ABSTRACT

Title of Document:	THE INFLUENCE OF MOTIVATION ON EMOTION REGULATION AND MOTOR PERFORMANCE: EXAMINATION OF A NEURO-AFFECTIVE MODEL
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Mental stress is known to disrupt the execution of motor performance and can lead to decrements in the quality of performance, however, individuals have shown significant differences regarding how fast and well they can perform a skilled task according to how well they can manage stress and emotion. The purpose of this study was to advance our understanding of how the brain modulates emotional reactivity under different motivational states to achieve differential performance in a target shooting task that requires precision visuomotor coordination. In order to study the interactions in emotion regulatory brain areas (i.e. the ventral striatum, amygdala, prefrontal cortex) and the autonomic nervous system, reward and punishment interventions were employed and the resulting behavioral and physiological responses contrasted to observe the changes in shooting performance (i.e. shooting accuracy and stability of aim) and neuro-cognitive processes (i.e. cognitive load and reserve) during the shooting task. Thirty-five participants, aged 18 to 38 years, from the Reserve

Officers' Training Corp (ROTC) at the University of Maryland were recruited to take 30 shots at a bullseye target in three different experimental conditions. In the reward condition, $1 was added to their total balance for every 10-point shot. In the punishment condition, $1 was deducted from their total balance if they did not hit the 10-point area. In the neutral condition, no money was added or deducted from their total balance. When in the reward condition, which was reportedly most enjoyable and least stressful of the conditions, heart rate variability was found to be positively related to shooting scores, inversely related to variability in shooting performance and positively related to alpha power (i.e. less activation) in the left temporal region. In the punishment (and most stressful) condition, an increase in sympathetic response (i.e. increased LF/HF ratio) was positively related to jerking movements as well as variability of placement (on the target) in the shots taken. This, coupled with error monitoring activity in the anterior cingulate cortex, suggests evaluation of self-efficacy might be driving arousal regulation, thus affecting shooting performance. Better performers showed variable, increasing high-alpha power in the temporal region during the aiming period towards taking the shot which could indicate an adaptive strategy of engagement. They also showed lower coherence during hit shots than missed shots which was coupled with reduced jerking movements and better precision and accuracy. Frontal asymmetry measures revealed possible influence of the prefrontal lobe in driving this effect in reward and neutral conditions. The possible interactions, reasons behind these findings and implications are discussed.

THE INFLUENCE OF MOTIVATION ON EMOTION REGULATION AND
MOTOR PERFORMANCE: EXAMINATION OF A NEURO-AFFECTIVE
MODEL

By

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I dedicate this to my Mother who, even at the last days of her life, put the importance of my academic success above her own needs.

Table of Contents

List of Tables

List of Figures

Chapter 1: Emotion and the Autonomic System Response

One of the many definitions of emotion describes the phenomenon as a set of coordinated physiological responses that prepares the organism for appropriate action and is triggered by salient environmental stimuli (Kleinginna & Kleinginna, 1981; Frijda, 2010). Emotion is then seen as an adaptive response and creates an allostatic state to help in survival and daily functioning (Frijda, 1988; Levenson 1992, Bradley & Lang, 2000).

The study of emotions has led to the general consensus that emotional activation has three main functions; namely, 1) identifying and assessing the value of environmental stimuli, 2) activating physiological and psychological support systems for the organism to react effectively and efficiently, and 3) evaluating the executed behaviors to reinforce or modify responses, if necessary (Scherer, 2005). As mentioned above, the emotional response system can be divided into lower and higher functions through which the lower functions are quick, involuntary reflexes that are coordinated and synchronized for immediate responding while the higher functions are driven mainly by motivational forces for deliberate for action selection, evaluation, and learning (Berntson & Cacioppo, 2008). The two systems work cooperatively or synergistically to help the organism adapt and react to events happening in their environment. In this manner, lower regulatory functions influence the activation of the autonomic system to support the motor behaviors planned and intended by the higher functions.

The role of the amygdala in autonomic response

The central amygdala (CEA) is responsible for triggering the autonomic response when presented with an emotional stimulus. It projects onto the lateral hypothalamus and the brainstem autonomic centers, such as the vagus nerve, nucleus of the solitary tract, periaqueductal grey and parabrachial nucleus (Swanson & Petrovich, 1998). Lesions to CEA disrupt autonomic response,

but not fear behavior such as avoidance and escape (LeDoux, Iwata, Cicchetti & Reis, 1988). This structure is also implicated in the production of the eyeblink startle response (Davis, Falls, Campeau & Kim, 1993; Davis, 2006) and the differential amplitudes of the startle is often used to infer amygdala and emotional reactivity (Cuthbert et al., 1996).

The earliest studies of emotion were particularly focused on defining emotion based on the bodily expressions, such as pulse racing, increased skin conductance and distinct facial expressions. The experience of an emotional episode is an iterative one; while James (1884) argued that we experience emotions because we meaningfully appraise these physiological changes, Darwin (1998) argued that our emotions guide the changes we experience in our bodies. Cannon (1927) would later support Darwin's argument to define emotions as a conditioned stimulus-response, which laid the foundation for the fight-or-flight response that complements the known defense mechanisms (Jänig, 2006).

More recently, psychologists have been trying to map autonomic responses in order to understand the physiological changes that accompany the different basic emotions; namely, happy, sad, fear, anger, surprise and disgust (Ekman, Levenson & Friesen, 1983; Levenson, 1992; Lang, Greenwald, Bradley & Hamm, 1993; Stephens, Christie & Friedman, 2010). Through the use of Directed Facial Action, films and pictures, targeted emotions were elicited and physiological responses, such as, heart rate, skin conductance and respiration rate, were monitored. Sadness was mainly found to be accompanied by parasympathetic arousal characterized by heart rate deceleration and reduced arousal. On the other hand, fear was mainly found to be accompanied by sympathetic arousal characterized by heart rate acceleration and increased arousal (Kreibig et al., 2007).

The consensus is that the basic emotions that we experience are adaptive; supporting appropriate action to maximize survivability by preparing the organisms for specific action tendencies and dispositions to environmental stimuli (Frijda, 1988; Lang, Bradley & Cuthbert, 1990; Levenson 1992, Bradley & Lang, 2000; Scherer, 2005). As in the case of fear, which is activated by threatening stimuli in the environment, the activation of the sympathetic response allows for maximal muscle activation with increased heart rate and blood flow. Thus, the main aim for the organized psychological and physiological responses associated with each specific emotion was to support organisms in their intended and adaptive motor behaviors.

Berntson and Cacioppo (2008) term autonomic responses as the "low primitive function" - designed for dangerous situations that require quick, instinctive reflexes. Incidentally, LeDoux and Phelps (1993) defined projections from the CEA as the reaction pathway as it is highly involuntary, considered simply as a stimulus-response system, and is present so that higher level cognitive functions such as planning and problem-solving according to aims and goals can take place. In essence, low level functions set the stage, enabling the body to be prepared and higher level function makes the decision whether or not to perform the inclined behavior (Cardinal et al., 2002). Consequently, these autonomic activations influence our preferences, attitudes, interpersonal stance, mood, and affective dispositions.

In the next chapter, the possibility of an organized and synchronized structure in autonomic response is explored.

Chapter 2: Exploratory Analysis of Differential Physiological Responses to Emotional Film Clips

Abstract

A number of studies have attempted to classify various physiological responses according to different emotion states and this study continues on that effort. Additionally, this exploratory analysis employs factor analysis to find strong autonomic system activity correlates amongst different physiological systems (i.e. cardiovascular, respiratory and galvanic skin response) in order to find coordinated responses that have been proposed. Targeting a selected group of participants who rated feeling a relatively high level of the targeted emotion, a coordinated response between the cardiovascular and galvanic skin response system has been found in the fear condition but not in other emotion conditions. The fear condition also accounted for most of the variance in the data and this is followed by the sad condition. The fear and sad conditions also show significant differences against other emotion conditions in a number of physiological measures. Using several derived features, discriminant analysis for all emotion conditions yielded a correct classification rate of 86%. When the number of emotion conditions were reduced to just include the neutral, fear and sad conditions, classification results improved by 10.7% to 96.7%. Support Vector Machine was able to classify new, unseen cases from both the fear and sad conditions with 100% success. These results are encouraging and future studies to link autonomic nervous system activity and neural correlates to further understand the mechanisms are proposed.

Keywords: emotion, classification, autonomic nervous system

6

The evidence that distinct patterns of autonomic nervous system response exist for the six basic emotions, namely, happy, sad, fear, anger, surprise and disgust, was first presented by Ekman, Levenson and Friesen in 1983, using "directed facial action" and "relived emotion". Since then, for the past thirty years, researchers across different domains of psychology and computer science have tried to uncover methods to differentiate and predict emotional states (Levenson et al., 1990; Lang & Bradley, 1993; Picard et al., 2001; Kim et al., 2004; Kreibig et al, 2007; Stephens et al., 2010).

The interest grew as the applications for being able to decode emotional states were far and wide. Other than to obtain greater evolutionary and theoretical understanding (Ekman, 1999; Levenson 1999), computer scientists viewed it as a way to improve artificial intelligence. By allowing machines to accurately identify users' emotional reactions in their interactions, it encourages users to become fonder of using the machine and develop a stronger attachment, thereby making the invention more successful (Picard et al., 2001; Kim et al., 2004). Psychological studies of human emotions, memory and decision making (Damasio et al., 1996; Phelps, 2004; Phelps, 2006; Kensinger, 2007) also prompts computer scientists to envision machine systems that might one day make use of emotion states to make more human-like and "intelligent" decisions. Others study this field to understand how affective disorders through physiological disruptions and sustained arousal can affect physical health (Gross and Levenson, 1997; Gross, 1998; Carney et al., 2001, Rottenberg & Gross, 2003; Carney et al., 2005).

In this present study, other than exploring the possibility of classifying data according to emotion conditions, the study of whether physiological systems are recruited as a coherent whole or independently is also conducted. Mauss and colleagues (2005) have reported coherent responses

between physiology and behavior, but to date, no known studies correlating simultaneously activated responses between different physiological systems of the autonomic nervous system within a human body has been investigated. This is important for the determination of the proposed synchronized set of responses existing for different emotion states and understanding how functional or dysfunctional that could be towards affecting cognitive performance and physical health.

Methods

Participants

Sixty participants (30 males and 30 females, M = 19.4, SD = 1.25 years, range = 18 – 23 years) were recruited through polytechnics in Singapore via their teachers and the school's online announcement platform. As the measurement electrodes are placed on the participants' left hand, their hands were loosely restrained to prevent movement artifacts. Thus, we only recruited right-handed participants. They received S$50 for their participation. They were excluded if they indicated that they had a history of, or were suffering from, cardiovascular disease, psychological or psychiatric problems. They were advised to abstain from caffeine and alcohol for 24 hours before the experiment. The study was approved by the Institutional Review Board of DSO National Laboratories Singapore.

Materials

Film clips. Twelve film clips were presented to evoke the targeted basic emotions of happiness, sadness, fear, anger, surprise and disgust (See Appendix A for detailed descriptions of film clips). Two film clips were used to elicit each of the emotion conditions and one neutral film was also selected to be played at the beginning of each experiment as the neutral condition. They

were presented in six different pseudo-randomized orders. The orders were designed in a way in which no two film clips intended to elicit the same emotion states were presented consecutively and that the happy and sad conditions were not presented consecutively. Participants were randomly placed in one of these presentation orders. The film clips were selected and validated out of 42 films clips. They were highly rated and ranked by one hundred and thirty participants (63 males and 67 females, $M = 19.0$, $SD = 1.44$, range $= 18 - 23$ years) in group and individual settings. Most films were taken from Gross and Levenson's (1995) and Schaefer's et al. (2010) studies but included Asian films catered for the local population. The films ranged from 45 to 370 seconds and were presented on a 13.1" LCD monitor. Sounds from the clips were delivered through headphones to attenuate extraneous noise and allow participants to stop the sounds easily by taking the headphones off any time during the film clip if they felt distressed.

Post-film questionnaire. A post-film questionnaire modelled after Rottenberg and Gross' (2007) suggestion was used in this study to evaluate the emotions felt while watching the clips. The questionnaire was administered on a laptop next to the monitor with a USB mouse attached. There were six emotions that participants had to rate and they were the six targeted emotions: happy, sad, fearful, angry, surprised and disgusted. Questions included the intensity of emotions felt on a scale from $0 - 8$ (where 0 is *neutral* and 1 to 8 as the emotion increases in intensity), any other emotions they felt while watching the films and their perceived intensity based on the provided scale, whether they watched the film before and if they closed their eyes during the presentation. Participants were encouraged not to change their answers once they have entered it in the questionnaire.

Procedure

Experimental sessions were conducted in a sound attenuated room where the participants and experimenters were separated by an opaque screen and participants were observed and recorded via a webcam installed on top of the monitor. Participants were seated comfortably in a stationary chair approximately 50 – 60 cm away from the screen. The top frame of the monitor was levelled with the participants' eyes. Their left hands were loosely restrained and rested in a comfortable position on a table next to their seat. The table was up to the participant's waist level when they sat. They were told to refrain from moving when the clip was playing. Participants were instructed to pay close attention to their emotions while watching the clips so that they could accurately answer the post-film questionnaire. They were allowed to take the headphones off, close their eyes or look away at any time during the playing of the clip if they felt uncomfortable. After viewing each clip, they were prompted to enter their responses on a laptop next to the monitor. Before the experiment began and in between film clips, participants were given a 6.5 minute "washout period" (Stephens et al., 2010), where they copied excerpts from articles that described the history of transportation and vehicles. These passages were controlled to be as emotionally neutral as possible. This "washout period" was designed to help participants forget about the previous film and enable their physiological responses to return to baseline. Participants were informed about the intent of the "washout period" and were told to concentrate on the film that was being shown without ruminating about the previous film clips they have watched. In between 2 – 3 clips, participants are given a one minute break to move their restrained hand (with sensors still attached) and move around in their seat.

Physiological Measures and Quantification of Physiological Data

Physiological measurements were recorded using the Procomp Infiniti Encoder (SA7500; Thought Technology Ltd., Montreal, CA) at 256 Hz and digitized using the accompanied software,

BioGraph Infiniti's Physiology Suite. All quantified measures were input as features for analysis and modeling.

   Standardization. For pattern classification algorithms to work optimally, it is best that data values are close to one another across variables. Therefore, the arbitrary values of skin conductance and respiration were standardized using the below equation:

$$x_i = \frac{x_i - \overline{x}}{\sigma_x}$$

where x_i is the observed value, $\overline{x}$ is the mean of time series and σ_x is the standard deviation of the time series. For cardiovascular measures, since interbeat intervals (IBIs) have to be derived from the EKG measure, they were not standardized. The IBI values were not standardized as well as their values are important indices for heart activity. Moreover, their values ranged from $0 - 2$ in our experiment, which was within the standardized values.

   Cardiovascular. Electrocardiogram was obtained using the provided EKG-Flex/Pro sensor with Uni-Gel self-adhesive electrodes (T3425; Thought Technology Ltd., Montreal, CA) attached to the participants' thoracic areas in a Lead II configuration. Measurement sites were first prepared with 70% isopropyl alcohol. A peak detection algorithm was written in MATLAB to identify R peaks in the *PQRST* wave of an electrocardiogram (ECG). The times between two consecutive peaks are then computed as the IBI. Excessive short (less than 300 ms) or long beats (more than 2000 ms) were corrected by removal as artifacts or insertion as missed beats respectively (Berntson et al., 1990). The mean, variance, maximum and minimum values were obtained for the IBI and amplitudes for the fluctuations of the IBI. The root mean squared successive difference (RMSSD) of the IBI was also calculated as an index for heart rate variability (Task Force of the European Society of Cardiology, 1996).

Skin Conductance. Skin conductance was measured using the SC-Flex/Pro sensor with two Uni-Gel electrodes attached to the participants' left palm, specifically the thenar and hypothenar eminences. From the standardized values, the mean, variance, maximum and minimum values were obtained for the skin conductance levels, the amplitude of the fluctuations and the period of fluctuation. The number of peaks was also counted as an index of fluctuation.

