

## ABSTRACT

Title of Document: THE NEURAL CORRELATES OF  
PSYCHOLOGICAL MOMENTUM

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Psychological momentum has been described as an emergent pattern of competitive success. However, the psychomotor processes underlying psychological momentum have not been characterized. Method: In accord, EEG data were recorded during a head-to-head shooting competition to examine the psychomotor processes underlying psychological momentum. Given that expert level performance has been characterized by psychomotor efficiency (see Hatfield & Hillman, 2001), high levels of momentum were hypothesized to be characterized by psychomotor efficiency, as indicated by reduced task-irrelevant cortical processing (i.e., greater high alpha power and lower gamma power in T3) and reduced non-essential neural networking (i.e., lower T3-Fz low-beta coherence) relative to low levels of momentum. Results: In accordance with psychological momentum theory, the high momentum group exhibited greater self-confidence relative to the low momentum group. Contrary to the hypothesis, the high momentum group exhibited reduced high alpha power relative to the low momentum group. Discussion: As the participants were not expert performers, psychological momentum appeared to facilitate cortical dynamics indicative of superior performance given the stage of motor learning.

THE NEURAL CORRELATES OF PSYCHOLOGICAL MOMENTUM

By

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## **Introduction**

Psychological momentum has been described as a psychological advantage that the athlete gains through early performance success or a series of successful performances, leading to greater control over the outcome of the event relative to the competitor (Iso-Ahola & Mobily, 1980; Hamberger & Iso-Ahola, 2004).

Psychological momentum develops as the athlete experiences gains in self-confidence, perceived likelihood of winning and feelings of superiority over the opponent within the social-evaluative context of competition (Iso-Ahola & Mobily, 1980). These psychological changes lead the athlete to exert greater effort, which fuels an emerging pattern of performance success (Iso-Ahola & Mobily, 1980).

Phenomenologically, the psychological momentum state has been characterized by increased energy, confidence, mind-body synchrony, effort, optimism and focus (Vallerand, Colavecchio and Pelletier, 1988). However, although widely investigated, the psychomotor processes underlying psychological momentum have yet to be directly assessed.

Psychophysiology has shown to be a viable means to assess the psychological state (Cacioppo & Tassinari, 1990). Notably, electroencephalography (EEG) can be used to record the electrical activity of the cortex, which then provides an objective measure of various psychological constructs. A corpus of EEG studies has implicated a reduction in task-irrelevant cortical processing as underlying superior motor performance, a phenomenon that has been termed the psychomotor efficiency hypothesis (Hatfield & Hillman, 2001). Specifically, cross-sectional studies comparing expert and novice marksmen have shown that there is relatively greater

alpha power (8-13 Hz), which is inversely related to cerebral-cortical processing, in the left temporal region (T3) in experts as compared to novices during the seconds prior to shot execution (Hatfield, Landers & Ray, 1984; Hatfield, Landers, Ray & Daniels, 1982; Haufler, Spalding, Santa Maria & Hatfield, 2000). Additionally, a motor learning study employing a comparable shooting task has shown that alpha power in the seconds leading up to trigger pull decreases in the left and right temporal regions as a function of practice (Kerick, Douglass & Hatfield, 2004). Visuo-spatial processes have been attributed to the left temporal lobe (Cohen, 1993) and are posited to be maladaptive for superior performance on a visuo-motor task, such as marksmanship. Thus, these studies indicate that superior performance is characterized by a reduction in task-irrelevant cortical processing, suggesting psychomotor efficiency.

Relative increases in alpha power are commonly used examined to infer deactivation of the underlying cortex (Pfurtscheller, Stancak & Neuper, 1996), such that alpha power and task engagement hold an inverse relationship (von Stein & Sarnthein, 2000). More specifically, low alpha frequencies (8-10 Hz) have been interpreted to reflect general cortical arousal, while high alpha frequencies (10-13 Hz) have been used to infer task-specific cortical arousal (Pfurtscheller & Lopes da Silva, 1999). Conceptually, gamma power (30-44 Hz) and high alpha power are inversely related (Oakes et al., 2004), such that elevations in gamma power can be used to infer local processing (von Stein & Sarnthein, 2000). Thus, estimates of high alpha and gamma power can be used to infer the degree to which various attentional processes are engaged during task performance. As verbal-analytical

processes have been attributed to the left temporal region (Cohen, 1993), estimates of high alpha power and gamma power in the left temporal region can be examined used to infer psychomotor efficiency during visuo-motor performance.

In addition to spectral power, cerebral cortical networking, as indexed by spectral coherence, has been examined used to characterize the underpinnings of superior motor performance (Hatfield & Kerick, 2007). High coherence indicates higher levels of communication between two brain regions, while lower coherence posits relative independence. Coherence values index the degree of linear correlation between the power estimates for a specific frequency band (e.g., beta), derived from the data recorded from two electrode sites (e.g., Fz-T3). Coherence values are traditionally estimated for the alpha and beta frequencies, which reflect midrange cortico-cortical communication (von Stein & Sarnthein, 2000). Superior motor performance has been specifically characterized by reduced non-essential neural networking between the motor and non-motor regions of the cortex (Hatfield & Kerick, 2007). Recently, Deeny et al. (2009) observed that expert marksmen exhibited reduced low-beta coherence between Fz and T3 in the seconds leading to trigger pull compared to novices, as well as reduced coherence across the scalp topography. Importantly, higher coherence was positively correlated with greater aiming point variability in the experts while no such relationship was observed for the novice performers indicating that increased cortico-cortical communication introduced “noise” to the motor system resulting in reduced stability while aiming in the moments prior to trigger pull. A similar study reported reduced low-beta coherence in expert level marksmen relative to highly skilled marksmen, which was

isolated to Fz-T3, such that the coherence values between Fz and the remaining topographical sites were undifferentiated between the groups (Deeny et al., 2003). Collectively, these studies suggest that reduced non-essential neural networking underlies superior motor performance.

In light of the extant literature relating superior motor performance with psychomotor efficiency, it is likely that psychological momentum, a pattern of performance success relative to an opponent, is similarly characterized by psychomotor efficiency. Although psychological momentum theory asserts that momentum develops through psychological changes (i.e., increased confidence and perceived superiority over the opponent) and increased mental effort (Iso-Ahola & Mobily, 1980), the psychomotor processes underlying psychological momentum have yet to be characterized quantitatively. Thus, the present study examined electrocortical data recorded during a head-to-head, target-shooting competition to investigate the psychomotor processes underlying psychological momentum. Participants were assigned to high or low momentum groups based upon the win-loss outcome of the competition, such that the winners were assigned to the high momentum group and the losers were assigned to the low momentum group. A supplementary analysis (see Appendix I) was also conducted that defined high and low momentum groups based on early performance success, such that the participants that established an early lead and also won the competition overall were assigned to the high momentum group, while those who were losing initially and also lost the competition overall were assigned to the low momentum group.

The specific purpose of the present study was to determine whether or not

whether or not psychological momentum is characterized by psychomotor efficiency. Psychomotor efficiency was indexed by high alpha power, gamma power and low-beta coherence, which are measures that reflect task-relevant cortical arousal, local cortical activation and medium-range cortico-cortical communication, respectively (Pfurtscheller & Lopes da Silva, 1999; von Stein & Sarnthein, 2000). Specifically, it was hypothesized that the high momentum group would exhibit greater high alpha power and lower gamma power in the left temporal region, as well as lower low-beta coherence between the left temporal and motor planning regions relative to the low momentum group. In addition, in light of the extant literature examining EEG and human motor performance cited previously, more comprehensive EEG analyses were conducted in an exploratory manner and are further described in the methods section. Concurrently, self-reported confidence and state anxiety levels were analyzed in order to determine whether or not whether or not high and low levels of levels of psychological momentum are characterized by increasing confidence and anxiety, respectively. It was expected that the high momentum group would exhibit increasing confidence levels, such that self-reported confidence would be higher later in the competition relative to earlier in the competition. Similarly, it was predicted that the low momentum group would exhibit increasing anxiety levels, such that self-reported anxiety levels would be greater later in the competition relative to earlier in the competition. An exploratory analysis of salivary cortisol was also conducted, as salivary cortisol samples have been shown to be valid and reliable indicators of the stress response (Rose, 1980) and have yet to be examined in the context of psychological

momentum. It was predicted that the low momentum group would exhibit increasing cortisol levels throughout the competition, while cortisol levels in the high momentum group would remain stable.

## Literature Review

### Psychological Momentum Theory

Several theories have been proposed to explain psychological momentum. Iso-Ahola and Mobily (1980) have suggested that early performance success leads to increased self confidence, perceived likelihood of winning and perceived superiority over the opponent. These psychological changes lead to an increase in physical or mental effort (Hamberger & Iso-Ahola, 2004). According to this model, low levels of momentum are characterized by a lack of early success, increased anxiety and a failure to increase mental and physical effort. Taylor & Demick (1994) have proposed the Multidimensional Model of Momentum, wherein precipitating events lead the athlete to judge his or her performance against a set of personal norms or expectations. More specifically, precipitating events prompt changes in affect, cognition and/or the physiological state, and these changes subsequently alter behavior, performance and the eventual outcome. The Multidimensional Model is advantageous because it is empirically testable (Kerick, Iso-Ahola & Hatfield, 2000) and provides a framework for physiological as well as psychological investigations of psychological momentum.

