are critical to performance (Nideffer, 1976), especially during competition, during which he or she may be constantly aware of his or her performance being evaluated by others. In sports, the phenomenon of choking is of great interest to coaches and scientists and stimulates investigation of the underlying mechanisms accounting for inferior performance outcomes (e.g., Baumeister, 1984; Beilock & Carr, 2001; see Beilock & Gray, 2007, for a review). One of the central tenets of the phenomenon of choking under pressure is that the performer tends to direct his or her attention explicitly on the details of skill execution, which can elevate cognitive load and interfere with the central organization of a movement when skill has progressed beyond the cognitive stage as defined by Fitts and Posner (1967). Such a state of conscious control in movement or a reinvestment of learned and explicit knowledge in movement mechanics (see Masters & Maxwell, 2008, for a review) has been investigated and associated with state anxiety, which then results in degraded performance (Zhu et al., 2011; Lo, 2015, Study 1). Furthermore, a state of conscious control in movement or reinvestment engage was observed in a head-to-head competition as evidenced by an elevation in cortico-cortical communication between motor planning and non-motor regions (Hatfield et al., 2013). As such, a performer’s focus of attention may reflect his or her mental strategy to cope with elevated state anxiety as induced during competitions. Specifically, the underlying psychological state may serve as one of the mediating mechanisms to help understand how cognitive motor performance is planned and executed under stress.

Focus of attention and conscious control processing

External and internal foci of attention are two fundamental styles of attentional focus characterized in the motor control and learning literature. Both styles of attentional focus have revealed varying degrees of influence on the effectiveness and efficiency of performance (see Wulf, 2012, for a review). An external focus of attention guides one's attention to the ultimate action on a target or to a critical cue in the surrounding environment, whereas an internal focus of attention directs attentional focus to the action, itself, in terms of the body movements engaged to achieve the desired outcome such as hitting a target in a throwing or pitching task (Wulf, Höß, & Prinz, 1998). Research has revealed that implementing an external focus of attention in task instructions of learning and training can help players acquire and perform better compared to those who preferred using an internal focus of attention (see Wulf, 2012, for a review).

According to the constrained action hypothesis (e.g., McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001), internally focused attention involves processing of conscious control cues, which require greater attentional demand and resources on the motor system to fulfill task requirements and, therefore, adds a varying degree of noise in the motor system. It is plausible that the involvement of conscious control interferes with the intended flow of neural processes or networks activated during motor control and learning. In contrast, the employment of an externally focused state of attention is often associated with a better performance outcome than its internal counterpart due to a relative lack of conscious control and ensuing noise in the motor system. According to Fitts and Posner (1967), the lack of conscious control is considered as the major characteristic in the stage of automatic control processing or automaticity. Collectively, it is plausible that a common mechanism mediating the progressive stages of motor skill learning may concurrently mediate the use of internal and external foci of attention on motor behavior of neuromotor performance in a similar manner.

The focus of attention and principles of economy in neuromuscular system

A few studies have revealed that the adoption of an external focus of attention is beneficial to efficiency of the neuromuscular system during performance. An external focus of attention is associated with reduced muscular activity measured by surface electromyography (EMG) in precision-aiming tasks such as basketball free throws and dart throws (Zachry, Wulf, Mercer, & Bezodis, 2005; Lohse, Sherwood, & Healy, 2010). The surface EMG recorded from a group of involved skeletal muscles in a motor task is indicative of the pattern of energy organization allocated from an assembly of motor units. Research in motor learning has observed that a decrease in the magnitude of EMG after practice is indicative of the emergence of economy (Lay, Sparrow, Hughes, & O'Dwyer, 2002). Furthermore, the observed change in EMG is indicative of an association between the quality of performance and the psychological state. For example, co-contraction is defined as the simultaneous activity of agonist and antagonist muscles surrounding a joint (Kellis, 1998) and represents a maladaptive pattern of changes in neuromuscular activity (Mills et al., 2013). By employing a series of timing analyses on EMG to construct patterns from two antagonistic muscles of the arm (i.e., the flexor carpi ulnaris, extensor carpi radialis, biceps, and triceps), Weinberg and Hunt (1976) revealed that high-trait anxious individuals exhibited impaired efficiency of muscular activity by expending more contractile energy over a longer period of time and greater co-contraction than their low-anxious counterparts during an overarm throwing action. The finding of a positive relationship between trait anxiety and co-contraction suggests that high-trait anxious individuals expend more energy than low-trait anxious individuals under stress. Specifically, the finding suggests that the pattern of EMG activity may reflect a translational impact on the behavioral outcome from the underlying psychological state while an individual is performing a cognitive-motor task.

Principles of economy and cerebral cortical processes

To advance understanding of the factors facilitating or impeding neuromotor performance in sports, EEG has been employed as an objective measure to examine the relationship between cognitive-motor performance and the underlying psychological state (Hatfield, Haufler, Hung, & Spalding, 2004; Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). An index that supports the principle of economy or efficiency as proposed by Hatfield and Hillman (2001) (i.e., psychomotor efficiency hypothesis) is provided by EEG coherence, which is defined as the spectral cross-correlation between two EEG recordings. Coherence provides an index of cortico-cortical communication. Deeny, Hillman, Janelle, and Hatfield (2003) observed that superior rifle marksmen who held more competitive experience exhibited lower levels of EEG coherence (i.e., refined networking) between the left temporal (T3) and the midline frontal (Fz) regions compared to marksmen with relatively abbreviated competitive histories. Deeny et al. also suggested that the refinement or reduction of 'input' from the left temporal association region (T3) to the motor planning region (Fz) is a contributor to superior motor performance due to attenuation of 'neuromotor noise.' More specifically, Hatfield and Kerick (2007) offered further explanation for the relationship between cortical processes and motor behavior by advancing the notion that the reduction of such 'neuromotor noise' to the premotor region leads to efficient recruitment of motor units in skeletal muscle in the case of the superior performer. However, the relationship between cortical and muscle activation was not directly tested by them. In accord with this notion, Deeny, Haufler, Saffer, and Hatfield (2009) observed generally lower coherence between the frontal region and a number of other cerebral cortical regions in expert marksmen, relative to that observed in novices, during the aiming period of a precision visuomotor task (i.e., rifle marksmanship), and the magnitude of EEG coherence was positively correlated with aiming movement variability in the experts. That is, greater coherence was associated with greater variability of the aiming trajectory while lower coherence was associated with stability, a desirable state. This finding suggests an inverse relationship between functional connectivity and the consistency of the aiming movement. Furthermore, spectral EEG measures employed in the study of motor behavior provide a high-resolution metric to capture the temporal dynamics of regional cerebral cortical activation under various psychological states. Specifically, motor preparation has been associated with an increase in EEG alpha (8-13 Hz) power and a decrease in beta (14-30 Hz) band power (Pfurtscheller & Lopes da Silva, 1999). The positive relationship between broadband EEG alpha (8-13 Hz) power in the left temporal region (T3) and cognitive-motor performance has been studied and based on contrasts between novices and experts (see Hatfield et al., 2004, for a review). Broadband EEG alpha power is considered to be the “idling frequency” of the cerebral cortex and elevations in such bandwidth power are commonly considered to infer reduced activation (Pfurtscheller, 1992; Pfurtscheller, Stancák, & Neuper, 1996). More recently, increases in EEG alpha power such as event-related synchrony (ERS) in the alpha frequency band have been considered to reflect inhibitory processing (see Klimesch, 2012, for a review). In regard to visuomotor tasks, an elevation in broadband EEG alpha power, more specifically in the high-alpha (11-13 Hz) frequency range, is interpreted as a disengagement of task-irrelevant cognitive processes (Doppelmayr, Klimesch, Hödlmoser, Sauseng, & Gruber, 2005; Hatfield et al., 2004; Klimesch, Sauseng, & Hanslmayr, 2007). When compared to novices, expert performers typically exhibit EEG synchrony or elevated alpha power across the cortex, and particularly in the left hemisphere, which is responsible for analytical processing, during the readiness period of self-paced visuo-motor tasks such as golf, archery, and shooting. The elevated alpha power observed in the left hemisphere during the preparatory period of self-paced precision-aiming tasks, relative to that observed in the right, suggests attenuation of verbal-analytic processing and relative engagement of visual-spatial processing (Hatfield, Landers, & Ray, 1984). It has been suggested that experts manage to inhibit non-motor and task-irrelevant information processing under task challenge and that such observation indicates a reduction in the allocation of central neural resources during motor performance; an essential attribute of superior performance.

In contrast to the functional indication of high-alpha power in task-relevant engagement of attention, low-alpha (8-10 Hz) activity is indicative of general cerebral cortical activation (Klimesch, 1999; Pfurtscheller & Lopes da Silva, 1999). In addition, EEG theta activity (4-7 Hz) in the frontal region has been observed and associated with sustained attention and mental effort (Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007). To further understand the influence of conscious control manipulated by the internal focus of attention on neuromotor performance, there is a need to explore the underlying processes captured by both EEG spectral and coherence measures, along with EMG, and its translating effect on the quality of motor performance.

Conscious control processing and cerebral cortical dynamics

The notion of reinvestment of the conscious control in movement, or the reinvestment hypothesis (Masters & Maxwell, 2008), and its psychophysiological findings would help to explain why the use of an internal focus of attention leads to inferior performance. According to Zhu, Poolton, Wilson, Maxwell and Masters (2011, study 1), there is a positive relationship between the propensity for reinvestment and the magnitude of cortico-cortical communication. Their results revealed that EEG coherence between sites T3 and Fz in the high-alpha (10-12 Hz) frequency band was significantly greater in novice golfers of high-reinvestment propensity relative to those characterized by low-reinvestment tendencies. Furthermore, in a follow-up study, Zhu et al. (2011, study 2) observed elevated T3-Fz high-alpha coherence in individuals performing golf putting under conditions of videotaping or social evaluation. Elevation of T3-Fz coherence in the high-alpha band implies elevated communication between the motor planning region (i.e., Fz) and non-motor, associative functions such as verbal-analytical processing (i.e., T3). Such elevated coupling is indicative of non-essential input of neuro-motor noise to the workspace mediating motor planning. As a result, it can lead to a sudden failure or degradation in the quality of motor performance in light of the alteration of critical preparatory processes during motor planning.

Purpose

General purpose

As such, the reinvestment hypothesis (Masters & Maxwell, 2008) along with the psychomotor efficiency hypothesis (Hatfield & Hillman, 2001) serve as the underlying mechanisms for the processes of internal focus of attention employed to manipulate conscious control in movement. The observed heightened Fz-T3 high-alpha coherence in Zhu et al. (2011) provides a mediating mechanism for the inferior performance due to conscious control in movement during motor behavior. However, without an examination of the quality of movement, the translating effect of conscious control in movement on effectiveness and efficiency of performance is unknown. Therefore, the present study was designed to investigate the mediating impact of conscious control in movement via manipulating internal focus of attention on the relationship between the cerebral cortical dynamics, neuromuscular activity, and the quality of performance.

