

ABSTRACT

Title of Document: AROUSAL AND SKILLED MOTOR
 PERFORMANCE: THE MEDIATING ROLE
 OF CEREBRAL CORTICAL DYNAMICS

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Despite achievement of a highly skilled level of motor competence, elucidation of the multiple factors contributing to variability of motor performance remains somewhat enigmatic. The inverted-U hypothesis posits moderate levels of arousal as essential to optimal performance; this suggests that arousal may be a key player of this variability. The purpose of this study was to examine the psychophysiological concomitants of moderate as compared to low arousal. Specifically we hypothesized a decrease in coherence between the temporal lobes (T3-verbal-analytical processing & T4-visuo-spatial processing) and the motor planning region (Fz), accompanied by an increase in task performance. Fifteen college undergraduates (9 females, 6 males, mean age = 23.4, SD = 4.22) participated in two days of testing. Day one consisted of 340 trials of a novel visuomotor pointing task to achieve task competency. On the second day, EEG data were recorded during both a Performance Alone (PA) condition vs. a Social-Evaluation and Competition (SE&C) condition, which were counterbalanced. Coherence estimates were subjected to a 2 x 2 ANOVA comparing Condition x Hemisphere; post hoc testing was completed using paired-t tests. The arousal-manipulation check of the two experimental protocols (PA vs. SE&C) provided by the autonomic measures and self-reports indicated an increase from a low

to moderate level of arousal during the SE&C condition. There was a statistical interaction between condition and hemisphere revealing reduced coherence during SE&C only between T4-Fz ($t(14) = 3.084$, $p = 0.008$). Additionally, there was a increase in motor performance ($t(13) = 2.171$, $p = 0.049$). Consistent with the inverted-U hypothesis and our predictions as stated for moderate arousal relative to performing alone, there was a subsequent increase in performance coupled with a decrease in coherence between the visuo-spatial and the motor planning regions. In light of the significantly improved kinematics, the reduction in networking between these task relevant areas is seen as an adaptive refinement of cortico-cortical communication as one moves from low towards optimal arousal.

AROUSAL AND SKILLED MOTOR PERFORMANCE: THE MEDIATING
ROLE OF CEREBRAL CORTICAL DYNAMICS

By

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Arts
2006

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ACKNOWLEDGEMENTS

First, I would like to thank my advisor, Brad Hatfield, for his guidance and friendship. The knowledge and research skills he has imparted are invaluable to my professional future. I would also like to thank the committee, Drs. Seppo Iso-Ahola and Amy Haufler, for their contribution to this document and related publication. Additionally, the Cogmo Lab as well as the entire Kinesiology Department deserve thanks for making work a place I look forward to going each day. Special thanks go to Ron Goodman who was a driving force behind completion of my thesis as well as a good friend. Last, but certainly not least, I would like to thank my family for their love and support; especially my parents for teaching me the values of hard work, responsibility, and doing what you enjoy.

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CHAPTER I

INTRODUCTION

Successful performance of a skilled motor behavior results from continued practice and dedication (Ericsson & Charness, 1994). Despite adherence to these tried and true tenets, significant fluctuations in performance have been observed. It has been shown that multiple factors (e.g. level of competence, task complexity, social context, and arousal/motivation) exert marked influence on consistency of performance (Zaichkowsky & Baltzell, 2001). The present study investigated the psychophysiological underpinnings related to arousal that may mediate this variability of skilled motor performance.

It has been well established across all disciplines of the physical, biological and social sciences that all dynamical and living systems must operate within a specified range (Inverted-U) of complexity and or homeostatic parameters. Yerkes and Dodson (1908) proposed an inverted-U relationship between arousal and performance that describes an optimal level of arousal as prerequisite for one's best performance, with low and high levels of arousal resulting in sub-optimal performance (Fig. 1). Although alternative views have been expressed, recent evidence provided by Arent and Landers (2003) have supported the inverted-U model through inducing multiple levels of arousal by assigning participants to perform varying aerobic workloads (ranging from 20-90% of heart rate reserve) while performing a reaction time task. Furthermore, at moderately arousing conditions, they observed participants' best performances. On the other hand, states of low

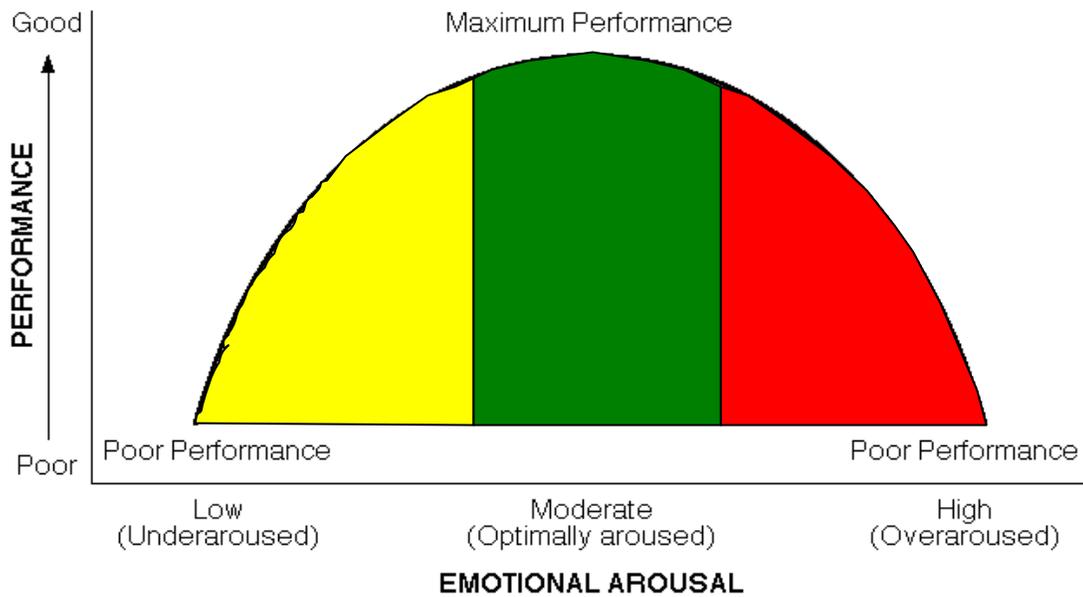


Figure 1. A graphical representation of the hypothesized relationship between arousal and performance

arousal due to inconsequential tasks and characterized by an absence of self-relevance result in minimal engagement of task related attentional and motivational systems. As reported by Zajonc (1965), Bergum and Lehr (1963) observed reduced performance when military personnel executed an attentional task in a low motivation condition (task alone), compared to subjects with higher motivational demands (monitored by superiors). More recent evidence by Hedden and Gabrieli (2006) supports the notion that lapses of attention, i.e. daydreaming, may fail to deactivate additional task-irrelevant neural networks, thus contributing to poor performance. A phenomenological level of analysis by athletes of their best performances indicate a keen focus on task-relevant cues, a sense of effortlessness and the absence of cognitive investment; hence the phrase, “they act and do not have to think about what they are going to do” (Csikszentmihalyi, 1990). Underlying these experiences, Hatfield and Hillman (2001) have proposed that during optimal levels of performance

task-relevant processing may be enhanced, while task-irrelevant processing is quieted; they also suggest an electrophysiological basis for networking efficiency. These refinements result in cortical simplicity and this simplicity, specifically resulting from decreased inputs to the motor cortex, is reflected in consistent performance and efficient limb coordination. Conversely, excess arousal may also decrease attention due to distracting thoughts and increasing non-task related networking leading to inefficient processes related to skilled motor production (Masters, 1992). Thus, both high and low levels of arousal (and the subsequent poor performance) are associated with task-irrelevant networking, while moderate arousal/performance is associated with efficient networking.

In order to assess the impact of arousal on performance variability, task competency of the performer to execute the task must be addressed in order to eliminate additional sources of variability. Traditional motor learning theory depicts skill acquisition as a progression through three stages of motor learning (cognitive, associative, and autonomous). The initial, cognitive stage is characterized by a continual monitoring of both goal and task production. The performer uses cognitive evaluation in an attempt to guide movement and produce the desired outcome (Fitts & Posner, 1967). The intermediary, associative stage is distinguished by commission and correction of gross errors, which possibly occurs at a conscious level, and can last for varying time periods based on task complexity. Finally, deliberate practice brings one to the autonomous stage, characterized by minimal cognitive investment, fewer errors and development of a non-verbal internal model under the direction of an implicit procedural memory system (Fitts & Posner; Graybiel, 2000; Cavaco et al.,

2004). Explicit knowledge is often defined as observations that may be articulated, while implicit/procedural memory describes knowledge beyond the reach of conscious, declarative awareness (Masters, 1992). Thus, beginners think about task production while experts quiet this verbal, analytic component during performance.

Research utilizing electrophysiological recordings of brain activity or central arousal provides a high resolution, objective measure of cortical dynamics and further support this model of skill acquisition via reductions in activity within the verbal-associative areas of the brain and decreased networking between task-irrelevant and task-relevant regions (Hatfield et al., 2004). Experts demonstrated increased left temporal (T3) alpha activity prior to motor task execution compared to novices (Hatfield et al., 1982, 1984; Haufler et al., 2000). Alpha (8-13 Hz) is reputedly known as the idling frequency of the human brain and reductions in alpha power are commonly used to infer activation or current engagement in a specified task (Steriade et al., 1990). The left temporal lobe (T3) has been robustly linked to language and memory via lesion and neuroimaging studies whereas the right temporal lobe (T4) has been associated with visual-spatial processes (Cohen, 1993). Additionally, intervention studies in which participants learn a skilled visuo-motor task via deliberate practice and coaching, demonstrated that participants subsequently exhibited a marked increase in T3 alpha power accompanied with a higher rate of increase in both T3 and T4 alpha power during motor planning of a visuo-motor task (Landers et al., 1994; Kerick et al., 2004). Therefore, in those that become highly skilled at a motor task, regional relaxation and refinement in the brain is observed; a trend one would expect to continue as one achieves higher levels of performance.