Respiration. Respiration was measured using the Respiration-Flex/Pro stretch sensor strapped around the participants' upper chest. The values were passed through a peak detection algorithm in MATLAB to obtain its amplitude, period and rate (respiration per minute). From the standardized values, the mean, variance, maximum and minimum values were obtained for the inspiration and expiration depth, the amplitude of the fluctuations and the period of fluctuation. The number of peaks was also counted to infer respiration rate.

Analysis

Film and Case Selection

Due to the fact that not all participants reported feeling the targeted emotion or that they reported feeling a blend of emotions, there was a need to extract data that exhibits strong characteristics of the emotion condition (i.e. targeted emotion rated highly) and is consistent across participants (i.e. participants do not show too much variability in ratings between them) so that the patterns of physiological reactions experienced for each emotion condition can be inferred with better confidence. Otherwise, there could be the possibility that the variability might be attributed to other extraneous factors other than feeling the targeted emotion.

Hence, instead of collapsing data across film in similar emotion conditions, only data from the more effective film per emotion condition was chosen. The surprise condition was not analyzed here as the film clips that were chosen could only elicit the targeted emotion towards the end of

the clip. As a result, there were insufficient data points for analysis (i.e. less than 60 seconds). The anger condition was also not considered for analysis as the films were unable to elicit a reasonable level of the targeted emotion (mean of less than 4.0) and also elicited a comparable level of sadness as shown in Figure 1 below.
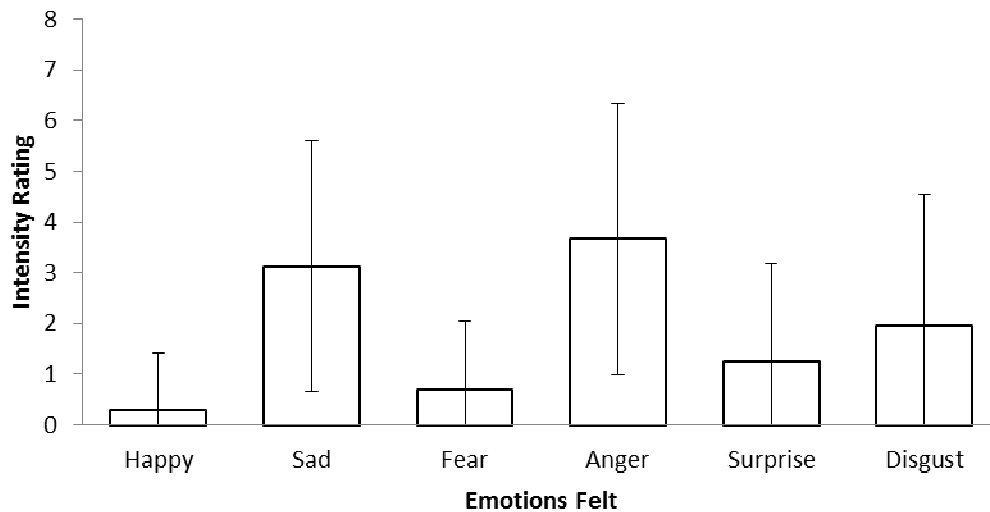
Figure 1. Self-reported ratings for film clip inducing anger obtained from post-film questionnaire. Whiskers represent 1 standard deviation of the mean.

Additionally, two criteria based on self-report ratings in the post-film questionnaire were established for case selection.

a) Participants must rate the targeted emotion of the film to be at least a '4'.

b) Participants must not rate other emotions other than the targeted emotion to be more than '2'.

Based on these criteria, only twenty participants qualified in the disgust condition. As such, for comparison purposes, participants for each condition were ranked according to the rating of the targeted emotion (where participants who gave the highest rating were ranked first) in the emotion condition and the first twenty cases were selected. The results before and after case selection are presented in Table 1 below. When all participants were included, targeted emotions

were rated statistically higher than non-targeted emotions (all $p < 0.05$). No statistically significant differences were found between randomization orders or genders. For the selected group of participants, the mean ratings for targeted emotions are higher than when all participants were included. Non-targeted emotions are also rated lower or were almost non-existent.

Table 1. Mean (SD) of self-report ratings for each emotion-by-emotion condition for all participants and selected group of participants.

All Participants	Emotion Condition									
	Neutral		Happy		Sad		Fear		Disgust	
Emotion Self-Report	M	SD	M	SD	M	SD	M	SD	M	SD
Happy	1.23	1.83	5.84	2.19	0.90	1.69	0.48	1.47	1.29	2.11
Sad	0.02	0.13	0.02	0.13	5.05	2.30	0.44	1.10	0.15	0.57
Fear	0.06	0.51	0.00	0.00	0.89	1.86	5.21	2.57	0.44	0.97
Anger	0.00	0.00	0.11	0.77	0.81	1.82	0.35	1.34	0.13	1.02
Surprise	1.29	1.95	0.79	1.54	0.26	0.89	2.21	2.53	1.89	1.99
Disgust	0.00	0.00	0.02	0.13	0.16	0.63	0.27	0.85	5.08	2.61
Selected	Emotion Condition									
	Neutral		Happy		Sad		Fear		Disgust	
Emotion Self-Report	M	SD	M	SD	M	SD	M	SD	M	SD
Happy	0.00	0.00	7.65	0.49	0.25	0.55	0.05	0.22	0.10	0.31
Sad	0.00	0.00	0.00	0.00	6.35	0.99	0.20	0.41	0.05	0.22
Fear	0.00	0.00	0.00	0.00	0.05	0.22	7.05	1.23	0.30	0.66
Anger	0.00	0.00	0.00	0.00	0.15	0.37	0.05	0.22	0.00	0.00
Surprise	0.00	0.00	0.00	0.00	0.05	0.22	0.60	1.23	0.55	0.76
Disgust	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22	6.60	1.57
Gender	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
	12	7	8	12	11	9	15	5	14	6

Data Extraction

Due to the nature of films, where emotions can fluctuate over time (Mauss et al., 2005) or takes time to develop (Kreibig et al., 2007), it is important to capture the moment where the emotion experience is at its peak. It is also important for different emotion conditions to have similar data bin lengths for comparison purposes. In order to achieve this, one minute intervals

were extracted from each emotion condition. For neutral, disgust, happy and fear conditions, where films tend to be shorter because they are easier to elicit almost immediately, the first seventy seconds of data was considered and the first ten seconds of data was ignored. For the sad condition, where films tend to be longer as context has to be given (Kreibig et al., 2007) the last seventy seconds of data were extracted and the last ten seconds of data ignored.

Results

All statistical analysis was performed using SPSS 21.0. This includes repeated measures ANOVA accompanied by subsequent post-hoc tests with Sidak correction, factor analysis employing principal component extraction and discriminant analysis. Support vector machines modeling was done using the Statistical Toolbox in MATLAB 2013a. The functions include svmtrain and svmclassify.

Univariate Analysis of the Effects of Emotions

Univariate ANOVA was conducted on all derived features to investigate if there are significant main effects between emotion conditions. Table 2 presents the descriptive statistics and univariate analyses by emotion condition. Tukey honestly significant difference (HSD) post hoc test was conducted if significant differences were found. This was presented on the last column of the table.

The fear condition showed significantly lower mean IBI (i.e. higher heart rate) than the sad condition and higher variance and number of peaks for skin conductance levels than the neutral and sad conditions. This reflects a heightened state of arousal and reactivity to stimuli as seen in the heart and skin conductance response respectively that is often described to facilitate the escape or avoidance tendencies of fear (Ekman, 1999; Levenson, 1999, 2003).

The sad condition revealed significantly longer respiration periods than the happy condition and lower variance than the disgust condition. It also revealed significantly lower maximum skin conductance levels and variance in respiration depth than the neutral condition. This is consistent with a depressed, withdrawn state that is described by Levenson (1999) that arises from the tendency to remain passive rather than react actively so as to seek help and sympathy from others.

The disgust condition showed significantly higher variance of respiratory period than the sad condition that could be caused by the gag and vomit reflex to expel toxins from the body (Purves et al., 2013). In the happy condition, participants were observed to be laughing when watching the film clip during the experiment. It was expected that as a result, a lower mean period of respiration would be produced. Indeed, it was found that the mean period of respiration in the happy condition was significantly lower than in the sad condition. Although there were no significant differences in the minimum period of respiration, the disgust and happy conditions displayed lower values than the other emotion conditions due to their automatic triggering of gag and laughter.

It was surprising to see that the neutral condition produced higher values than all other emotion conditions for mean skin conductance levels and minimum skin conductance level. This could be attributed to the apprehension or excitement from participating in the study.

Table 2. Statistical summary for physiological features.

Physiological Feature	Abbreviation	M (SD)					F	p	Post Hoc Tests (Tukey HSD) Differences
		Neutral	Disgust	Happy	Fear	Sad			
Cardiovascular									
RMSSD	rmssd	0.07 (0.05)	0.12 (0.11)	0.08 (0.08)	0.11 (0.16)	0.12 (0.15)	0.86	0.49	
Amplitude									
Mean	mHRa	0.09 (0.04)	0.14 (0.12)	0.11 (0.09)	0.13 (0.20)	0.14 (0.18)	0.54	0.71	
Variance	vHRa	0.01 (0.02)	0.03 (0.05)	0.02 (0.06)	0.05 (0.15)	0.02 (0.03)	0.76	0.56	
Maximum	maxHRa	0.30 (0.28)	0.48 (0.41)	0.35 (0.33)	0.48 (0.59)	0.42 (0.40)	0.75	0.56	
Minimum	minHRa	0.03 (0.03)	0.03 (0.02)	0.02 (0.01)	0.05 (0.10)	0.05 (0.09)	0.55	0.70	
IBI									
Mean	mHRp	0.83 (0.12)	0.96 (0.19)	0.86 (0.12)	0.83 (0.27)	0.94 (0.17)	3.48	0.01	f < s*
Variance	vHRp	0.01 (0.01)	0.02 (0.02)	0.02 (0.03)	0.03 (0.08)	0.02 (0.04)	0.46	0.77	
Maximum	maxHRp	1.13 (0.34)	1.35 (0.44)	1.16 (0.36)	1.25 (0.66)	1.29 (0.45)	0.77	0.55	
Minimum	minHRp	0.70 (0.08)	0.75 (0.15)	0.69 (0.08)	0.68 (0.15)	0.79 (0.09)	2.26	0.07	
Skin Conductance Levels									
Mean	mSC	1.07 (0.68)	0.06 (0.27)	-0.08 (0.76)	0.29 (1.09)	-0.05 (1.13)	6.29	< 0.01	n > d**, h**, f*, s**
Variance	vSC	0.26 (0.32)	0.51 (0.28)	0.40 (0.43)	0.68 (0.64)	0.25 (0.42)	3.37	0.01	f > n*, s*
Maximum	maxSC	1.94 (0.97)	1.57 (0.68)	1.12 (1.04)	1.57 (1.47)	0.69 (1.58)	3.24	0.02	n > s*
Minimum	minSC	0.33 (0.71)	-1.06 (0.36)	-0.84 (0.68)	-1.50 (1.10)	-0.67 (0.88)	14.83	< 0.01	n > d**, h**, f**, s** f < s*
Amplitude									
Mean	mSCa	0.47 (0.62)	0.74 (0.77)	0.59 (0.54)	0.42 (0.36)	0.44 (0.48)	1.10	0.36	
Variance	vSCa	0.18 (0.42)	0.28 (0.43)	0.24 (0.54)	0.12 (0.20)	0.09 (0.24)	0.78	0.54	
Maximum	maxSCa	0.68 (0.84)	1.09 (1.04)	0.89 (0.90)	0.82 (0.74)	0.65 (0.82)	0.83	0.51	
Minimum	minSCa	0.30 (0.57)	0.42 (0.72)	0.33 (0.43)	0.17 (0.16)	0.29 (0.36)	0.70	0.60	
Period									
Mean	mSCp	10.22 (15.71)	12.20 (12.03)	11.48 (12.80)	3.29 (3.09)	15.12 (17.21)	1.96	0.11	
Variance	vSCp	45.71(122.16)	66.84 (131.92)	36.73 (51.12)	11.54 (22.29)	23.85 (44.13)	1.20	0.32	
Maximum	maxSCp	12.95 (17.07)	17.12 (13.68)	16.06 (13.25)	6.99 (6.64)	19.00 (16.86)	2.25	0.07	
Minimum	minSCp	7.80 (15.50)	7.70 (12.21)	8.05 (13.47)	1.03 (1.21)	12.81 (18.02)	2.24	0.07	
No. of Peaks	nSC	1.55 (2.26)	2.55 (2.46)	2.90 (3.55)	5.20 (4.88)	2.20 (2.42)	3.61	< 0.01	f > n**, s*
Respiration									
Mean	mR	0.15 (0.48)	0.02 (0.13)	0.32 (0.43)	-0.03 (0.58)	0.03 (0.64)	1.70	0.16	
Variance	vR	1.12 (0.72)	0.82 (0.25)	0.72 (0.35)	0.85 (0.42)	0.66 (0.59)	2.56	0.04	n > s*
Maximum Inspiration	maxR	3.93 (2.11)	2.57 (0.78)	2.88 (1.12)	2.79 (1.75)	2.21 (1.42)	3.66	0.01	n > d*, s**
Maximum Exhalation	minR	-1.46 (0.90)	-2.11 (1.14)	-1.72 (0.96)	-1.77 (0.50)	-1.41 (0.59)	2.22	0.07	
Amplitude									
Mean	mRa	1.84 (0.53)	1.72 (0.58)	1.39 (0.58)	1.90 (0.69)	1.67 (0.68)	2.12	0.08	
Variance	vRa	1.32 (1.70)	0.88 (0.41)	0.60 (0.51)	0.65 (0.56)	0.60 (0.96)	2.08	0.09	
Maximum	maxRa	4.30 (2.17)	3.99 (1.12)	3.45 (1.42)	3.66 (1.68)	3.22 (1.55)	1.41	0.24	
Minimum	minRa	0.57 (0.55)	0.37 (0.45)	0.44 (0.47)	0.54 (0.44)	0.71 (0.62)	1.29	0.28	
Period									
Mean	mRp	2.21 (0.51)	2.03 (0.44)	1.83 (0.32)	1.99 (0.42)	1.99 (0.32)	3.14	0.02	h < s*
Variance	vRp	0.71 (0.74)	1.00 (0.99)	0.68 (0.64)	0.42 (0.35)	0.37 (0.40)	2.85	0.03	d > s*
Maximum	maxRp	3.67 (1.29)	3.97 (1.63)	3.44 (1.02)	3.25 (0.83)	3.24 (0.97)	1.38	0.25	
Minimum	minRp	0.89 (0.56)	0.59 (0.47)	0.58 (0.29)	0.86 (0.49)	1.01 (0.58)	2.23	0.07	
No. of Peaks	nR	17.35 (3.07)	18.80 (3.92)	19.85 (3.20)	18.50 (3.33)	18.50 (2.35)	1.54	0.20	

Note. n: neutral, d: disgust, h: happy, f: fear, s: sad, RMSSD: root mean squared successive differences, ANOVA: df = 4,95, Post Hoc Test: Tukey Honestly Significant Differences *p < 0.05, **p < 0.01

Factor Analysis

This method was employed to investigate if different features for different emotion conditions can be grouped according to their emotion condition and if different emotion conditions can be considered different from one another based on these features. More importantly, highly correlated features grouped under a single factor can also inform us about what kind of physiological responses are occurring in synchrony and which emotion condition would bring about this coherent state.