The Projected Performance Model (Cornelius, Silva, Conroy, & Petersen, 1997) asserts that momentum states are post hoc explanations for performance shifts. Rather than causes of performance changes, momentum states are descriptions of past performances that are susceptible to personal and memory biases. The Projected Performance Model also outlines two phenomena that add to

the complexity of psychological momentum: positive inhibition and negative facilitation. Positive inhibition occurs when performance successes prompt the athlete to “coast,” causing performance to suffer; negative facilitation occurs when performance failures lead the athlete to rally from behind, facilitating better performance.

### **Empirical Momentum Literature**

Empirical studies have examined psychological momentum perceptions, psychological momentum effects, and to a lesser extent, psychological momentum mechanisms. It has been widely demonstrated that athletes and spectators perceive psychological momentum following precipitating events (Eisler & Spink, 1998; Kerick, Iso-Ahola & Hatfield, 2000; Miller & Weinberg, 1991; Shaw, Dzewaltowski & McElroy, 1992; Silva, Cornelius & Finch, 1992; Eisler & Spink, 1998; Vallerand et al., 1988; Perreault, Vallerand, Montgomery & Provencher, 1998). A recent investigation (Markman & Guenther, 2007) provided a particularly thorough description of the commonly held perceptions of psychological momentum. Four studies were conducted in which athletes were presented with a series of hypothetical scenarios where psychological momentum was either present or absent, and the participants were asked to describe their expectations for performance. The first study demonstrated that athletes generally agree on what kinds of events precipitate positive momentum (e.g., a three point shot to tie the game) and negative momentum (e.g., a technical foul). The second study showed that perceptions of positive momentum increased following the defeat of a major

rival. The majority of the participants felt that defeating a rival rather than a non-rival generated the greatest amount of positive momentum to bring to the next contest. The third study indicated that the greater the amount of momentum gained in one competition, the greater the amount of momentum available to use in the subsequent competition. Lastly, the fourth study showed that performance expectations were greater for a performer who experienced steady positive momentum than for a performer whose positive momentum was interrupted. Thus, it is believed that psychological momentum is difficult to lose once it is gained, but it is difficult to recover once it is lost.

Although it has been widely demonstrated that precipitating events lead to perceived psychological momentum and altered performance expectations, the extent to which psychological momentum perceptions lead to real performance shifts remains unclear. A variety of unobtrusive studies indicate that in many sports, early success does in fact breed further success (Iso-Ahola & Mobily, 1980; Iso-Ahola & Blanchard, 1986). However, several similar studies have failed to report momentum effects (Gilovich, Vallone & Tversky, 1985; Mizruchi, 1991).

Psychological momentum may not be readily detectable in unobtrusive, macro-level investigations because it may be a short-lived phenomenon that is susceptible to contextual and individual factors (Hamberger & Iso-Ahola, 2004; Vallerand et al., 1988). Thus, it is unlikely to be apparent in year-to-year or season-to-season analyses (Hamberger & Iso-Ahola, 2004). However, one statistically rigorous study tested several mathematical models on results from grand slam tennis tournaments.

Psychological momentum best explained the competitive results, far beyond simple independence and day-to-day fluctuations in ability (Jackson and Mosurski, 1997).

Much of the prior psychological momentum literature has failed to address the subjective state, intricacies or mechanisms of psychological momentum (Crust & Nesti, 2006; Kerick et al., 2000). In order to fully account for psychological momentum effects, psychological and physiological mechanisms must be examined concurrently with outcome analyses. However, the mechanisms of psychological momentum have only recently come under empirical investigation. Kerick et al., (2000) examined the impact of perceived psychological momentum on affective states and performance outcomes in a psychophysiological investigation. False feedback was used to manipulate momentum perceptions; however, the study failed to detect a causal relationship between perceived psychological momentum, affective states and performance. Correlational analysis did reveal a relationship between psychological momentum and affect in all conditions. Two laboratory studies (Shaw et al., 1992; Silva, et al., 1992) utilized fine motor tasks to examine the influence of psychological momentum perceptions on performance. Although both studies successfully induced momentum perceptions with false feedback, no relationship between psychological momentum perceptions and performance was reported.

Perreault, Vallerand, Montgomery & Provencher (1998) reported that perceived psychological momentum did improve athletic performance in a cycling task, such that participants generated greatest power output under psychological momentum conditions. Interestingly, participants performed better in both the

negative and positive momentum conditions compared to the no momentum condition, lending support for the notion of negative facilitation (Cornelius et al., 1997). The authors attributed performance improvements to increases in physiological effort and arousal. Adams (1995) reported that psychological momentum perceptions led to performance improvements in billiards players. Given the constraints of the fine motor task, Adams (1995) argued that cognitive mechanisms like heightened attention, concentration and confidence generated the shifts in performance. The effort precipitating psychological momentum could be a combination of physiological or cognitive processes (Taylor & Demick, 1994) depending upon the nature of the task (Kerick et al., 2000), such that self-paced tasks requiring high levels of concentration likely rely on cognitive mechanisms for the development of psychological momentum (Adams, 2005). However, the cognitive processes underlying psychological momentum have not been directly assessed.

### **Utility of EEG**

Psychophysiology has shown to be a viable means to objectively measure the psychological state (Cacioppo & Tassinari, 1990). Specifically, electroencephalography (EEG) can be used to record voltage fluctuations in the cortex through scalp electrodes placed accordance with the International 10-20 system described by Jasper (1958). Various cognitive processes have been ascribed to specific regions of the cortex, such that various psychological constructs can be inferred through topographical evaluation of the EEG recording. The relative

activation of any particular cortical region can be estimated through spectral power analysis of the component frequency bands (e.g., alpha) of the EEG recorded at the corresponding electrode site. Further, the high temporal resolution of the EEG allows for the changes in cortical activity to be recorded on the order of milliseconds, allowing the dynamic changes in on-line cognitive processing to be readily inferred. The utility of the EEG for providing an objective measurement of the cortical dynamics underlying motor performance has been widely demonstrated (Hatfield & Hillman, 2001).

### **Psychomotor Efficiency**

The theoretical basis of motor skill acquisition associates explicit, verbal-analytical analysis of movement execution with lower levels of skill and expert performance with automaticity of perceptual-motor processing (Fitts & Posner, 1967). During the early stages of learning, conscious regulation of movement and effortful attention to visuo-spatial cues may be necessary to facilitate successful performance on a relatively novel task. However, conscious control processes become progressively reduced as the performer reaches the more advanced stages of learning through hours of deliberate practice (Ericsson, Krampe & Tesch-Romer, 1993; Hatfield & Hillman, 2001). A corpus of EEG studies has provided evidence that superior performance is specifically characterized by psychomotor efficiency, such that there is relatively reduced activation of task-irrelevant cortical processes during highly skilled performance as compared to less skilled performance. This

streamlined cortical processing leads to more consistent and economical motor execution (Hatfield & Hillman, 2001).

### **High alpha power.**

EEG studies have frequently utilized spectral power estimates in the high alpha frequency band to index cortical arousal. High alpha power is inversely related to task-specific cortical arousal (Pfurtscheller & Lopes da Silva, 1999), such that relatively increased high alpha power over a particular region of cortex indicates that the corresponding neural population is relatively disengaged in the task. Several motor performance studies employing target-shooting tasks have examined high alpha power in the left-temporal region to index psychomotor efficiency. Verbal-analytic processes have been attributed to the left temporal lobes (Cohen, 1993), and are thus posited to be unnecessary for a visuo-motor task, such as shooting. Left-temporal alpha power has been shown to progressively increase in the seconds leading up to trigger pull in expert marksmen (Hatfield, Landers, & Ray, 1984), while left-temporal high-alpha power has been shown to be relatively greater in expert shooters as compared to novices (Haufler et al., 2000). Motor learning studies have shown that high alpha power in the left and right temporal regions increases as a function of practice (Kerick et al., 2004; Landers, Han, Salazar et al., 1994). Collectively, these studies indicate that EEG power spectral analysis is an effective means to examine the psychomotor processes underlying superior motor performance. Specifically, left-temporal high alpha power indexes the degree to which task-irrelevant attentional processes become engaged during visuo-motor performance.

### **Gamma power.**

Conceptually, gamma power and high alpha power hold an inverse relationship (Oakes et al., 2004). Activity in the gamma bandwidth reflects local processing (Von Stein & Sarnthein, 2000), such that relatively increased gamma power observed at a particular recording site denotes active engagement of the corresponding neural population. Thus, relatively increased gamma power in the left-temporal region observed during target-shooting performance would indicate that task-irrelevant cortical processes are being recruited to perform the task.

### **Low-beta coherence.**

Coherence is a statistical measure of the amount of repeated linear correlation between two power spectral densities (e.g., beta) recorded at two different electrode sites. The motor performance studies have traditionally estimated coherence in the alpha and beta frequencies (Deeny et al., 2003; Deeny et al., 2009), as these frequency bands have been postulated to reflect long to midrange cortical distances (von Stein & Sarnthein, 2000).