Electrophysiological studies suggest that the refinement of neural processes responsible for increased efficiency/proficiency of visuo-motor behavior is active in both temporal regions. Kerick et al. 2001, 2004 demonstrated a reduction in cortical activity during marksmen shooting in the right hemisphere, both in experts compared to novices and as a result of a three-month training protocol coupled with an increase in performance. With practice (autonomous stage) the verbal-associative sections of the left temporal region appear to become task-irrelevant, while the visuo-spatial integration associated with right hemispheric activation becomes refined (decrease in activity, i.e. increase in alpha activity, although the magnitude of difference was higher in the left compared to the right). In addition, a behavioral level of analysis, DiRusso et al. (2003) in a standard vs. distracter task, demonstrated that expert shooters vs. controls exhibited faster and less variable visual-spatial integration for visual saccadic trajectory toward target. Further findings from the same study showed that intervention (training a control) achieved a similar proficiency in task performance. These data support the notion that practice modulates fundamental visuo-motor processes making them more consistent. The study of cortical dynamics provides insights into those neural processes likely to be associated with moderate levels of arousal in those that have reasonable levels of skill.

In order to assess the refinement of neural networks, one can employ measures of coherence, via electrophysiological recordings. Deeny et al. (2003) examined coherence between multiple brain areas and the motor planning region (Fz). More specifically, coherence is a statistical measure of the degree of repeated linear correlation between the power spectral densities (frequency domain) of two separate

electrodes taken from the same time series. Thus, coherence values are an index of the correlation of the amount of power present (or the regularity of the phase relationship) in a specific bandwidth (i.e., alpha) between two different electrode sites (i.e. T3-Fz, T4-Fz). High coherence implies communication between these areas, while low coherence indicates independence. All participants in Deeny et al.'s study were highly skilled marksmen (approximately 18 years of shooting experience) but were separated into two groups based on history of competition success. Across the scalp and between the two groups, EEG coherence measures were almost identical, except between the T3 (verbal-analytic) and Fz (motor planning) electrodes in the alpha and beta bandwidths¹. Superior competitors exhibited a reduction T3-Fz coherence which, again, implies a reduction in task-irrelevant communication. In other words, those who had a history of performing well under competition maintained a more streamlined network.

A more recent study that actually manipulated arousal, has found similar results (Chen et al. 2005). Participants trained on dart throwing were instructed to perform under conditions of higher (threat of mild nociceptive stimuli) and lower (no threat) arousal. During higher arousal, greater T3-Fz coherence was observed concurrent with a significant decrease in performance reflecting task-irrelevant communication during sub-optimal arousal.

¹The frequency of interaction (bandwidth) in which coherence values are calculated reflect varying cortical distances of neural integration (von Stein & Sarnthein, 2000). Theta (3-7 Hz) and alpha (8-13 Hz,) are thought to reflect longer distances (frontal-occipital), whereas beta (13-30 Hz) is thought to reflect mid-range distances (frontal-parietal).

It should be noted that the threat of nociceptive pain, specifically mild electrical shock, is not commonplace in conventional motor performance arenas. Instead social evaluation is much more realistic in competitive sport situations and has been robustly linked to inducement of arousal (Cottrell, 1972). Based on the above model of cortical dynamics and performance, we predict refined networking during moderate levels of arousal. Also, arousal induced through social evaluation and motivation has been shown to exert a moderate effect on arousal (Dickerson & Kemeny, 2004). Thus, our present study investigated this relationship through a performance alone (PA), and performance during social evaluation and competition condition (SE&C), while we infer neural networking via EEG recordings.

The aim of this study is to further clarify the psychophysiological underpinnings of the hypothesized Inverted-U relationship between arousal and performance. Logically, the neural substrates explicated by EEG and involved in mediating motor performance, should exhibit a similar curvilinear relationship with arousal. Specifically, we hypothesized that during the SE&C compared to the PA condition, participants will exhibit a moderate increase in arousal, improved motor performance, and decreased regionally and bandwidth specific coherence.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The review of literature in chapter II is subdivided into five sections. The first section summarizes the arousal-performance inverted-U hypothesis and presents a validation of this hypothesis in humans. In the second section, the traditional stages of motor learning are discussed and a study is presented concerning arousal's possible effects on performance in the context of the motor learning stages. Section three describes the psychophysiological measure electroencephalography (EEG) as well as its advantages and disadvantages, and concludes by summarizing the EEG computation of coherence. The fourth section reviews relevant EEG coherence studies and describes their contribution to the underlying causes of the inverted-U hypothesis. Finally, section five summarizes the major points of Chapter II.

Arousal and Performance

The inverted-U relationship between arousal and performance was first observed by Yerkes and Dodson in 1908. In their study, mice were presented with two boxes, a darker and a lighter box; the mice were required to enter the lighter box while avoiding the darker box. If the mice entered the darker box they received an electrical shock and subsequently learned avoidance of this box. Yerkes and Dodson investigated the level of intensity of the aversive shock which was most conducive to the acquisition of this discrimination task. Mice that were exposed to weak shocks and mice that were exposed to strong shocks during task acquisition both required

more trials to learn the task compared to mice that received a moderate electrical shock. The authors concluded, at least in mice, that there was an inverted-U relationship between level of arousal (intensity of shock) and performance (learning a discrimination task). This phenomenon has become known as the inverted-U hypothesis.

The inverted-U holds that during low levels of arousal poor performance is observed. As arousal increases, so does performance—to a point. This point is referred to as optimal arousal, and the best performance is achieved. Excess arousal beyond this point results in sub-optimal performance and as arousal increases beyond this optimal level, performance continues to decline. Additionally, factors such as skill level, skill complexity, and individual differences have been shown to exert an influence on the level of arousal associated with optimal performance. The introduced variability from factors such as these has spurred alternative models such as the catastrophe, multidimensional-anxiety theory, and reversal theory. However, the inverted-U hypothesis has since been shown to be a viable metric in humans by the Arent and Landers's (2003) study.

In Arent and Lander's (2003) study, arousal was manipulated via varying aerobic intensity (heart-rate reserve) while participants performed a reaction time task. The 104 participants were separated into eight groups with each group performing the task at different level of participants' respective heart-rate reserves: 20, 30, 40, 50, 60, 70, 80, or 90%. Once participants achieved a steady state of their specific aerobic intensity via a cycle ergometer, they performed a reaction-time task. The task consisted of 12 trials where the participants, upon a signal light cue, left a

home button, pressed a target button, and returned to the home button as quickly as possible. To ensure all participants were motivated, monetary compensation was given to the three fastest responders. Arent and Landers observed that the quickest reaction times occurred during moderate levels of aerobic intensity, while low and high levels of intensity resulted in slower responses. Thus, there was a curvilinear relationship between level of arousal and performance. They concluded that the inverted-U hypothesis was a valid model, explaining the relationship between arousal and performance.

Although the inverted-U hypothesis was first proposed by Yerkes and Dodson (1908) through observation of mice learning a discrimination task under varying levels of electric shock, this relationship has been further validated in humans. Arent and Landers (2003) observed that at least in a simple reaction time task, moderate levels of arousal resulted in better performances compared to both low and high levels of arousal.

Motor Learning

In order to investigate arousal's effect on performance, it is important to consider the skill level of the performer in order to eliminate additional sources of variability. Fitts and Posner (1967) proposed that learning a new motor task involved a progression through three stages, cognitive, associative, and autonomous. The initial, cognitive stage was characterized by the learners attempt to understand the task demands. The learner attends to multiple cues and responses that will later go unnoticed. During this stage the learner develops and uses explicit knowledge of the task. In the intermediate (associative) stage new motor patterns are tried out and

modified by the learner. Gross errors are present at first, but are gradually eliminated with practice. Finally, during the autonomous stage of motor learning the learner has developed an internal model of a motor pattern to execute the task and begins to rely more on implicit rather than explicit knowledge of the task. During this final stage cognitive processes exert minimal influence on task production. Fitts and Posner relate highly practiced tasks to reflexes and suggest that verbalization or attempt at conscious control during skilled performance may interfere with task production.

Masters (1992) examined whether this proposed reinvestment of explicit knowledge during task production underlies the performance decrement associated with excess arousal. All participants learned a putting task by performing four sessions of 100 putts each. After skill acquisition participants were subjected to an arousing test condition in which they performed 100 putts. Arousal was induced through being told their performance would be monitored by a professional golfer and that their performance would influence monetary compensation. One group received written instructions on how to putt prior to the learning sessions and subsequent testing revealed they had explicit knowledge of the task. Another group received no such instructions and performed a dual-task consisting of random letter generation during all four training sessions. Follow-up testing revealed this group had significantly less explicit knowledge of task production compared to the group that had received written instructions. During the arousing test condition, both groups exhibited a comparable increase in arousal via heart rate and self-report. However, while the explicit knowledge group performance degraded under the excess arousal, the implicit knowledge group maintained their performance. Masters attributed the

explicit group's performance decrement to a reinvestment of explicit knowledge interfering with the internal motor pattern they had developed. Conversely, the implicit group had little explicit knowledge of the task, preventing an explicit reinvestment, thus, maintaining their performance under highly arousing conditions.