As shown in Table 3, most of the features were grouped under each component according to their emotion conditions.The fear and sad conditions accounted for most of the variance in the factor analysis. No emotion conditions, other than the fear condition, had both cardiovascular features and skin conductance features grouped under one component (i.e. *Fear 1*). This could indicate a coordinated response in two physiological systems that could be brought about only by fear. The components named *Sad 1*, *Sad 2* and *Sad 3* show the three different physiological systems grouped under three different components. There were three components for fear as well, but *Fear 2* included only skin conductance features and other skin conductance features were already grouped under *Fear 1*. *Fear 3* represented distinctly respiration features for the fear condition. Thus, the fear and sad conditions seem to be very well represented by the three physiological systems measured as compared to the other emotion conditions.

Discriminant Analysis

In order to distinguish between different emotion conditions and to see if it is possible to model the different emotion condition, discriminant analysis was carried out on all features. The results are presented in Table 4. Overall, 86% of cases were classified correctly.

Table 3. Results from factor analysis. Component headings were replaced with inferred grouping factors.

Fear 1		Sad 1		Sad 2		Happy 1		Disgust		Neutral 1		Fear 2		Sad 3		Neutral 2		Fear 3	
mHRa f	0.98	minHRa s	0.96	maxRa s	0.90	rmssd h	0.96	minSCa d	0.94	rmssd n	0.94	mSC f	0.90	mSCp s	0.91	minHRa n	0.91	vR f	-0.93
minHRa f	0.98	mHRa s	0.94	vR s	0.87	vHRa h	0.93	minSCp d	0.89	maxHRp n	0.87	mSCa f	0.83	maxSCp s	0.88	mRp n	0.82	maxRa f	-0.91
vHRp f	0.98	vHRp s	0.94	vRa s	0.84	mHRa h	0.93	minSCa n	0.86	maxHRa n	0.86	maxSC f	0.80	minSCp s	0.88	nR n	-0.75	maxR f	-0.91
vHRa f	0.98	rmssd s	0.89	maxR s	0.81	maxHRa h	0.91	mSCp d	0.83	vHRa n	0.85	nSC f*	0.77	vSCa n	0.74	mHRa n*	0.73	vRa f	-0.82
rmssd f	0.96	mHRp s	0.80			maxHRp h	0.90	mSCa n	0.81	vHRp n*	0.74	maxSCa f*	0.76						
mHRp f	0.92	minHRp s	0.72			vHRp h	0.86	mSCa d	0.79			minSCa f	0.74						
maxHRp f	0.90					mHRp n	0.82					minSC f	0.74						
vSCp f	0.90																		
maxHRa f	0.87																		
vSCa f	0.81																		
minHRp f	0.72																		
mSCp f	0.71																		
mHRa d	0.88																		
mHRp d	0.80																		
vHRp d	0.76																		
minR h	-0.85																		
maxRp n	0.72																		
Eigenvalue	22.73	Eigenvalue	20.36	Eigenvalue	18.25	Eigenvalue	14.50	Eigenvalue	12.19	Eigenvalue	11.00	Eigenvalue	9.36	Eigenvalue	8.50	Eigenvalue	8.44	Eigenvalue	7.52
% Total Variance	12.99	% Total Variance	11.63	% Total Variance	10.43	% Total Variance	8.29	% Total Variance	6.97	% Total Variance	6.28	% Total Variance	5.35	% Total Variance	4.86	% Total Variance	4.82	% Total Variance	4.30
Cumulative Variance (%)	12.99	Cumulative Variance	24.62	Cumulative Variance	35.05	Cumulative Variance	43.34	Cumulative Variance	50.30	Cumulative Variance	56.59	Cumulative Variance	61.94	Cumulative Variance	66.79	Cumulative Variance	71.62	Cumulative Variance	75.91

Note. Extracted using Principal Component Extraction, rotated using Varimax with Kaizer normalization. Only variables with loadings more than 0.70 are shown. *also loaded on other components.

Table 4. Discriminant analysis results for all emotion conditions.

		Predicted Group Membership					Total
		Neutral	Disgust	Happy	Fear	Sad	
Original	Neutral	17 (85%)	0 (0%)	1 (5%)	1 (5%)	1 (5%)	20
	Disgust	0 (0%)	19 (95%)	1 (5%)	0 (0%)	0 (0%)	20
	Happy	3 (15%)	2 (10%)	13 (65%)	1 (5%)	1 (5%)	20
	Fear	0 (0%)	0 (0%)	0 (0%)	18 (90%)	2 (10%)	20
	Sad	1 (5%)	0 (0%)	0 (0%)	0 (0%)	19 (95%)	20
	Total	21	21	15	20	23	100

86% of cases correctly classified

As revealed by ANOVA and factor analysis, fear and sad conditions were physiologically distinct from many of the other emotion conditions. When the classification analysis was ran with only those two conditions and the neutral condition, the classification improved by 10.7% as shown in Table 5.

Table 5. Discriminant analysis results with only neutral, fear and sad conditions.

		Predicted Group Membership			Total
		Neutral	Fear	Sad	
	Neutral	19 (95%)	0 (0%)	1 (5%)	20
Original	Fear	0 (0%)	19 (95%)	1 (5%)	20
	Sad	0 (0%)	0 (0%)	20 (100%)	20
	Total	19	19	22	60

96.7% of cases correctly classified

In summary, discriminant analysis did well in modeling existing data, however, when trying to fit new, unfamiliar cases it performed poorly (i.e. only 40 – 60% correct classifications). For future prediction purposes, it is necessary to find another method to classify the data. While discriminant analysis tries to find a linear relationship between features and places new cases according to probabilistic models, support vector machine (SVM) identifies patterns between data points in the same conditions and simply finds a hyperplane that can separate data points from different conditions in a multidimensional space. The hyperplane that induces the least cost is chosen.

Since SVM in MATLAB only allowed for binary classification, the emotion conditions fear and sad were chosen for analysis. This stems from the fact that these two conditions have shown considerable differences from other conditions and good component representation results thus far.

Support Vector Machine (SVM)

The existing data set for fear and sad conditions were used as the training set. Two test sets were used for validation. The first test set was derived from selecting the next five ranking participants after the twenty used in the training set. Based on the case selection criteria described earlier, the top five participants viewing the other film for each of the emotion conditions were chosen as the second test set. For the first test set, SVM only managed to group 40% of the cases (i.e. 2 out of 5) correctly for the fear condition and 60% of the cases (i.e. 3 out of 5) correctly for the sad condition. However, for the second test set, SVM managed to group all new cases correctly with 100% success. This result hints at a possible threshold level for subjective feeling for it to have an effect on the autonomic nervous system.

<u>*Discussion*</u>

Present study

The results show that the fear and sad conditions were distinct from one another and from baseline. The separation from and between the other emotion conditions were not so clear cut, but this was to be expected. Kreibig and colleagues (2007) recognized the "psychological, experiential, expressive, and behavioral distinctions between fear and sadness" and set out to only try to distinguish between these two emotion conditions with relatively high success rates of 69 to 84.5% in their classification analysis. For this study, successful classification rates were higher; from

96.7% up to even 100%. This difference could be due to the selection of participants according to how successful the film clip elicited the targeted emotion, which gave a more accurate representation of the resultant autonomic nervous system activity.

The results from SVM also showed that for emotion conditions to have an effect on the autonomic nervous system, participants will first have to feel a certain level of the emotion first. This could be a high intensity of $7 - 8$ as represented by the second test set. It could also be that the model was trained using data from participants that rated the targeted emotions highly. However, discriminant analysis showed that this would yield better differentiation between emotion conditions and so, this should not be a disadvantage.

Even though the results are optimistic, the finding might only apply to a young, Asian population. It is often said that basic emotions and their resultant responses in facial expression and autonomic nervous system activity are universal (Ekman, 1999; Purves et al., 2013), but more evidence is needed to support this claim.

It was unfortunate that the neutral condition was unable to create a representative baseline state for comparisons with other emotion conditions as it has shown significantly higher skin conductance level, indicating a high level of arousal that could have been a product of the excitement from starting the experiment. If the study were to be repeated, it might be wise to randomize the presentation order of the neutral film clip as well. Instead of presenting it first all the time, like in this study, perhaps it would be advisable to insert it in between other films as well to prevent experiment novelty from triggering high skin conductance levels.

In trying to investigate the coherence between different physiological systems, factor analysis yielded correlations between cardiovascular response and skin conductance in the fear condition only. The other emotion conditions, including the sad condition, showed that

physiological systems might be working independently from one another, causing perhaps an incoherent activity state. This could stem from the fact that the fear response is for fight-or-flight, and it has been the most common emotion that has been described with the most detail about the consequent coordinated responses from different systems (for example, increase in heart rate, increase in skin conductance, increase in respiration) (Ekman, 1999; Levenson, 2003; Kreibig et al., 2007; Stephens et al., 2010). Synchronicity and coherence in the brain has been found to improve neural efficiency and cognitive performance (Hogan et al., 2003; Uhlhaas & Singer, 2006; Rietschel et al., 2012). It will be of interest to investigate if the same applies to the autonomic nervous system as well. Better yet, maybe incorporating a more holistic system and interaction between the brain and the body can give better predictions and explanations regarding emotion states and its effect on cognitive performance.

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Emotion	Credits	Timing	Brief Description
Neutral	Anonymous (2009). *How to Fold a Sky King* [Online Video]. Wired. Retrieved from http://www.youtube.com/watch?v=c1fXWVhd6dU	Full video	Instructional video on how to fold a complex paper aeroplane.
Happy	Birnbaum, R., Davis, A. Z., Glickman, J., Sarkissian, A., Stern, J. (Producers), & Ratner, B. (Director). (2007). *Rush Hour 3* [Motion Picture]. United States, USA: MMVII New Line Productions.	0:16:16 – 0:16:51	Puns involving Chinese names are used to confuse an American man.
Happy	Shadyac, T. (Producer and Director), Carrey, J., Brubaker, J. D., Bostick, M., Koren, S., & O'Keefe, M. (Producers). (2003). *Bruce Almighty* [Motion Picture]. United States, USA: Universal Studios.	53:01 – 55:12	A man with special powers uses it to make a news-anchor blabber nonsense on

			national television.
Sad	Bay, V., Tee, B. L. (2009). *Going Home* [Online Video]. Singapore, Alzheimer's Disease Association. Last retrieved from http://www.youtube.com/watch?v=9iXPHhfk_7E on 7 March 2011.	0:40 – 1:35; 2:07 – 2:52; 3:09 – 4:43; 5:30 – 8:26	A grandmother heads out to buy food for her hungry grand-daughter but forgets how to go home. They are reunited at the end.
Sad	Lovell, D. (Producer), & Zeffirelli, F. (Director). (1979). *The Champ* [Motion Picture]. United States, USA: Turner Entertainment.	01:54:21 – 01:56:21; 01:56:43 – 01:59:08	A boy pleads desperately for his father to be brought back to life.
Fear	Maligool, J. (Producer), Thongkonthun, Y., Pisanthanakun, B., Wongpoom, P., & Purikitpanya, P. (Directors). (2008). *4Bia* [Motion Picture]. Thailand: Siam Media Corporation.	18:39 – 24:30	A woman receives strange text messages on

			her phone even though she switched it off. The person on the line seems to know her every move.
Fear	Sudsawad, Y. (Producer), Pisanthanakun, B., & Wongpoom, P. (Directors). (2004). *Shutter* [Motion Picture]. Thailand: Phenomena Motion Pictures.	1:23:25 – 1:26:51	A man searches for a spirit in his house using a Polaroid camera and realises the spirit has been sitting on his shoulders all the while.
Anger	Attenborough, R. (Producer and Director), Spencer, N., & Briley, J. (Producers). (1987). *Cry Freedom* [Motion Picture]. United States, USA: Universal Home Video.	02:26:16 – 02:28:50	African people including children are

			shot randomly without good reason.
Anger	Roumel, K., Simpson, J. H., Vachon, C., Winterstern, H., Turen, K. (Producers), & O'Haver, T. (Director). (2007). *An American Crime* [Motion Picture]. United States, USA: First Look Studios.	57:50-59:41	A group of children and teenagers are encouraged to inflict pain on another girl who is tied up.
Surprise	Lazarus, P. (Producer), & Hyams, P. (Director). (1978). *Capricorn One* [Motion Picture]. Capricorn One Associates.	01:33:15 – 01:34:00	Policemen barge into a quiet room.
Surprise	Milito, L. S. (Producer), & Smight, A. (Director). (2006). *CSI Crime Scene Investigation - The complete Sixth Season : Episode 618 "The Unusual Suspect"* [Motion Picture]. United States, USA: Paramount Pictures.	02:14 – 03:49	A little girl at the witness stand suddenly confesses to a murder.
Disgust	Gross, J.J., Levenson, R.W. (1995). *Amputation* [Online Video]. Retrieved from http://www-psych.stanford.edu/~psyphy/movs/surgery.mov	Full video	Amputation scene.

Disgust	Richard, C. (Producer and Director). (2006). *Man Vs. Wild Season 2: Zambia* [Motion Picture]. United States, USA: Discovery Communications.	11:59 – 13:23.	A documentary-host demonstrates worm-eating.

Chapter 3: Motivation, Emotion Regulation and Motor Performance

From the previous chapter, a possibility of an organized and synchronized autonomic response is shown for two emotions states – fear and sad. In short, the physiological responses that were uncovered in that study represent the response tendencies that were previously proposed by other researchers. It is hopeful, therefore, that they can be used to infer emotion states in future experiments to investigate neural correlates and discover neural mechanisms that bring about these systemic responses.

One dimension of interest that could be added is the study of frontal asymmetry. Frontal asymmetry has been known for classifying approach and withdrawal behaviors (Sutton & Davidson, 1997; Coan & Allen, 2003; Harmon-Jones, 2003, 2010). While some emotions such as sad or depression produce more right asymmetry compared to the left, indicating withdrawal behavior, other negative emotions such as anger could produce a bias on either side depending on the intended course of action (Harmon-Jones, 2010). Even though fear has been traditionally seen as an adaptive response as mentioned earlier, and could be seen as an approach behavior, the name "fight-or-flight" suggests that the response could potentially be either an approach or withdrawal, similar to the anger response. Resting asymmetries can also predict emotional reactivity (Sutton & Davidson, 1997; Coan & Allen, 2004). These results suggest that for one, future classification studies can use this measure to distinguish emotions with greater confidence. For another, differential frontal asymmetry (if it exists) can help evaluate differences in cognitive performance.

Individual differences in motivation and its effects on motor behavior

According to the biopsychosocial (BPS) model of arousal regulation (Blascovich & Tomaka, 1996; Blascovich et al., 2004; Seery, 2011), different individuals react differently to the same situation because of their appraisal of the event as a challenge or a threat. In the case of a challenge, individuals deem their resources sufficient to meet the demands of a task and the

autonomic system. In particular, the heart increases cardiac output without increasing total peripheral resistance by dilating the blood vessels. This ensures sufficient blood supply is brought to the muscles. On the other hand, when individuals deem their resources insufficient to meet the demands of a task, they view it as a threat and cardiac output reflects little or no change, while total peripheral resistance is increased. The combination of a greater cardiac output and lower total peripheral resistance concurs with the notion that the body is changing adaptively to meet external demands by pumping more blood to the extremities through dilated blood vessels. Failure to do so in the case of threat perceivers, when cardiac output does not change but total peripheral resistance increases, points to a maladaptive response (Seery, 2011). This phenomenon is believed to reflect the avoidance property after a threat evaluation - individuals are not ready to engage in the task and the physiological changes are only to support heightened attention.

For example, Blascovich and colleagues (2004) reported distinct cardiovascular profiles in college softball players who perceive the game scenario as a challenge (i.e. manageable, within their control) versus those who perceive the game scenario as a threat (i.e. unmanageable, out of their control). Players who perceived the game scenario as a challenge exhibited greater cardiac output and lower total peripheral resistance. This pattern of activation was interpreted as the heart pumping more blood to the extremities through dilated blood vessels. On the other hand, players who perceived the game scenario as a threat showed lower total peripheral resistance, but no change in cardiac output. This pattern of activation was interpreted as the heart pumping the same amount of blood to the extremities through constricted blood vessels. The cardiovascular profile of challenge and threat correlated significantly with the players' performance during the next season; players who perceived challenge performed better than those who perceived threat. Seery (2011) commented that the observed cardiovascular profile associated with challenge

corresponded to engagement while the cardiovascular profile associated with threat corresponded to avoidance.