Specific aims and hypotheses

The specific aims of the study were to investigate the internal and external foci of attention and examine the cerebral cortico-cortical communication between critical brain regions of interest, as well as regional cortical activity, while examining the quality of motor performance as participants performed a precision-aiming task for accuracy. The changes in EEG coherence and spectral power were expected to occur at any or all time epochs during the preparatory period of dart throws. Therefore, the hypotheses were:

(1) In accord with the theoretical hypotheses of Reinvestment and Psychomotor Efficiency, EEG coherence for the high-alpha (11-13 Hz) frequency band between the left temporal (T3) and midline-frontal motor planning region (Fz) was expected to be elevated during the internal focus of attention condition when compared to the external focus of attention. Note: EEG coherence in the other

frequency bands (theta, low-alpha, and beta) was examined in an exploratory manner with the same directional expectation).

(2) Mental effort and sustained attentional processing, which is indexed by theta (4-7 Hz) and beta (14-20 Hz) power, was expected to be higher when participants employ the internal focus of attention compared to the external focus of attention.

(3) General cortical activation, which is indexed by the magnitude of low-alpha power, was expected to be elevated during the internal focus of attention relative to that observed during the external focus. Therefore, a decrease in the low-alpha power would be observed in the internal focus of attention condition compared to the external focus condition. This finding would imply heightened arousal and elevated cognitive load during internally focused attention.

(4) Task-specific attention processes such as visual-spatial processing, which are indexed by high-alpha power, (11-13 Hz) were expected to be similar across the two attentional conditions. This prediction was based on the notion that participants would be equally engaged with the attentional demands of both approaches to the dart-throwing task.

(5) The magnitude of T3-Fz cortico-cortical communication would be positively related to motor unit activation (RMS) of the four muscles of the upper extremity in the internal focus of attention condition.

(6) Motor unit activation (RMS of the four muscle groups) would be positively related to performance variability in the internal focus of attention condition.

(7) There will be greater co-contraction between agonist and antagonist muscles in the internal focus of attention condition than that in the external focus of attention condition.

(8) Performance accuracy was expected to be lower and performance variability would be higher in the internal focus of attention when compared to the external condition.

(9) Variability of performance would be inversely related to performance accuracy in the internal focus of attention.

Materials and Methods

Participants

Thirty-five paid volunteers (19 women), who are right-hand dominant men and women aged between 18 and 50 (*M* = 24.34, *SD* = 5.08) years, were recruited for the study. All participants gave provided informed consent to participate in the study, which was approved by the Institutional Review Board at the University of Maryland at College Park.

Task

A printed version of commercially available competition bristle dartboard was set to a regulation height and distance. The horizontal distance from the participant (i.e., with feet that are evenly positioned) to the dartboard was 2.37 m and positioned with the center of the target at a standard height of 1.74 m. The printed dartboard consisted of 10 concentric rings. A hit breaking the innermost ring (a bull’s-eye) is scored as a 10 and a hit placed outside of the outermost ring (a miss) is scored as a 0. Participants threw a regulation steel tip dart that weighed 22 g.

Each participant performed 60 dart throws, 10 throws in each of six blocks in both conditions. The standardized procedures are described below.

Self-report

To check compliance with the directions for attentional focus (i.e., external and internal) for each condition, participants were asked to respond to three items of a visual analog scale (VAS) for each of the six blocks after a completion of 10 throws. This technique, which calls for an indication by the participant by marking the distance between two verbal anchors separated by a 100-mm line was validated by Folstein and Luria (1973). During the internal focus of attention condition, the three VASs employed were the following: 1) How much did I have to concentrate to focus on the movement of my wrist and elbow? (0 = A little concentrated, 100 = Concentrated a lot.), 2) I was able to exclusively focus my attention on the muscular contractions of elbow and wrist movements during each trial. (0 = Strongly disagree, 100 = Strongly agree), and 3) How attentive do I feel? (0 = Very inattentive, 100 = Very attentive.). For the external focus of attention condition, the three VASs employed were: 1) How much did I have to concentrate to focus one the bull’s eye? (0 = A little concentrated, 100 = Concentrated a lot.), 2) I was able to exclusively focus my attention on the target during each trial. (0 = Strongly disagree, 100 = Strongly agree.), and 3) How attentive do I feel? (0 = Very inattentive, 100 = Very attentive.).

In addition, a qualitative evaluation check adapted from Weiss (2011) for the assigned attentional manipulation instructions, for which the details are described below, was implemented during the two experimental conditions. Six times (i.e., after every 10 throws) throughout both experimental conditions, participants were specifically asked an open-ended question: “On your last dart-throw, what was your exact focus of attention?” The experimenter recorded and evaluated the participant’s response. The purpose of such real-time interactive feedback was to guide the participant to emphasize the importance and specific elements of the given conditional instruction.

Furthermore, according to the reinvestment hypothesis (Masters & Maxwell, 2008) and Zhu et al. (2011), the engagement of conscious control in movement is associated with an increase in effort during performance. Therefore, the NASA TLX (Hart & Staveland, 1988), which included six subscales, was employed to assess participants’ subjective experience of cognitive workload. The six subscales consisted of the following indices: Mental Demands, Physical Demands, Temporal Demands, Performance Problems, Effort, and Frustration. Each subscale ranged from 0 to 100 with higher scores reflecting greater work demands and concern for failure.

Lastly, the state anxiety inventory - SAI (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was employed to assess participants’ anxiety states prior to the beginning of the two experimental conditions. It is a 4-point Likert-type scale ranging from ‘not at all’ to ‘very much so’ in terms of how the participant feels at the moment. Scores range from 20 to 80, with higher scores reflecting greater state anxiety.

Performance

Performance accuracy and variability of the dart-throwing movement behavior were subjected to statistical analysis. Absolute error served as the measure of performance accuracy and was measured to the nearest half-inch as the linear distance from the center of the dartboard (i.e., bull's eye) to the location where the dart landed. The standard deviation of the absolute error was used as the measure of the performance variability.

Electroencephalography (EEG)

The BrainAmp DC system (Brain Vision Inc.), linked to BrainVision Recorder Professional software installed on a PC running Windows 7 operating system, was used to record scalp electroencephalographic (EEG) data. EEG was recorded from 31 sites (FP1, FP2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, T3, T4, CP1, CP2, CP5, CP6, TP9, TP10, Pz, P3, P4, P7, P8, Oz, O1, O2, and A2) referenced to the left earlobe (A1), and labeled in accordance with the modified International 10-20 system (Jasper, 1958). At all sites of interest, impedances were maintained below 10 kΩ. The ground electrode was located at the frontal pole (AFz).

The range of all EEG channels was +/- 3.7 millivolt (mV) and the resolution was 0.1 microvolt (uV). The low and high cutoff frequencies were set at 0.015-500 Hz and the sampling rate was set to 1000 samples/s.

Electromyography (EMG)

The Trigno^{TM} Wireless EMG system (Delsys Inc.), linked to EMGworks 4.0.7 software on a PC with a Windows 7 operating system installed on it, was used to record surface electromyographic (EMG) data. Four sensors were placed on the right arm from two pairs of antagonistic muscles. The first pair of antagonistic muscles was the flexor carpi ulnaris (Sensor 1) and extensor carpi radialis (Sensor 2), and the second pair was biceps brachii (Sensor 3) and triceps brachii (Sensor 4). Lastly, a fifth sensor was placed on the right extensor retinaculum, whose three-axial accelerometer signals were used to detect the initiation of forward extension throwing movement for each trial.

The range of EMG sensors was +/- 11 mV and the resolution was 168 nanovolt (nV)/bit. The frequency range of EMG sensor was 20-450 Hz and the sampling rate was set to 2000 samples/s. A customized transistor-transistor logic (TTL) digital circuit device was implemented to synchronize and initiate EEG and EMG system recording.

Procedure

The EEG and EMG assessments were conducted during the dart-throwing performance under each of the two conditions of the internal and external foci of attention. The order of conditions was counterbalanced with a 10-minute rest period in between.

After arriving at the laboratory, participants were fitted with the EEG cap. Conducting gel was applied to all sites via a blunt-tipped medical syringe. Additionally, EMG sensors were attached as described above. When impedances reached 10 kohm or below, participants were tested individually in a sound-attenuated room where the standard equipment for dart-throwing task was installed. After warm-up, participants were informed about the assigned conditional instruction to throw darts.

Task instructions were given to participants prior to each condition to assist them with employment of the desired strategy for the focus of attention. During the internal condition, participants were instructed as follow: “For the following throws, I would like you to mentally focus your attention on the movement of your elbow and wrist while aiming to the bulls-eye. When you’re off target, think about how you can correct the mistake by changing the [motion of your elbow and wrist].” On the other hand, during the external focus of attention condition, the participants were instructed as follows: “For the following throws, I would like you to simply focus your attention on the bulls-eye.” Prior to each set of 10 throws, the participant was reminded of the assigned instruction.

During each condition, participants completed the SAI immediately before the initiation of the first set of 10 throws for both the internal and external foci of attention. After a set of 10 throws was completed, participants were then asked to answer the open-ended questions and to complete the items that comprised the VAS and NASA TLX. Prior to each set of 10 throws, participants were reminded of the assigned conditional instruction.

Compliance with the manipulation check

To ensure the conformity of the condition manipulation, a screening evaluation was employed in order to accept the psychophysiological and associated performance data for further analyses. A cutoff threshold or criterion of compliance was set as 60 % or above and applied to the participants’ means on the three VAS items applicable to each condition. As a result, data collected from twenty (10 males and 10 females) participants (*M* = 23.45, *SD* = 3.9 years old) were subjected to further analyses.

Data processing

Three-axial accelerometer signals collected from the right extensor retinaculum were used to determine the initiation of the extension of the elbow to initiate the throwing movement for each trial. The movement onset of elbow extension served as the basis for EEG and EMG segmentation. Specifically, two seconds of EEG recording were segmented prior to the movement onset whereas two seconds of EMG signals were segmented immediately after the movement onset (See Figure 1).

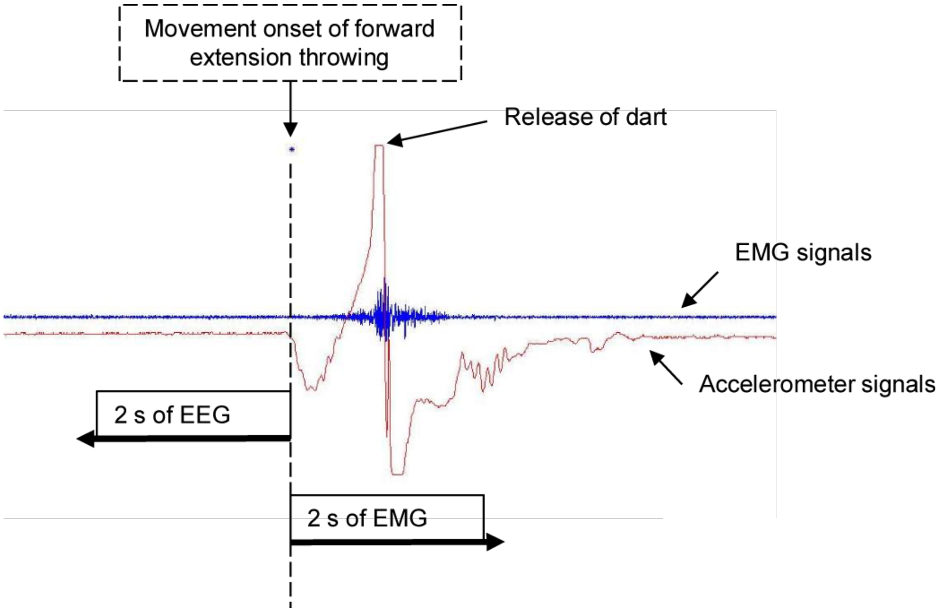


Figure 1. Illustration of EEG and EMG signal segmentation.