As one progresses through the stages of motor learning they develop an internal motor map (explicit to implicit knowledge) to perform the task. Excessively arousing conditions may elicit a reversal from this implicit model back to the use of explicit resources, thus interfering with task production. Masters (1992) supported this notion through observation of maintained performance under highly arousing conditions in a group that was inhibited from utilizing explicit resources. It has been proposed by Hatfield and Hillman (2001) that increased complexity in neural networks causes additional variability in motor performance; a relationship they refer to as the psychomotor efficiency hypothesis. Further, engagement of explicit knowledge during skill production adds a non-essential component to an already complex, but largely sub-cortical and implicit visuo-motor process (Graybiel, 2000; Cavaco et al., 2004), thereby increasing complexity and variability with poorer performance a probable result. EEG coherence provides insights into these cortical networks and can be used to investigate possible mediating causes of the inverted-U relationship.

Review of EEG

A demonstration of human brain electrical activity via EEG was first published in 1929 by Hans Berger, such that, electrodes on the scalp that detect electrical activity were referenced to a non-brain electrode. Common mode rejection

(subtraction of non-brain electrical activity from the sum of brain and non-brain electrical activity) was then used to extract a cleaner brain signal at the scalp electrodes. This signal is typically sampled between 256-1024 Hz and can be displayed with time on the x-axis and amplitude of the signal (in micro volts) on the y-axis. In the years that have followed, its wide acceptance as a viable objective measure in the biobehavioral disciplines has been accompanied by marked improvements in the technology of data acquisition, signal processing and sophisticated experimental design. Dynamic brain activity is thought to be the result of interactions of neurons and assemblies of neurons that form at multiple spatial scales (Freeman, 1975; Harth, 1993; Scott, 1995; Nunez, 1995; Nunez & Srinivasan, 2005). As the skull acts as a spatial low-pass filter, the electrical activity of the brain, as recorded by EEG, is believed to be the net spatial and temporal summation of the slower frequency (0.05-100 Hz) excitatory and inhibitory post-synaptic field potentials. The currents responsible for these potentials are thought to be generated by the synchronous firing of radially-oriented pyramidal neurons of the cortex (Davidson et al., 2000). Additionally, it has been suggested that the area of cortex beneath one electrode needed to generate this activity is approximately 2-6 cm² and may involve anywhere from 100 million-1 billion neurons (Tao et al., 2005; Nunez & Srinivasan).

By far the greatest advantage of EEG is its fine-grained temporal resolution that allows discrimination at the millisecond scale. This high temporal resolution provides a metric capable of forming meaningful inferences regarding real-time psycho-behavioral processes and their temporal evolution from correlations with brain electrical activity (Andreassi, 2000). In other words, one has the ability to look

at extremely fast, possibly functional, changes in the brain and correlate them to behavior.

The major disadvantage of EEG is its poor spatial resolution due to the inverse problem and volume conduction; diffusion of the current within the electrolytic medium of the cortex. However, the current use of high density electrode arrays, realistic head-shape models, and well-informed functional connectivity information as a priori constraints to modern inverse solutions promises major advances toward increasing the spatial resolution of EEG (Michel et al., 2004). Nunez & Srinivasan (2005) postulate that a reasonable goal of the many new EEG methods aimed at localization of brain sources be set at 1 cm (10 million neurons) as this represents the theoretical limit of spatial resolution caused by the physical separation of sensor and scalp.

Gevins et al. (1997) suggest that “changes in EEG spectra are probably more closely related to changes in the state of the functional networks underlying task performance while evoked responses probably more closely index different operations being performed on internal representations” (p. 383). Further, Sobotka, et al. (1992) found spectral measures (decomposition of the signal into the various frequencies contributing to the raw signal) were more sensitive than event related potentials (summed average of repeated trials in the time domain) to incentive variations. Pfurtscheller and Lopes da Silva (1999) propose that EEG oscillations are determined by, (1)-intrinsic membrane properties of the neurons and the dynamics of synaptic processes, (2)-the strength and extent of the interconnections between the network elements and (3)-the modulating influences from general or local

neurotransmitter systems. Paulson and Sejnowski (2006) describe the current understanding of the function of oscillatory activity, “Based on converging evidence from different species... Network oscillations may take part in representing information, regulate the flow of information in network circuits and help store and retrieve information in synapses distributed throughout cortical networks” (p. 1661). Von Stein and Sarnthein (2000) discuss the notion that the changing pattern of synchronization and desynchronization within and between different cell assemblies generates the ongoing EEG and that these changes are reflected in the measurements of amplitude within the various frequency bands, thus, supporting studies of induced spectral changes as viable metrics of stimulus-locked changes in the network dynamics of the human cortex.

While amplitude within a specified bandwidth is indicative of the amount of synchronous activity within the cell assemblies beneath an electrode, the level of interactions between two signals may be inferred through coherence. Coherence is a statistical measure of the degree of repeated linear correlation between the power spectral densities (frequency domain) of two separate electrodes taken from the same time series. Thus, coherence values are an index of the correlation of the amount of power present (or the regularity of the phase relationship) in a specific bandwidth (i.e. alpha) between two different electrode sites (i.e. T3-Fz, T4-Fz). High coherence implies communication between these areas, while low coherence indicates independence. Von Stein and Sarnthein (2000) suggest a “relation between the size and distance of an [neural] interaction and the frequency of synchronization...” (p. 308). In other words, the larger the distributed network of localized and functionally

connected neural populations, the slower the frequency necessary to coordinate activity between these regions. Corroborating this from a physics standpoint, Nunez (1995) makes the analogy to two people holding a rope and creating a wave by moving their arms up and down. As they move further apart, while putting the same amount of energy into the wave, the frequency decreases. Furthermore, faster frequencies, i.e. gamma, reflect local processing, while beta synchronizes these local assemblies across mid-range distances. Von Stein and Sarnthein (2000) found increased beta coherence over mid-range topographic distances during integration of visually coherent stimuli (pattern vs. non-pattern) while, previous coherence-performance literature has investigated multi-modal task-relevant versus task-irrelevant processing over comparable distances.

Relevant EEG Studies

Busk and Galbraith (1975) first demonstrated both a reduction in coherence due to practice of a visuo-motor task and an increase in coherence with increasing task difficulty. Fifteen participants learned a pursuit-rotor task (a dot rotating on a turntable) while scalp EEG was recorded from sites C3, C4, Fz, and Oz. Coherence estimates were calculated for all possible electrode pairs. Participants were divided into three-equal groups, eye-tracking of pursuit rotor (E) (had to follow the dot with their eye as it moved), hand-tracking of pursuit rotor (had to keep a flexible metal rod on the dot as it moved) (H), or eye-hand tracking of pursuit rotor (EH) (most difficult task consisting of both eye and rod tracking the dot as rotated). Each session contained a total of 32 trials; trials 1-6 consisted of two pre-test trials of each of the three tasks, trials 27-32 consisted of post-test trials on the same tasks,

while trials 7-26 consisted of practice trials with each group practicing their respective task (E, H, or EH). The EH condition elicited the highest coherence values at pre-test for all participants, while the EH group demonstrated the greatest reduction in coherence compared to the other groups due to practice. Additionally, the EH group showed the greatest overall improvement on the EH post-test compared to the other two groups. Due to the higher level of difficulty of the EH task as compared to the E and H tasks, the results support the notion that greater task difficulty is associated with increased coherence. Moreover, upon completion of the practice regime participants showed a reduction in coherence coupled with an increase in performance, further supporting the psychomotor efficiency hypothesis (Hatfield & Hillman, 2001). The authors also point out that this reduction in coherence may reflect dynamic properties of the underlying anatomical pathways as one performs a visuo-motor task. Bell and Fox (1996) later expanded these findings to the developmental literature relating changes in coherence to synaptic proliferation and pruning.

Bell and Fox (1996) investigated a critical period of development, learning to crawl, while measuring coherence. Coherence was used to infer changing synaptic connections that occur due to expectation, learning and acquisition of stage specific visuo-motor skills. Participants included 80 infants, approximately eight months old, who were separated in to four groups based on crawling experience; pre-locomotion, 1-4 weeks, 5-8 weeks, or 9 or more weeks. EEG was collected for 3 minutes from sites F3, F4, F7, F8, P3, P4, O1, and O2 while each participant sat on their mother's lap. Pre-locomotion infants displayed the lowest coherence values, 1-4 week

crawling experience infants exhibited the most coherence, and there was a significant decrease in coherence as crawling experience increased. The authors interpreted these findings as reflective of normal development during specific stages of learning. Accordingly, in anticipation of new task learning (crawling) great proliferation of synapses occur in the cortex causing an increase in coherence. Then, as learning continues, there is a pruning of the synapses that were not used and strengthened during task production accounting for the reduction in coherence. This phenomenon is consistent with the conclusions of both Busk and Galbraith (1975) and Hatfield and Hillman (2001) cortical efficiency experience by adults; practice streamlines cortical activity and improves performance.

Acquisition of a new skill is associated with a decrease in coherence and increased performance but what are the variables that account for differences in performance once a certain level of competence has been attained. Deeny et al. (2001) explored this phenomenon through studying coherence in groups with comparable experience (approximately 20 years) but different competitive performance histories. The authors hypothesized that subjects of comparable experience but who perform better in competition than their counterparts would exhibit less coherence between the verbal-associative (T3) and motor-planning (Fz) regions of the brain. Such a finding, consistent with cortical efficiency, would provide an explanation for the variability in performance.