The BPS model can be likened to the Gray's behavioral activation system (BAS) and behavioral inhibition system (BIS). The prefrontal cortex appears to be consolidating the activation and inhibition dispositions as shown in studies of frontal asymmetry. Carver and White (1994) measures the opposing actions dispositions on a scale based on Gray's BAS and BIS. Research has found that higher relative resting right alpha (i.e. higher left PFC activation) corresponds to higher BAS scale scores (Sutton & Davidson, 1997; Coan & Allen, 2003). This shows that the frontal lobe biases an individual towards approach or withdrawal behavior.

The autonomic consequences described in BPS correspond to frontal asymmetry measures of approach and withdrawal behavior. Alluding to the concept of facing a challenge, greater relative left frontal lobe activation which generates greater bias towards approach behavior (Harmon-Jones, 2003; Davidson, 2004; Pizzagalli et al., 2005; Harmon-Jones, Gable, Peterson, 2010) has been found to reduce attention to a less global level (Gable & Harmon-Jones, 2008), predict more positive ratings to positively-valenced emotional film clips (Tomarken, Davidson & Henriques, 1990; Wheeler, Davidson & Tomarken, 1993) and more likely to respond to reward (Pizzagalli et al., 2005). Relative left frontal lobe activation or increased approach motivation during task engagement is associated with reduced amygdala reactivity (Jackson et al., 2003; Price, Dieckman & Harmon-Jones, 2012; Goodman et al., 2013). This hints at a possible emotional modulation effect when reward seeking behavior is engaged. The BPS concept of threat or the avoidance nature can be seen in depressed individuals who exhibit higher relative right activation compared to nondepressed individual (Henriques & Davidson, 1997). This finding corresponds to

decreased autonomic activation (Kreibig, Wilhelm, Roth & Gross, 2007) associated with reduced voluntary goal-directed behavior (Levy & Dubois, 2006).

Among the many connections in the brain that links emotion to cognition, there is evidence that an intricate link between the medial prefrontal lobe, amygdala, and the central nervous system exists (Cardinal et al., 2002; Phelps, 2004; Pessoa, 2013). The autonomic nervous system is influenced by the central amygdala via the brainstem and hypothalamus, which highlights the relationship between emotion and physiological responses. While it has been proposed that there should be a "dynamic coalition of networks of brain areas" (Pessoa, 2008), perhaps the autonomic nervous system should be included in the consideration as well and not as a separate entity that only receives input with no chance of providing feedback to the brain.

The role of the amygdala in motor behavior

Considering that the amygdala projects not only to the autonomic centers, but also the behavioral centers of the brain, it is not complete to just look at the autonomic changes caused by emotional stimuli. Emotions create both sensory and motor consequences (Cardinal et al., 2002) and this is evident with the Acb as a mediator to the motor areas. The decision to choose how and whether or not to act is voluntary. The higher level functions are more flexible, typically making use of the associative cortices to make behavioral decisions that are more goal-oriented and strategic (Berntson & Cacioppo, 2008). They are sensitive to the incentive value of stimuli and targets to adjust motivation for approach or avoidance. However, the cognitive aspect of this voluntary action generation means it is restricted by the availability of cognitive resources since higher level functions need more time and cognitive resources to integrate information and develop more complex reactions. Thus, one effect of emotional reactivity would be extraneous noise in cortical areas.

Projections from the basolateral nucleus of the amygdala (BLA) are referred by LeDoux and Phelps (1993) as the action pathway. The BLA is required in second-order conditioning of pairing a conditioned stimulus to an unconditioned stimulus which requires the coding of incentive and affective value. The learning aspect of this conditioning response is supported by the BLA's connections to the hippocampus (Swanson & Petrovich, 1998, Dolcos et al., 2004). It not only projects onto CEA to control autonomic functions to support complex behavior, but also the ventral striatum and prefrontal cortex (PFC) to generate the behaviors. Rats which have their BLA lesioned can voluntarily avoid pressing the lever producing CS and shock (Cardinal et al., 2002).

The CEA, with inputs from the BLA, projects to dopaminergic ventral tegmental area (VTA), substantia nigra pars compacta (SNc), noradrenergic locus coeruleus, serotonergic raphe nuclei and basal forebrain cholinergic nuclei. In response, noradrenergic, cholinergic and serotonergic outputs go on to support attentional processes and control arousal levels. Additionally, it also controls autonomic functions, such as increased heart rate and blood pressure, to complement action and behavior (Jänig, 2006). The Acb is activated by the released dopamine, which then goes on to influence the prefrontal cortices to code for incentive values and prediction errors (Kandel, Schwartz, Jessell, Siegelbaum & Hudspeth, 2013).

The action dispositions created by emotions are the basis for the motivation to either engage in approach or withdrawal behavior to achieve internal aims and goals (Humphreys and Revelle, 1984; Frijda, 2010). Usually the aims and goals involve either the achievement of a reward or avoidance of punishment.

The role of reward and punishment in motivation and motor behavior

The nucleus accumbens (Acb) of the ventral striatum, with its input from the amygdala and its dopaminergic output to the prefrontal cortex and the ventral pallidum of the basal ganglia, is also called the "limbic motor interface." Dopamine is deemed to be a learning signal in response to rewarding stimuli (Levy & Dubios, 2006; Kandel et al., 2013) as spiking activity is observed in dopamine neurons during the presentation of a reward. When the reward is increased or unexpected, spiking activity is enhanced. When reward is withheld, no spiking activity is observed (Schultz, Dayan & Montague, 1997). Phasic release of dopamine is also found to be involved in maintenance of tasks aims and goals (Bilder, Volavka, Lachman & Grace, 2004). Additionally, it is involved in motivational reward mechanisms in the brain underlying addictive behaviors (Cardinal et al., 2002). When activation in the Acb is low, the inclination to perform goal-directed or reward seeking behavior is reduced (Levy & Dubios, 2006). Vialou and colleagues (2010) found that rats with increased dopamine D1 receptors have decreased immobility, increased approach motivation, and reduced depression during stressful periods; whereas transgenic mice with no D1 receptors exhibit increased immobility, avoidance behavior, and exhibit depression-like behavior during stressful periods. Thus, the Acb and released dopamine are important aspects that support motivational approach behavior.

The activation in the ventral striatum is also found to be graded according to the amount of gains and losses during incentive presentation - higher amounts of potential reward or losses were positively correlated to the activation in the ventral striatum (Chib et al., 2012; 2014). During motor task performance, the effect is reversed - greater amounts of potential rewards or losses were negatively correlated to the activation in the ventral striatum. This decrease in activation has been found to be predictive of motor task performance decrements. The authors concluded, through the

use of mediation analysis, that the ventral striatum is affecting motor performance directly. Additionally, they found that the activation between the ventral striatum and premotor cortex are linked. When the coherence between the ventral striatum and premotor cortex decreases, participants display performance decrements. The authors posit that interference from the ventral striatum can affect motor performance (Chib et al., 2012). Hence, winning or losing can be different stressors to different people based on their level of loss aversion.

Pessiglione and colleagues (2007) also observed a link between the striatal and motor areas. With a greater amount of reward subliminally presented, striatal activation and effort were also significantly higher. Furthermore, this muscular effort was found to be associated with activation in the supplementary motor area (SMA) and primary motor area (M1), leading the authors to conclude that the motor areas were very likely modulated by the motivational effects generated by the striatal area.

Individual differences have been found in the level of sensitivity to reward and punishment. Hardin and colleagues (2006) have shown that shy individuals are more sensitive to rewards than punishment while non-shy individuals are sensitive to both reward and punishment. Chib and colleagues (2012; 2014) posited that different people are stressed differently based on the value they affix on the incentive when they are performing a skilled task. In accordance with the BPS model, the incentive value varies according to the amount of resources that the participants deemed they have. This was termed by the authors as an "endogenous reference point of value influencing skilled task performance". They do not respond exclusively to reward or punishment, wins or losses. Participants who have higher loss aversion were found to suffer performance degradations when presented with large possible incentives and participants who have lower loss aversion were found to suffer performance degradations when presented with large possible losses. The

perception of loss aversion is mediated via the ventral striatum. This can affect performance through the ventral striatum's role in neuromotor control. The activity in the ventral striatum is heightened with an increase in reward and this could add to the nonessential activity in the brain leading to the choking response.

Feedback and modulation of emotional reactivity and motor behavior

The prefrontal cortex (PFC) is known for generating new rules or strategies or shifting from one mental and behavioral set to another. It integrates the information from external and internal states needed to generate adaptive responses or correct maladaptive ones (Levy & Dubios, 2006).

As mentioned earlier, Costanzo and Hatfield (2013) observed that elite football players demonstrated higher left activation in the prefrontal cortex when they are engaging in cognitive reappraisal, as measured by fMRI. This left frontal activation has also been found to be related to attenuated eyeblink startle response, which corresponds to lower amygdala activation (Jackson et al., 2003; Goodman et al., 2013). This could potentially translate into less noise for the cognitive or affective system to process.

The medial prefrontal cortex (mPFC) with its impacting influence on the amygdala serves to adjust emotional sensitivity and behavior. When the mPFC is altered by stress, there is evidence that the activation in the amygdala is enhanced and this causes an exaggerated emotional experience, like the fear response in anxiety (LeDoux & Phelps, 1993). Damage to this area has been involved in mood disorders, such as major depressive disorder and bipolar disorder (Öngür & Price, 2000). It has been found that this was due to the failure to unlearn old associations and shift to develop new strategies (Ragozzino, 2007).

An important part of the mPFC in the emotional process is the anterior cingulate cortex (ACC). The dorsal division is known to process cognitive information, such as modulating attention, monitoring competition, error and cognitive load. One of main role of the ACC is in the monitoring of the information between brain areas so as to attenuate or enhance activity between them to resolve conflict. The ventral division is known to influence autonomic functions with input from the amygdala, hypothalamus, anterior insula and autonomic centers (Bush et al., 2000). Bush and colleagues (1999) have found that these two divisions are mutually exclusive; when the affective division is activated, the cognitive division has been found to be suppressed and deactivated. One of the main inputs to the ACC seems to be coming from the insula, which is involved in internal states monitoring.

The increase in cortico-cortical communication, or coherence, could stem from the ACC being unable to resolve the conflicts due to the increase in information added into the cognitive process. Alternatively, the cognitive function of the ACC could be suppressed as it is preoccupied with processing the affective stimuli associated with the increased stress (Bush et al., 1999), so much so that is not able to exercise conflict resolution.

The function of error monitoring can be measured along the frontal midline using electrophysiological methods by using event related potentials (ERPs). The resultant ERP is also called error-related negativity (ERN) which appears and peaks about 100 ms when an error is made. This is congruent with the ACC function of error monitoring and it is argued that the ACC compares the present response with the correct one. When an error is made, the ACC is activated. Motivational states can affect how the ACC is functioning. When accuracy is emphasized over speed, the ERN amplitude is amplified (Gehring et al., 1993).

Participants with obsessive-compulsive disorders (Gehring et al., 2000) and high negative emotionality and affect (Luu et al., 2000), are found to exhibit higher ERN amplitudes than others without the disorder and those who are more prone to positive emotionality and affect. These studies show that higher levels of distress can increase the error monitoring response for people who are more emotionally affected by these errors.

Another version of the ERN is feedback-related error negativity (fERN) which occurs about 250 – 300 ms after feedback has been presented after a response (Gehring, Liu, Orr & Carp, 2011). It is reportedly similar to the ERN and its amplitude most likely tied to evaluation of good or bad outcomes.

With the 'go' system, there needs to be a 'stop' system. Just as the striatum is necessary in producing approach behavior, it is essential in the production of avoidance and inhibition. Reduced D2/D3 dopamine receptors in the caudate and putamen of the striatum encourages impulsive behavior (Lee et al., 2009). Receptor availability is also correlated to the speed of response inhibition (Ghahremani et al., 2012).

Another kind of frontal asymmetry divides the PFC into the ventrolateral division and the dorsolateral division. Ventrolateral PFC was found to increase their activation during NoGo trials (Sakagami et al., 2001). Additionally, lesion studies in human has found that the inferior frontal cortex (IFC) essential for inhibiting responses. The IFC depends on the noradrenaline released from the locus coeruleus, and activates more strongly to intended targets than unintended ones (Arnsten & Goldman-Ravic, 1984). The IFC has been hypothesized to intercept the Go signal from the basal ganglia (Aron et al., 2007). The dorsal PFC projects mainly to the amygdala and the basal ganglia, which establishes it as an important relay station for the cortico-striatal-pallidal circuit to

control behavior associated with reward and motivation as previously mentioned (Mcdonald, Mascagni & Guo, 1996). The dorsolateral PFC (dlPFC) has commonly been found to be involved in the maintenance of working memory, fed primarily by phasic releases of dopamine (reviewed in Arnsten, Wang & Paspalas 2012). It also participates in top-down regulation of attention, presumably utilizing the the incentive values coded and transmitted by the basal ganglia. Uninhibited activity of the dlPFC has been implicated in schizophrenic disorder and low activity in the dlPFC has been implicated in Alzheimer's disease.

In summary, the PFC has proved to be an important gateway for the final execution, control and monitoring of arousal and voluntary, motivated behaviors which could account for the individual differences in emotion regulation and subsequently, motor performance.

Definition of efficient motor performance

Fitts and Posner's (1967) theory of motor skill learning states that motor skills are usually acquired in three stages, the 1) cognitive stage, 2) associative stage and 3) autonomous stage. During the cognitive stage, movements are conscious and effortful. After sufficient practice, performance becomes coordinated in the association stage. Finally, when the movement is mastered to generate high-quality performance, the performance is efficiently organized and autonomous.

When a set of motor actions are being practiced by a novice for the first time, there is little or no coordination between the brain and the peripheral motor effectors, and every motion is consciously generated and maintained in memory. During this cognitive stage, the basal ganglia transmits and compares the motor command via the cerebellum. Additionally, the basal ganglia communicate with the hippocampus during motor learning. However, as the behavior is practiced

over an extended period of time, coordination increases as the basal ganglia now chunks and refines an entire series of actions into a single functional unit. After this association stage, this functional unit sends motor commands to the motor cortex directly to execute smooth and refined movements that are generally characterized as efficient. The contribution of the anterior cingulate cortex at this time is to monitor errors and any deviations from the intended motion and to transmit feedback to the basal ganglia if corrections are needed and to determine if motor loop units need to be recoded (Graybiel & Mink, 2009). Studies have revealed that this development is translated to less muscular (Weinberg & Hunt 1976; Weinberg, 1978) and neural effort as characterized by a reduction in the electromyographical record of the skeletal muscles accompanied by elevated alpha activity and lower coherence between motor and nonmotor brain areas in electroencephalography (EEG) measures (Busk & Galbraith, 1975; Masters, 1992; Deeny et al., 2003; Kerick et al., 2004; DiRusso et al., 2005; Deeny et al., 2009).

Typically, cerebral cortical activity as recorded by EEG alpha power (i.e. 8-13 Hz) is associated with a relaxed state; the neurons are assumed to be doing the least amount of work during the periods that they fire mostly in unison. Power in the 8 to 10 Hz frequency band has been linked to general arousal while that in the 11-13 Hz band reflects the employment of attentional resources that are task-specific (Smith, McEvoy & Gevins, 1999). A brain actively engaged with the processing of information during task performance results in populations of neurons engaged with different tasks and the synchronous firing, noted during periods of relative disengagement, is disrupted (Hatfield & Kerick, 2007). This desynchrony is characterized by frequencies in the beta (i.e. 13-30 Hz) and gamma (i.e. 36-44 Hz) bands and can be interpreted as periods of high variability of neuronal engagement. The higher frequencies are often observed more often during the cognitive stage of motor skill learning, during which brain areas communicate frequently.