The coherence value for any electrode pair reflects the degree of interaction between two regions, such that high coherence indicates communication between neuronal populations and low coherence indicates functional independence (Silverstein, 1995). Psychomotor efficiency has been specifically characterized by a lack of non-essential communication between the motor and non-motor regions in the cortex (Hatfield & Kerick, 2007). Thus, communication between the motor planning and left temporal regions is indicative of task-irrelevant neural networking during the performance of a visuo-motor task.

Lower low-beta coherence between the left temporal region and the motor planning region has shown to be associated with superior visuo-motor performance. Deeny et al. (2009) reported decreased low-beta coherence between Fz and T3 in the period leading up to trigger pull in expert performers as compared to novices, as well as an association between lower low-beta coherence and decreased aiming point variability in the expert group only. Deeny et al. (2003) compared low-beta coherence values for elite level performers identical in performance experience but dissimilar in competitive success. The high performance group showed comparably lower low-beta coherence between the motor planning and left temporal regions. Coherence between the motor planning region and all other sites across the scalp topography were undifferentiated between the groups. Collectively, the results from these studies indicate that low-beta coherence is an appropriate means to assess cortico-cortical communication during motor performance, and that superior motor performance is characterized by a reduction in non-essential cortico-cortical communication.

### **Confidence and Anxiety**

The psychological momentum state is characterized by a continuous pattern of superior performance relative to the competitor, coupled with phenomenological changes (i.e., increased optimism, focus and confidence). Psychological momentum theory asserts that the gain and loss of momentum are predicated on increased self-reported confidence and anxiety, respectively (Hamberger & Iso-Ahola, 2004). Athletes report that experiencing increased self-confidence is a fundamental

component of harnessing positive momentum, and also that anxiety typically leads to negative momentum (Jones & Harwood, 2008). Increased feelings of self-efficacy and positive affect have also been shown to accompany positive momentum perceptions (Kerick et al., 2000; Mack & Stevens, 2000). A variety of investigations utilizing false-feedback manipulations have reported favorable changes in the psychological state (e.g., optimism, confidence and feelings of invincibility) during positive momentum feedback conditions (Kerick et al., 2000; Perreault et al., 1998; Shaw et al., 1992).

### **Cortisol**

Psychoendocrine measurement is a psychophysiological technique that has been widely employed to measure the human stress response. Cortisol is a corticosteroid hormone secreted from the hypothalamic pituitary adrenal axis, which was developed initially to cope with physical stressors and orchestrate the fight-flight response (Rohleder, Beulen, Chen, Wolf & Kirschbaum, 2007). Currently, cortisol responds to psychological stressors like social-evaluative threat, uncontrollability, novelty and anticipation of negative consequences (Mason, 1968), as well as physical stressors like threat of bodily injury (Dickerson & Kemeny, 2004). Threats triggering elevations in cortisol have been shown to be associated with self-reported psychological distress like negative affect and anxiety (Dickerson & Kemeny, 2004).

Although cortisol has been explored in the context of competitive sport (Rohleder et al., 2007), it has yet to be examined in the context of psychological

momentum. It has been suggested that anticipatory worry about the competitive outcome oftentimes inhibits successful performance (Beilock and Carr, 2001). Thus, it is possible that conditions of negative momentum are characterized by anticipatory anxieties about the eventual outcome that serve to elicit cortisol elevations beyond those triggered by normal competitive stress.

## **Summary**

Psychological momentum theory postulates that early competitive success leads to psychological changes (i.e., increased self-confidence, perceived superiority over the opponent and perceived likelihood of winning) that fuel an emergent pattern of competitive success (Iso-Ahola & Mobily, 1980). However, the psychomotor processes underlying psychological momentum have not been characterized quantitatively. Electroencephalography (EEG) has been successfully employed to characterize superior levels of motor performance. Specifically, superior motor performance has been characterized psychomotor efficiency, as indicated by reduced task-irrelevant cortical processing (Haufler et al., 2000; Kerick et al., 2004) and reduced non-essential cerebral cortical networking (Deeny et al., 2003; Deeny et al., 2009). As psychological momentum is characterized as a pattern of competitive success, it is likely to be similarly characterized by psychomotor efficiency. Thus, the present study investigated the psychomotor processes underlying psychological momentum by examining spectral and coherence estimates derived from the EEG. Based upon the extant literature relating superior levels of performance with psychomotor efficiency, high levels of psychological

momentum were hypothesized to be characterized by reduced task-irrelevant cortical processing and reduced task-irrelevant neural networking relative to low levels of momentum. Also, based on the extant literature relating psychological momentum with high levels of self-confidence (Iso-Ahola & Mobily, 1980; Jones & Harwood, 2008; Mack & Stevens, 2000), it was expected that high levels of momentum would be characterized by increasing self-confidence levels. Also, it is possible that low levels of momentum are characterized by increased stress levels relative to high levels of momentum. Given that cortisol has been shown to be a robust biomarker of the stress response (Kirschbaum & Hellhammer, 1994) and that cortisol has not been examined in the context of psychological momentum, cortisol data were analyzed to determine whether or not low levels of momentum are characterized by increasing cortisol levels.

## Methodology

Secondary analyses were conducted on an existing dataset as provided by the “Brain Processes and Precision Psychomotor Performance Under Stress” study conducted in the Cognitive Motor Neuroscience Laboratory at the University of Maryland in 2008 (ARMYY W911NF0510538). Institutional Review Board approval was obtained prior to conducting the analysis of these data (see Appendix II).

### Participants

For the original data collection, 22 participants<sup>1</sup> between the ages of 18 and 38 ( $M = 22$ ,  $SD = 4.33$ ) from the ROTC program at the University of Maryland were enrolled. Participants were right hand dominant as assessed by the Edinburgh Handedness Inventory (EHI) (see Appendix III) and were ipsilateral eye dominant (Crovitz & Zenner, 1962). No participant reported any exclusionary health condition (e.g., neurological disorder, psychotropic medication) on the Health Status Questionnaire (HSQ) (see Appendix IV). All participants satisfied the inclusion criterion with regards to task performance competency, that is, participants had to hit the target for at least 80% of practice trials (shooting task) during the study orientation session. All participants provided informed consent and were advised to refrain from caffeine and alcohol intake 24 hours prior to testing day and to sleep 7 to 8 hours the night before testing day. All participants gave informed consent.

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<sup>1</sup> There were a total of 11 competitions. However, during one of the competitions, there was only one participant who was included in the study, who competed against a confederate.

## **Task**

Each participant completed a 40 shot, dry fire, pistol shooting task in a head-to-head competition versus one other participant. Shooting performance was estimated via the Noptel Shooter Training System (ST-2000, Version 2.33), an optical device consisting of a barrel-mounted light emitting/sensing unit and target with reflective borders. Participants stood five meters from the target, which was modified so that it met the International Shooting Sport Federation guidelines for an official air-pistol competitive target. Participants stood with their feet shoulder width apart, perpendicular to the shooting line. Participants sighted with their right eye and extended their right arm to the shooting position. The left eye was occluded.

## **Psychophysiological Acquisition**

### **Electroencephalographic (EEG) recording.**

Continuous EEG (tin electrodes suspended within a stretchable lycra cap manufactured by Electro-Cap International, Inc.) was recorded during task performance. Data were acquired at 30 sites referenced to linked earlobes with a common ground located at Fpz. Electrodes were positioned in accordance with the modified 10-20 international system (Jasper, 1958) in order to assess sites corresponding to the frontal (F3, F4), central (C3, C4), parietal (P3, P4), temporal (T3, T4), and occipital (O1, O2) regions. Impedance at each electrode was maintained below 10 k $\Omega$  across the testing session. All channels were amplified 500 times using Neuroscan Synamps 1, linked to Neuroscan v. 4.3.3 acquisition and edit software on a Gateway Pentium computer running the Windows XP operating

system. Bandpass filters were set at .01-100 Hz and the sampling rate was set to 1,000 Hz. Vertical and horizontal electro-oculograms were recorded by placing electrodes superior and inferior to the orbicularis oculi muscle (VEOG) of the right eye and the outer canthi of the right and left eyes (HEOG).

### **Cortisol.**

Salivary cortisol was acquired according to recommended standard procedures (Salimetrics, 2005a) at four intervals across the testing session. Cortisol has been shown to be a robust biomarker of the human stress response (Kirschbaum & Hellhammer, 1994).

### **Group Assignment**

Out of the original 22 participants that completed the competition protocol, five participants were excluded.<sup>2</sup> Out of the remaining 17 participants (2 female; Mean age = 22.18,  $SD = 4.79$ ), the participants who won the 40-shot target shooting competition were assigned to the high momentum group ( $n = 10$ , Mean age = 23.66,  $SD = 5.46$ ), while those participants who lost the 40-shot target shooting competition were assigned to the low momentum group ( $n = 7$ , Mean age = 20.14,  $SD = 1.57$ ).