Nineteen highly-experienced marksmen were separated into two groups. Ten participants were labeled experts based on their history of performing well in competition, while nine participants were labeled skilled and had less success in

competition compared to the experts. The task consisted of firing 40 shots in 80 minutes on a simulated shooting range while EEG was recorded from 13 sites (F3, F4, Fz, T3, T4, C3, C4, P3, P4, O1, and O2). Coherence estimates were calculated in three-frequency ranges (8-10 Hz, 10-13 Hz, and 13-22 Hz) between Fz paired with all the other sites. As predicted, coherence between T3 and Fz was lower in the experts compared to the skilled marksmen in the two higher frequency bands, while coherence values were undifferentiated between all other Fz pairings. The authors concluded the similarity in cortical networking was probably due to the multiple years of shooting experience in both groups. The remarkable, singular difference of T3-Fz coherence suggests a specific reduction in networking between the verbal-analytical and motor-planning regions of the brain in experts. Further, this finding is consistent with Fitts and Posner's (1967) stage of automaticity where explicit knowledge of the task is non-essential during its production and may actually interfere with highly skilled motor performance. Thus, this specific reduction in networking in experts may be an example of psychomotor efficiency in which verbal-analytical communication to the motor planning region is unnecessary. Additionally, excess inputs to the motor-planning region may induce reductions in performance via increased complexity in the region of the brain ultimately responsible for motor unit recruitment. Finally, excess inputs to the motor-planning region may underlie other variables known to influence motor performance variability.

In order to expand the notion of cortical efficiency to the inverted-U relationship, Chen et al. (2005) measured coherence between Fz-T3 and Fz-T4 during varying levels of arousal. Twenty-one participants were trained on a dart-throwing

task for three months. They then performed the task under two conditions, (1)-low arousal, no consequences based on performance, and (2)-high arousal, told poor performance would result in them to receiving an electric shock. Under conditions of high arousal (validated via self report), participants exhibited a reduction in performance as well as an increase in coherence between the verbal-analytical region (T3) and the motor planning region (Fz). Thus high arousal resulted in increased communication to the motor-planning region and a reduction in motor performance followed. These findings support cortical efficiency as an underlying cause of successful motor performance and expanded the coherence literature by explaining how psychological state may influence motor performance via excess networking.

The literature to date investigating cortical dynamics and motor performance have implicated coherence as a viable metric to study networking of various brain regions. Learning a new visuo-motor task has been associated with a reduction in coherence thought to reflect a more efficient brain state and ultimately improved performance. This reduction in coherence may in part be due to a pruning of unnecessary synaptic connections (developmentally induced). Additionally, the observed reduction in coherence during successful task performance demonstrates alterations in the dynamical network processes of these anatomical connections specifically a reduction in task-irrelevant communication (T3-Fz). This reduction results in less complexity in the motor-planning region possibly leading to enhanced performance (Hatfield & Hillman, 2001). Finally, psychological states known to have a negative impact on performance (i.e. high levels of arousal) increase task-

irrelevant communication. These changes in networking may be mediating the relationship between psychological state and motor performance.

Summary

Although there appears to be a curvilinear relationship between arousal and performance (Arent & Landers, 2003), the psychophysiological underpinnings mediating this relationship is unclear. It has been proposed that excess arousal causes a reinvestment of explicit knowledge of task which may be responsible for a reduction in performance (Masters, 1992). Previous EEG studies (Busk & Galbraith, 1975; Bell & Fox, 1996; Deeny et al., 2001; Chen et al., 2005) investigating performance variability have unanimously implicated reductions in networking to the motor planning region as conducive to improved performance. It follows that the same increases in networking may, in part, be responsible for the performance variability associated with arousal. Specifically, greater coherence between the verbal-associative and motor-planning regions is associated with reductions in performance (Deeny et al.; Chen et al.) thus implying engagement of explicit knowledge of the task, as outlined in the Master's reinvestment hypothesis. Consistent with Hatfield & Hillman's (2001) psychomotor efficiency hypothesis, increased networking to the motor-planning region would increase the complexity, ultimately causing greater performance variability. Through EEG coherence it is possible to investigate networking to the motor planning region under varying levels of arousal to unmask the mediating causes explicating the inverted-U hypothesis.

CHAPTER III

METHODS

Participants

A total of 18 participants were recruited from year 2005 undergraduate Summer and Fall sessions in the Kinesiology Department at the University of Maryland, College Park. Three individuals were excluded due to high impedances. The 15 remaining participants consisted of 9 females and 6 males (mean age = 23.4, SD = 4.22). Only right handed and ipsilateral eye dominant participants were included as determined by the Edinburgh Handedness Inventory (EHI) (Appendix 1). No participant reported any exclusionary health condition via a Health Status Questionnaire, (HSQ) (Appendix 2). In addition, all participants reported refraining from alcohol, caffeine, and nicotine for at least 24 hours and from food or large quantities of water (>1 quart) for at least 75 minutes before psychophysiological testing began. All participants completed a University of Maryland Institutional Review Board (IRB) approved informed consent form (Appendix 3). The EHI, HSQ, and informed consent form, including dietary restriction advisory were administered 1 day prior to EEG testing.

Task

Participants completed a novel visuomotor pointing task, which consisted of a center-out movement, drawing as straight a line as possible to one of four peripheral, circular targets.

Participants were seated in a comfortable chair without arm rests, approximately 20" away at eyelevel from a 15" Gateway monitor (model FPD1520). Their right hand was occluded from view via an 18"x18" upright board placed adjacent to the participant's axillary fossa (Fig. 2). A chin rest was positioned to minimize head movement artifact. Participants used an indicator pen compatible with a 12" x 12" digitized drawing tablet (Intuos Graphics Tablet, WACOM Co.; model GD-1212-R) which tracked X-Y movement coordinates at a 100 Hz sampling rate during task performance. Participants were presented five circles 1 cm in diameter (see Figure 3 for pictorial description of the layout). Initially, subjects viewed only the center, red (home) circle, then as participants moved the indicator pen into the home circle the four peripheral circles (targets) appeared.

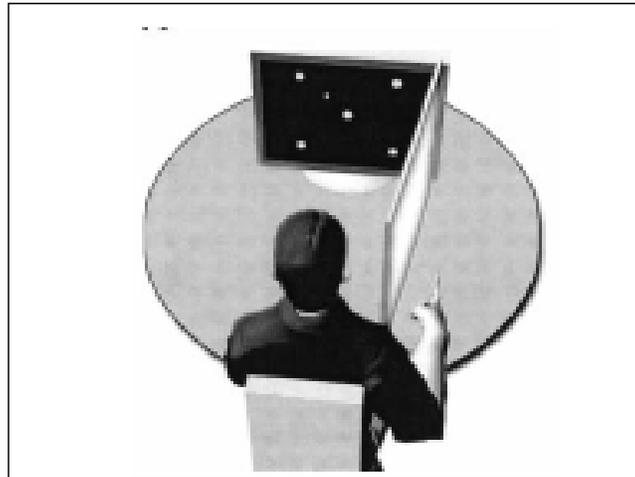


Figure 2. Visual description of experimental setup. Participants hand is occluded from their view and the participant receives visual feedback from the monitor.

Participants were instructed to keep the pen within the center circle for a minimum of two seconds otherwise the targets would disappear and the trial repeated. If the minimum time constraint was met (>2 seconds), then participants were able to

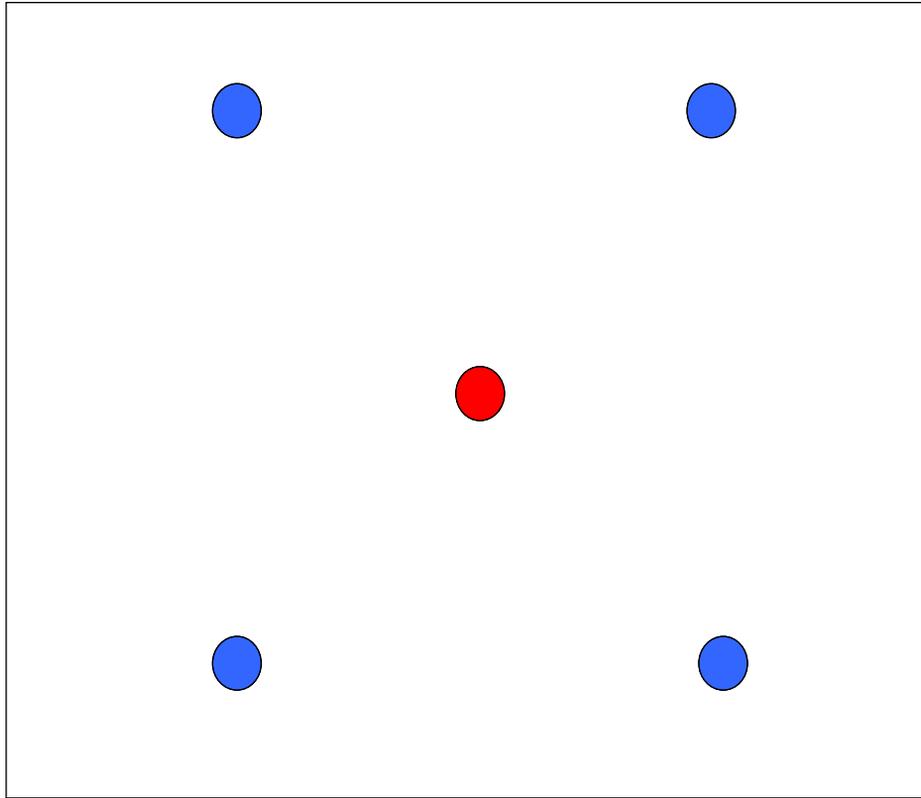


Figure 3. A pictorial description of the target layout. The red dot was the home circle while the peripheral dots were the targets. The participants began at the red dot, the blue dots appeared, they wait at least two seconds before initiating movement. They were instructed to move as quickly and accurately as possible to the target of their choice.

move to any peripheral target. When participants entered any of the peripheral targets, trial completion was signaled, via removal of targets from view. Participants then returned to the home circle, initiating the next trial. Visual feedback of pen movement trajectories was provided via real time tracings. Task consisted of two trial types: 1-visual consistent (baseline) where feedback was isomorphic with pen trajectory and 2-visually distorted (incongruent) where visual feedback was rotated 60°clockwise thereby initiating a visual-proprioceptive discontinuity (Fig. 4). The incongruent trials were used as novel stimuli, eliminating initial biases in skill level,

and causes subjects to internalize a new motor map. Subsequently, these incongruent trials were the only trials used during testing conditions.