46

Incidentally, the highly variable activity observed in the brain resembles the uncoordinated muscle action of the limbs. On the contrary, heightened alpha band power are often observed in skilled, autonomous motor behaviors demonstrated by experienced and elite athletes. For example, Haufler and colleagues (2000; 2002) observed greater alpha power, particularly in the left hemisphere, in experts than novices during a shooting task. More importantly, this was positively associated with shooting performance.

Complementary to spectral analysis, EEG coherence estimates can indicate which regions are communicating. As coherence estimates between motor and nonmotor brain areas rise, the connections between them are assumed to be rising as well (Hatfield & Kerick, 2007). As mentioned previously, this phenomenon results in greater variability complexity of central neuromotor activity that translates to a reduction or degradation of refined muscle activity and performance accuracy. This is especially true when the premotor areas (i.e., Fz) is communicating with the left temporal area (i.e. T3). There is evidence that T3 activation during the aiming period of the shooting task is related to verbal and analytical processes (Hatfield, Landers & Ray, 1984) that is prominent during early training periods, but decreases over the course of practice (Kerick et al., 2004). Lower T3-Fz coherence was observed in expert marksmen as compared to the lesser skilled (Deeny et al., 2009). As expected, the elevation in coherence estimates observed in the lesser skilled group was associated with an increase in the amount of displacement from the center of the target; indicating more neuromuscular noise and resulting in less accurate shooting performance (Deeny et al., 2009).

47

Motor performance is often executed under conditions of mental stress, which is known to reduce the quality of motor performance. Mental stress causes engagement in nonessential thoughts and makes one lose efficient neural processing, probably reverting from the autonomous stage to the cognitive stage, leading to the phenomenon known as 'choking' (Baumeister, 1984; Beilock & Carr, 2001; Beilock et al., 2004; Rietschel et al., 2012). For example, Rietschel and colleagues (2012) reported an increase in coherence as a task increased in difficulty. There is also evidence of heightened cortical activity and cortico-cortical communication between motor and non-motor areas when marksmen are under stress during a competition in the presence of an audience than when shooting alone (Hatfield et al., 2013). This phenomenon also resulted in increased variability in the aiming trajectory 1 second prior to the trigger pull. This result concurs with the finding that individuals who are highly anxious are observed to engage more muscle units resulting in excess tension and inefficient muscle activity than individuals who are less anxious (Weinberg & Hunt 1976; Weinberg, 1978).

Individual differences in emotion regulation and effects on motor performance

It is important to note, however, that individuals have shown significant differences regarding how fast and well they can perform a skilled task according to how well they can manage stress and emotion when stress is induced by social evaluation (Hatfield et al., 2013), increasing task difficulty (Rietschel et al., 2012) or the provision of incentives (Chib et al., 2014). These differences can be seen not only in EMG measures of the skeletal muscles underlying motor behavior (Weinberg & Hunt 1976; Weinberg, 1978), but also in measures of brain activity using functional magnetic resonance imaging (fMRI) (Chib et al., 2012; 2014; Costanzo & Hatfield,

2013) and EEG (Haufler, Spalding, Santa Maria & Hatfield, 2000, 2002; Hung et al;, 2004; Deeny, Haufler, Saffer & Hatfield, 2009; Hatfield at al., 2013).

Notably, those who are successful in regulating their emotional responses to stress will be more successful in maintaining task performance. It is apparent that elite performers have a tendency to engage in effective emotion regulation. For example, Costanzo and Hatfield (2013) observed that elite American football players are less likely to be affected by negative emotional stimuli when compared to age-matched controls without competitive playing experience as they are more effective in engaging cognitive reappraisal. This observation was associated with heightened left prefrontal activation and reduced overall activation in the cortex relative to controls. The ability to regulate emotions effectively could attenuate the detrimental effects of mental stress on motor performance. When comparing novices to skilled marksmen and elite shooters, the latter exhibited lower cortical activity and cortico-cortical coherence (i.e. synchronized activity between cortical areas) during the aiming period (Haufler et al., 2000, 2002; Deeny et al., 2009). There was also less disruption or nonessential activity in motor behavior as demonstrated by aiming displacement distances from the center of the shooting target (Deeny et al., 2009). As such, there is substantial evidence that efficient employment of muscular and cerebral cortical resources by elite athletes, when compared to novices and controls, is closely associated with effective emotion regulation, positive motivation, and superior motor performance.

Summary

While it is clear that extraneous activity in the brain and muscles, along with the engagement of maladaptive peripheral responses, is detrimental to motor performance the

underlying source of influence is not known. More recently, evidence points to activation in the 1) amygdala (Goodman, Rietschel, Lo, Costanzo & Hatfield, 2013), 2) ventral striatum (Chib et al., 2012) and 3) prefrontal lobe (Costanzo & Hatfield, 2013) as critical to the neurocognitive and peripheral physiological state of the individual when challenged with stress. These regions are the three prominent brain areas that are commonly mentioned in studies of emotional processing (Cardinal, Parkinson, Hall & Everitt, 2002). The amygdala is the control center of lower functions, apportioning attention toward salient stimuli in the environment (Holland & Gallagher, 1999) and exerting appropriate influence on the autonomic nervous system. The ventral striatum assesses and assigns the value of reward while the prefrontal cortex (PFC) plans and directs motor action to facilitate the organism's response to situational demands and consequent problem solving.

The various regions that orchestrate emotion regulation are anatomically connected and play an active role in both the activation and suppression of brain activity. For example, there is evidence that the medial PFC (mPFC) is capable of modulating (i.e., reducing) the activity of the amygdala (Dioro, Viau & Meaney, 1993), thus, promoting stress regulation. Accordingly, lesions to the mPFC are associated with failure to extinguish conditioned fear responses and result in greater reactivity to fearful stimuli (Milad & Quirk, 2002; Sotres-Bayon, Bush & LeDoux, 2004). The anterior cingulate cortex (ACC) of the mPFC is also involved in the regulation of amygdala activity as it monitors the information between brain regions so as to attenuate or enhance activity between them in order to direct executive areas to resolve conflict. The ACC also influences autonomic functions through input from the amygdala, hypothalamus, anterior insula and autonomic centers (Bush, Luu & Posner, 2000). Amplitude measurements of eyeblink startle response and error related negativity (ERN) have been used previously to infer differential activity

in the amygdala (Cuthbert, Bradley & Lang, 1996, Goodman et al., 2013) and ACC (Bush et al., 2000), respectively.

Another interaction between brain regions during emotion regulation is that between the ventral striatum and the PFC. While the PFC can exert influence on the amygdala, the amygdala can also influence the PFC through the ventral striatum. In this manner the amygdala projects to the ventral striatum, which codes for reward (Knutson, Taylor, Kaufman, Peterson & Glover, 2005) via dopamine release from the ventral tegmental area (VTA) (Cardinal et al., 2002). The coding of rewards is associated with asymmetric PFC activation, with rewards associated with approach motivation (and relative left frontal activation) while punishment is associated with withdrawal motivation (and relative right frontal activation) (Pizzagalli, Sherwood, Henriques & Davidson, 2005; Schmidt et al., 2008). These motivational forces can then exert influence on the amygdala as mentioned above. Accordingly, the three areas work together to produce an adaptive behavioral response.

It is apparent that emotion with the activation of associated brain areas and the peripheral nervous system is closely linked to behavioral response systems that help guide motor function. The evidence presented in this chapter illustrates how various dysregulations in emotion regulation could have a detrimental effect on motor performance. However, it is unlikely that one brain area or simply the autonomic nervous system is acting alone; it is highly probable that they work in concert.

Various attempts have been made to understand how activation (and deactivation) in the three prominent brain areas discussed above, in combination with the autonomic nervous system and the processes underlying motor function, could explain superior or inferior cognitive-motor

51

performance. However, these components have not been examined together even though it is very likely that they work in concert. Understanding how each of these components acts to regulate emotions and affect motor performance will allow for better mediation strategies. Therefore, the next study aims to examine the interactions among the amygdala, the ventral striatum, the prefrontal cortex, the autonomic system and cerebral cortical activity in the orchestration of cognitive-motor performance.

With the intention of studying the effects of emotion regulation on motor performance in a real-life scenario, the employment of skilled marksmen as study participants and examination of psychophysiological processes during the aiming task is ideal as the quiescent and motionless state is conducive to high-fidelity recordings of the biomarkers (i.e., reduced motion artifact in EEG and ECG) and ease of scoring of performance. The purpose of this study is to advance our understanding of the processes underlying emotional reactivity under different motivational states during a precision shooting task. In order to study the interactions in the aforementioned brains areas and physiological systems, the proposed study manipulated the administration of reward and punishment to observe the changes in physical (i.e. shooting accuracy and stability of aim) and cognitive performance (i.e. cognitive load and reserve) during the task.

Chapter 4: Proposed Model of Motivation on Emotion Regulation and Motor Performance

Based on evidence gathered from published literature in the previous chapter, a proposed model of motivation on emotion regulation and motor performance is shown below in Figure 2.
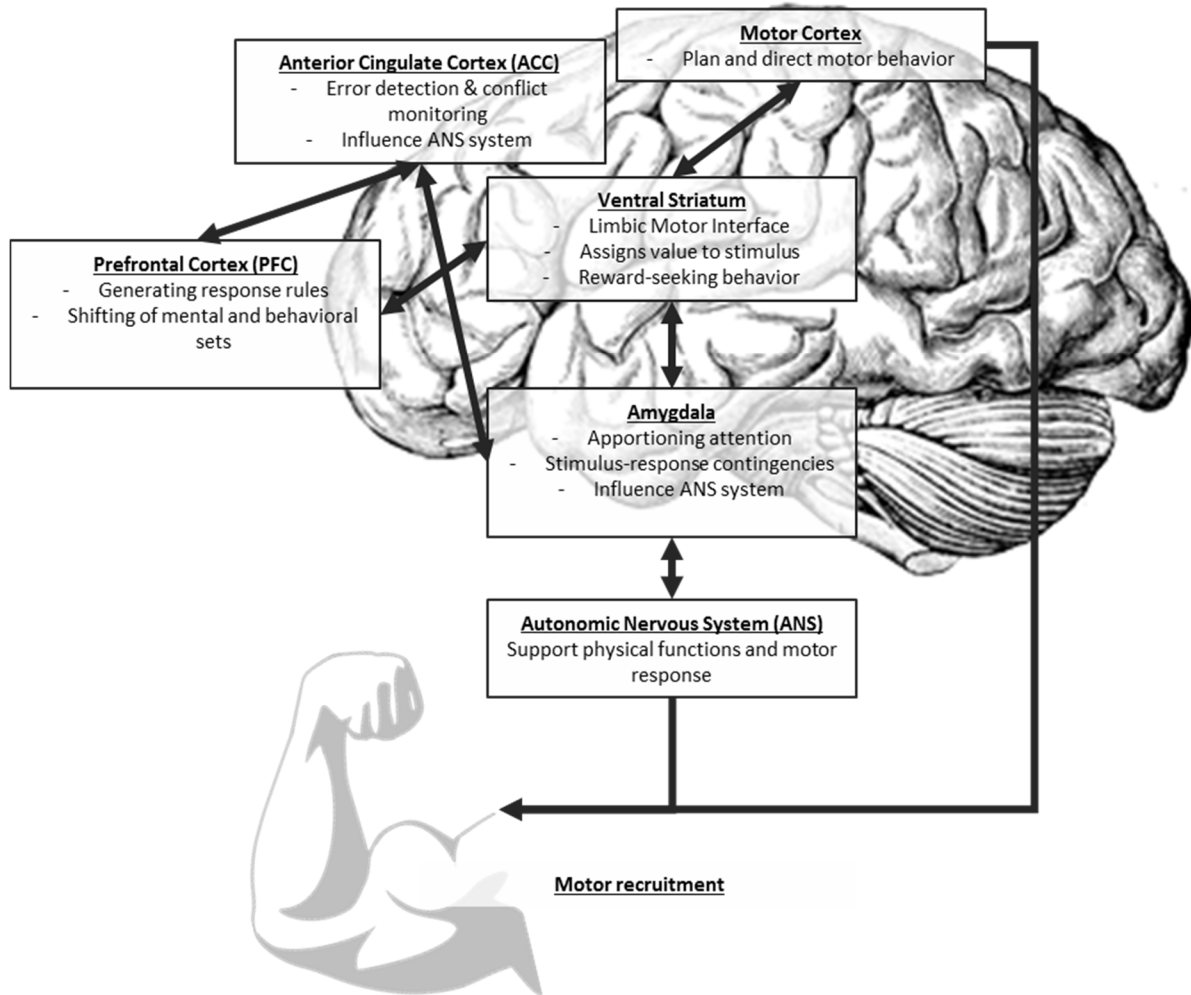
Figure 2. Proposed model of motivation on emotion regulation and motor performance.

An explanation of the processes illustrated in Figure 1 follows. Accordingly, the amygdala, with inputs from sensory areas, sends the emotional and motivational value to the ventral striatum through the release of dopamine. The ventral striatum, in turn, promotes goal-seeking behavior by sending the value signals to the PFC to generate response rules. Next, the

ventral striatum signals the motor cortex to execute the planned behaviors in accordance to the response rules set by the PFC. Conflicts between brain areas and between set and achieved goals are monitored by the ACC. The ACC also signals and receives feedback from the amygdala to generate appropriate ANS responses. If necessary, the PFC can shift mental and behavioral sets to resolve conflict. Additionally, there is evidence that the PFC can moderate the reactivity of the amygdala. As such, it plays a pivotal role as the regulator of the emotional network.

Most non-reflexive or volitional motor actions affected by this regulatory system would be executed in the cognitive or associative stage as they are conceived only when the situation arises; they are not well-practiced and automatic. As a result, performance planning requires more cognitive resources and the more active it is, the more it will affect overall cortical activation and cortico-cortical dynamics. Ultimately, the neuromotor processes will interfere with skilled tasks and degrade the quality of movement. There is also a possibility, especially in a novel situation, that the neuromotor processes generated could be maladaptive. Therefore, this system has to be well regulated through the PFC. The left PFC is related to approach and appetitive behavior, while the right PFC is related to withdrawal behavior (Sutton & Davidson, 1997; Coan & Allen, 2003). The activation of the left and right PFC could be caused by dopamine as the value of reward and the release of dopamine is related to the inclination to perform voluntary goal-directed or reward seeking behavior (Levy & Dubios, 2006) and inhibitory control in the striatum (Lee et al., 2009; Ghahremani et al., 2012). There is evidence that during approach and appetitive mode, there is better regulation of emotion reactivity and this can lead to improved motor control and behavioral outcomes as demonstrated by elite or experienced athletes (Costanzo & Hatfield, 2013; Goodman et al., 2013).