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<sup>2</sup> Two participants were excluded due to a tie score (i.e., absence of psychological momentum). Two additional participants that lost the competition were excluded due to failure of EEG acquisition. Lastly, 1 participant was excluded due to his role as a confederate.

## **Self-report Measures**

### **State-trait anxiety inventory.**

The State-Trait Anxiety Inventory was administered to assess state anxiety (STAI-S; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1970) (see Appendix V). Participants were asked to rate 42 items on four-point Likert scales ranging from “not at all” to “very much so” with regards to momentary feeling states. A higher score indicates greater anxiety (range: 20-80). The STAI-S (state) yields interval level data. Construct validity has been established for the STAI-S (Spielberger & Vagg, 1984).

### **Visual analogue scale.**

A Visual Analogue Scale (VAS) was employed to provide a rating of self-confidence, anxiety, stress and relaxation (see Appendix VI). The Visual Analogue Scale yields interval level data and has demonstrated test-retest reliability for assessing a variety of health states, pain and quality of life (Badia, Monserrat, Roset & Herdman, 1999; De Boer et al., 2004; Roach et al., 1997), construct validity for a variety of health states (Badia et al., 1999) and concurrent validity for pain, vigor and affect (Monk, 1989; Lee, Hicks & Nino-Murcia, 1991).

## **Data Collection Procedures**

Data collection procedures for the purposes of the original study were completed over a two-day period. For a detailed description of these procedures, see Appendix VII.

## **Data Processing**

### **Spectral analysis.**

Spectral power estimates were computed on EEG data recorded during the four seconds leading up to the trigger pull for each of 40 shots. As part of the original study, these data had been cleaned (ocular artifact reduced, baseline corrected and linear detrended) and epoched into four successive 1-second increments, such that second one was concurrent to shot completion. In the present study, spectral power estimates were computed in Neuroscan by averaging 1 Hz bins in the delta (1-3 Hz), theta (3-8 Hz), alpha (8-13 Hz), low alpha (8-10 Hz), high alpha (10-13 Hz), beta (13-30 Hz), and gamma (30-44 Hz) frequency bands at 10 topographically distributed sites, F3, F4, C3, C4, T3, T4, P3, P4, O1 and O2. To approximate a normal distribution, the data were natural log transformed prior to statistical analyses.

### **Coherence.**

Amplitude coherence values were computed in Neuroscan between Fz (motor planning region) and each of the following sites: F3, F4, C3, C4, T3, T4, P3, P4, O1 and O2 to yield ten electrode pairings. The 1-Hz bins were averaged across the theta (3-8 Hz), alpha (8-13 Hz), low-beta (13-20Hz) and high-beta (20-30 Hz) frequency bands, which have been postulated to reflect low to medium range cortical distances (von Stein & Sarnthein, 2000). In order to approximate a normal distribution, the data were subjected to a Fisher-z transformation prior to statistical analyses.

## Statistical Design

Confidence scores recorded from the VAS and anxiety scores recorded from the STAI-S were subjected to separate 2 x 2 (Group x Block) ANOVAs with Group (High Momentum and Low Momentum) as a between subjects factor and Block (Block 1 and Block 2) as a within subjects factor. For exploratory purposes, separate 2 x 2 (Group x Block) ANOVAs were applied to the relaxation, stress and competitiveness scores recorded from the VAS. All effect sizes were calculated using Cohen's *d* and are reported in the results.

As high alpha power, gamma power and low-beta coherence index unique psychological constructs (task-specific cortical processing, local cortical processing and medium range cortico-cortical communication, respectively; Pfurtscheller & Lopes da Silva, 1999; von Stein & Sarnthein, 2000) they were subjected to separate 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVAs with Group as a between-subjects factor and Hemisphere, Region and Epoch as within-subjects factors. Hemisphere contained two levels referring to the recording sites located on the area of the scalp above the left and right cerebral hemispheres, respectively. Region referred to the electrode sites located on the area of the scalp corresponding to five cortical regions: frontal, central, temporal, parietal and occipital. Epoch contained four levels referring to each of the four one-second epochs leading up to the trigger pull. In the exploratory analysis, spectral power estimates for delta, theta, alpha, low alpha and beta bandwidths and coherence estimates for theta, alpha, beta and high-beta bandwidths were entered into separate 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) univariate ANOVAs with Group as a

between-subjects factor and Hemisphere, Region and Epoch as within-subject factors.

Salivary cortisol recordings were subjected to a 2 x 4 (Group x Time) univariate ANOVA with Group as a between subjects factor and Time as a within subject factor. Time refers to the series of repeated measurement of salivary cortisol taken across the competition.

Although the order of Performance Alone and Competition conditions was counterbalanced across participants in the original study, it is possible that the participants who performed alone as their first condition gained a performance advantage over those who competed as their first condition and then performed alone. A phi correlation between Order (Performance Alone followed by Competition, or Competition followed by Performance Alone) was computed in order to test for order effects.

## Results

### Correlation Between Order and Group

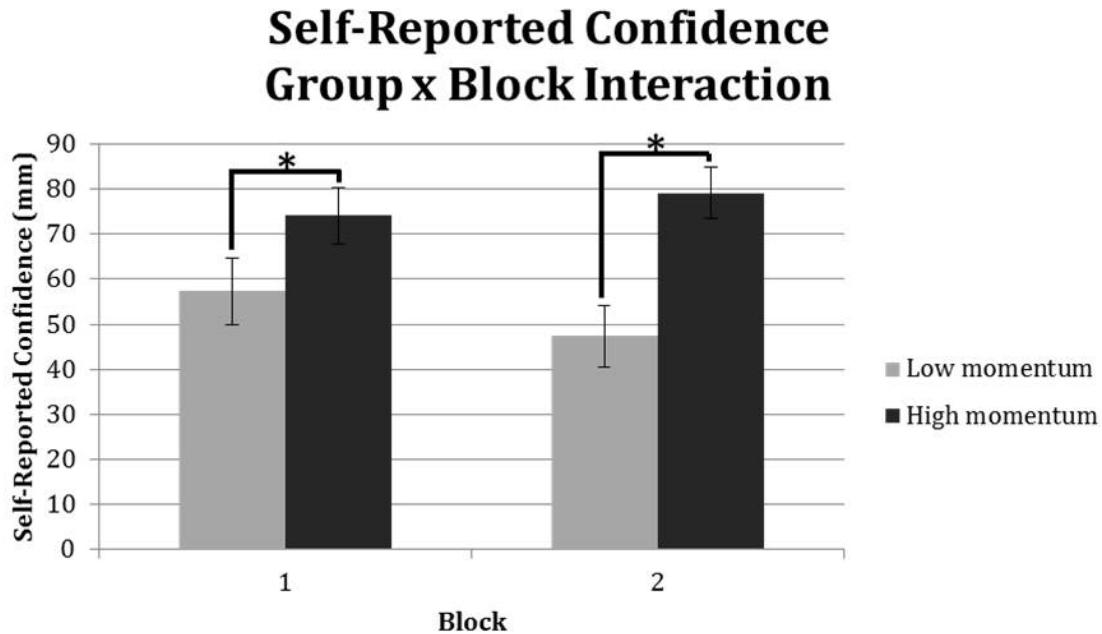
Order (Competition before Performance Alone or Performance Alone before Competition) was not significantly correlated with Group (High Momentum or Low Momentum),  $\phi = -0.0286$ ,  $p > .05$ .

### Self-Report Measures

The 2 x 2 (Group x Block) ANOVA applied to the confidence data as measured by the VAS yielded a Group x Block interaction,  $F(1,16) = 5.950$ ,  $p = .028$ . Tukey's HSD post hoc inspection of the means revealed an effect due to Group, such that the high momentum group reported greater confidence levels relative to the low momentum group in Block 1 and in Block 2,  $p < .05$ ,  $d = 1.0, 2.02$  respectively. Self-reported confidence levels within each momentum group were undifferentiated between Block 1 and Block 2, although the means trended in the expected directions (see Figure 1). The interaction occurred due to varying magnitudes of difference between the group means observed at each Group by Block. However, the means were directionally consistent, such that the high momentum group reported greater self-confidence levels regardless of block.

The 2 x 2 (Group x Block) ANOVA applied to the stress scores as assessed by the VAS yielded a main effect of group,  $F(1,16) = 10.689$ ,  $p = .005$ , such that the high momentum group reported lower stress levels relative to the low momentum group.

The 2x2 (Group x Block) ANOVA applied to the anxiety data as measured by the STAI-S failed to reach significance,  $F(1,16) = .181, p = .677$ .