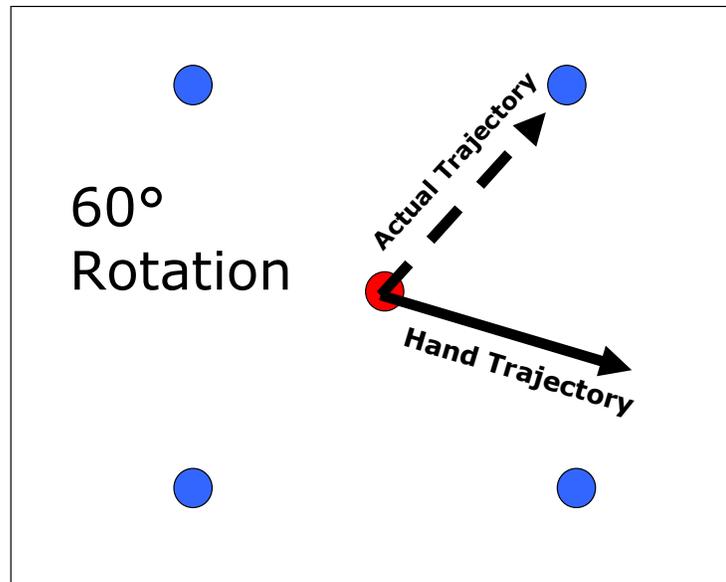


Figure 4. Example of the incongruence of the actual pen movement and the visual feedback that the participants received

Psychophysiological Recordings

EEG acquisition

Scalp electroencephalographic data was collected using tin electrodes housed within a stretchable lycra cap, (Electrode-Cap Instrumentation, Inc.). Data was recorded from 58 unipolar sites, labeled in accordance with the 10-20 international system (Jasper, 1958). At all sites of interest, impedances were maintained below 10 k Ω , signal was referenced to linked earlobes and a common ground. All channels were amplified 1,000 times using Neuroscan Synamps 1, linked to Neuroscan 4.3 acquisition/edit software on a Gateway Pentium computer running Windows XP

operating system. Bandpass filters were set at 1-100 Hz with a 60 Hz notch filter and the sampling rate was 1,000 Hertz.

Autonomic acquisition

All autonomic measures were recorded from the left hand using a Thought Technology (TT) Procomp Infiniti system, (encoder model # SA7500). Autonomic measures of Heart Rate (HR), and Skin Conductance (SC): HR was sampled at 2048 Hertz through a Blood Volume Pulse (BVP) sensor (model # SA9308M), sensor placement was 2nd digit of index finger, SC (model #SA9309M) was sampled at 256 Hertz, sensors were attached to the 2nd digit of the 2nd & 4th finger.

Event marker

An electronic event marker was transmitted into the Neuroscan Synamps 1 amplifiers and simultaneously into the TT encoder as the indicator pen left the home circle through a parallel cable via TTL (cable constructed by the University of Maryland Electronic Development Group). The event marker served the purpose of time locking task events with EEG and autonomic recordings.

Procedures

Experiment entailed two days of testing. The first day included training of the novel visuomotor task. On the second day, participants completed both the performance alone and a social evaluation with competition conditions while aforementioned psychophysiological measures were recorded.

Participants completed the informed consent form, EHI, and HSQ on the first day of testing. Task instructions were given to subjects placing particular emphasis

on moving as quickly and accurately as possible during target trajectory. Subjects then performed 400 trials of task training (40 trials congruent, 360 incongruent) while wearing the EEG cap and autonomic sensors to limit the novelty effect on day two (although data was not recorded).

On the second day, participants were fitted with the EEG cap. Omni-prep conducting gel was applied to all 58 sites via a blunt tipped medical syringe. Additionally HR and SC sensors were attached as described above. Subjects were given the same task instructions as per first day. When impedances reached the specified levels, participants entered a sound proof room and began the task under one of the conditions; condition order was counter-balanced. Each condition consisted of 60 incongruent trials. Regardless of condition, at the 30th trial subjects completed a Visual Analog Scale (VAS) (Appendix 4) assessing stress, relaxation, confidence and competitiveness. Subjects were allowed a 10 minute rest period between the two conditions. A technician was present to monitor equipment and administer inventories in both conditions; however the technician did not interact otherwise.

Practice alone condition

During the low arousal condition, no confederates or cameras were present. At the beginning subjects were reminded that their performance in no way affected the competition or their chances of winning the money, but they should still be as quick and accurate as possible.

Social evaluation and competition condition

Arousal was induced both through social evaluation and by utilizing competition. Throughout this condition two confederates stood immediately behind the participant. One confederate, held a clipboard and both recorded and verbalized false starts (exiting center circle before 2 seconds had elapsed). Additionally, two video cameras were aimed at the participant's face, one directly in front and the other within their peripheral visual field. Finally, the participants were told that the entire lab would analyze their performance and evaluate the film of their reactions to assess how they compared to established norms.

The competition included a monetary reward to the subject who performed the quickest, most accurate trajectories with the least number of false starts. Participants were reminded at the start of the SE&C that a cash prize (\$150) would be awarded to the 'winner'.

Data Processing

Arousal manipulation validation

Due to conditional order, it was noted that the slower temporal dynamics of SC was more accurately described through rate of change computations. HR was averaged per condition. SC signals were divided into three equal length segments within condition and then each segment was averaged. The VAS was scored through a measurement of where the participant drew a vertical line on a 100 mm horizontal line that was anchored by adjectives consistent with the dimensions listed above.

EEG signal processing

All EEG data reduction were performed using Neuroscan 4.3 edit/acquire software on electrode pairs of interest. Data were visually inspected, artifact reduced and band passed at 1-50 Hz with a 24 dB/octave rolloff. Sweeps of the two second span prior to the movement onset event marker were epoched and visually inspected, baseline corrected and spline fit (2048 data points). Epochs contaminated with significant artifact were removed from further computations. Coherence was calculated between two electrode pairs (T3-Fz, T4-Fz) (Fig. 5) in one-half hertz bins and averaged across the frequency bandwidths (theta 3-7 Hz, alpha 8-13 Hz, beta 13-30 Hz) postulated to reflect mid to long range cortical distances (von Stein & Sarnthein, 2000). Finally, a spectral average was calculated through a Fast Fournier Transform of the temporal sites (T3, T4) in the bandwidths of interest (theta 3-7 Hz, alpha 8-13 Hz, beta 13-30 Hz, gamma 30-44 Hz).

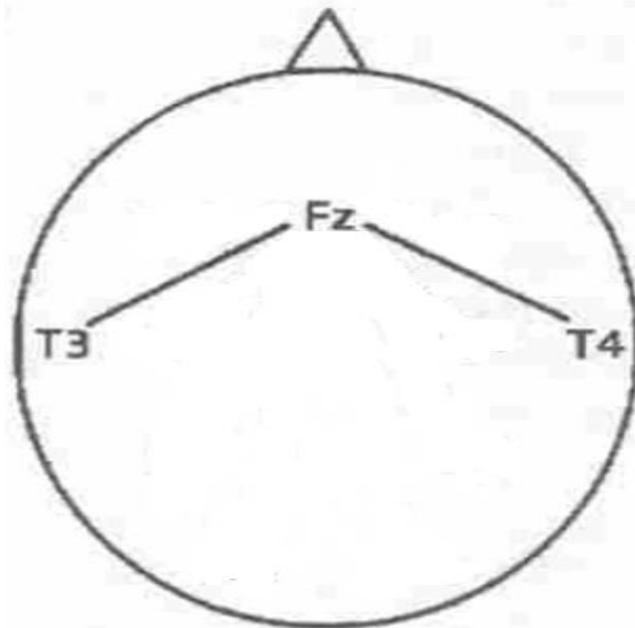


Figure 5. Montage of electrode pairs used for coherence analysis

Kinematic processing

Kinematic data processing was completed using MATLAB (version 6.1). All Cartesian position data was low passed at 10 Hz and then dual passed eighth-order Butterworth filtered. Then, each trial was visually inspected to ensure movement onset occurred when participants left the center circle and movement cessation occurred when participants entered any target circle; any trial containing artifact was excluded from further analysis. The resultant trajectory segments (path between movement onset and offset) were compared to the optimal trajectory for each given target (shortest line segment between home and target circles) to calculate Root Mean Square Error RMSE (Fig. 6A). RMSE is index of the deviation from optimal trajectory, thus providing index of the quality of performance consistent with Kragerer et al, (1997).

Statistical analysis

HR and all psychological inventories were subjected to paired-t tests after validation of absence of order interactions. SC values were entered into to a 2 x 2 x 3 mixed design ANOVA (Order x Condition x Averaged segment). To account for an order interaction, the kinematic variable (RMSE) was treated as a between subjects variable. RMSE of the only first condition completed by the participants was subjected to an independent-t test. After confirmation of absence of order effects, coherence values for specified bandwidths were subjected to 2 x 2 ANOVAs (Condition x Hemisphere). Finally, a 2 x 2 x 5 ANOVA (Condition x Hemisphere x Region) were utilized to test for spectral average differences in the gamma band. Tukey's HSD was used in post-hoc testing for gamma power. All other post-hoc

testing was completed utilizing paired t-tests. Analyses of the arousal manipulations were directional, while all other analyses were two-tailed.