The model of approach motivational influence on emotional regulation and motor performance is illustrated in Figure 3.
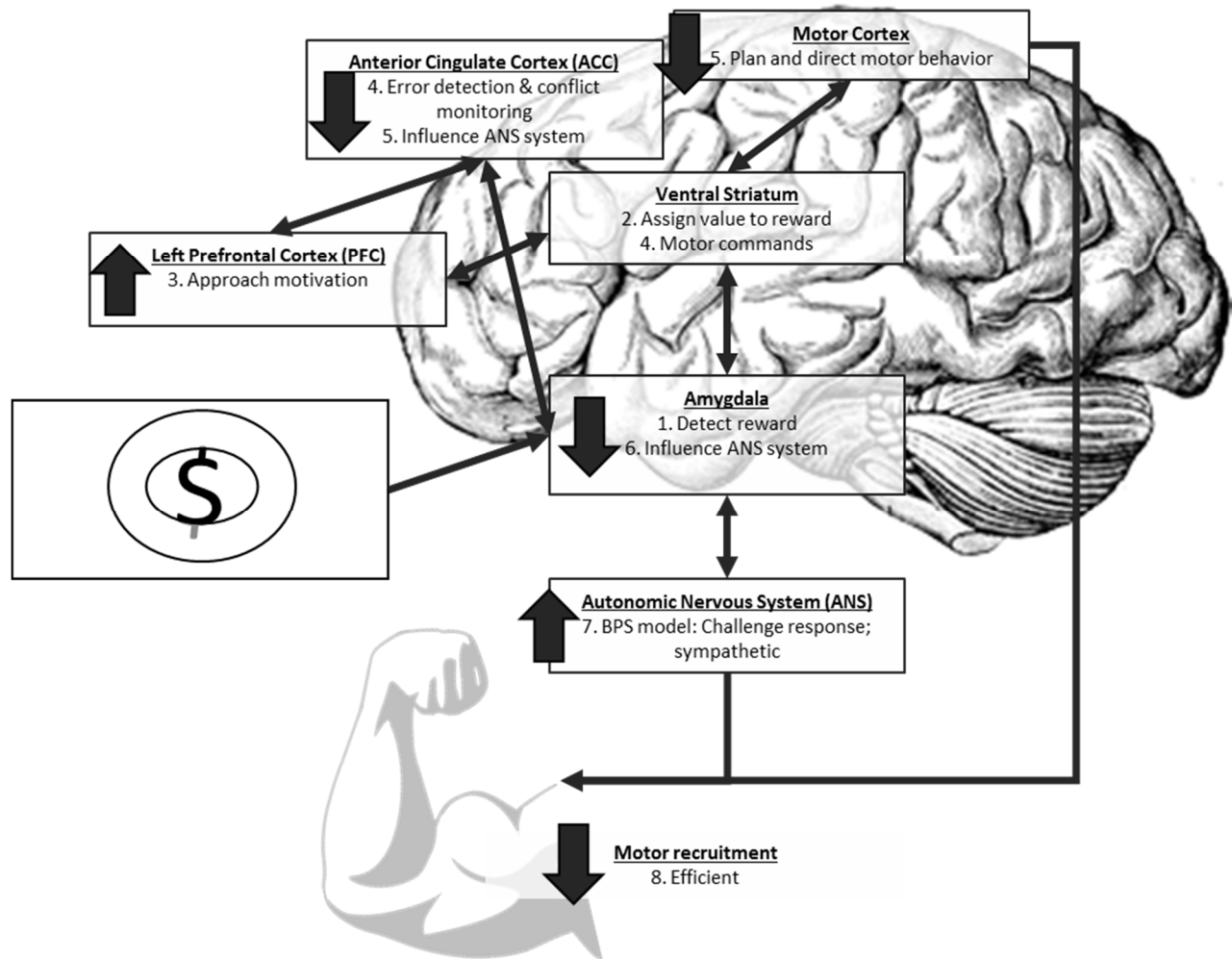
Figure 3. Proposed model of approach motivational influence on emotional regulation and motor performance. The direction of the arrows imply increased or decreased activation. 1. The amygdala detects a reward stimulus and send the information to the ventral striatum which 2. assigns a value to the reward and 3. triggers the left PFC to engage in approach motivation. 4. The left PFC attenuates the activation in the amygdala and 4. the ACC is downregulated as a result. 5. The planned motor behavior is communicated to the motor cortex and at the same time, the ACC sends signals to the 6. amygdala to influence the 7. ANS to engage in a challenge response. 8. The motor unit is activated to generate an efficient response.

Possible empirical findings that could arise from this model are:

1. Reward will encourage approach and appetitive behavior (relative left frontal activation), while punishment is expected to encourage withdrawal behavior (relative right frontal activation).

    i. Pizzagalli and colleagues (2005) have observed that during a reward condition, during which participants earned money for a correct trial, there was greater left-prefrontal activation. Although the relationship between the punishment condition and right-prefrontal activation was not observed, the authors believe the relationship would emerge under stronger punishment conditions that would make them give up easily.

2. Increased trait and/or state relative left frontal activation during task performance is expected to decrease eye blink startle amplitude (i.e. amygdala activation).

    i. Goodman and colleagues (2013) observed that higher state left-frontal asymmetry scores were associated with significant reduction in eye-blink startle amplitude compared to the amplitude observed during lower state frontal asymmetry scores. This finding indicates an underlying mechanism of the frontal lobe to regulate the reactivity of the amygdala, consequently playing a part in emotion regulation.

3. Increased trait and/or state relative left frontal activation during task performance is expected to decrease ERN amplitude (i.e. an index of ACC activation).

    i. Luu and colleagues (2000) observed that individuals with higher negative emotionality disengaged more readily from the task and exhibited larger ERN amplitude. Incidentally, negative emotionality and withdrawal from tasks have been related to relative right frontal activation (Henriques & Davidson, 1997). Thus,

it is reasonable to believe that relative left frontal activation would be related to lower ERN amplitudes.

4. Increased trait and/or state relative left frontal activation during task performance is expected to elevate EEG alpha band power in analytical associative (i.e., left temporal) regions.

    i. Hatfield and colleagues (1984) reported that skilled marksmen demonstrated higher alpha power in the left temporal region (T3) when preparing for a shot, which suggested a reduction in verbal-analytic processes, as their attention focused mainly on visuospatial elements of the task while suppressing such nonessential activity in the brain. Thus, it is reasonable to believe that with greater approach motivation and better emotion regulation, less activity or "noise" will be observed in the higher cognitive areas.

5. Increased trait and/or state relative left frontal activation during task performance is also expected to attenuate EEG coherence between verbal-analytical (left temporal) and motor areas (frontal and central midline regions).

    i. Deeny and colleagues (2003) reported that EEG coherence between such cognitive and motor areas was decreased in experts during the aiming period just prior to trigger pull as compared to that observed in novices. With evidence that experts exhibit superior emotion regulation than novices (Costanzo and Hatfield, 2013), it is highly likely that relative left-frontal activation could account for the differences between experts and novices.

6. Increased trait and/or state relative left frontal activation during task performance is expected to activate sympathetic nervous system response.

i. According to Blascovich and colleagues' (2004) biopsychosocial model of challenge and threat, relative left frontal activation and approach motivation is associated with challenge while relative right frontal activation (and withdrawal motivation) is associated with threat. Thus, the sympathetic response should be activated to support approach behaviors while the parasympathetic response is activated to support withdrawal behavior.

7. Increased trait and/or state relative left frontal activation during task performance is expected to improve accuracy.

i. With positive emotion regulation that results from relative left frontal activation and approach motivation, it is reasonable to believe that this would bring about better behavioral task performance due to economy of motor unit recruitment in the upper extremities and resultant steadiness due lack of excess tension in the involved musculature.

8. Increased trait and/or state relative left frontal activation during task performance is expected to decrease unnecessary movement (i.e., dysfluency of the aiming trajectory or path prior to trigger pull).

i. With increased EEG alpha power and decreased coherence as expected from relative left frontal activation, it is highly likely that the decrease in nonessential activity in the brain that would bring about less extraneous movement in aiming point tracing or trajectory (Deeny et al., 2009).

From the possible findings, expected correlation results are presented in Table 6 below.

Table 6. Hypothesized correlation analysis results. '+' denotes predicted positive relationship. '–' denotes predicted negative relationship.

	Eyeblink startle amplitude	ERN amplitude	High alpha band power	EEG coherence scores	HR variability	Shooting score	Displacement
Frontal asymmetry score	-	-	+	-	+	+	-
Eyeblink startle amplitude		+	-	+	-	-	+
ERN amplitude			-	+	-	-	+
High alpha band power				-	+	+	-
EEG coherence scores					-	-	+
HR variability						+	-
Shooting score							-

Chapter 5: The Present Study

Participants

Thirty-five healthy right-handed participants (26 males), as determined by the Edinburgh Handedness Inventory (EHI), aged 18 to 38 years (M = 21.8, SD = 4.5) were recruited. These participants belonged to the same battalion in the Reserve Officers' Training Corps (ROTC) at the University of Maryland, College Park. They provided informed consent on a form approved by the University of Maryland Institutional Review Board (IRB).

Using the statistical values provided by the previous studies on coherence, emotional regulation and shooting performance (Deeny et al., 2003; 2009; Rietschel et al., 2012; Goodman et al., 2013), a power calculation was conducted to determine a suitable sample size. The minimum number of participants needed to achieve 0.80 power with alpha set at 0.05 was 16.

Materials

State-Trait Anxiety Inventory for Adults (STAI-AD)

The STAI developed by Spielberger and Gorsuch (1983) is a 40-item inventory used commonly to measure anxiety objectively via 20 statements to evaluate state anxiety and 20 statements to evaluate trait anxiety. Scores on both dimensions are related positively to levels of state and trait anxiety. Each item, used to describe a general or present feeling, is rated on a 4-point scale, for which '1' represents 'Almost Never' and '4' represents 'Almost Always'. These measures were used to assess differences in state and trait anxiety and also served to estimate amygdala reactivity (i.e., by proxy) between the three experimental conditions – (i.e., reward, punishment and neutral).

Behavioral Activation System/Behavioral Inhibition System Scales (BAS/BIS)

The BAS/BIS scales provide measures of individual appetitive and withdrawal motivation as developed by Carver and White (1994). Studies have shown that the scales, particularly the BAS scale, correlate well with measures of frontal asymmetry (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997; Coan & Allen, 2003). That is, higher BAS scale scores have been associated with higher left frontal activation. The BAS scale is further divided into three scales, namely, BAS drive, fun-seeking, and reward responsiveness to measure different aspects of approach-oriented behavior. The BIS scale, on the other hand, is associated with higher right frontal activation although evidence for this relationship has been scant.

National Aeronautics and Space Administration (NASA) Task Load Index (TLX)

The NASA TLX includes 6 subscales, which provide for subjective assessment of 1) mental demands, 2) physical demands, 3) temporal demands, 4) performance, 5) effort and 6) frustration on a scale that is divided into 20 equal intervals by 21 vertical tick marks. The tick marks represent values from 0 to 100 and each mark increases by a value of 5. '0' implies 'Very Low' in physical and temporal demands, effort, frustration or 'Perfect' performance and '100' implies 'Very High' in physical and temporal demands, effort, frustration or 'Failure' in performance. This measure was used to control for individual differences in perceived workload.

<u>*Instrumentation*</u>

Shooting simulator

The Meggitt Training Systems Firearms Training System (FATS®) was used to administer the shooting task and to collect data on aimpoint stability 4 s before each shot as well as shooting scores. The FATS is a portable system that supports marksmanship training in a simulated live-firing range environment that is projected onto a large screen. It is capable of generating realistic

shot sounds and a camera system detects shots coming from the weapon simulator. The sound of each shot fired was fed directly into the EEG system from the FATS audio output to mark the execution or triggering of a shot.

EEG-derived error related negativity (ERN) and eyeblink startle (EBS) response measurements were used to infer the activation of the ventral striatum and amygdala, respectively. ECG was used to infer the sympathetic and parasympathetic responses.

EEG

Data from scalp recorded EEG were collected from 32 electrodes using the International 10/20 system (Jasper, 1958). Band-pass filtering was set at 0.1 Hz to 40 Hz with a 60-Hz notch filter. All sites were referenced to the left ear (A1). An electrode was attached to the right ear (A2) for offline re-referencing. Vertical and horizontal eye movements (VEOG and HEOG) were recorded for offline processing to address ocular artifact. This arrangement was chosen according to recommendations provided in previous published studies of frontal asymmetry (Davidson, Jackson and Larsen, 2000; Davidson, 2004). Impedance of all electrodes was maintained be below 5 kOhm.

Eyeblink startle (EBS) response was recorded with EMG electrodes, interfaced with the EEG system amplifiers, placed over the right inferior orbicularis, below the inner and outer canthi (Lang et al., 1990).

ECG was recorded with an electrode attached to the amplifiers of the EEG system, which was placed on the lower left rib. This position was chosen to reduce muscle artifact as typically created when performing the shooting task.

Data Processing

EEG

The data were re-referenced to an averaged-ears reference. Next, the data were visually inspected and subjected to artifact detection. Ocular independent component analysis (ICA) were also employed to remove eyeblink artifacts. Artifact-free data were extracted in 1-second epochs from the EEG time series. Four 1-s epochs were extracted before the trigger pull and a one 1-second epoch was extracted after the trigger pull to investigate the changes in brain activity over time. The five epochs were subjected to fast Fourier Transform (FFT) and then averaged across shots within each condition. More specifically, spectral analysis, using a hamming window with 50% overlap via Fast Fourier Transform, was applied to the segmented EEG data in order to obtain alpha power for each measured site. The frontal asymmetry score was calculated using the formula:

log F4 alpha - log F3 alpha.

EEG coherence estimates between electrodes, calculated in 1-Hz bins and summed across the appropriate frequencies for each power band, was also determined. This metric was calculated using the algorithm (i.e., correlation method equation) provided by BrainVision Vision Analyser,

$$c_{xy}(\lambda) = \frac{|f_{xy}(\lambda)|^2}{|f_{xx}(\lambda)||f_{yy}(\lambda)|},$$

where c is the coherence and f is the covariance as a function of frequency λ.

Feedback-related ERN

Performance feedback was provided to the participant 1 to 2 second following each shot. Event-related potentials (ERPs) were obtained for each condition by time averaging across

epochswithin a condition for a time window beginning 500 ms before performance feedback to 1000 ms after performance feedback at site Cz. The averaged ERP obtained from the error (MISS) trials were subtracted from the averaged ERP of the correct (HIT) trials in each condition (Dikman & Allen, 2000).

ECG

Electrocardiography (ECG) was recorded using EEG electrodes from through Brain Vision amplifier (Brain Products GmbH, Gliching, Germany) at a sampling rate of 1000 Hz. Inter-beat intervals (IBI) were extracted from the ECG time series by R peak detection using the software: QRSTool (http://jallen.faculty.arizona.edu/qrstool_and_cmetx_software_calculating_metrics_cardiac_varia bility). An illustration of an IBI is shown in Figure 4. The signal was also visually examined for artifacts.

Data for the entire duration of each condition were used to calculate heart-related variability metrics. Time-domain metrics such as the standard deviation of the IBI (SDNN) and the root mean squared of the successive differences (RMSSD) of the IBI were used (Task Force of the European Society of Cardiology, 1996). Frequency information from the IBI intervals was also extracted using a Welch periodogram (pwelch) to generate the Power Spectral Density values for each condition. A Hanning spectral window of 100s (to get a minimum of 0.01 Hz resolutions to distinguish high and low frequencies) with 50% overlap was employed. Low frequencies range from 0.04 Hz to 0.15 Hz. High frequencies range from 0.15 Hz to 0.4 Hz. A ratio of low frequency over high frequency was subsequently calculated to obtain LF/HF ratios to determine sympathetic/parasympathetic activity (Berntson et al., 1997).
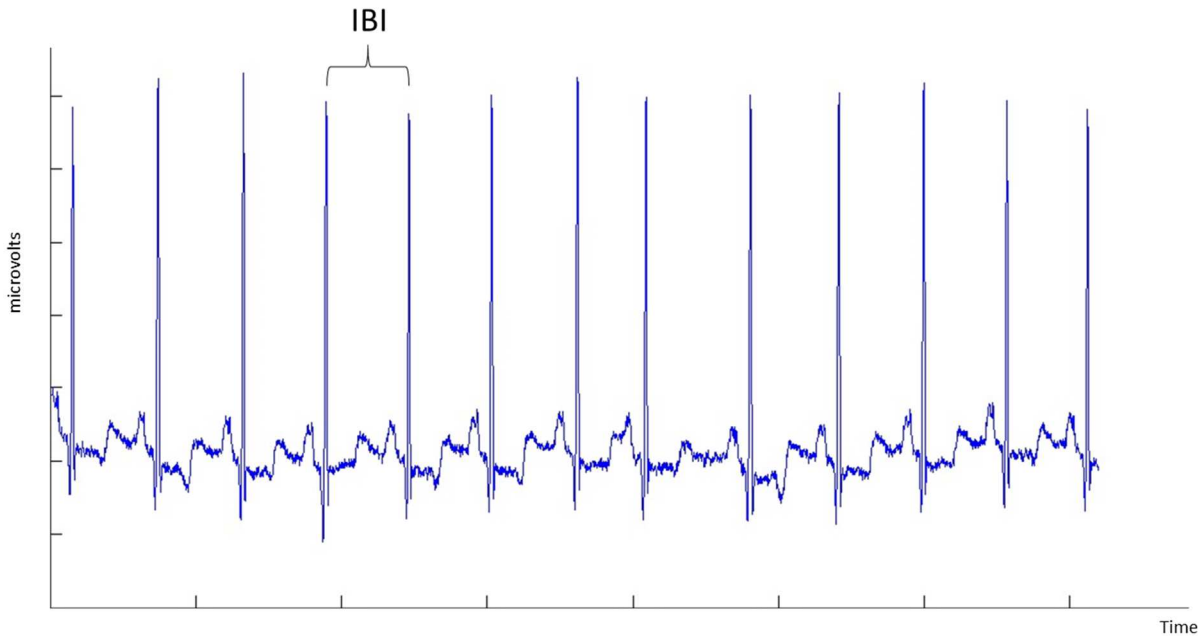
Figure 4.Sample ECG reading. IBI is marked.