Data reduction of EEG recordings was performed using custom written Matlab code (Mathworks, Natick, MA). Raw EEG signals were subjected to a fourth-order Butterworth band-pass filter with cutoff frequencies of 1 and 50 Hz. Filtered EEG records captured two seconds prior to the initiation of elbow extension throwing movement were subsequently segmented into four successive 0.5-s epochs. Each filtered EEG epoch was subjected to discrete Fast Fourier Transform (FFT) via Welch's method using a Hamming window with 50% overlap for each frequency bin (0-500 Hz with 1-Hz bin size; pwelch.m in Matlab Signal Processing Toolbox; MathWorks Inc.) to gain estimates of EEG power density. The absolute power for a frequency band of interest was calculated for each EEG epoch by averaging varying sizes of 1-Hz bins. The means and standard deviations of the absolute power were obtained for four frequency bands: theta (4-7 Hz), low-alpha (8-10Hz), high-alpha (11-13Hz), and beta (14-20 Hz) across all trials of both conditions. These averages were then natural log-transformed prior to statistical analysis.

Furthermore, the coherence between EEG channels of interest for the four frequency bands was measured by amplitude-squared coherence $Cxy\ (f)$ (mscohere.m in MATLAB signal toolbox; MathWorks, Inc.), which is an estimate of the input signals x and y using Welch's method. The midline-frontal electrode site (Fz) located in the premotor region was the common site of interest to pair with each of the 10 following recording sites in the five cortical regions: the bilateral frontal (F3 and F4), temporal (T3 and T4), central (C3 and C4), parietal (P3 and P4), and occipital (O1 and O2). All computed coherence values were then subjected to a Fisher z-transformation prior to statistical analysis to ensure a normal distribution.

The root-mean-square (RMS) was applied to the segmented EMG signals to estimate the amplitude of signal, which gives an estimate of motor unit activation via a measure of the magnitude of the signal, on a trial-by-trial basis. The co-contraction index between a pair of muscle groups was defined as the ratio of the means of RMS in one muscle group of the pair divided by the sum of the means of RMS in both muscle groups of the pair (e.g., means of RMS in triceps / (means of RMS in biceps + means of RMS in triceps).

Statistical analysis

Paired t-tests were performed to contrast the third item (i.e., the intensity of attentional focus: 'How attentive do I feel?') of the VAS series, which was common to both conditions, the six items that comprised the NASA TLX, performance accuracy, performance variability, and the RMS of the four muscle groups, as well as the co-contraction indices, between the internal and external foci of attention. 2 x 2 x 5 x 4 (Condition x Hemisphere x Region x Epoch) ANOVAs, with repeated measures on all factors, was applied separately to each of the four frequency bands of EEG spectral power and coherence to evaluate the impact of the focus of attention on cerebral cortical dynamics across the four time intervals or epochs of the preparatory period just prior to dart-throwing.

Conventional degrees of freedom were reported throughout and the Greenhouse-Geisser correction (ε) was provided when sphericity was violated. Furthermore, the probabilities reported for each effect were based on the corrected degrees of freedom. Partial eta squares (η_p^2), the percentage of variance that is explained by the treatment effects, were presented as a measure of effect size in the event of significant effects. The Bonferroni correction method was applied in the event of any post-hoc comparisons of the means. A conventional alpha level of $p \leq .05$ was adopted in all analyses.

In addition, as in Appendix A, a series of Pearson product-moment correlation coefficient analyses were computed for three types of data collected: EEG coherence;

muscle activity (the RMS of the four muscles); and the variability (the SD of absolute errors) of performance accuracy (absolute error). These correlations were conducted to separately assess the relationships between muscle activity and EEG coherence in each of the four frequency bands for each of the ten pairs of electrodes (i.e. F3-Fz, F4-Fz, C3-Fz, C4-Fz, T3-Fz, T4-Fz, P3-Fz, P4-Fz, O1-Fz, and O2-Fz) for each of the four time periods leading up to the initiation of elbow extension. In this manner, each electrode pair was correlated with the RMS of the four muscle groups, while the RMS was also correlated with standard deviations of absolute error. This series of correlations was conducted for both internal and external focus of attention conditions; however, only those correlations relevant to the internal focus of condition are reported and discussed in the text of the present study (Study 2). Correlations for both the internal and the external focus are reported in Appendix A.

Results

Self-report

VAS. Paired-t testing revealed no significant difference in the intensity of attentional focus (*t* (19) = -.483, *p* = .635, two-tailed) between the internal (*M* = 81.61 (*SEM* +/- 2.1)) and external (*M* = 80.61 (*SEM* +/- 1.99)) conditions. (Note: Therefore, participants exhibited equivalent levels of attentional engagement in both conditions, but it is important to note that the direction of attention was opposite, as intended via the manipulation).

NASA TLX. Paired-t testing revealed no differences between the conditions for perceived Mental Demands (*t* (19) = .552, *p* = .587, two-tailed), Physical Demands (*t* (19)

= .717, *p* = .482, two-tailed), Temporal Demands (*t* (19) = 1.285, *p* = .214, two-tailed), Effort (*t* (19) = -.856, *p* = .403, two-tailed), and Frustration (*t* (19) = 1.185, *p* = .251, two-tailed). The only exception was a significant difference in the item pertaining to Performance Problems (*t* (19) = 2.264, *p* = .035, two-tailed) for the internal (*M* = 34.5 (*SEM* +/- 3.85) and external (*M* = 43 (*SEM* +/- 4.62)) foci of attention. Specifically, participants reported fewer problems in the internal focus condition than they did during the external condition.

SAI. Paired-t testing revealed no difference in state anxiety (*t* (19) = -1.412, *p* = .174, two-tailed) between the internal (*M* = 26.38 (*SEM* +/- 1.26)) and external (*M* = 25.1 (*SEM* +/- 1.04)) conditions. As such, participants exhibited relatively low levels of state anxiety in both conditions.

Performance

Accuracy. Paired-t testing revealed no difference in the means for absolute error (*t* (19) = -.923, *p* = .368, two-tailed) between the internal (*M* = 3.76 (*SEM* +/- .26)) and external (*M* = 3.62 (*SEM* +/- .22) conditions.

Variability. In addition, no difference in the standard deviations of the absolute error (*t* (19) = -1.066, *p* = .3, two-tailed) was observed between the internal (*M* = 2.08 (*SEM* +/- .15)) and external (*M* = 1.97 (*SEM* +/- .12)) conditions.

EEG

Theta (4-7 Hz) coherence. A significant Condition x Hemisphere x Region x Epoch interaction ($\varepsilon = .361$, *F* (4.328, 82.236) = 3.125, *MSE* = 0.005, *p* = .017, $\eta_p^2 = .141$) as well as a main effect of Condition ($F\ (1, 19) = 58.235$, $MSE = 0.011$, $p < .001$, $\eta_p^2 = 0.754$) were observed. Examination of the means (Fisher's z-transformed theta coherence) indicated elevated coherence between all regions of interest and the midline frontal region (Fz) during the internal ($M = .834$ (SEM +/- .01)) focus of attention compared to the external condition ($M = .794$ (SEM +/- .01)). The interaction, in conjunction with the main effect for Condition, is explained by the overall heightened coherence during the internal focus, but variation in the magnitude of difference between the conditions in some regions compared to others and specific to each epoch. See Figure 2.

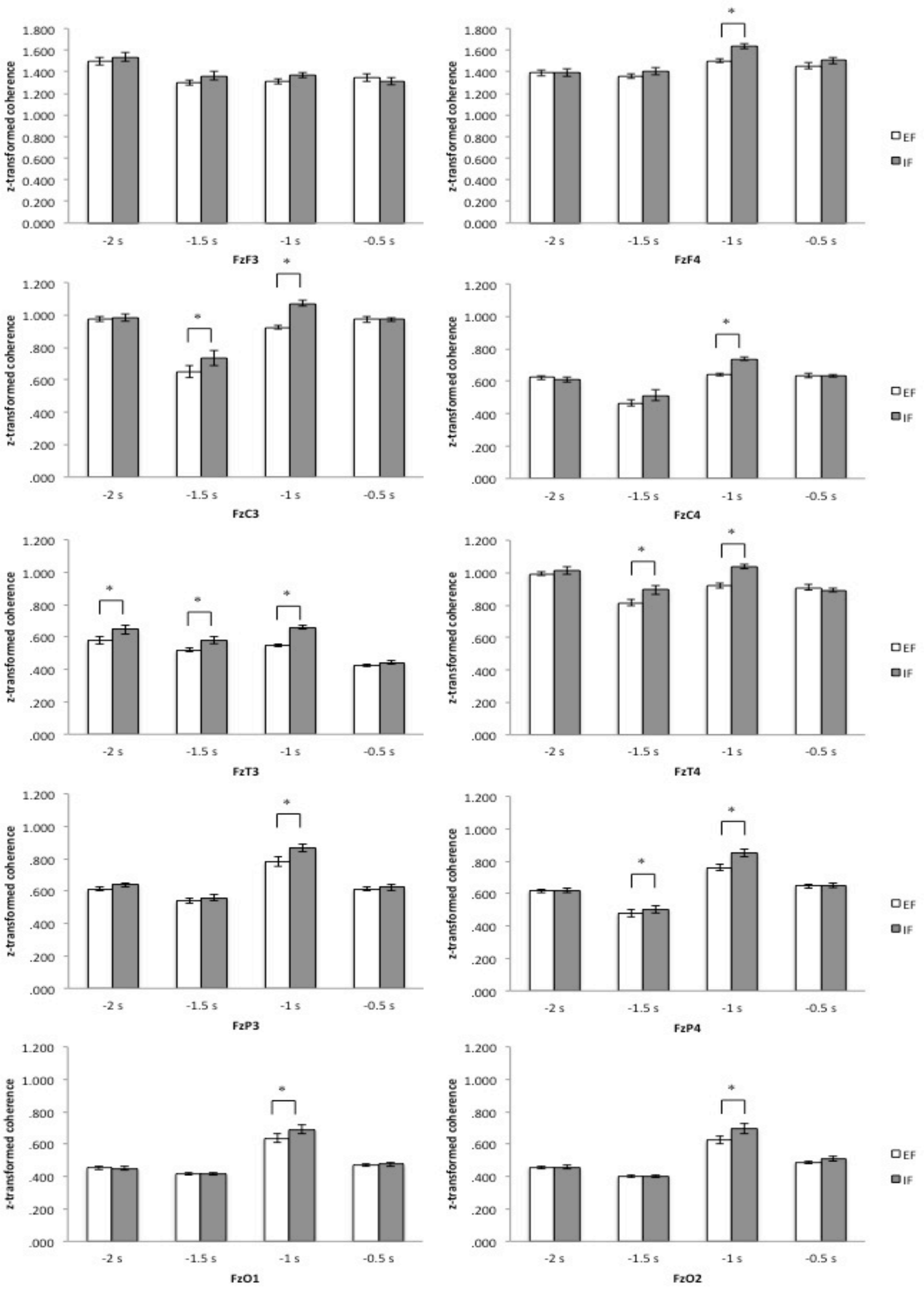
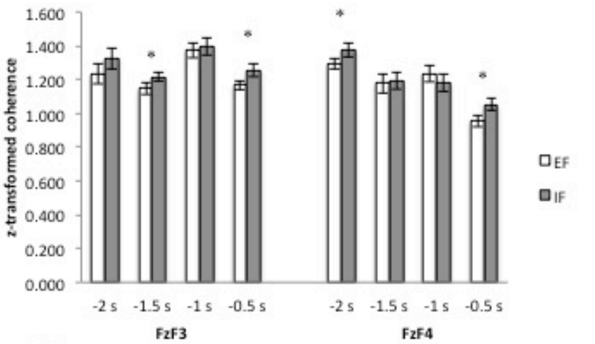


Figure 2. Theta (4-7 Hz) coherence between Fz (representing the motor planning region) and all other recording sites during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at *p* < .002. Note: error bars represent SEM.