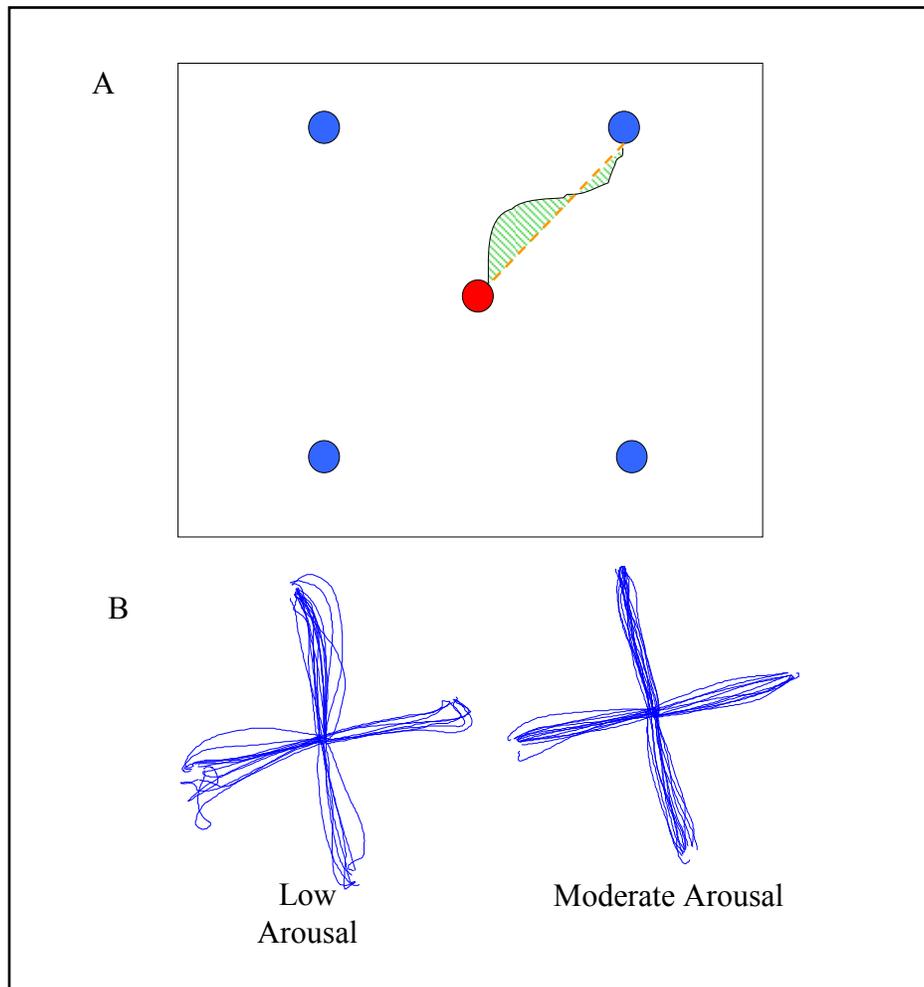


Figure 6. A) Description of RMSE overlaid on targets B) Actual trajectories from one subject during low and moderate arousal conditions

CHAPTER IV

RESULTS

Arousal Manipulation

Heart rate was significantly higher during the SE&C condition ($M = 76.845$, $SD = 7.814$) than the performance alone ($M = 70.845$, $SD = 9.19640$), one-tailed $t(14) = 5.393$, $p < 0.001$. The SC ANOVA revealed a marginal interaction between condition and time, $F(2,14) = 2.618$, $p = 0.055$. Post hoc analysis revealed that, for condition, only the third and final mean segment was significantly different. During the third mean, SC was higher during the SE&C condition, $t(14) = 2.840$, $p = 0.007$ (Fig. 7).

Statistical analysis of the self-report revealed that only the differences between stressed $t(14) = 2.841$, $p = 0.007$) and competitive ($t(14) = 4.841$, $p < 0.001$) variables were significant (Fig. 8). Both stressed and competitive values were higher during the SE&C condition.

Kinematic Results

Movement variability measured via RMSE was significantly reduced during the SE&C compared to PA, $t(13) = 2.171$, $p = 0.049$. This result indicates better performance during the SE&C condition.

EEG Results

For the main effect of condition, only beta coherence reached significance ($F(1,14) = 7.301$, $p = 0.017$), but there was a condition x hemisphere interaction

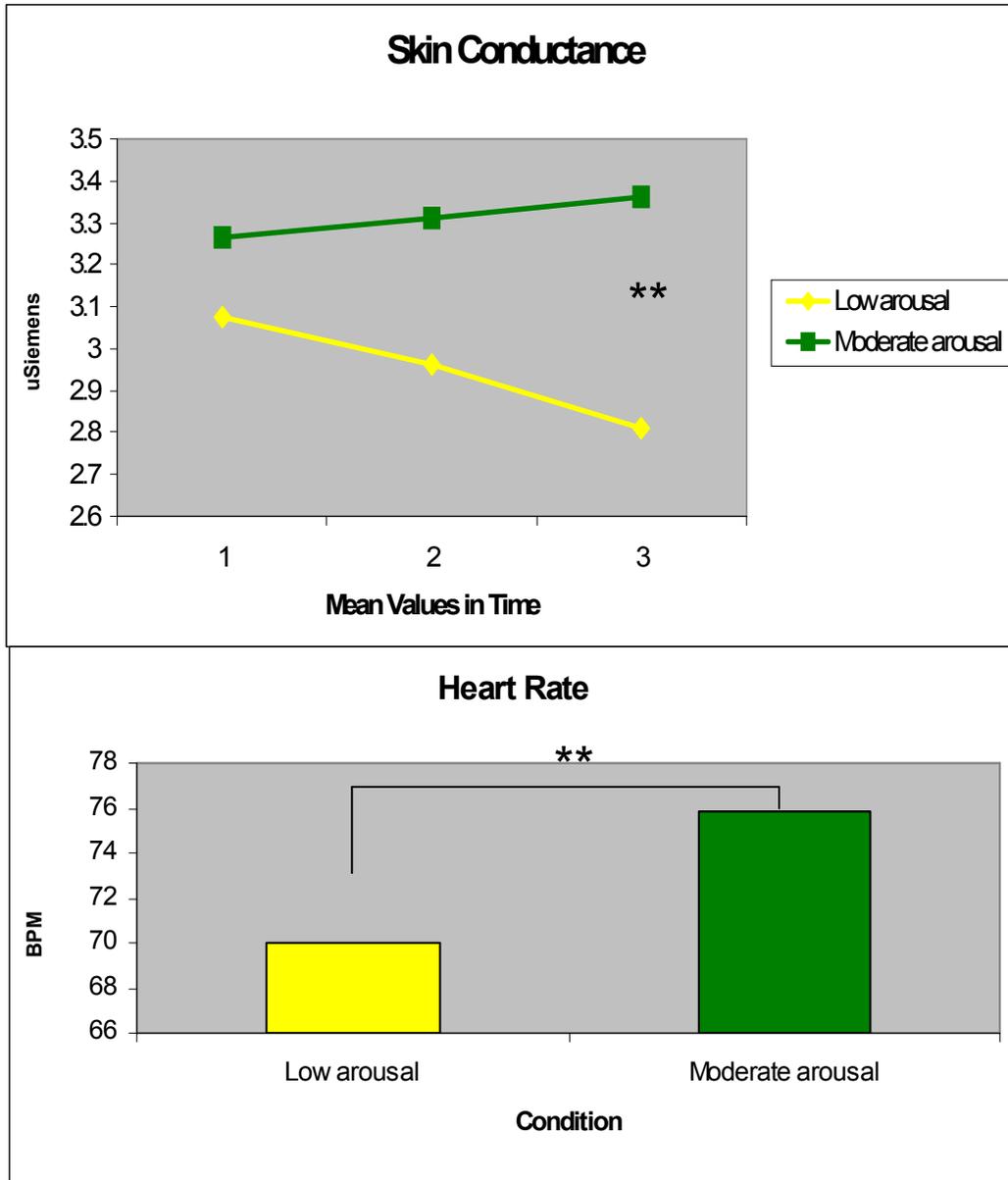


Figure 7. Physiological indicators of arousal manipulation, ** $p < 0.01$

($F(1,14) = 4.977, p = 0.047$). Post hoc testing revealed reduced coherence between T4 and Fz ($t(14) = 3.084, p = 0.008$) during the SE&C condition, but no change in T3-Fz coherence. Additionally, for gamma power, there was a Condition x Hemisphere interaction ($F(4,11) = 4.238, p = 0.026$) Post hoc analysis via Tukey's

HSD revealed that between conditions, only the temporal lobes increased in gamma power during the SE&C.

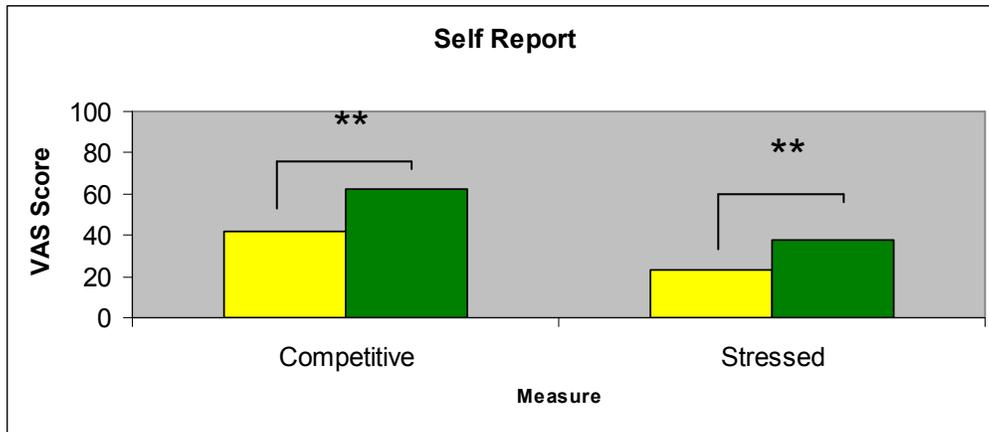


Figure 8. Self-report indicating a moderate level of arousal as well as an increase in competitiveness during the SE&C condition, ** $p < 0.01$

CHAPTER V

DISCUSSION

The arousal manipulation check of the two experimental protocols (PA vs. SE&C) provided by the autonomic measures and self-reports indicated an increase from a low to moderate level of arousal during the SE&C condition. Consistent with the inverted-U hypothesis and our predictions, there was a subsequent increase in performance coupled with a decrease in coherence between the right temporal hemisphere and motor planning region. In light of the significantly improved kinematics (decreased RMSE, Fig. 6B), decreased networking between these putatively relevant areas suggests this reduction in coherence serves an adaptive purpose.