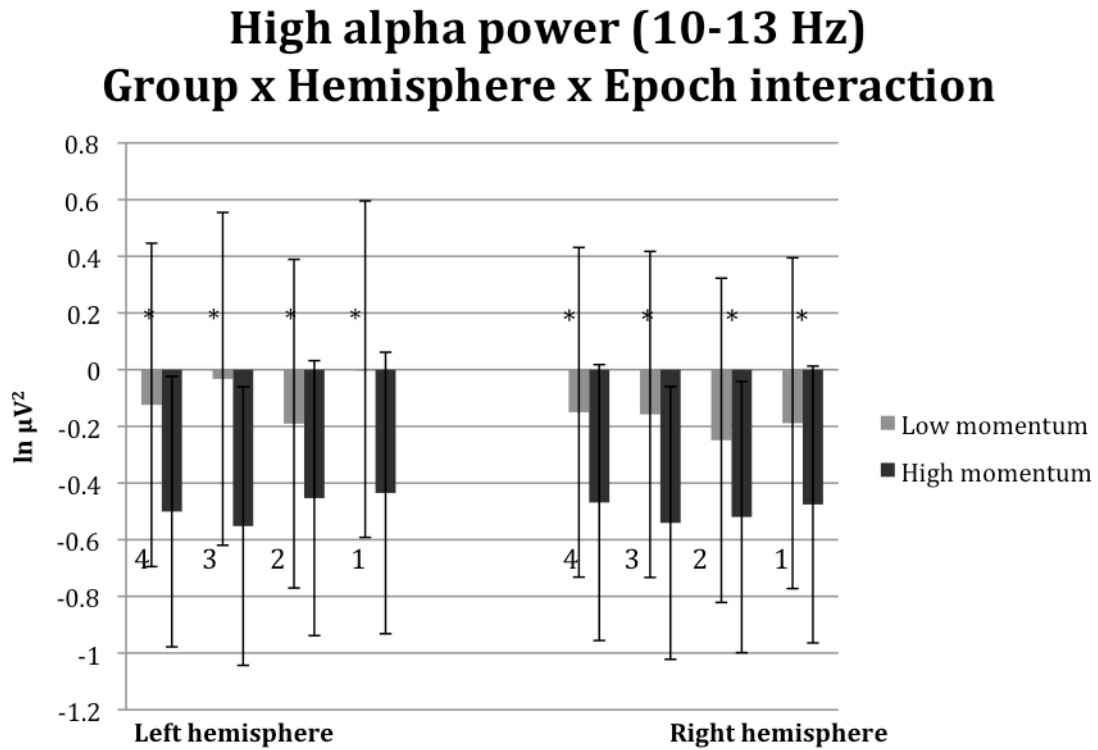
**Figure 1:** Self-reported confidence levels as measured by the VAS. The high momentum group reported greater self confidence in Block 1 and in Block 2,  $*p < .05$

### Spectral Power

The  $2 \times 2 \times 5 \times 4$  (Group x Hemisphere x Region x Epoch) ANOVA applied to high alpha power yielded a Group x Hemisphere x Epoch interaction,  $F(1,16) = 2.815, p = .05$ . Tukey's HSD post hoc analysis revealed that the high momentum group exhibited greater reduced high alpha power relative to that exhibited by the low momentum group at each Hemisphere by Epoch,  $p < .05, d = .07-.36$  (see Figure 2). The interaction occurred due to varying magnitudes of difference between group means observed at each Hemisphere by Epoch. However, the means were always directionally consistent, such that high alpha power was lower in the high

momentum group relative to the low momentum group regardless of hemisphere or epoch.

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVAs applied to of gamma power and low-beta coherence failed to reach significance.

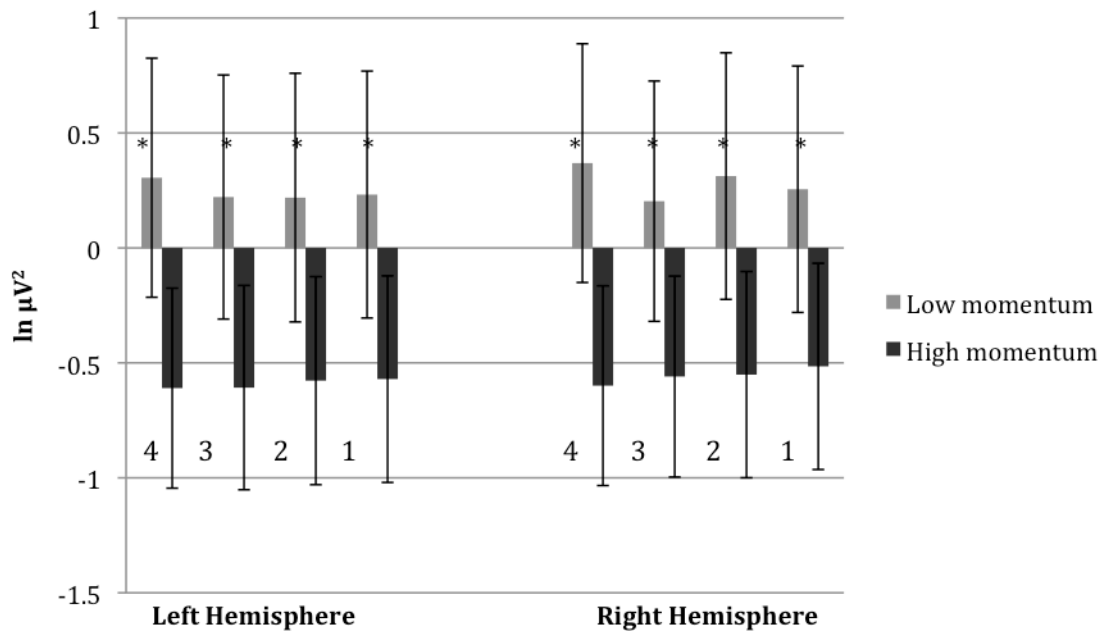


**Figure 2:** High alpha power in the four one-second epochs leading up to trigger pull. The high momentum group exhibited reduced high- alpha power relative to the low momentum group at each Hemisphere by Epoch,  $*p = .05$ . In the left hemisphere, high alpha power in the low momentum group was statistically differentiated between epochs 3 and 2, epochs 2 and 1 and epochs 1 and 4, while high alpha power in the high momentum group in the left hemisphere was statistically differentiated between epochs 2 and 4,  $p < .05$ .

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVA applied to theta (3-8 Hz) power yielded a Group x Hemisphere x Epoch interaction  $F(1,16) = 3.014, p = .040$ . Tukey's HSD post hoc analysis revealed an effect due to Group, such that the high momentum group exhibited reduced theta power relative to that exhibited by the low momentum group at each Hemisphere by Epoch,  $p < .05, d = .71-1.0$  (see Figure 3). The interaction occurred due to varying magnitudes of difference between group means observed at each hemisphere by epoch. However, the means were directionally consistent, such that theta power was lower in the high momentum group relative to the low momentum group regardless of hemisphere or epoch.

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVAs applied to the delta (1-3 Hz), alpha (8-13 Hz), low-alpha (8-10 Hz), beta (13-30 Hz) frequency bands did not yield any significant effects,  $p > .05$ .

### Theta power (3 - 8 Hz) Group x Hemisphere x Epoch interaction



**Figure 3:** Theta power in the four one-second epochs leading up to trigger pull. The high momentum group exhibited reduced theta power at each Hemisphere by Epoch relative to the low momentum group,  $p < .05$ .

To ensure that the significant effects observed were not due to initial differences between the two groups (i.e., prior to the start of the competition), the dependent measures that reached significance (i.e., high alpha power and theta power) were computed for the pre-competition baseline EEG recording (described in Appendix VII) and subjected to separate 2x2x5 (Group x Hemisphere x Region) univariate ANOVAs. Both analyses failed to reach significance ( $p > .05$ ), indicating that the observed between-groups differences in high alpha and theta power were due to changes in cortical dynamics that occurred during the competition as opposed to any preexisting differences.

## **Coherence**

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVA applied to the coherence estimates failed to reach significance,  $p > .05$ .

## **Cortisol**

The 2 x 4 (Group x Time) ANOVA applied to the cortisol data failed to reach significance,  $F(1,16) = .776$ ,  $p = .777$ .

## Discussion

Psychological momentum theory asserts that feelings of superiority over the opponent, high levels of self-confidence and increased effort collectively fuel an emerging pattern of performance success (Iso-Ahola & Mobily, 1980). Although widely investigated, psychological momentum has not been characterized using psychophysiology. Thus, the present study employed psychophysiological, behavioral and psychoendocrine assessments to examine the mechanisms underlying psychological momentum. As the development of psychological momentum is contingent upon positive self-evaluation of performance relative to an opponent and the ability to attain high levels of self-confidence under conditions of competitive pressure, participants were assigned to high or low momentum groups based upon their performance relative to a single opponent in a target shooting competition. Those participants that outperformed the competitor were assigned to the high momentum group, while those that lost to the opponent were assigned to the low momentum group. As psychological momentum theory would predict, the high momentum participants reported greater self-confidence throughout the competition relative to the low momentum participants. The low momentum group also exhibited greater levels of stress throughout the competition. These behavioral results suggest that the two groups differed by their ability to attain psychological momentum within the social-evaluative context of competition.