Low-alpha (8-10 Hz) coherence. A significant Condition x Hemisphere x Region x Epoch interaction ($\varepsilon = .284$, $F\ (3.41, 64.798) = 8.775$, $MSE = 0.008$, $p < .001$, $\eta_p^2 = .316$) accompanied by a main effect of Condition ($F\ (1, 19) = 42.962$, $MSE = 0.011$, $p < .001$, $\eta_p^2 = 0.693$) were observed. Examination of the means (i.e., Fisher's z-transformed low-alpha coherence) in each condition revealed elevated coherence between the midline frontal and all other regions of interest (i.e., globally) during the internal ($M = .728$ (*SEM* +/- .01)) compared to the external condition ($M = .693$ (*SEM* +/- .01)). Again, similar to theta coherence, the interaction is explained by the overall elevation during the internal focus, but variation in the magnitude of difference between the conditions as a function of the specific regions and epochs. See Figure 3.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1.400
1.200
1.000
0.800
0.600
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-2 s
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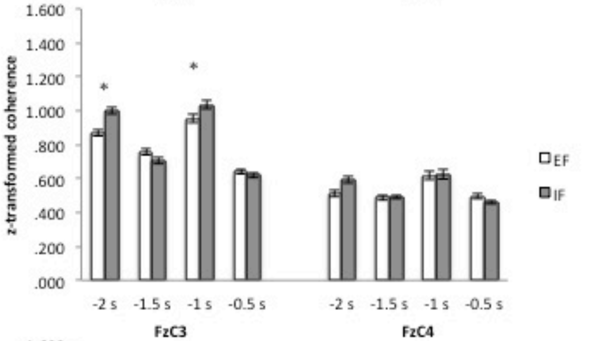
FzF3
FzF4
*
EF
IF


z-transformed coherence
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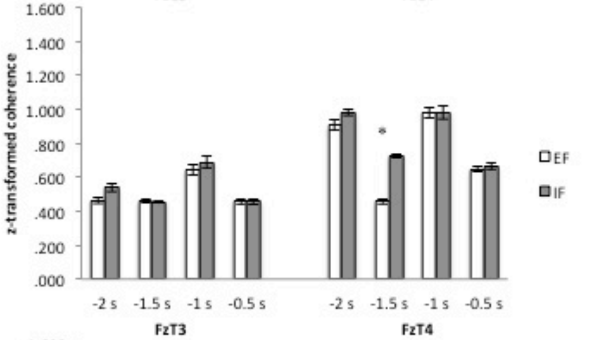
FzC3
FzC4
*
EF
IF


z-transformed coherence
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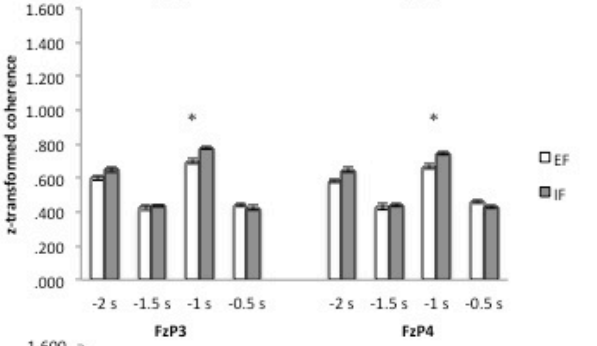
FzT4
*
EF
IF


z-transformed coherence
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FzP3
FzP4
*
EF
IF

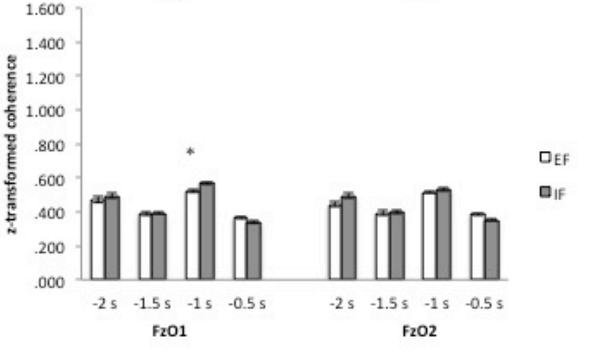

z-transformed coherence
1.600
1.400
1.200
1.000
.800
.600
.400
.200
.000
-2 s
-1.5 s
-1 s
-0.5 s
FzO1
FzO2
*
EF
IF

Figure 3. Low-alpha (8-10 Hz) coherence between Fz (representing the motor planning region) and all other recording sites during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at $p < .002$. Note: error bars represent SEM.

High-alpha (11-13 Hz) coherence. A significant Condition x Hemisphere x Region x Epoch interaction ($\varepsilon = .389$, $F(4.664, 88.62) = 8.013$, $MSE = 0.003$, $p < .001$, $\eta_p^2 = .297$) was observed. No significant main effect of Condition was obtained. The interaction is explained by the variation in the magnitude of difference between the conditions in the frontal and parietal regions in relation to the hemispheres and epochs during the internal focus condition. Specifically, increases in the high-alpha coherence were obtained in the electrode pairs of F3-Fz and F4-Fz at the second time epoch and in the electrode pair of P3-Fz at the third time epoch. See Figure 4.

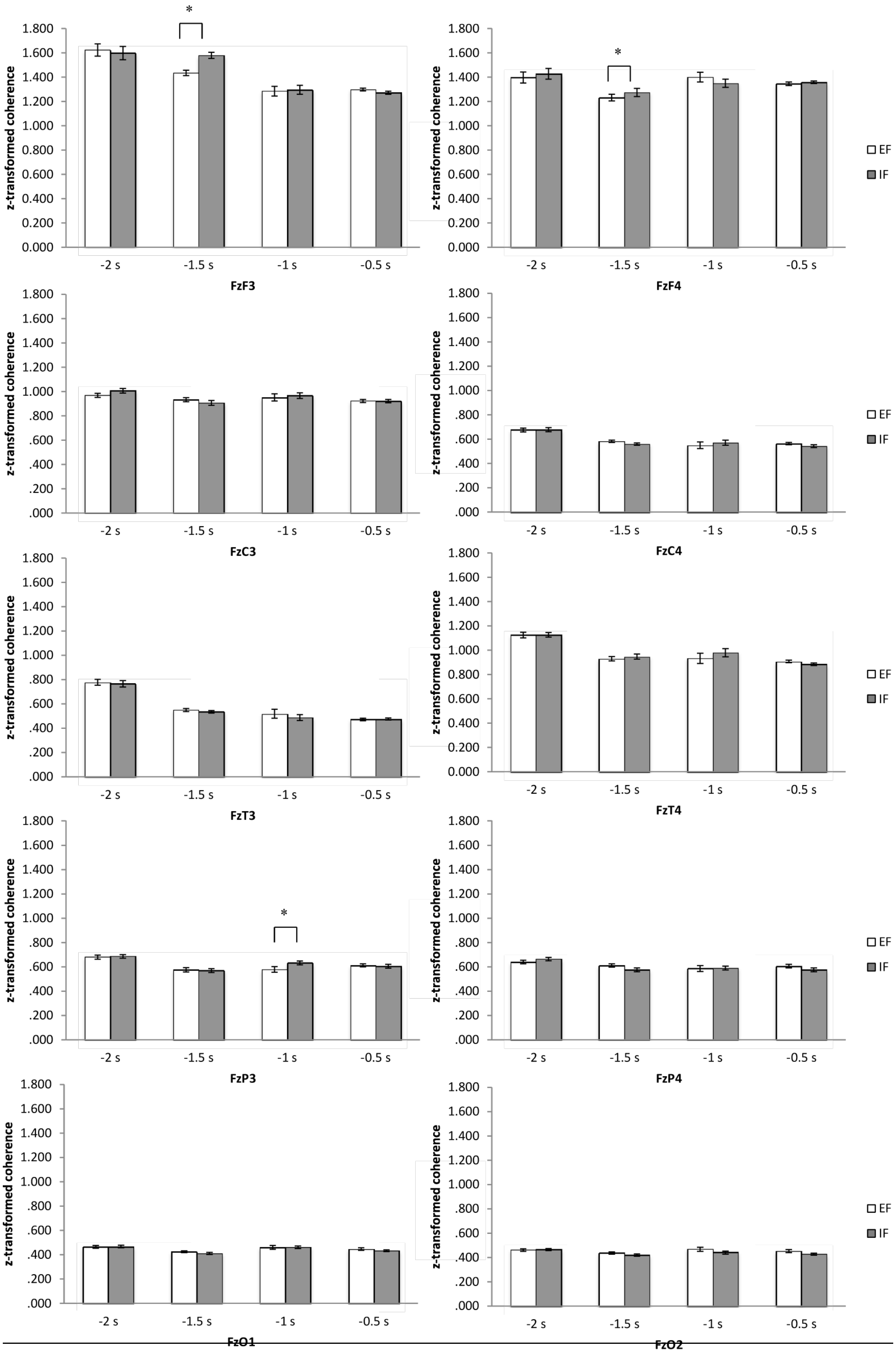

z-transformed coherence
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-2 s
-1.5 s
-1 s
-0.5 s
*
EF
IF
FzF3
FzF4
FzC3
FzC4
FzT3
FzT4
FzP3
FzP4
FzO1
FzO2

Figure 4. High-alpha (11-13 Hz) coherence between Fz (representing the motor planning region) and all other recording sites during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at $p < .005$. Note: error bars represent SEM.

Beta (14-20 Hz) coherence. A significant interaction for Condition x Hemisphere x Region ($\varepsilon = .712$, $F(2.849, 54.133) = 3.461$, $MSE = 0.002$, $p = .024$, $\eta_p^2 = .154$) was observed (See Figure 5). Examination of the means indicated that coherence between the right occipital and midline frontal regions was lower during the internal focus of attention (IF: $M = .472$ (SEM +/- .005) < EF: $M = .485$ (SEM +/- .004)). In addition, a Condition x Hemisphere x Epoch ($F(3, 57) = 7.02$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .27$) effect was obtained, but post hoc analysis failed to reveal any differences between the means.