Eyeblink startle (EBS)

EMG data, collected to determine EBS, was processed to calculate the amplitude of the eyeblink during the time of the trigger pull. Accordingly, the EBS was generated by the loud sound generated at the time of the trigger pull. The sound was 120 dB with the peak of the sound lasting about 50 ms.

Aimpoint stability

The variability in aimpoint tangential displacement from the center of the target was tracked 4 s before each shot until the shot was executed.

When participants arrived in the laboratory on the day of the experiment, they were provided with an explanation of the aims of the study, the nature of the experiment, and briefed about the contents of the consent form before they provided informed consent. Next, they completed the EHI, BIS/BAS Scales and STAI questionnaires before the EEG cap and electrodes were placed. Once the EEG cap and electrodes were secured and the fidelity of the signal checked, participants were given up to 15 shots to zero their weapon on the simulator. Thereafter, they executed a practice scenario, similar to the actual scenario, with 15 shots. They were encouraged to make any seating adjustments during this time and told that no further adjustments would be allowed after the experiment began so as to ensure comparability across the conditions. Subsequently, a baseline measurement of EEG and ECG activity was taken. Participants were asked to sit still for 2 min with their eyes open and 2 min with their eyes closed while EEG was being recorded. Once that was completed, the experiment commenced.
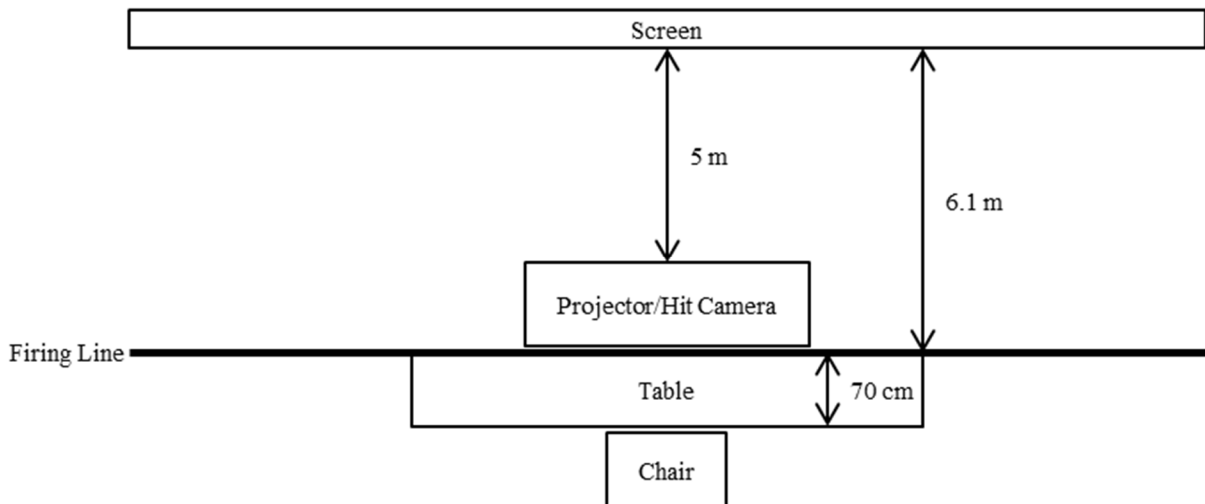

Figure 5. Experimental room set-up.

Figure 5 shows the experimental room set up. The hit camera was stacked on top of the projector, which was connected to the simulator located at a distance of 5 m from the screen on the wall. The firing line, as stipulated in the simulator manual was 6.1 m away from the screen. A long table was aligned with the firing line and the participants were seated behind the table. The experimenter sat behind and to the right of the participant.
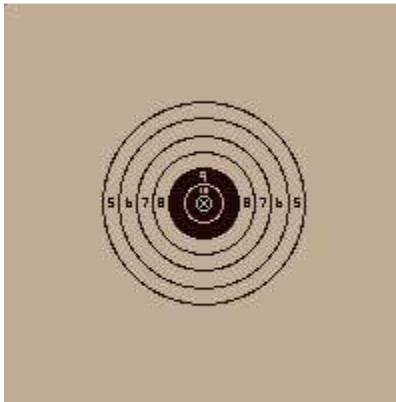
Figure 6. Image of presented bullseye target. The shaded area measured 8 cm in diameter when projected onto the screen.

Participants were instructed to aim and shoot at a bullseye located on a target (see Figure 6) while seated; their hips were to remain in contact with the stationary four-legged chair upon which they were sitting with both feet to remain on the ground and their elbows positioned to stay on the table directly in front of them the whole time while they were aiming firing shots. The recoil function was disabled on the modified pistol to ensure consistency throughout the consecutive shots. Participants had to rack the gun after every shot. The numbers on the rings of the bullseye target represented the respective score earned when a shot landed in the respective area of the ring. The participants were allowed to lean forward or place their hands on the table, just as long as the butt of the pistol did not cross the far end of the table (i.e. the firing line). The seated posture was

69

employed to eliminate the possibility of differences in the participants' facility with shooting in the standing position.

As indicated above, there were three levels of the motivational condition employed in the design of this experiment – (i.e., reward, punishment and neutral). Participants executed 30 shots per condition in six blocks of five shots as each magazine in the pistol only allowed for 5 shots at a time. At the beginning of each condition, the experimenter informed the participant of the condition they were about to enter, the contingency of the condition and encouraged them to try their best to maximize their earnings while minimizing their losses. They were to try their best to get as many hits as possible. They were then told to load their weapon and instructed to begin the aiming process. Participants were also advised to hold still after each shot until feedback was provided before they could proceed to rack the weapon. This strategy was employed to reduce artifact in the EEG associated with the ERN measure. After the 5 shots were taken, the participants were instructed to unload their weapon. All participants had $30 in their starting balance at the beginning of the experiment.

In the reward condition, for each shot that the participants hit *inside* the central ring of the target (i.e. 10 points), participants received one dollar, which was added to their total balance. In the punishment condition, for each shot that the participants hit *outside* the central ring of the target (i.e. 10 points), a dollar was deducted from their total balance. In order to boost their motivation, they were told that the highest performer at the conclusion of the study would receive a $100 bonus. In the neutral condition, no amount was added or deducted from their total balance. The participants received immediate feedback about 1 s after each shot on their performance (i.e. hit, miss, won, lost), their score and their remaining balance, which was displayed on the top of the screen (see Figure 7 for example).
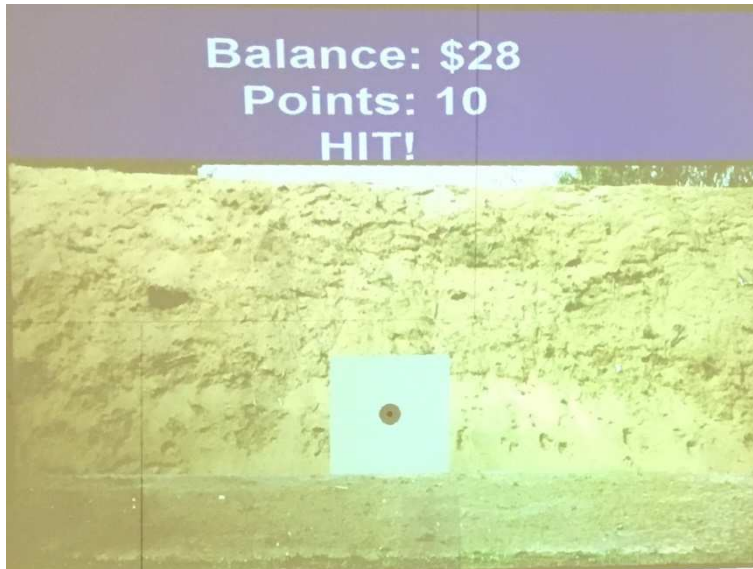
Figure 7. Image of shooting scenario and an example of feedback given in the reward condition.

They were also shown their individual aimpoint trajectory / behavior for each shot, which were presented successively for the preceding 5 shots (see Figure 8 for illustrative example).
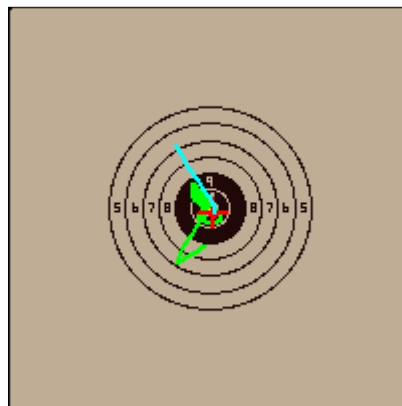
Figure 8. Example of aimpoint tracing provided by the shooting simulator. Green line represents aim 5s before shot, red cross represents where shot was taken and blue line represent barrel movement 1s after shot.

Participants were reminded of the motivational demands of the condition in which they were currently performing after 15 shots. They were also reminded of the performance

contingency of the condition (i.e. win, lose a dollar or no money at stake) and to maximize their earnings, minimize losses and to try their best to get as many hits are possible.

At the end of each condition, participants were asked to complete the STAI-State questionnaire and NASA TLX scales. Finally, a manipulation check in the form of a short interview was conducted to ensure that participants adhered to the intended purpose of the experiment. They were then asked if they felt that they had responded differently in regard to the explicit motivational demands under each of the three conditions and to rank the three conditions according to 1) how stressful and 2) how enjoyable that they felt the conditions were.

The task protocol and measurements taken at each time point is illustrated in Figure 9.
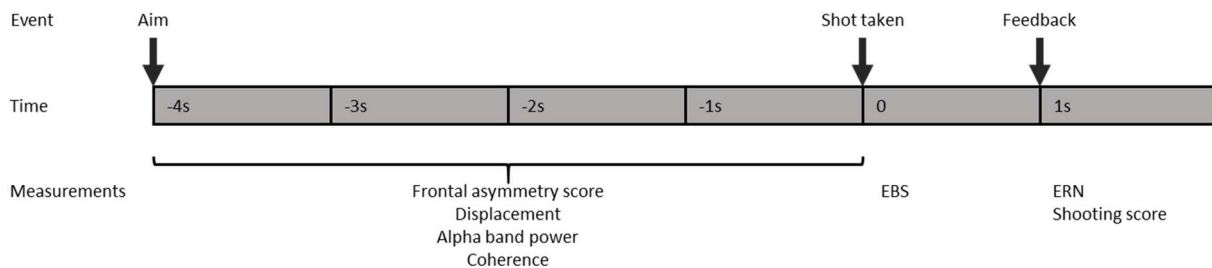
Figure 9. Task protocol illustrating events and measurements taken at each time point.

Statistical analysis

Using the median of the total balance participants had at the end of the experiment, they were divided into 2 equal groups to compare the differences between superior and inferior performers. All measures were subjected to a 3 x 2 (Condition x Performance Group) repeated measures analysis of variance (ANOVA) unless otherwise stipulated.

In addition, and based on the manipulation check at the end of the experiment, all measures were subjected to additional repeated-measures ANOVA to assess, separately, the influence of three levels of stress (i.e., 3 x 2; Stress x Performance Group) and three levels of enjoyment (i.e., 3 x 2; Enjoyment x Performance Group).

Results

End of experiment interview (debriefing)

Out of 35 participants, 2 participants failed to provide clear answers to the interview, insisting that they treated all conditions the same and are removed from Stress and Enjoyment ANOVAs. For the remaining participants, the results of their ranking are shown in Table 7.

Table 7. Summary of participants' ranking on stressfulness and enjoyment.

Condition	Rank Stressful			Rank Enjoyable		
	1 - Most	2	3 - Least	1 - Most	2	3 - Least
Reward	7	20	6	19	10	4
Punishment	22	7	4	7	9	17
Neutral	4	6	23	7	14	12

Five participants ranked the neutral condition as the least stressful but also the least enjoyable; in this case, they also ranked the more stressful condition as less enjoyable. Another five participants gave the same ranking - punishment condition as most stressful and neutral condition as least stressful; reward condition as most enjoyable and punishment condition as least enjoyable. Incidentally, 14 out of 33 participants ranked the most stressful condition as the least enjoyable condition.

Shooting scores

Three participants (two males) were excluded from any further analysis due to unsatisfactory performance. They were observed to have struggled during the shooting task, their shooting scores consistently fell below 1.5 times the interquartile range and the standard deviation of their scores higher than 1.5 times the interquartile range for all three conditions. Repeated measures ANOVA revealed no significant differences in shooting scores or standard deviation of shooting scores across the three motivational conditions.

Repeated measures ANOVA confirmed a significant main effect in total shooting scores between Performance Group ($F(1,30) = 32.38$, $p < 0.01$). The better performing group scored on average about 16 points more in the reward condition, 14 points more in the punishment condition and 9 points more in the neutral condition. The better performing group also attained about 9 more 10-point shots or bulls-eye placements on the target in the reward condition, 7 more in the punishment condition and 5 more in the neutral condition than the worse performing group ($F(1,30) = 59.07$, $p < 0.01$). The former group hit, on average, 5 more consecutive 10-point shots in the reward condition, 3 more in the punishment condition and 1 more in the neutral condition than the latter group ($F(1,30) = 19.33$, $p < 0.01$).

Repeated measures ANOVA applied to the 3 levels of Stress (based on the end of experiment rankings) revealed a significant main effect on the number of consecutive 10-points scored ($F(2,58) = 4.04$, $p < 0.05$). Post-hoc analysis with Bonferroni correction revealed that participants hit 2 more consecutive 10-point shots in the least stressful condition than in the most stressful condition.

Repeated measures ANOVA applied to the 3 levels of Enjoyment (based on the end of experiment rankings) revealed a significant main effect on the number of 10-point shots ($F(2,58)$

= 4.64, *p* < 0.05) and consecutive 10-point shots (*F*(2,58) = 6.38, *p* < 0.01). Post-hoc analysis with Bonferroni correction revealed that participants hit more 10-point shots in the most enjoyable condition than in the second most enjoyable condition. They also hit more consecutive 10-point shots in the most enjoyable condition than in the other 2 less enjoyable conditions.

STAI-State score

A significant main effect of STAI state score was revealed across the different Conditions at the start of the experiment (*F*(3,90) = 6.75, *p* < 0.01). Post-hoc tests with Bonferroni corrections revealed that the punishment and neutral condition were scored higher in terms of self-reported anxiety than at the start of the experiment.

There was a significant main effect of STAI state score across the 3 levels of Stress (*F*(2,58) = 7.12, *p* < 0.01) and 3 levels of Enjoyment (*F*(2,58) = 4.34, *p* < 0.05). Participants reported significantly lower STAI scores in the least stressful and most enjoyable conditions compared to the most stressful and least enjoyable conditions.

NASA TLX

A significant main effect was revealed of reported frustration between Performing Groups (*F* (1, 30) = 5.87, *p* < 0.05). The worse performing group reported feeling more frustration than the better performing group.