Although the participants did not achieve expertise in accordance with Ericsson's notion of consistent superior performance (Ericsson & Smith, 1991), they were likely in a skilled state. This task entailed drawing a straight 10 cm line, far less complicated than learning sport-specific motor skills. Furthermore, the autonomous stage is not characterized by flawless performance; rather, the "speed and efficiency with which some skills are performed continue to increase during this phase, although improvement...is at a continually decreasing rate" (Fitts & Posner, 1967 (p.14)). Recent literature investigating visuo-motor distortion of a 60 degree rotation reveals a plateauing of skill acquisition after less than 240 trials (Krakauer et al., 2000; Contreras-Vidal & Kerick, 2004). Additionally, this same literature demonstrates after-effects during congruent visuo-motor performance due to the previous

distortion, indicative of a relatively permanent change in behavior. The simplicity of this task along with 340 acquisition trials suggests learning of a skilled, albeit simple, motor behavior had taken place.

During the PA condition the average heart rate was approximately 70 bpm, considered low during a motor task (Andreassi, 2000). While during the SE&C manipulation there was an approximate six bpm increase, significant but considerably less than the heart rate increases (up to a 70 bpm) recorded during the highly arousing conditions in Fenz's (1972) classic work with skydivers. Also, during SE&C compared to PA, tonic skin conductance activity was moderately increased (Andreassi, 2000). Behaviorally, between the PA and SE&C conditions the means of the self report measures of stress and competitiveness went from 23.50 to 37.78 and 42.00 to 62.33 respectively (maximum of 100). Observationally, many subjects reported that they did feel a little 'ramped up' when being evaluated, but felt confident about their performance and chances at winning the money. Taken as a whole, the autonomic and self-report results strongly suggest that (1) the PA condition represents a low level of arousal as pertinent to motor performance that (2) the SE&C condition represents a moderate increase in arousal and (3) based on 1 and 2, the SE&C condition indeed advanced participants towards an optimal level of arousal compared to the PA condition.

Consistent with extant literature, changes in coherence during the moderate arousal condition were significant only in the beta bandwidth. Von Stein and Sarnthein (2000) suggest a "relation between the size and distance of an [neural] interaction and the frequency of synchronization..." (p. 308). In other words, the

larger the distributed network of localized and functionally connected neural populations, the slower the frequency necessary to coordinate activity between these regions. Furthermore, faster frequencies (i.e. gamma) reflect local processing, while beta synchronizes these local assemblies across mid-range distances. Von Stein and Sarnthein (2000) found increased beta coherence over mid-range topographic distances during integration of visually coherent stimuli (pattern vs. non-pattern), while our study investigated multi-modal task-relevant versus task-irrelevant processing over comparable distances.

T3-Fz beta-coherence remained unchanged while beta-coherence between T4-Fz decreased significantly from the PA to the SE&C condition. The right temporal lobe's (T4) integral involvement in visual-spatial processes (Cohen, 1993) situates it as an essential component in execution of virtually any visuo-motor task. Despite this reduction in T4-Fz beta-coherence, local processing (i.e., gamma power) increased in the right temporal lobe, implying increased tuning/activity with reduced cross-talk between visuo-spatial and motor planning regions. Support for a fine-tuning of the sensorimotor/arousal relationship can be found in the neuropsychological literature. A network of sympathetically driven noradrenergic projections from brainstem nuclei to thalamic and cortical systems has been implicated in mediating central arousal, subsequently enhancing environmentally salient stimuli while inhibiting irrelevant stimuli (Critchley, 2005). In light of improved performance, these changes in cortical dynamics likely reflect a refinement within the relevant network as one progresses towards a state of optimal arousal.

Programmatically, within the realm of human motor performance, we are interested in exploring the full range of arousal (low, moderate and high) explicated by the inverted-U hypothesis. While there appears to be a refinement in task-relevant communication when ascending the inverted-U (low to moderate arousal), task irrelevant networking increased when descending the inverted-U (moderate to high). During high levels of arousal there is an increase in coherence between the verbal-analytical areas of the cortex (T3) and the motor planning region (Fz), but no change between T4-Fz coherence during production of a skilled motor task (Chen, 2005). Masters (1992) reinvestment hypothesis provides a plausible explanation for this observation as one exceeds states of optimal arousal. The skilled performer reverts back to explicit knowledge reliance under excess arousal and this may result in increased networking between the verbal-analytical and motor planning regions. In addition, findings from cellular-molecular neuroscience provide further support for the arousal-sensorimotor performance relationship. In this regard, mechanistic studies of the Inverted-U have been substantiated in hippocampal neurons via corticosterone levels and memory formation efficiency. Stimuli eliciting moderate levels of cortisol/arousal improve memory formation over inconsequential (low cortisol) conditions, while excess arousal (high cortisol) overloads the system attenuating memory formation (Kim & Diamond, 2002).

Adaptive strategies aimed at decreasing metabolic costs / increasing bio-efficiency are ubiquitous in the life science literature. Lay (2002) reported that due to deliberate practice, there was a marked decrease in motor unit recruitment while force production remained constant. Bell and Fox (1996) in a groundbreaking, longitudinal

study of infants tracked EEG coherence across 3 developmentally distinct stages (pre, during and post) of crawling acquisition. Anatomical literature pertaining to neural linkage between visual and motor areas of the developing brain supports the notion of sparse (pre), surplus (during) and streamlined (post) neuronal connectivity.

Remarkably, mirroring these developmental changes in brain tissue were parallel changes in coherence; cortico-cortical communication was low, became over abundant, and ultimately refined. A relevant study (Busk & Galbraith, 1975) in adult motor performance literature has revealed: increased coherence between regions of higher density anatomical connections, increased coherence due to task complexity and practice induced decreases in coherence. Likewise, the present results suggest a refinement in task-relevant regions when approaching optimal arousal and the subsequently improved performance

We propose that the neural substrates responsible for these decreases in coherence play a causal role in mediating motor performance quality. Regardless of the source (excess task-relevant communication or task-irrelevant communication), unnecessary networking to the motor planning region increases complexity, reduces efficiency, and subsequently increases the variability of motor performance. Thus, it follows that cortical patterns reflective of a refinement in networks involving the motor planning regions will result in more consistent coordinated muscle activation consistent with the Hatfield and Hillman (2004) psychomotor efficiency hypothesis wherein:

$$\text{Efficiency} = \frac{\text{Psychomotor Behavior}}{\text{Neural Resource Allocation}}$$

Increased efficiency would be achieved via a reduction of the denominator, such that, the behavior would be executed with less neural resource allocation.

Inducement of arousal within the laboratory albeit not equivalent to real world stressors has been validated via a long history of research literature (Dickerson & Kemeny, 2004). Additionally, it should be noted that extreme levels of arousal, such as those experienced by military personnel, medical emergency technicians and even high level athletes, are nearly impossible to induce in the laboratory. Future studies investigating the arousal-performance relationship and its neural concomitants may consider utilizing virtual reality in order to induce higher levels of arousal, while maintaining experimental control, and operating within the constraints of neuroimaging. Expanding the previous literature, the present experiment manipulated the psychological environment resulting in changes in cortical dynamics and provided an explanation for variability in the quality of motor behavior.

APPENDIX I

Subject ID:

EDINBURGH HANDEDNESS INVENTORY

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++*. If in any case you are really indifferent *put + in both columns*.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all of the questions, and only leave a blank if you have no experience at all of the object or task.

		Left	Right
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking match (match)		
10	Opening box (lid)		
i.	Which foot do you prefer to kick with?		
ii.	Which eye do you use when using only one?		

APPENDIX II

Subject ID:

Health Status Questionnaire

Name _____ Telephone _____

Address _____

Date of birth _____ Age _____ Height _____ Weight _____

Hearing impairment Yes _____ No _____ If yes, describe _____

Color blind Yes _____ No _____ Gender M _____ F _____

Years of education (high school = 12, college + 16) _____

Current marital status Married _____ Single _____ Widowed _____ Divorced _____

Medications Are you presently taking or have taken any of the following medications within the past two months?

Aspirin, Bufferin, Anacin Tranquilizers

Blood pressure pills Weight reducing pills

Cortisone Blood thinning pills

Cough medicine Dilantin

Digitalis Allergy shots

Hormones Water pills

Insulin or diabetic pills Antibiotics

Iron or blood medications Barbituates

Laxatives Phenobarbital

Sleeping pills Thyroid medicine

Other medications not listed

Have you taken any non-prescription medications or drugs in the past two weeks?

Name what for? Dose/frequency last dose

1

2

3

Do you currently or have you ever had any of the following medical disorders?

Heart attack Yes ____ No ____

Chest pain Yes ____ No ____

Hardening of the arteries Yes ____ No ____

Irregular heart beat Yes ____ No ____

Kidney disease Yes ____ No ____

Diabetes Yes ____ No ____

Cancer Yes ____ No ____

Gout Yes ____ No ____

Asthma Yes ____ No ____

Epilepsy or seizure disorder Yes ____ No ____

Migraine headaches Yes ____ No ____ if yes, frequency/intensity ____

Psychiatric disorder Yes ____ No ____ if yes, what diagnosis _____

List the name of any diseases, illnesses or accidents you have had which required hospitalization.