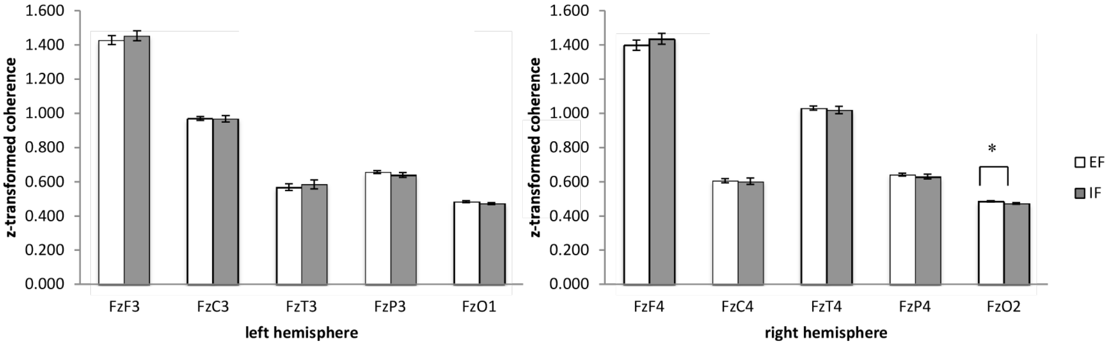
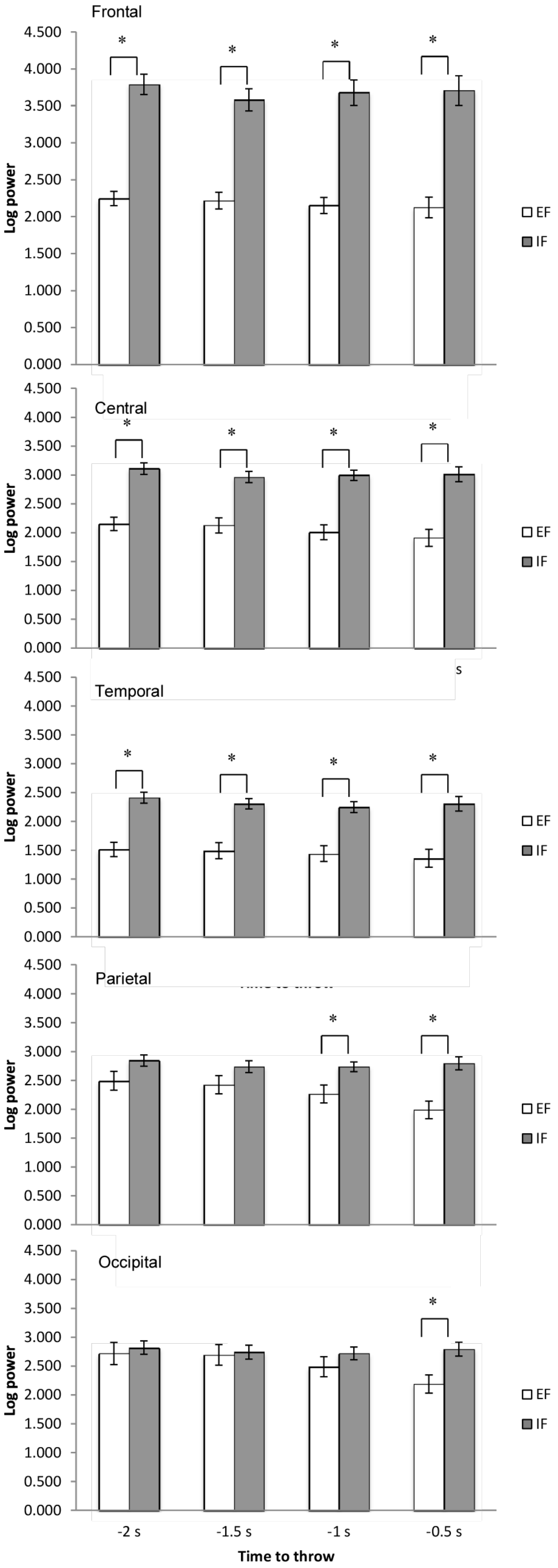


Figure 5. Beta (14-20 Hz) coherence between Fz (representing the motor planning region) and all other recording sites during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at $p < .05$. Note: error bars represent SEM.

Theta (4-7 Hz) power. A significant Condition x Region x Epoch interaction (ε = .302, F (3.625, 68.868) = 5.699, MSE = 0.116, p = .001, η_p^2 = .231) and the main effect of Condition (F (1, 19) = 50.336, MSE = 5.274, p < .001, η_p^2 = 0.726) were observed. Examination of the means of the log-transformed theta power indicated elevated power globally during the internal (M = 2.91 (SEM +/- .09)) focus of attention compared to the external focus (M = 2.1 (SEM +/- .13)). The interaction can be explained by overall heightened power across the scalp topography, but variation was observed in the magnitude of difference between the conditions that were particularly prominent in the anterior (i.e., frontal, central, and temporal) regions during each epoch. See Figure 6.


Frontal
Central
Temporal
Parietal
Occipital
Log power
4.500
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3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
*
EF
IF
-2 s
-1.5 s
-1 s
-0.5 s
Time to throw

Figure 6. Regional theta power (4-7 Hz) during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at $p < .002$. Note: error bars represent SEM.

Low-alpha (8-10 Hz) power. A significant Condition x Epoch interaction ($F(3, 57) = 3.068$, $MSE = 0.171$, $p = .035$, $\eta_p^2 = .139$) was observed. Post hoc examinations of the means indicated heightened low-alpha EEG power during the internal ($M = 2.08$ (*SEM* +/- .15) focus of attention relative to that during the external ($M = 1.91$ (*SEM* +/- .14) condition during the fourth epoch prior to the onset of elbow extension. See Figure 7.

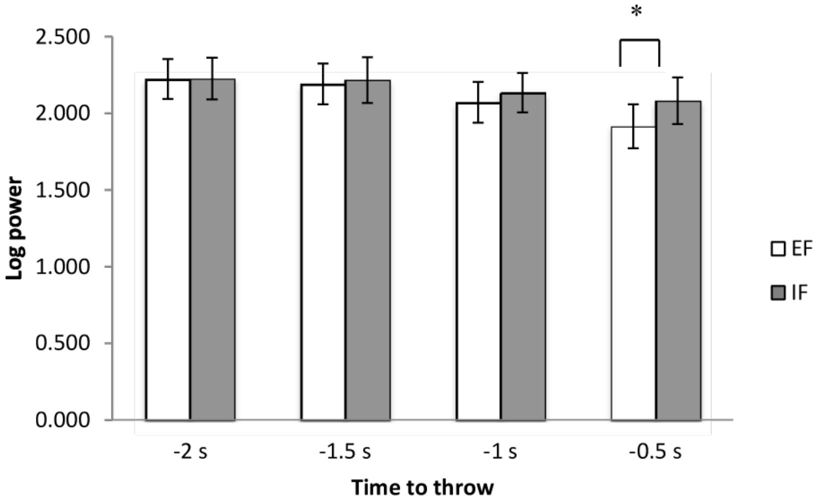

Figure 7. Low-alpha power (8-10 Hz) during internal (IF) and external (EF) focus of attention conditions. Asterisk (*) indicates statistical significance at $p < 0.05$. Note: error bars represent SEM.

High-alpha (11-13 Hz) power. No significant main effect or interaction involving Condition was observed.

Beta (14-20 Hz) power. A significant main effect of Condition (F (1, 19) = 5.5, MSE = 0.255, p = .03, η_p^2 = 0.224) was observed. Examination of the means of log-transformed beta power in each condition revealed that beta power was higher during the internal (M = 1.97 (SEM +/- .13)) focus of attention compared to the external focus (M = 1.91 (SEM +/- .12)).

EMG

RMS. Paired-t tests revealed no significant differences between the conditions for RMS in the forearm flexor carpi ulnaris (t (19) = -.309, p = .761, two-tailed), forearm extensor carpi radialis (t (19) = -.474, p = .641, two-tailed), biceps brachii (t (19) = -.766, p = .453, two-tailed), and triceps brachii (t (19) = -1.436, p = .167, two-tailed).

Co-contraction index. No differences were observed between the conditions for the co-contraction index for the forearm flexor (t (19) = -.02, p = .984, two-tailed), forearm extensor (t (19) = -.019, p = .985, two-tailed), biceps brachii (t (19) = .198, p = .845, two-tailed), and triceps brachii (t (19) = -.209, p = .837, two-tailed.

Correlation

A series of Pearson product-moment correlation coefficients revealed that there were positive correlations between the T3-Fz EEG coherence in each frequency band and the biceps RMS. Specifically, the positive correlations were revealed in the theta band at the first and third time epochs (see Tables A2 and A4 in Appendix A), low-alpha band at the first epoch (see Table A6 in Appendix A), high-alpha band at the first and fourth epochs (see Tables A10 and A13 in Appendix A), and beta bands (see Tables A14 and A15 in Appendix A) at the first and second epochs.

In addition, there was a positive correlation between the biceps RMS and standard deviations of absolute error in the internal focus of attention, $r = .581$, $n = 20$, $p = .007$, two-tailed. Furthermore, there was a positive correlation between the SD of absolute error and absolute error in the internal focus of attention, $r = .9$, $n = 20$, $p < .001$, two-tailed.

Discussion

The tested hypotheses were supported or disputed as following:

(1) Compared to the external focus of attention condition, result fails to support the expected increase of EEG high-alpha (11-13 Hz) coherence between the left temporal (T3) and midline-frontal motor planning region (Fz) during the internal focus. However, increases of EEG high-alpha coherence in the pairs of F3-Fz, F4-Fz, and P3-Fz were obtained.

(2) Compared to the external focus of attention, increases in the theta (4-7 Hz) and the beta (14-20 Hz) power were supported in the internal focus of attention.

(3) Result fails to support the expected decrease in the low-alpha power during the internal focus of attention when compared to the external focus. The low-alpha power in the internal focus was greater than that in the external focus.

(4) No change in the high-alpha power between the two attentional conditions was supported.

(5) During the internal focus of attention, positive correlations between the magnitude of T3-Fz cortico-cortical communication and the RMS of the four muscles of

the upper extremity were partially supported. Specifically, the T3-Fz EEG coherence in all frequency bands was positively correlated with the RMS of biceps in the internal focus of attention condition.

(6) During the internal focus of attention, positive correlations between the RMS of the four muscle groups and performance variability were partially supported. The RMS of biceps was positively correlated with performance variability.

(7) Result fails to support the expected greater co-contraction between agonist and antagonist muscles in the internal focus of attention when compared to the external focus of attention. No change in the co-contraction index between the internal and external focus of attention conditions was obtained.

(8) Result fails to support the expected decreased performance accuracy and increased performance variability in the internal focus of attention when compared to the external focus.

(9) An inverse relationship between the variability of performance and the performance accuracy was supported during the internal focus of attention condition. Specifically, the means of absolute error were positively correlated with the standard deviations of absolute error.