The psychomotor processes underlying psychological momentum were investigated by examining spectral power and coherence estimates derived from the

EEG. In light of the extant literature in psychophysiology relating superior performance with psychomotor efficiency, it was hypothesized that the high momentum group would exhibit reduced task-irrelevant cortical processing relative to the low momentum group as indicated by greater high alpha power and lower gamma power in the left temporal region, as well as reduced task-irrelevant neural networking as indicated by lower low-beta coherence between the left temporal and motor planning regions. Contrary to expectation, the high momentum group exhibited a global reduction in high alpha power relative to the low momentum group in both hemispheres. As high alpha desynchrony reflects relative activation of task-specific attentional processes (Pfurscheller et al., 1999), the results suggest that task-specific attentional processes were relatively engaged in the high momentum group as compared to the low momentum group. As verbal-analytical processes and visuo-spatial processes have been attributed to the left and right hemispheres, respectively (Cohen, 1993), the results suggest that the high momentum participants were more actively engaged in processing both verbal-analytical and visuo-spatial information compared with the low momentum participants.

The unexpected finding that the high momentum group exhibited greater engagement of task-specific attentional processes (i.e., high alpha desynchrony) is likely related to the participants' target shooting experience. Previous psychomotor investigations of performance have examined elite competitors (see Hatfield & Kerick, 2007), whereas the current participants were less experienced and thus were likely in an earlier stage of motor learning. Fitts & Posner's (1967) theory of

motor skill acquisition attributes successful performance during earlier stages of motor learning to verbal-analytical analysis of each component step of the motor task. These earlier phases of motor acquisition are characterized by reliance upon a set of conscious control structures that must be held in working memory and processed sequentially (Gray, 2004). Thus, the current results (i.e., greater engagement of task-specific attentional processes in the high momentum group) are consistent with this conceptual framework, given the skill level of the participants.

The results in the theta frequency band suggest that the high momentum participants' greater engagement of task-specific attentional processes (i.e. high alpha desynchrony) was related to the level of cognitive demand imposed by the competitive environment. A corpus of studies employing EEG has robustly characterized conditions of increased mental workload during cognitive and motor performance by increased theta activity, particularly in the frontal region (Brooking, Wilson & Swain, 1996; Fairclough, Venables & Tattersall, 2005; Gevins et al., 1998; Jensen & Tesche, 2002; Schacter, 1977; Sauseng et al., 2007; Yamada, 1998). The high momentum group exhibited reduced theta power in both hemispheres relative to the low momentum group. These results suggest that the competition imposed less cognitive demand on the high momentum participants, which may have contributed to enhanced task-specific attentional engagement, thus facilitating competitive success.

Collectively, the high alpha desynchrony and theta desynchrony in the high momentum group suggest that engagement of task-specific attentional processes best suited to facilitate best performance given the skill level of the participant

underlies psychological momentum. Additionally, the behavioral self-report findings indicate that this enhanced task-specific attentional engagement is related to the ability to attain high levels of self-confidence in competition. These results collectively relate to psychological momentum theory, which postulates that momentum develops through successful navigation of cues presented in the competitive context (i.e., the opponent's performance) in order to increase self-confidence and exert greater effort in order to outperform the competitor (Iso-Ahola & Mobily, 1980). The findings from the present study indicate that psychological momentum is indeed characterized by high levels of self-confidence and engagement of task-specific attentional strategies, given the performer's skill level, to facilitate competitive success.

Psychological momentum is a complex phenomenon that is comprised by both cognitive and affective components. Specifically, psychological momentum likely leads to both increased self-confidence and an approach orientation, which collectively facilitate cortical dynamics that translate to improved motor behavior. This enhanced motor performance further perpetuates psychological momentum, thus contributing to an emergent pattern of competitive success.

## **Limitations and Future Directions**

The present study did not manipulate momentum perceptions directly. However, the findings of the present study provide evidence that appropriate engagement of task-specific attentional processes contributes to the psychological momentum state. In the future, it would be beneficial to employ a competitive shooting task including a higher number of shooting trials, such that the cortical dynamics underlying high and low momentum states could be compared within each participant. That is, for each individual participant, the cortical dynamics underlying patterns of competitive success (i.e., win streaks) could be compared with patterns of performance failure. This analysis would require a significantly greater number of trials than were included in the present study in order to obtain an appropriate signal-to-noise ratio. If employed, this procedure would allow us to examine the cortical dynamics underlying high and low momentum states with a higher degree of resolution than was possible in the present study.

It is recommended that false feedback conditions be employed in future investigations in order to investigate the specific influence of perceived competitive success on attentional processes and actual competitive success. In addition, future studies should assess self-report measures more rigorously in tandem with the psychophysiological measures in order to examine the degree to which psychological changes (i.e., increased confidence) relate to changes in cortical dynamics and competitive success. Such strategies would facilitate mapping the behavioral response with the psychophysiological observations.

## Appendices

### Appendix I: Analysis of high and low momentum groups defined by early performance success

Psychological momentum theory asserts that early performance success leads to a sense of superiority over the opponent, increased self-confidence and the maintenance of psychological momentum throughout the remainder of the competition (Iso-Ahola & Mobily, 1980). Thus, present secondary analysis defined high and low momentum groups based upon early performance success, such that the participants that were leading after Block 1 and also won overall were assigned to the high momentum group, while those that were losing after Block 1 and also lost overall were assigned to the low momentum group. All dependent measures used to index psychomotor efficiency, confidence and anxiety, and cortisol levels were computed from the data that were recorded during Block 2 only.

As in the principle analysis, the purpose of the secondary analysis was to determine whether or not psychological momentum is characterized by psychomotor efficiency. Psychomotor efficiency was indexed by high alpha power, gamma power and coherence computed from the data recorded during Block 2. It was hypothesized that the high momentum group would exhibit psychomotor efficiency, such that there would be greater high alpha power and lower gamma power in the left temporal region, as well as lower coherence between the left temporal and motor planning regions relative to the low momentum group. Self-reported confidence and anxiety levels recorded during Block 2 were analyzed in

order to determine whether or not and low levels of psychological momentum are characterized by increased confidence and anxiety, respectively. It was predicted that the high momentum group would exhibit greater self-confidence relative to the low momentum group during Block 2. Similarly, it was predicted that the low momentum group would exhibit greater anxiety levels relative to the high momentum group during Block 2. For the exploratory analysis of cortisol, it was predicted that the low momentum group would exhibit higher cortisol levels relative to the high momentum group during Block 2.

## **Methodology**

### **Participants**

Data from 15 participants (2 female) were included. Participants that were winning in score after the completion of the last shot of Block 1 and also won the competition overall were assigned to the high momentum group ( $n = 9$ ,  $M = 22.00$  yrs,  $SD = 5.78$ ). Participants who were losing (determined by shooting score) after the completion of Block 1 and also lost the competition overall were assigned to the low momentum group ( $n = 6$ ,  $M = 20.16$  yrs,  $SD = 2.07$ ).

### **Data Analysis**

#### **Spectral analysis.**

Spectral estimates were computed on the EEG data for each of the four one-second epochs leading up to trigger pull for the Block 2 trials only, according to the procedures used in the principle analysis (see Methodology).

#### **Coherence.**

Amplitude coherence values were computed on the EEG data recorded during each of the four one-second epochs leading up to trigger pull for the Block 2 trials only, according to the procedures used in the principle analysis (See Methodology).

### **Statistical Design**

Self-reported confidence scores from the VAS and self-reported anxiety scores from the STAI-S were subjected to separate one-way between subjects ANOVAs. Spectral and coherence estimates for all bandwidths were entered into separate 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) univariate ANOVAs with Group as a between-subjects factor and Hemisphere, Region and Epoch as within subjects factors. Salivary cortisol recordings were subjected to a 2 x 2 (Group x Time) univariate ANOVA with Group as a between subjects factor and Time as a within subject factor. Time refers to the series of repeated measurements of salivary cortisol acquired during Block 2 (immediately prior to the start of Block 2 and 5 minutes after the completion of Block 2).