Serious illnesses you have had not requiring hospitalization.

Have you ever been told you have high blood pressure?

Yes ____ No ____ if yes, when _____

Do you have any other chronic illnesses or disabilities?

Have you ever lost consciousness in the last 10 years?

Yes ____ No ____ if yes, when and why

Do you use tobacco products?

Yes ____ No ____ if yes, number of years

Cigarettes ____ Pipe ____ Cigar ____ Chewing tobacco ____

How many alcoholic drinks do you drink on any given day?

(1 drink = 12 oz. Beer, 4 oz. Wine, or 1oz. Hard liquor)

How much caffeine do you drink on any given day?

(number of cups of coffee, tea, cola; how many ounces)

Time since last intake of:

Caffeine _____

Tobacco _____

Alcohol _____

APPENDIX III

INFORMED CONSENT FORM **Cognitive Motor Neuroscience Laboratory** **Department of Kinesiology** **University of Maryland College Park**

- Project Title:** **Brain Processes and Motor Learning under Stress.**
- Statement of Age of Participant:** I hereby state that I am over 18 years of age, in good physical and emotional health, and would like to participate in a program of research being conducted by Dr. Bradley Hatfield and Ron Goodman of the Department of Kinesiology at the University of Maryland, College Park, Maryland 20742.
- Purpose of the Research Project:** The purpose of the current research is to study the relationship between brain activity and the quality of motor learning under a stress versus a non-stressed condition.
- Procedures Used:** Participants will sit in a comfortable chair, with his/her hand resting on a table. Participants will perform movement tasks, using a pen to draw on a digitizing tablet. Participants will be asked to move the pen towards a target, while wearing a cap with EEG sensors on their head. This study will involve one session of approximately 2-3 hours and will be divided into two phases. You will be asked to refrain from consuming any alcoholic beverages prior to your session. Additionally, you will be asked to refrain from eating, drinking large amounts of water (> 1 qt.) or consuming caffeinated beverages for at least 75 minutes prior to the drawing task. You will be fitted for an EEG (ElectroEncephaloGram) cap, similar to a swim cap that will be placed on your head. The purpose of the cap is to record brain electrical activity. Electrodes will be placed on the skin above and below your left eye for the recording of eye blinks and clipped to your ear lobes to serve as a reference. These sensor sites will be lightly rubbed with a 3M plastic abrasive pad and then rubbed with alcohol and prepared with an FDA (Food and Drug Administration) approved non-toxic conducting gel that enables continuous connection between the skin

of the scalp and the sensor or electrode surface. Your skin will be lightly rubbed at each electrode site with the blunt end of a wooden q-tip but the skin will not be broken. Using a blunt applicator and syringe, the previously described conducting gel will be applied to each electrode site. Again, the skin will not be broken. After the cap is prepared you will complete three questionnaires so the investigators can assess your level of anxiety and readiness to participate in the drawing task. Examples of two questions are as follows: 1-I feel strained, 2-I feel self confident. The questionnaires will take about 10-15 minutes to complete. You will then be asked to deposit a small amount of saliva in a test tube before, during, and after the drawing task. Lastly, 2 electrodes will be placed on your chest area near your heart in order to measure your heart rate, three small sensors will be placed on your non-dominant hand to measure your skin conductance and peripheral temperature and an elastic strap will be placed snugly (not tightly) around your chest at the level of your solar plexus to measure your rate of breathing.

Initials _____ Date _____

Procedures Used: In one of the phases of the drawing task you will complete the task at a moderate pace as if you were practicing and no observers will be present. In the other phase you will have a time limit, you will be filmed and a research team member will observe and evaluate your performance.

Confidentiality: All information collected in the study is confidential, your name will not be identified at any time. The data you provide will be grouped with the data of others for the purpose of reporting and presentation so that your individual data will not be identified. All data will be kept at the University of MD, in the HLHP Building Room 2303A in a locked cabinet that only research team-members have access to.

Risks: You understand that as a result of wearing the EEG cap to measure brain electrical activity you may experience slight sensations and irritation of the skin as the scalp is

lightly rubbed at the electrode sites. There are no known risks associated with the measurement techniques used in this study to access Heart Rate, Skin Conductance, Peripheral Temperature, Breathing Rate or Cortisol levels. Even so, there are minimal risks to you if you participate in this study, Lastly, there is a risk of fatigue since you will be wearing the EEG cap and drawing over a long period of time (2-3 hours).

- help
- Benefits:** You understand that the experiment is not designed to you personally but that the investigators hope to learn more about the mental processes involved in motor performance in order to improve performance in others.
- Freedom to Withdraw:** You understand that you are free to ask questions about the study, or to withdraw from the study at any time, without penalty. You understand that you must have a signed copy of this consent form given to you and that the investigators will provide you with the results of the study
- Where Medical Care is Available:** You understand that the University of Maryland does not provide any medical care or hospitalization insurance coverage for participants in this research study, nor will the University of Maryland pay any medical expenses or provide any compensation for any injury sustained as a result of participation in this research study, except as required by law.

Initials _____ Date _____

—

Informed Consent: *"I am voluntarily making a decision whether or not to participate in the research study described above. My signature indicates that I have decided to participate having read the information provided above and having had all of my questions answered. I will be given a copy of this consent form to keep."*

Printed Name of
Participant _____

Signature of
Participant _____

Signature of
Witness _____

Date of
Signatures _____

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If you have any questions about your rights as a research subject or to report a research-related injury you may contact:

HSRC Chair
Department of Kinesiology
301-405-2484
mrogers1@umd.edu

Initials _____ Date _____



UNIVERSITY OF MARYLAND

INSTITUTIONAL REVIEW BOARD

April 24, 2006

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MEMORANDUM

Addendum Approval Notification

To: Dr. Brad Hatfield
Dr. Jose Contreras-Vidal
Ron Goodman
Jeremy Rietschel
Li-Chuan Lo
Department of Kinesiology

Rosanne C. Friedman

From: *for* Roslyn Edson, M.S., CIP,
IRB Manager
University of Maryland, College Park

Re: **IRB NUMBER:** 05-0307
PROJECT TITLE: "Brain Processes and Fine-Motor
Performance/Learning under Stress"

**Approval Date Of
Addendum:** April 20, 2006

**Expiration Date of
IRB Project Approval:** June 27, 2006

Application Type: Addendum/Modification; *Approval of request, submitted to the
IRB Office on 11 April 2006, to add the following persons to the
research team: Dr. Jose Contreras-Vidal as Co-Investigator and
Mr. Jeremy Rietschel and Li-Chuan Lo as Student Investigators.*

**Type of Review of
Addendum:** Expedited

Type of Research: Non-exempt

The University of Maryland, College Park Institutional Review Board (IRB) Office approved your IRB application. The research was approved in accordance with the University's IRB policies and procedures and 45 CFR 46, the Federal Policy for the Protection of Human Subjects. Please reference the above-cited IRB application number in any future communications with our office regarding this research.

Recruitment/Consent: For research requiring written informed consent, the IRB-approved and stamped informed consent document is enclosed. The IRB approval expiration date has been stamped on the informed consent document. Please keep copies of the consent forms used for this research for three years after the completion of the research.

(Continued)

Continuing Review: If you want to continue to collect data from human subjects or to analyze private, identifiable data collected from human subjects, after the expiration date for this approval (indicated above), you must submit a renewal application to the IRB Office at least 30 days before the approval expiration date.

Modifications: Any changes to the approved protocol must be approved by the IRB before the change is implemented, except when a change is necessary to eliminate an apparent immediate hazard to the subjects. If you would like to modify an approved protocol, please submit an addendum request to the IRB Office. The instructions for submitting an addendum are posted at: http://www.umresearch.umd.edu/IRB/irb_Addendum%20Protocol.htm.

Unanticipated Problems Involving Risks: You must promptly report any unanticipated problems involving risks to subjects or others to the IRB Manager at 301-405-0678 or redson@umresearch.umd.edu.

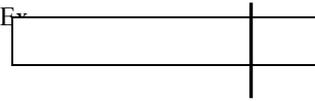
Student Researchers: Unless otherwise requested, this IRB approval document was sent to the Principal Investigator (PI). The PI should pass on the approval document or a copy to the student researchers. This IRB approval document may be a requirement for student researchers applying for graduation. The IRB may not be able to provide copies of the approval documents if several years have passed since the date of the original approval.

Additional Information: Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns.

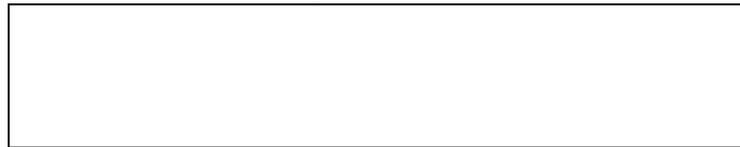
APPENDIX IV

Visual Analog Scale

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



How *competitive* do I feel?



Not competitive

Ultra competitive

How *stressed* am I?



No stress

Completely stressed

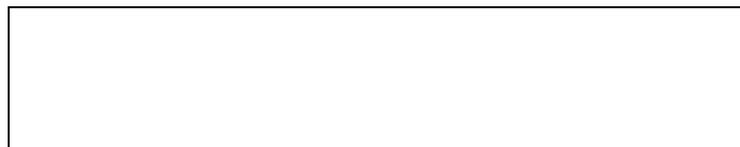
How *confident* do I feel?



No confidence

Extremely confident

How *relaxed* am I?



Not relaxed

Completely relaxed

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