The employment of an internal focus of attention, which was an attempt to experimentally achieve a state of reinvestment, resulted in a significant elevations in cortico-cortical communication between motor planning and all other non-motor regions as indicated by the theta and low-alpha frequency band coherence. In addition, the internal focus contributed to cognitive load as indicated by elevated theta and beta band power. Such an increase in cognitive load would imply a reduction in attentional reserve and the ability to respond quickly in case of a sudden demand in task complexity. The elevation in cognitive load under during the internal focus of attention is consistent with the notion of a need for heightened elemental interactivity as articulated by Sweller (2011). Attention to the elbow action and wrist extension certainly does seem consistent with increased interactivity and this was supported by the results for the spectral power.

It is important to note that confidence in the attentional focus manipulation was achieved by selecting only those participants who indicated 60 % or above compliance as obtained from the self-reported measures such as VAS of concentration, exclusive concentration, and perceived attention intensity. Although there were no differences between the conditions in muscular activity or performance according to the contrasts enabled by the study designs (i.e. contrasts enabled by ANOVA), the observed correlations between the cortico-cortical communication (i.e., T3-Fz) and quality of muscle activity (i.e., RMS of the biceps) as well as that between RMS and the performance variability (i.e., SD of absolute error) provide support for the notion that changes in the quality of muscle activity mediate the relationship between brain dynamics and performance.

As expected, greater increments in EEG coherence between motor planning and non-motor regions mainly in the theta and low-alpha bands were observed in the condition of internal focus of attention than that of external focus of attention. EEG coherence provides an estimate of functional interactions and integration between neural systems modulating in various frequency bands and across brain regions (Srinivasan, Winter, Ding, & Nunez, 2007). The results of animal studies have revealed that the coupling of theta band activity is functionally associated with learning and memory consolidation between the medial prefrontal region and hippocampus (Benchenane et al., 2010; Jones & Wilson, 2005). The current finding of cortico-cortical communication between the motor planning (i.e., Fz) and other non-motor regions in theta band at different time epochs suggest that the employment of internal focus of attention in a precision-aiming task actively exerts neural resources such as mental efforts and sustained attention to support system maintenance of working memory demanding in the task during motor planning in a dynamic manner. On the other hand, previous studies revealed that elevated T3-Fz EEG high-alpha coherence (Lo, 2015, Study 1; Zhu et al, 2011, study 2) and elevated bilateral frontal (i.e., F3 and F4) and Fz (Hatfield et al., 2013) in broadband alpha frequency band were observed under stress and competition associated with maladaptive performance outcome (i.e., degraded accuracy in golf-putting and dart-throwing and dysfluency of aiming trajectory in air-pistol shooting), whereas increments in P3-F3 and P4-F4 EEG low-alpha and P3-C3 and P4-C4 EEG high-alpha coherence was observed to associate with successful golf-putting performance (Babiloni et al., 2011). Collectively, cerebral cortico-cortical communication between two topographical regions in each frequency band may indicate functional specificity in varying degrees.

The current finding of elevated cortico-cortical communications between the motor planning and other non-motor regions in each frequency band at different time epochs suggests that the employment of internal focus of attention may not impact the dart-throwing performance in the same manner as mental stress would. Specifically, such topographical, function-specific coupling in each frequency band may indicate the underlying neural network engaged in the internal focus of attention differs from that recruited in the state of reinvestment or conscious control in movement under stress. Furthermore, although the use of internal focus of attention during dart-throwing task may involve much more non-motor processing than merely verbal-analytic processing observed in previous studies (Deeny et al., 2003; Hatfield et al., 2013; Lo, 2015, Study 1; Zhu et al., 2011) during motor planning, it is plausible that some of non-motor processing are adaptive to compensate potential inefficient neural processing resulted from recruitment of a variety of neuromotor noises. Such speculation may provide an explanation for the finding of no difference between the internal and external foci of attention on skeletomuscular activity and performance observed in current study.

In addition, consistent with expectation, participants exhibited increases in theta and beta band power across regions at different time epochs when employing the internal focus of attention to throw darts. Elevated theta power revealed in the anterior regions and overall increased beta power at the last epoch observed in the condition of internal focus of attention suggest that the use of internal focus of attention involves greater level of mental effort and engagement of attentional processing than its external counterpart. However, participants exhibited greater low-alpha power and relative comparable level of high-alpha power in the condition of internal than external focus of attention. Such findings indicate that the state of internal focus of attention evokes reduced cerebral cortical arousal but employs same amount of neural resource to engage in task-relevant demands and inhibit in task-irrelevant processing to achieve the task demands compared to its external counterpart.

Lastly, contrary to expectation and the finding of Lohse, Sherwood, Healy (2010), there was no increase in the skeletomuscular activity and performance including accuracy and variability in either pair of agonist and antagonist muscle groups when participants employed the internal focus of attention to throw darts. Such finding not only corresponds with the plausible compensating effect indicated by the cortico-cortical communication in the theta, low-alpha, and high-alpha coherence between the motor planning and non-motor regions but also agrees with the subjective performance evaluation. According to the results of self-reported NASA TLX, participants reported fewer performance problems in internal focus attention condition than they did during external focus of attention condition. The perceived performance problems to a lesser degree may be indicative of a state boost in self-confidence and self-efficacy participants held while employing the internal focus of attention to accomplish dart-throwing task. It is plausible that increments in self-confidence and self-efficacy may compensate or counteract the potential degradation effect of reinvestment on motor processing and performance outcome.

In conclusion, current study revealed the use of internal focus of attention associates with increments in cortico-cortical communication between motor planning and non-motor regions in all frequency bands, mainly in theta and low-alpha frequency bands, and increased cerebral cortical activity in the theta, low-alpha, and beta band power. However, such volatility in cerebral cortical dynamics fails to further translate into changes in skeletomuscular activity measures such as RMS and co-contraction and performance outcome including accuracy and variability. Future research may consider individual difference in preference use of attentional focus such that the likelihood of underlying mediating effect can be maximized to reflect on brain and skeletomuscular activity concurrently.

General Discussion

Although there was no stress manipulation in the Study 2, the collective findings from both studies considered in tandem offer a plausible mechanism for the influence of mental stress on fine motor performance. Generally, an interactive and cascading model of performance anxiety was supported by which heightened and non-essential input to the motor planning region from other (i.e., non-motor) regions, which appears due to an internal focus on the details of movement behavior (conscious control of the mechanics of limb motion), underlie performance degradation. It is noteworthy that connectivity between the left temporal region (T3), which is associated with verbal-analytic processes, and the frontal motor control region (Fz) was significantly elevated during mental stress, as predicted by the Reinvestment theory. In addition, and based on the findings from Study 2, it appears that an internal focus underlies, at least in part, this rise in connectivity. Further, and in accord with the Psychomotor Efficiency, it appears that the excess source association of neuromotor noise with the left temporal and parietal regions (as well as more global association with across the scalp) was positively related to motor unit activity.

In addition, it is noteworthy that the topographical, function-specific coupling in each frequency band in Study 2 may indicate the underlying neural network engaged in the internal focus of attention differs from the network recruited in the state of reinvestment or conscious control in movement under stress. It appears that some cerebral cortical coupling occurred in the internal focus of attention is adaptive and compensatory. However, these compensatory coupling may be diminished due to an override of maladaptive coupling such as non-essential verbal-analytical processing intensified by elevated state anxiety under mental stress. It is unclear from the present studies, but it is reasonable to assume that the inefficiency observed in the cerebral cortical dynamics during mental stress would translate into inefficiency of motor unit recruitment

Appendix A

Table A1. Pearson correlation coefficients for the internal (IF) attentional focus condition between the four muscle groups of means of RMS and performance measures. * *p* < .05, two-tailed.

	IF	
	Absolute Error	SD of Absolute Error
Flexor RMS	-.135	-.073
Extensor RMS	-.076	-.134
Biceps RMS	.332	.581*
Triceps RMS	-.235	-.196

Table A2. Pearson correlation coefficients for the internal focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * *p* < .05, two-tailed.

IF: EEG theta coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.099	-.15	.462*	.149	.033	.214
F4-Fz	.262	-.188	.585*	.184	.099	.254
C3-Fz	.231	-.247	.665*	.008	.075	.261
C4-Fz	.158	-.357	.471*	-.045	-.068	.09
T3-Fz	.168	-.152	.617*	.208	-.043	.194
T4-Fz	.047	-.268	.64*	-.032	.184	.396
P3-Fz	.108	-.205	.476*	.112	.081	.25
P4-Fz	.15	-.335	.554*	.233	.055	.267
O1-Fz	.186	-.336	.366	-.05	.164	.304
O2-Fz	.096	-.273	.379	.007	.111	.258

Table A3. Pearson correlation coefficients for the internal focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * *p* < .05, two-tailed.

IF: EEG theta coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.195	.052	.276	.305	-.319	-.118
F4-Fz	.131	.112	.186	.189	-.399	-.182
C3-Fz	.041	-.023	.408	-.083	-.115	.093
C4-Fz	.075	-.012	.422	-.071	-.107	.089
T3-Fz	.128	.035	.413	.171	-.296	-.023
T4-Fz	.124	-.074	.371	.015	-.291	-.042
P3-Fz	.163	-.091	.378	.073	-.272	-.02
P4-Fz	.035	-.016	.397	-.069	-.071	.104
O1-Fz	.318	-.33	.506*	.311	.02	.143
O2-Fz	.098	-.108	.269	.323	-.041	-.007

Table A4. Pearson correlation coefficients for the internal focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * *p* < .05, two-tailed.

IF: EEG theta coherence at the third epoch (-1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	-.192	-.206	-.05	-.385	.087	.004
F4-Fz	-.139	.267	-.142	.026	-.293	-.245
C3-Fz	-.124	.033	.186	-.012	.077	.276
C4-Fz	-.284	-.195	.133	-.233	.149	.155
T3-Fz	.015	-.152	.498*	-.215	-.002	.122
T4-Fz	-.138	-.429	.363	-.151	.254	.355
P3-Fz	-.177	-.118	-.084	-.464*	.337	.233
P4-Fz	-.192	-.051	-.045	-.384	.3	.269
O1-Fz	-.121	-.093	-.122	-.44	.332	.207
O2-Fz	-.143	-.072	-.073	-.474*	.379	.273

Table A5. Pearson correlation coefficients for the internal focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * $p < .05$, two-tailed.

IF: EEG theta coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.146	.09	.025	.512*	-.196	-.109
F4-Fz	.224	-.026	.229	.515*	-.098	.043
C3-Fz	.057	.302	-.009	.339	-.26	-.12
C4-Fz	-.072	.189	.32	.247	.012	.213
T3-Fz	-.014	-.102	-.335	.155	.123	.021
T4-Fz	-.072	.111	-.187	.152	-.367	-.246
P3-Fz	-.053	.257	-.091	.361	-.414	-.235
P4-Fz	-.104	.241	.061	.184	-.318	-.118
O1-Fz	-.03	.198	-.095	.363	-.311	-.147
O2-Fz	-.032	.147	-.075	.383	-.349	-.208

Table A6. Pearson correlation coefficients for the internal focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * *p* < .05, two-tailed.