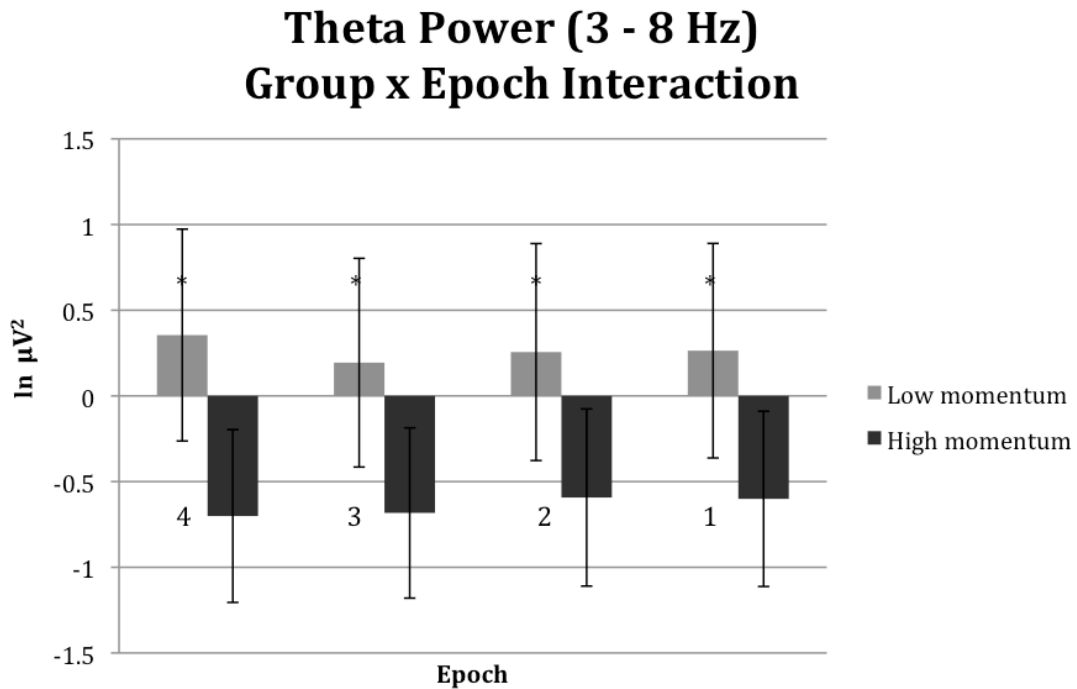
## **Results**

### **Confidence and Anxiety**

The one-way ANOVA applied to the confidence data as measured by the VAS reached significance,  $F(1,14) = 10.332, p = .007$ . The high momentum group exhibited greater self-confidence ( $M = 78.00$  mm,  $SD = 16.13$ ) relative to the low momentum group ( $M = 45.667$  mm,  $SD = 23.04$ ). The one-way ANOVA applied to the anxiety data as measured by the STAI failed to reach significance,  $p > .05$ .

### **Spectral Power**

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVA applied to theta power yielded a Group x Epoch interaction  $F(1,14) = 3.003, p = .042$ . Tukey's HSD post hoc analyses revealed an effect due to Group, such that the high momentum group exhibited reduced theta power relative to the low momentum group in each epoch,  $p < .05$ . The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVAs applied to all other frequency bands failed to reach significance,  $p > .05$ .



**Figure 1:** Theta power computed for the 4 1-second epochs leading up to trigger pull for the final 20 shots of the competition (Block 2). The high momentum group exhibited reduced theta power at each Group by Block, \*  $p < .05$ .

## **Coherence**

The 2 x 2 x 5 x 4 (Group x Hemisphere x Region x Epoch) ANOVA applied to the coherence estimates failed to reach significance,  $p > .05$ .

## **Cortisol**

The 2 x 2 (Group x Time) ANOVA applied to the cortisol data failed to reach significance,  $p > .05$ .

## **Discussion**

Unlike the principle analysis, the secondary analysis failed to detect between-group differences in high alpha power. This suggests that the high momentum group's greater engagement of task-specific attentional processes inferred from the principle results (see Chapter 5) was influential in establishing initial competitive success. In the present supplementary analysis, the high momentum group exhibited reduced theta power relative to the low momentum group. Consistent with the interpretation of the results from the principle analysis, these results suggest that the competition imposed a lesser degree of cognitive demand on the high momentum participants, which may have contributed to competitive success.

In addition to cognitive demand, theta band activity has been interpreted to reflect working memory processes (i.e., processes requiring the individual to manipulate information on-line amidst the context of cognitive activity) (Gevins et al., 1997). Psychological momentum theory asserts that momentum is related to the competitor's self-evaluation of performance relative to another competitor (i.e., perceived likelihood of winning or losing) (Iso-Ahola & Mobily, 1980). After the high momentum participants established levels of superior performance over the low

momentum participants, it is possible that the low momentum participants subsequently directed their attention towards anxious, distracting thoughts about the eventual outcome of the event. These anxious thoughts may have placed them under greater conditions of increased working memory load, which may have contributed to competitive failure.

### References

- Gevins, A., Smith, M.E., McEvoy, L., Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice, *Cerebral Cortex*, 7, 374–385.
- Iso-Ahola, S.E., & Mobily, K. (1980). Psychological momentum: A phenomenon and an empirical (unobtrusive) validation of its influence in a competitive sport tournament. *Psychological Reports*, 46, 391-401.

## Initial Application Approval

To:

From: Re:

Approval

Date: Expiration Date: Application: Review Path:

Principal Investigator, Dr. Amy J Haugler, Kinesiology Co-Investigator, Jeremy Carl Rietschel, Kinesiology Co-Investigator, Marie Elise Oben, Kinesiology Co-Investigator, Kristin Ann Cipriani, Kinesiology Student, Carly Ann Hunt, Kinesiology

James M. Hagberg IRB Co-Chair University of Maryland College Park IRB Protocol: 10-0604 - The Neural Correlates of Psychological Momentum

October 08, 2010

October 08, 2013

Initial Exempt

The University of Maryland, College Park Institutional Review Board (IRB) Office approved your Initial IRB Application. This transaction 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 Protocol 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 will be sent via mail. The IRB approval expiration date has been stamped on the informed consent document. Please note that research participants must sign a stamped version of the informed consent form and receive a copy.

**Continuing Review:** If you intend to continue to collect data from human subjects or to analyze private, identifiable data collected from human subjects, beyond the expiration date of this protocol, you must [submit a Renewal Application](#) to the IRB Office 45 days prior to the expiration date. If IRB Approval of your protocol expires, all human subject research activities including enrollment of new subjects, data collection and analysis of identifiable, private information must cease until the Renewal Application is approved. If work on the human subject portion of your project is complete and you wish to close the protocol, please [submit a Closure Report](#) to [irb@umd.edu](mailto:irb@umd.edu).

**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.

**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 [jsmith@umresearch.umd.edu](mailto:jsmith@umresearch.umd.edu)

**Additional Information:** Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns. Email: [irb@umd.edu](mailto:irb@umd.edu)  
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0101 Lee Building College Park, MD 20742-5125 TEL 301.405.4212 FAX 301.314.1475 [irb@umd.edu](mailto:irb@umd.edu) <http://www.umresearch.umd.edu/IRB>

## Appendix III

### 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.

		<b>Left</b>	<b>Right</b>
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 IV

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 V: STAI-S

**Self-Evaluation Questionnaire—State**

Developed by Charles D. Spielberger, In collaboration with R. L. Gorsuch, R. Lushene,

P. R. Vagg, and G. A. Jacobs

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and circle the appropriate number to the right of the statement to indicate how you feel *right now*, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	Not at all	Somewhat	Moderately so	Very Much so
1. I feel calm.....	1.....	2.....	3.....	4.....
2. I feel secure.....	1.....	2.....	3.....	4.....
3. I am tense.....	1.....	2.....	3.....	4.....
4. I feel strained.....	1.....	2.....	3.....	4.....
5. I feel at ease.....	1.....	2.....	3.....	4.....
6. I feel upset.....	1.....	2.....	3.....	4.....
7. I am presently worrying over possible misfortunes	1.....	2.....	3.....	4.....
8. I feel satisfied.....	1.....	2.....	3.....	4.....
9. I feel frightened.....	1.....	2.....	3.....	4.....
10. I feel comfortable.....	1.....	2.....	3.....	4.....
11. I feel self-confident.....	1.....	2.....	3.....	4.....
12. I feel nervous.....	1.....	2.....	3.....	4.....
13. I am jittery.....	1.....	2.....	3.....	4.....
14. I feel indecisive.....	1.....	2.....	3.....	4.....
15. I am relaxed.....	1.....	2.....	3.....	4.....
16. I feel content.....	1.....	2.....	3.....	4.....
17. I am worried.....	1.....	2.....	3.....	4.....
18. I feel confused.....	1.....	2.....	3.....	4.....
19. I feel steady.....	1.....	2.....	3.....	4.....
20. I feel pleasant.....	1.....	2.....	3.....	4.....

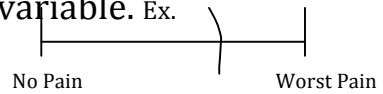
Appendix VI: Visual Analogue Scale

Subject # \_\_\_\_\_

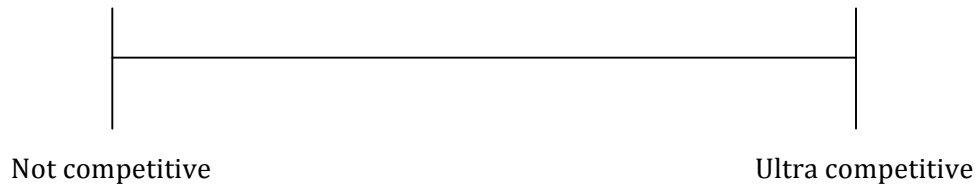
Trial # \_\_\_\_\_

### Visual Analog Scale

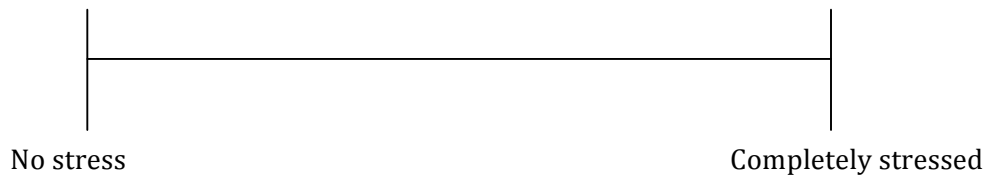
Please put a vertical line through the rectangle at the point that best represents how you feel right now. The ends of each rectangle represent the opposite extremes of the **same** variable. Ex.