IF: EEG low-alpha coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.186	.141	.209	.481*	-.212	-.057
F4-Fz	.172	.109	.126	.442	-.342	-.217
C3-Fz	.088	.051	.129	.077	-.315	.086
C4-Fz	.06	.032	.094	.262	-.365	-.096
T3-Fz	.318	.078	.448*	.445*	-.099	-.163
T4-Fz	.064	.018	.359	-.105	-.175	.046
P3-Fz	-.11	-.064	.026	-.037	-.232	-.036
P4-Fz	-.066	.206	-.254	.036	-.403	-.32
O1-Fz	-.053	-.129	-.083	-.04	-.336	-.156
O2-Fz	-.073	.152	-.279	.019	-.396	-.291

Table A7. Pearson correlation coefficients for the internal focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * $p < .05$, two-tailed.

IF: EEG low-alpha coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.334	.058	.198	.37	-.282	-.182
F4-Fz	.271	-.08	.29	.506*	-.265	-.075
C3-Fz	.068	-.012	.329	-.006	-.079	.102
C4-Fz	-.17	-.123	.24	-.004	.076	.296
T3-Fz	.127	.054	.12	-.261	.31	.276
T4-Fz	.023	.09	-.037	-.264	-.16	-.102
P3-Fz	-.276	.11	-.083	-.431	.116	.079
P4-Fz	-.311	.176	-.34	-.327	-.005	-.133
O1-Fz	-.269	-.048	-.283	-.19	.258	.124
O2-Fz	-.289	.07	-.436	-.221	.158	-.025

Table A8. Pearson correlation coefficients for the internal focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * *p* < .05, two-tailed.

IF: EEG low-alpha coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.163	-.173	.246	.404	-.162	-.014
F4-Fz	.074	-.088	.34	.23	-.211	-.004
C3-Fz	.165	-.013	.531*	.212	-094	.126
C4-Fz	.217	-.098	.639*	.147	-.073	.209
T3-Fz	.099	-.124	.38	.29	-.07	.115
T4-Fz	.137	-.063	.373	.309	-.061	.11
P3-Fz	-.065	.34	-.031	-.193	-.222	-.2
P4-Fz	-.032	.134	.307	-.157	-.139	.063
O1-Fz	-.205	.426	-.362	-.09	-.059	-.204
O2-Fz	-.069	.255	.111	.179	.13	.137

Table A9. Pearson correlation coefficients for the internal focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * $p < .05$, two-tailed.

IF: EEG low-alpha coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.219	-.011	.228	.334	-.343	-.219
F4-Fz	.236	-.091	.416	.252	-.182	.003
C3-Fz	.01	-.172	.574*	-.028	-.069	.184
C4-Fz	.101	-.215	.629*	-.007	.014	.26
T3-Fz	.15	-.019	.347	.139	-.075	.097
T4-Fz	.314	.091	.401	.282	-.283	-.106
P3-Fz	.192	-.083	.416	.215	-.118	.021
P4-Fz	.056	-.224	.507*	-.011	.110	.228
O1-Fz	.247	-.233	.36	.081	.311	.271
O2-Fz	.013	-.269	.155	-.088	.283	.145

Table A10. Pearson correlation coefficients for the internal focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * $p < .05$, two-tailed.

IF: EEG high-alpha coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.189	-.01	.195	.437	-.284	-.145
F4-Fz	.271	-.017	.225	.447*	-.167	-.047
C3-Fz	.379	-.138	.532*	-.098	.025	.046
C4-Fz	.266	-.239	.515*	.03	-.102	.158
T3-Fz	.24	-.069	.493*	.414	.007	.14
T4-Fz	.297	-.035	.454*	.354	.111	.178
P3-Fz	.255	-.127	.69*	.07	.113	.296
P4-Fz	.153	-.1	.496*	-.338	-.03	.162
O1-Fz	-.009	-.161	.458*	-.124	.181	.32
O2-Fz	.054	-.384	.634*	-.357	.355	.548*

Table A11. Pearson correlation coefficients for the internal focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

IF: EEG high-alpha coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.066	.274	-.041	.343	-.482*	-.401
F4-Fz	.104	.094	.147	.341	-.244	-.125
C3-Fz	.088	.152	.153	.395	-.4	-.218
C4-Fz	.09	.313	.2	.072	.218	.165
T3-Fz	-.005	.313	.223	.422	-.353	-.186
T4-Fz	.041	.127	.146	.46*	-.443	-.26
P3-Fz	.083	.124	.214	.397	-.347	-.213
P4-Fz	.131	-.043	.283	.269	-.147	-.063
O1-Fz	.175	-.238	.394	.224	.215	.206
O2-Fz	.182	-.162	.536*	.197	.078	.184

Table A12. Pearson correlation coefficients for the internal focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

IF: EEG high-alpha coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.167	-.001	.055	.411	-.333	-.265
F4-Fz	.174	-.127	.397	.461*	-.156	.004
C3-Fz	.092	-.008	.188	.411	-.109	.039
C4-Fz	.061	-.079	.445*	.028	-.088	-.055
T3-Fz	.076	-.044	.382	.091	-.163	.049
T4-Fz	.223	-.207	.41	.376	-.118	.057
P3-Fz	.141	-.189	.492*	.267	-.097	.087
P4-Fz	.155	-.111	.317	.255	.002	.045
O1-Fz	-.132	-.081	.236	-.11	-.266	-.093
O2-Fz	-.029	-.189	.169	-.27	-.195	-.183

Table A13. Pearson correlation coefficients for the internal focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

IF: EEG high-alpha coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	-.151	.179	-.102	.014	.268	.194
F4-Fz	-.104	.186	-.061	.328	.09	.115
C3-Fz	.087	-.085	.173	.041	-.415	-.165
C4-Fz	-.143	-.221	.138	-.181	.152	.286
T3-Fz	.288	-.111	.629*	.059	.147	.296
T4-Fz	.083	-.201	.551*	-.2	.25	.439
P3-Fz	-.099	.052	.037	-.361	-.148	-.059
P4-Fz	-.177	.059	.007	-.35	-.191	-.08
O1-Fz	-.115	-.093	-.037	-.34	-.296	-.181
O2-Fz	-.037	-.119	-.052	-.231	-.339	-.3

Table A14. Pearson correlation coefficients for the internal focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$, two-tailed.

IF: EEG beta coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.142	.162	.19	.567*	-.265	-.11
F4-Fz	.302	.077	.236	.56*	-.375	-.204
C3-Fz	.219	-.009	.033	.435	-.381	-.284
C4-Fz	.314	-.2	.280	.455*	-.129	-.033
T3-Fz	.194	.214	.674*	.236	.15	.39
T4-Fz	.155	-.032	.401	.3	-.21	-.019
P3-Fz	-.099	.083	.331	-.158	.104	.2
P4-Fz	.188	.094	.353	.391	-.121	.054
O1-Fz	-.139	.377	-.186	-.085	.19	.053
O2-Fz	-.072	.233	-.17	.206	.098	-.013

Table A15. Pearson correlation coefficients for the internal focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$, two-tailed.

IF: EEG beta coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.24	.197	.398	.298	-.241	-.13
F4-Fz	.063	-.088	.484*	.158	-.001	.171
C3-Fz	.04	.002	.276	.156	-.144	.027
C4-Fz	.073	-.088	.503*	.137	-.058	.142
T3-Fz	.091	-.093	.451*	.019	-.174	.03
T4-Fz	.17	-.189	.524*	.232	.084	.247
P3-Fz	.113	-.01	.343	.169	-.292	-.118
P4-Fz	.124	.004	.261	.299	-.302	-.123
O1-Fz	.238	.134	.452*	.308	-.277	-.055
O2-Fz	.17	.008	.499*	.091	-.102	.119

Table A16. Pearson correlation coefficients for the internal focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$, two-tailed.

IF: EEG beta coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.336	.082	.144	.265	-.076	-.158
F4-Fz	.138	-.172	.484*	-.148	.204	.212
C3-Fz	.064	.015	-.033	-.14	-.277	-.286
C4-Fz	.095	.284	.025	.086	-.475*	-.391
T3-Fz	.078	-.009	.345	.144	-.287	-.106
T4-Fz	.123	-.013	.22	.047	-.271	-.163
P3-Fz	.137	.037	.286	-.011	-.178	-.03
P4-Fz	.042	.142	-.026	-.194	-.298	-.262
O1-Fz	.037	-.011	.301	-.228	-.077	.103
O2-Fz	-.154	.258	-.131	-.353	-.192	-.178

Table A17. Pearson correlation coefficients for the internal focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * *p* < .05, two-tailed.

IF: EEG beta coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.207	.004	.293	.269	-.307	-.157
F4-Fz	.068	.121	.166	.239	-.353	-.189
C3-Fz	-.064	-.007	.215	-.183	-.246	-.094
C4-Fz	.004	-.049	.148	.02	-.352	-.199
T3-Fz	.025	-.02	.241	.2	-.279	-.105
T4-Fz	.022	.029	.311	.018	-.228	-.037
P3-Fz	-.111	-.005	.355	-.078	-.147	.04
P4-Fz	-.101	-.02	.246	-.38	-.191	-.076
O1-Fz	-.184	-.023	.307	-.194	-.06	.078
O2-Fz	-.144	-.006	.219	-.624*	.118	.089

Table A18. Pearson correlation coefficients for the external (EF) attentional focus condition between the four muscle groups of means of RMS and performance measures. * *p* < .05, two-tailed.

	EF	
	Absolute Error	SD of Absolute Error
Flexor RMS	-.043	-.123
Extensor RMS	-.279	-.245
Biceps RMS	.357	.285
Triceps RMS	-.272	-.294

Table A19. Pearson correlation coefficients for the external focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * $p < .05$, two-tailed.

EF: EEG theta coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.032	.03	.3	.27	-.18	-.055
F4-Fz	-.07	.075	.193	.137	-.197	-.074
C3-Fz	-.21	.075	.073	-.36	-.123	-.076
C4-Fz	-.278	-.038	-.241	-.148	-.224	-.085
T3-Fz	-.122	.063	.304	.063	-.255	-.169
T4-Fz	-.17	.43	.15	.211	-.391	-.326
P3-Fz	-.228	.527*	.149	-.033	-.188	-.177
P4-Fz	-.179	.387	.263	-.114	-.164	-.152
O1-Fz	.136	.42	.368	.095	-.16	-.249
O2-Fz	-.196	.28	.397	-.428	.327	.269

Table A20. Pearson correlation coefficients for the external focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * *p* < .05, two-tailed.

EF: EEG theta coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.249	-.13	.191	.267	-.177	-.042
F4-Fz	.274	-.03	.445*	.265	-.103	-.011
C3-Fz	-.096	-.139	.415	-.166	-.077	-.138
C4-Fz	-.048	-.192	.408	-.282	-.064	-.091
T3-Fz	-.085	-.189	.339	.142	-.116	-.012
T4-Fz	-.027	-.139	.398	.014	-.232	-.279
P3-Fz	-.021	-.062	.444*	.142	-.228	-.289
P4-Fz	-.077	-.123	.46*	-.162	-.052	-.061
O1-Fz	.057	-.095	.544*	.244	-.134	-.137
O2-Fz	.023	-.066	.593*	.021	.063	.126

Table A21. Pearson correlation coefficients for the external focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * *p* < .05, two-tailed.

EF: EEG theta coherence at the third epoch (-1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	-.001	.155	-.362	-.317	.004	-.005
F4-Fz	.106	.121	-.07	-.318	.134	.073
C3-Fz	.203	-.14	.396	.199	-.252	-.2
C4-Fz	.463*	-.014	.436	.321	-.284	-.158
T3-Fz	.091	-.213	.285	-.009	-.077	.081
T4-Fz	-.164	-.001	-.003	-.512*	.21	.114
P3-Fz	-.214	-.028	-.137	-.477*	.217	.101
P4-Fz	-.004	-.008	-.042	-.26	-.032	-.11
O1-Fz	-.248	.054	-.192	-.47*	.199	.099
O2-Fz	-.202	-.001	-.176	-.436	.109	.009

Table A22. Pearson correlation coefficients for the external focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the theta frequency band. * $p < .05$, two-tailed.

EF: EEG theta coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.141	.091	.064	.35	.023	.195
F4-Fz	.195	.153	.202	.418	-.037	.072
C3-Fz	-.102	.071	.149	.016	.213	.23
C4-Fz	-.236	-.193	.112	-.06	.09	.219
T3-Fz	.03	-.138	.137	-.195	.605*	.635*
T4-Fz	-.143	.012	.283	-.184	.394	.368
P3-Fz	-.07	.254	-.095	.217	-.394	-.396
P4-Fz	-.15	.035	-.035	.167	-.222	-.181
O1-Fz	.048	.412	-.244	.558*	-.598*	-.543*
O2-Fz	-.056	.175	-.172	.551*	-.428	-.314

Table A23. Pearson correlation coefficients for the external focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG low-alpha coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.345	-.052	.157	.483*	-.297	-.22
F4-Fz	.179	.249	.161	.492*	-.307	-.208
C3-Fz	.104	-.327	.105	.015	.067	.092
C4-Fz	-.197	-.19	.205	-.339	.348	.468*
T3-Fz	.21	-.162	.31	.154	-.27	-.405
T4-Fz	.246	.096	-.102	.35	-.479*	-.581*
P3-Fz	.221	-.171	-.122	-.154	-.036	-.091
P4-Fz	.007	-.427	-.004	-.178	.109	.073
O1-Fz	-.119	-.173	-.165	-.21	.078	.206
O2-Fz	-.114	-.405	-.018	-.278	.221	.2

Table A24. Pearson correlation coefficients for the external focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG low-alpha coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.37	.026	.157	.495*	-.313	-.221
F4-Fz	.196	-.098	.193	.37	-.267	-.156
C3-Fz	.15	-.001	.333	.146	-.12	-.162
C4-Fz	-.264	.185	.056	.093	-.138	-.174
T3-Fz	.044	-.37	.413	-.108	.053	.156
T4-Fz	-.235	-.257	.158	-.008	-.091	.034
P3-Fz	-.278	.137	.253	-.124	.119	.111
P4-Fz	-.307	.182	.214	-.139	.146	.041
O1-Fz	-.303	.228	-.156	-.085	-.124	-.143
O2-Fz	-.385	.116	-.05	-.204	.138	.118

Table A25. Pearson correlation coefficients for the external focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * $p < .05$, two-tailed.

EF: EEG low-alpha coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.218	-.089	.369	.203	-.064	.053
F4-Fz	.097	-.12	.356	.2	-.104	.011
C3-Fz	-.012	-.066	.329	.077	-.17	-.18
C4-Fz	-.012	-.122	.37	-.039	-.088	-.086
T3-Fz	.154	-.198	.511*	.308	-.114	-.11
T4-Fz	.053	-.111	.352	.165	-.2	-.183
P3-Fz	-.087	.024	.193	-.203	-.153	-.233
P4-Fz	-.138	.029	.103	-.31	-.192	-.259
O1-Fz	-.217	.118	-.023	-.39	-.076	-.049
O2-Fz	-.067	.31	-.149	-.28	-.357	-.323

Table A26. Pearson correlation coefficients for the external focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the low-alpha frequency band. * $p < .05$, two-tailed.

EF: EEG low-alpha coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.086	-.163	.251	.182	-.21	-.099
F4-Fz	.183	-.153	.327	.308	-.203	-.079
C3-Fz	.038	-.039	.335	-.105	-.309	-.371
C4-Fz	.183	-.101	.302	.183	-.287	-.305
T3-Fz	-.02	-.187	.437	.129	-.133	-.162
T4-Fz	.082	-.093	.429	.061	-.241	-.318
P3-Fz	-.006	.034	.368	.013	-.302	-.284
P4-Fz	.084	.132	.227	.072	-.455*	-.485*
O1-Fz	.088	-.086	.109	-.025	-.312	-.33
O2-Fz	.008	.143	.177	-.112	-.214	-.241

Table A27. Pearson correlation coefficients for the external focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG high-alpha coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.175	-.003	.203	.385	-.178	-.028
F4-Fz	.173	-.136	.25	.276	.051	.225
C3-Fz	-.144	-.363	.42	-.235	.237	.301
C4-Fz	-.065	-.3	.367	.081	.024	.106
T3-Fz	.069	-.117	.271	.357	-.17	-.032
T4-Fz	.026	-.148	.214	.277	-.1	.091
P3-Fz	-.13	-.332	.29	.014	-.106	-.006
P4-Fz	-.193	-.415	.369	-.257	.183	.224
O1-Fz	-.165	-.218	.349	-.162	.083	.165
O2-Fz	-.024	-.382	.303	-.039	.046	.127

Table A28. Pearson correlation coefficients for the external focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG high-alpha coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.207	-.086	.253	.247	-.021	.119
F4-Fz	.142	.079	.155	.285	-.259	-.094
C3-Fz	.19	.179	.061	-.011	-.147	-.054
C4-Fz	.188	.243	.3	.011	.124	.24
T3-Fz	.085	.084	-.048	.437	-.57*	-.46*
T4-Fz	.146	.175	-.003	.244	-.501*	-.48*
P3-Fz	.078	.132	.045	.168	-.467*	-.433
P4-Fz	.015	.196	-.056	.12	-.212	-.103
O1-Fz	.078	-.075	.12	.05	-.291	-.112
O2-Fz	-.027	.027	-.028	.172	-.05	.17

Table A29. Pearson correlation coefficients for the external focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG high-alpha coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.199	.034	.377	.322	-.264	-.206
F4-Fz	-.005	.101	.37	.296	-.209	-.079
C3-Fz	.358	.123	.539*	.454*	-.112	-.111
C4-Fz	.134	-.031	.591*	.249	.018	.081
T3-Fz	.096	-.344	.429	-.094	.06	.082
T4-Fz	.213	-.214	.442	.168	-.073	-.003
P3-Fz	.342	-.045	.479*	.224	-.027	-.079
P4-Fz	.442	-.058	.541*	.313	.11	.049
O1-Fz	.425	-.092	.213	.298	-.031	-.06
O2-Fz	.408	-.173	.217	.288	.228	.271

Table A30. Pearson correlation coefficients for the external focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the high-alpha frequency band. * *p* < .05, two-tailed.

EF: EEG high-alpha coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.285	.079	.145	.323	.308	.373
F4-Fz	-.24	-.146	.078	-.129	.243	.27
C3-Fz	-.035	-.27	.156	-.088	-.31	-.382
C4-Fz	-.279	-.446*	.186	-.569*	.158	.114
T3-Fz	.048	.085	.061	.377	-.466*	-.496*
T4-Fz	.308	.154	.487*	.247	-.013	-.151
P3-Fz	-.078	.048	-.006	-.312	-.149	-.344
P4-Fz	-.171	-.14	.073	-.315	-.203	-.365
O1-Fz	-.066	-.079	-.019	-.379	-.031	-.154
O2-Fz	-.092	-.173	-.035	-.517*	-.029	-.146

Table A31. Pearson correlation coefficients for the external focus of attention condition between the first epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * *p* < .05, two-tailed.

EF: EEG beta coherence at the first epoch (-2 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.09	.092	.069	.359	-.275	-.118
F4-Fz	.015	-.189	.213	.198	-.081	.081
C3-Fz	.015	-.127	.291	.03	.061	.236
C4-Fz	.113	-.163	.409	.209	.032	.166
T3-Fz	-.058	-.227	.264	.111	-.249	-.217
T4-Fz	-.31	-.097	.142	.072	-.206	-.172
P3-Fz	-.374	-.184	.18	-.119	-.046	-.046
P4-Fz	-.27	-.184	.197	-.086	-.123	-.055
O1-Fz	-.423	-.278	-.029	-.33	-.054	.012
O2-Fz	-.401	-.228	-.037	-.301	-.066	.061

Table A32. Pearson correlation coefficients for the external focus of attention condition between the second epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$, two-tailed.

EF: EEG beta coherence at the second epoch (-1.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	-.112	-.026	.237	.115	-.162	-.08
F4-Fz	-.092	-.08	.228	.277	-.009	.099
C3-Fz	-.217	-.061	.303	.114	.31	.29
C4-Fz	-.104	-.076	.369	-.003	-.045	0
T3-Fz	-.203	-.13	.304	-.062	-.057	.002
T4-Fz	-.04	-.129	.313	.297	.3	.354
P3-Fz	-.04	-.137	.256	.396	.002	-.041
P4-Fz	.221	-.015	.294	.428	-.065	-.088
O1-Fz	.148	-.127	.09	.587*	-.387	-.418
O2-Fz	.309	-.084	.154	.520*	-.317	-.341

Table A33. Pearson correlation coefficients for the external focus of attention condition between the third epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$, two-tailed.

EF: EEG beta coherence at the third epoch (- 1 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.166	.363	.116	.579*	-.371	-.322
F4-Fz	-.123	.329	.051	.165	-.279	-.338
C3-Fz	-.18	.225	-.101	-.061	-.364	-.481*
C4-Fz	-.22	.157	.008	.175	-.319	-.363
T3-Fz	.112	.189	.183	.312	-.317	-.314
T4-Fz	.074	.209	.03	.279	-.336	-.46*
P3-Fz	-.085	.238	.161	-.005	-.214	-.308
P4-Fz	-.287	.232	-.065	-.193	-.223	-.323
O1-Fz	-.012	.243	.227	-.162	-.026	-.081
O2-Fz	-.256	.207	.157	-.246	-.065	-.126

Table A34. Pearson correlation coefficients for the external focus of attention condition between the fourth epoch of coherence pairings and four muscle groups of means of RMS and performance measures such as absolute error and standard deviation of absolute error for the beta frequency band. * $p < .05$ two-tailed).

EF: EEG beta coherence at the fourth epoch (-0.5 s)	Flexor RMS	Extensor RMS	Biceps RMS	Triceps RMS	Absolute error	SD of Absolute error
F3-Fz	.054	.04	.158	.2	-.377	-.253
F4-Fz	.161	.273	.091	.565*	-.423	-.365
C3-Fz	.024	.152	.167	.235	-.462*	-.486*
C4-Fz	.047	.158	.163	.451*	-.429	-.37
T3-Fz	-.007	-.008	.196	.293	-.413	-.401
T4-Fz	.227	.072	.136	.418	-.619*	-.57*
P3-Fz	-.052	.085	-.05	.336	-.493*	-.54*
P4-Fz	-.036	.131	.037	.235	-.336	-.441
O1-Fz	-.159	.415	-.184	.398	-.192	-.166
O2-Fz	-.288	.411	-.308	.095	-.098	-.079

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