How *competitive* do I feel?



How *stressed* am I?



How *confident* do I feel?



How *relaxed* am I?



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## Appendix VII: Data collection procedures as part of the original study

### Day One

Participants came to the laboratory for an orientation session so that they could familiarize themselves with the testing equipment and satisfy the exclusionary criteria. Participants were shown a video in which a Division I NCAA pistol shooting coach provided step-by-step instructions and cues for competitive pistol shooting in a standing posture. Participants then completed 3 blocks of 20 shots in which they were required to hit the target 80% of the time during blocks 2 and 3 in order to participate in the experiment. Participants then completed the EHI, HSQ and the behavioral assessments (STAI-S and VAS). Participants were also given instructions regarding salivary cortisol sampling procedures. Participants wore all electrocortical (EEG cap) and physiological (skin conductance and heart rate) monitoring equipment while completing the behavioral assessments and the practice shooting session to reduce novelty effects.

### Day Two

Participants completed two blocks (Block 1 and Block 2) of 20 shots in each of two conditions: 1) Performance Alone and 2) Competition for a total of 40 shots in each condition. The Performance Alone condition was used to record data for the original study only. Performance Alone and Competition conditions were counterbalanced, such that half of the participants completed Performance Alone and then Competition, while the other half completed Competition followed by Performance Alone (see Figure 2). The present study analyzed data that were

recorded during the Competition condition only. These data collection procedures are described in detail below.

Participants entered the testing room and provided the first of four cortisol samples. Participants reviewed the instructional video from the orientation day and were prepared for EEG recording. Participants completed the VAS and the STAI-S and gave a second cortisol sample. EEG baseline data were recorded for one minute in the shooting position. Participants were then allowed to complete 10 sighting shots. Participants completed Block 1, which was followed by a second round of behavioral assessments (STAI-S and VAS). Participants then completed Block 2 and gave the fourth cortisol sample after a 5-minute waiting period.

Throughout the shooting protocol, several measures were taken to create a situation of head-to-head competition. The experimenter instructed each participant to defeat the other participant before the competition began. The participants were provided the following instructions as related to the head-to-head competition and are provided here due to the potential relevance to the emergence of psychological momentum.

This is the competition phase of the experiment. Your score *does* reflect on your team's score. In other words, how you perform now affects your team's chances of winning the overall competition between teams. Further, you are shooting to win the competition today between you and your opponent. You will both be given 3 minutes for dry fire practice and then 7 minutes for sighters. Immediately after these are completed you will have 30 minutes to complete your best 40 shots. There will be only 1 shot per target with no dry

firing. You and your opponent's scores will be read aloud at approximately the 10-, 20-, and 25- minute marks. The video tapes of your performance today will be evaluated by your coach. Both of your scores will be publicly posted for your team and the opposing team to see. It is important that you shoot as best as you can. After the 20<sup>th</sup> shot, you will complete the visual analog survey and then continue to complete the remaining 20 shots.

Remember, this is a *competition*. Today, you are representing your team. Do you have any questions? You may begin the 3-minutes of dry fire and 7-minutes of sighting shots." In addition and notably to the present investigation, competitors were provided shooting score feedback following each trial such that it was immediately evident which competitor won that particular round and by how much. Again, such feedback may be pertinent to the psychological momentum.

The shooting order was alternated at each round, such that Participant 1 shot first, and then Participant 2. Participant 2 began the next round of shots, and so on. Each participant was allowed thirty seconds to complete each shot. Following the completion of each round, the experimenter verbally declared the winner.

Participants were given twenty dollars at the outset of the competition, from which fifty cents were deducted for losing a round and fifty cents were awarded for winning a round. Participants earned a dollar bonus for hitting the bulls eye and lost a dollar for missing the target altogether. Performance feedback was continuously displayed on a video screen on the wall of the laboratory that depicted each participant's shooting accuracy relative to the bull's eye, numerical score, dollars

lost or earned and the remaining seconds allotted to complete the current shot (see Figure 1). The entire protocol was recorded with a video camera and participants were observed and rated for shooting performance by their ROTC program officer to enhance simulation of competition circumstances in the laboratory environment.

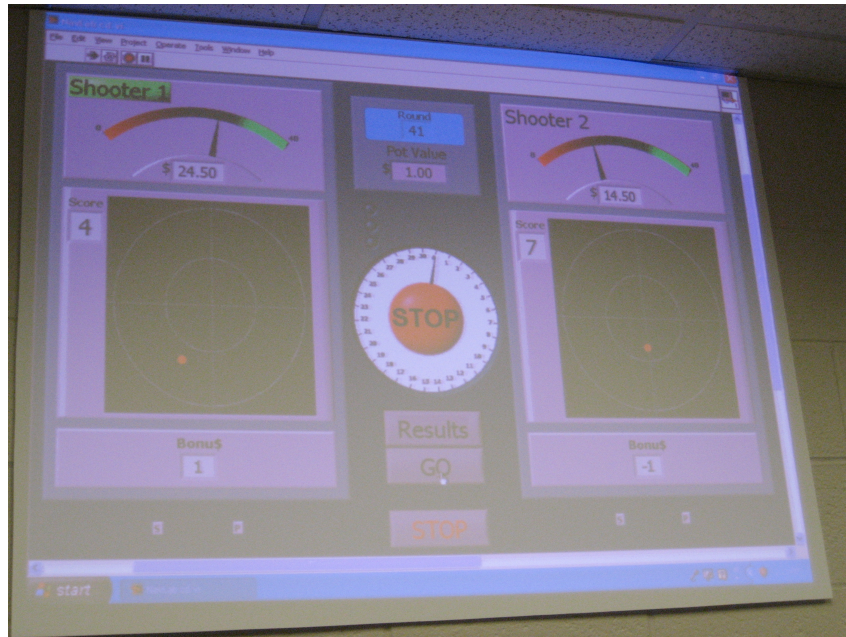


Figure 1: Visual illustration of performance feedback shown to participants after each round.

<b>Competitor 1</b>		<b>Competitor 2</b>	
<ul style="list-style-type: none"> <li>• 5-10 min shooting (w/feedback)</li> <li>• 2 min EO and EC (sitting)</li> <li>• 1 min Shooting Baseline (standing)</li> </ul>			
<ul style="list-style-type: none"> <li>• Cortisol</li> <li>• Instruction</li> <li>• VAS/STAI</li> <li>• 2nd Cortisol</li> <li>• <b>20 shots</b></li> <li>• VAS/STAI</li> <li>• <b>20 shots</b></li> <li>• Cortisol</li> <li>• 5 min</li> <li>• 2nd Cortisol</li> </ul>	<b>Practice</b>		
<ul style="list-style-type: none"> <li>• Exit room</li> </ul>		<b>Evaluator enters</b>	<ul style="list-style-type: none"> <li>• Enter room</li> <li>• 5-10 min shooting (w/feedback)</li> <li>• 2 min EO and EC (sitting)</li> </ul>
<ul style="list-style-type: none"> <li>• Re-enter room</li> <li>• 1 min Shooting Baseline (standing)</li> </ul>			<ul style="list-style-type: none"> <li>• 1 min Shooting Baseline (standing)</li> </ul>
<ul style="list-style-type: none"> <li>• Cortisol</li> <li>• Instruction</li> <li>• VAS/STAI</li> <li>• 2nd Cortisol</li> <li>• <b>20 shots</b></li> <li>• VAS/STAI</li> <li>• <b>20 shots</b></li> <li>• Cortisol</li> <li>• 5 min</li> <li>• 2nd Cortisol</li> </ul>	<b>Competition</b>		<ul style="list-style-type: none"> <li>• Cortisol</li> <li>• Instruction</li> <li>• VAS/STAI</li> <li>• 2nd Cortisol</li> <li>• <b>20 shots</b></li> <li>• VAS/STAI</li> <li>• <b>20 shots</b></li> <li>• Cortisol</li> <li>• 5 min</li> <li>• 2nd Cortisol</li> </ul>
<ul style="list-style-type: none"> <li>• Disconnect and Debrief</li> </ul>		<b>Evaluator exits</b>	<ul style="list-style-type: none"> <li>• Exit room</li> <li>• Break</li> <li>• Re-enters the room and Reck</li> <li>• 1 min Shooting Baseline (standing)</li> </ul>
		<b>Practice</b>	<ul style="list-style-type: none"> <li>• Cortisol</li> <li>• Instruction</li> <li>• VAS/STAI</li> <li>• 2nd Cortisol</li> <li>• <b>20 shots</b></li> <li>• VAS/STAI</li> <li>• <b>20 shots</b></li> <li>• Cortisol</li> <li>• 5 min</li> <li>• 2nd Cortisol</li> </ul>
			<ul style="list-style-type: none"> <li>• Disconnect and Debrief</li> </ul>

Figure 2: Illustration of the order of the data collection procedures for Performance Alone and Competition conditions.

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