In addition, a significant main effect was revealed of reported frustration across the three levels of stress (*F* (2, 58) = 3.64, *p* < 0.05) although post-hoc analysis with Bonferroni failed to reveal significant differences (worse performing group: M = 54.58, SD = 4.45; better performing group: M = 37.50, SD = 4.69).

Finally, a significant main effect for self-reported evaluation of performance was revealed across the three levels of Stress (F (2, 58) = 6.27, $p < 0.01$). Post-hoc analysis with Bonferroni correction revealed that participants reported a significantly closer level to failure in the most stressful condition than in other two less stressful conditions.

Mean Heart Rate

A significant main effect of Condition was revealed for heart rate such that it varied across the conditions (F (2, 56) = 5.99, $p < 0.01$). Post-hoc analysis with Bonferroni corrections revealed higher heart rates in the reward and punishment conditions compared to the neutral condition.

fERN

A significant main effect of Performance Group on fERN amplitude was revealed (F (1, 24) = 4.39, $p < 0.05$; see Figure 10). Worse performers displayed higher fERN amplitudes than better performers.
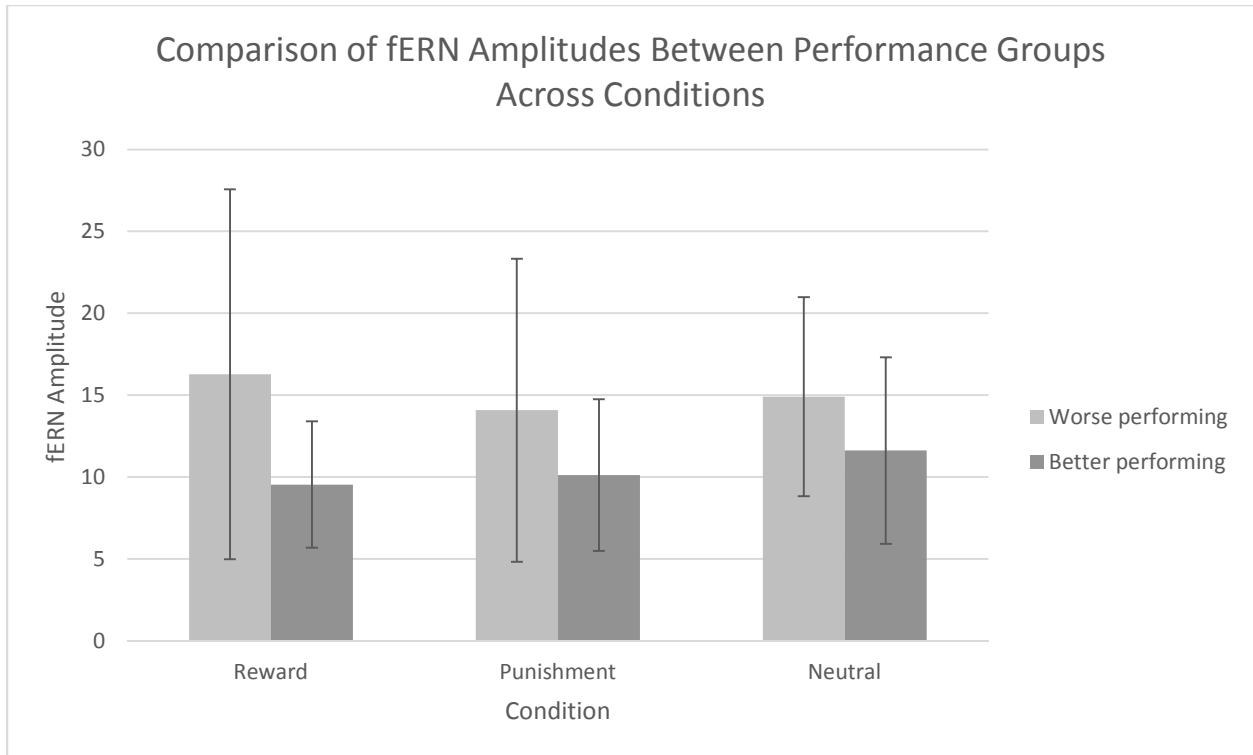
Figure 10. Comparison of fERN amplitudes between Performance Groups across Conditions. Error bars are 1 S.D..

T3 alpha power (8 – 13 Hz)

A significant main effect of Epoch for T3 alpha power was revealed (F (4, 120) = 6.09, p < 0.01). Post-hoc analysis with Bonferroni corrections revealed higher alpha power at 1-s before the shot was taken (i.e., immediately preceding the shot) than at all other time points except 2s before shot. Alpha power was significantly higher 2 s before shot relative to that observed 4s before the shot.

Analysis of high-alpha power (11 – 13 Hz) also revealed a significant effect of Epochs (F (4, 120) = 3.80, p < 0.01). Post-hoc analysis with Bonferroni correction revealed higher high-alpha power 1 s before the shot (i.e., immediately preceding the trigger pull) relative to that observed 4 s before the shot.

T3-Pz coherence

A significant main effect of Epochs was revealed for T3-Pz alpha band coherence (F (4, 120) = 6.08, $p < 0.01$). Post-hoc analysis with Bonferroni correction revealed lower coherence in the alpha bandwidth 1 s before shot execution relative to that observed 4 s before the shot.

There was also a significant interaction effect observed between Condition and Epochs (F (8, 240) 4.06, $p < 0.01$). Post-hoc analysis revealed that the coherence was lower in the neutral condition relative to that in the reward and punishment conditions, which were undifferentiated.

Correlational analysis

Frontal asymmetry score

In the reward condition, the frontal asymmetry score (FAS) was positively related to BAS reward responsiveness (r (32) = 0.37, $p < 0.05$), root mean square of successive differences (RMSSD) in IBI values (r (30) = 0.57, $p < 0.01$), low frequency IBI changes (r (30) = 0.40, $p < 0.05$), high frequency IBI changes (r (30) = 0.59, $p < 0.01$), alpha power at electrode T3 2 s before the shot (r(32) = 0.39, $p < 0.05$), and alpha power at electrode T3 1 s after the shot (r (32) = 0.36, $p < 0.05$). FAS was also negatively related to the standard deviation of jerking movements during the aiming period (r (32) = -0.39, $p < 0.05$).

In the punishment condition, FAS was positively related to BAS reward responsiveness (r (32) = 0.42, $p < 0.01$) and negatively related to the STAI state scores at the start of the experiment (r (32) = -0.36, $p < 0.05$).

In the neutral condition, FAS was positively related to the standard deviation of the score across all shots in the condition (r (32) = 0.40, $p < 0.05$) and negatively related to the number of

bulls-eye or 10-point hits (r (32) = -0.43, $p < 0.05$) as well as being negatively related to Pz-T3 coherence 1 s before shot execution (r (29) = -0.39, $p < 0.05$)..

In the most stressful condition, FAS was negatively related to STAI-trait scores (r (31) = -0.37, $p < 0.05$) as well as STAI-state scores at the start of the experiment (r (32) = -0.46, $p < 0.05$).

In the least stressful condition, FAS was positively related to BAS reward responsiveness (r (31) = 0.42, $p < 0.05$), root mean square of successive differences (RMSSD) in IBI values (r(29) = 0.46, $p < 0.01$), low-frequency (LF) IBI changes (r(29) = 0.39, $p < 0.05$), high-frequency (HF) IBI changes (r(29) = 0.45 $p < 0.01$). FAS was negatively related to the STAI-state scores at the start of the condition (r (31) = -0.51, $p < 0.01$) as well as STAI-state scores at the end of the condition (r(31) = -0.41, $p < 0.05$).

In the most enjoyable condition, FAS was negatively related to the STAI-state scores at the start of the experiment (r (31) = -0.46, $p < 0.05$) and fERN (r (28) = -0.50, $p < 0.01$).

In the least enjoyable condition, frontal asymmetry scores were significantly, positively related to BAS reward responsiveness (r(31) = 0.42, $p < 0.05$) and significantly, negatively related to STAI state scores at the start of the experiment (r(31) = -0.51, $p < 0.01$).

There were no significant correlations in the second most stressful or enjoyable scenario. The results are summarized in Table 8 below.

Table 8. Summary of correlation results for Frontal Asymmetry Score.

Measure: Frontal Asymmetry Score	Relationship	Condition(s)
BAS Reward Responsiveness	Positive	Reward, Punishment, least stressful, least enjoyable
RMSSD	Positive	Reward, least stressful
LF IBI	Positive	Reward, least stressful
HF IBI	Positive	Reward, least stressful

Alpha power T3	Positive	Reward
S.D. of the score across all shots in condition	Positive	Neutral
STAI Trait scores	Negative	Most stressful
STAI state scores at start of experiment	Negative	Punishment, most stressful, least stressful, most enjoyable, least enjoyable
STAI state scores at end of condition	Negative	Least stressful
10-point hits	Negative	Neutral
fERN	Negative	Most enjoyable
Pz-T3 coherence	Negative	Neutral
Standard deviation of amount of jerking movements during aiming	Negative	Reward

EBS amplitude

EBS amplitude was positively related to STAI-state scores at the start of the experiment in the punishment (r (29) = 0.50, p < 0.01), most stressful (r(29) = 0.51, p < 0.01) and least enjoyable conditions (r(29) = 0.49, p < 0.01).

In the punishment condition, EBS amplitude was negatively related to Pz-T3 coherence 1 s before the shot (r (29) = -0.44, p < 0.05).

In the most stressful condition, EBS amplitude was negatively related to Pz-T3 coherence 3 seconds before the shot (r(29) = -0.55, p < 0.01) and 1 second before the shot (r(29) = -0.47, p < 0.05).

In the second most stressful condition, EBS amplitude was significantly positively related to RMSSD of IBI values ($r(28) = 0.43$, $p < 0.05$) and high frequency IBI changes ($r(28) = 0.42$, $p < 0.05$).

In the least enjoyable condition, EBS amplitude was significantly, negatively related to Pz-T3 coherence 3 seconds before shot ($r(29) = -0.39$, $p < 0.05$).

The results are summarized in Table 9 below.

Table 9. Summary of correlation results for EBS amplitude.

Measure: EBS amplitude	Relationship	Condition(s)
STAI state scores at the start of experiment	Positive	Punishment, most stressful, least enjoyable
RMSSD	Positive	Second most stressful
HF IBI	Positive	Second most stressful
Pz-T3 coherence	Negative	Punishment, most stressful, least enjoyable

fERN amplitude

In the reward condition, fERN amplitude was negatively related to mean shooting score ($r(28) = -0.40$, $p < 0.05$), number of 10-point hits ($r(28) = -0.39$, $p < 0.05$) and monetary balance at the end of the experiment ($r(28) = -0.45$, $p < 0.05$). It was positively related to reported frustration ($r(28) = 0.41$, $p < 0.05$), mean amount of jerking movements ($r(28) = 0.39$, $p < 0.05$) and the standard deviation of the amount of jerking movements ($r(28) = 0.51$, $p < 0.01$) during aiming.

In the punishment condition, fERN amplitude was also negatively related to mean shooting score ($r(31) = -0.58$, $p < 0.01$), number of 10-point hits ($r(31) = -0.49$, $p < 0.01$) and monetary balance at the end of the experiment ($r(31) = -0.44$, $p < 0.05$). ERN was positively related to the standard deviation of shooting scores ($r(31) = 0.64$, $p < 0.05$), STAI-state scores at the end of the

condition (r (31) = 0.37, $p < 0.05$), self-reported mental demand (r (31) = 0.37, $p < 0.05$), temporal demand (r (31) = 0.38, $p < 0.05$), mean amount of jerking movements (r (31) = 0.53, $p < 0.01$), mean distance of shots from one another (r (31) = 0.47, $p < 0.01$), and mean distance of shots from the center of the target (r (31) = 0.47, $p < 0.01$).

In the neutral condition fERN amplitude was positively related to self-reported physical demand (r(31) = 0.38, $p < 0.05$).

In the most stressful condition, fERN amplitude was negatively related to mean shooting scores (r (30) = -0.61, $p < 0.01$), number of 10-point hits (r (31) = -0.57, $p < 0.01$), number of consecutive 10-point hits (r (30) = -0.44, $p < 0.05$) and monetary balance at the end of the experiment (r (30) = -0.43, $p < 0.05$). fERN was positively related to the standard deviation of shooting scores (r (30) = 0.55, $p < 0.05$), self-reported mental demand (r (30) = 0.39, $p < 0.05$), physical demand (r (30) = 0.36, $p < 0.05$) and mean amount of jerking movements (r (30) = 0.45, $p < 0.01$) during aiming.

In the second most stressful condition, fERN amplitude was significantly, positively related to STAI trait scores (r(28) = 0.43, $p < 0.05$) and self-reported temporal demand (r(28) = 0.43, $p < 0.05$).

In the least stressful condition, fERN amplitude was significantly, negatively related to mean shooting scores (r(30) = -0.43, $p < 0.05$), number of 10-point hits (r(30) = -0.37, $p < 0.05$) and monetary balance at the end of the experiment (r(30) = -0.46, $p < 0.05$).

In the most enjoyable condition, fERN amplitude was negatively related to frontal asymmetry score (as earlier reported), mean shooting scores (r (28) = -0.41, $p < 0.05$) and monetary balance at the end of the experiment (r(28) = -0.43, $p < 0.05$). FAS was positively related to self-reported temporal demand (r (28) = 0.39, $p < 0.05$), mean amount of jerking movements (r (28) =

0.41, $p < 0.05$), standard deviation of amount of jerking movements (r (28) = 0.54, $p < 0.01$) and standard deviation of the distance of shots from one another (r (28) = 0.40, $p < 0.05$) during aiming.

In the second most enjoyable condition, fERN amplitude was positively related to self-reported physical demand (r (30) = 0.55, $p < 0.01$).

In the least enjoyable condition, fERN amplitude was negatively related to mean shooting scores (r (30) = -0.61, $p < 0.01$), number of 10-point hits (r (31) = -0.60, $p < 0.01$), and monetary balance at the end of the experiment (r (30) = -0.49, $p < 0.01$). It was positively related to the standard deviation of shooting scores (r (30) = 0.59, $p < 0.01$), self-reported physical demand (r (30) = 0.39, $p < 0.05$), STAI-state scores at the end of the condition (r(30) = 0.44, $p < 0.05$) and mean amount of jerking movements (r (30) = 0.36, $p < 0.05$) during aiming.

The results are summarized in Table 10 below.

Table 10. Summary of correlation results for fERN amplitude.

Measure: fERN amplitude	Relationship	Condition(s)
Frustration	Positive	Reward
Mental demand	Positive	Punishment, most stressful
Physical demand	Positive	Neutral, most stressful, second most enjoyable, least enjoyable
Temporal demand	Positive	Punishment, second most stressful, most enjoyable
STAI trait scores	Positive	Second most stressful
STAI state scores at the end of the condition	Positive	Punishment, least enjoyable
Standard deviation of shooting scores	Positive	Punishment, most stressful, least enjoyable
Mean amount of jerking movements	Positive	Reward, Punishment, most stressful, most enjoyable, least enjoyable

Standard deviation of the amount of jerking movements	Positive	Reward, most enjoyable
Mean distance of shots from one another	Positive	Punishment
Standard deviation of the distance of shots from one another	Positive	Most enjoyable
Mean distance from center of the target	Positive	Punishment
Mean shooting score	Negative	Reward, Punishment, most stressful, least stressful, most enjoyable, least enjoyable
Number of 10-point hits	Negative	Reward, Punishment, most stressful, least stressful, least enjoyable
Number of consecutive 10-point hits	Negative	Most stressful
Monetary balance	Negative	Reward, Punishment, most stressful, least stressful, most enjoyable, least enjoyable
Frontal asymmetry score	Negative	Most enjoyable

T3 alpha power

The correlations for T3 alpha power are summarized in Table 11, Table 12 and Table 13 below. They are organized by the three experimental conditions, the ranked stressfulness of the three conditions and the ranked enjoyment of the three conditions.

Table 11. Summary of correlation results for T3 Alpha power across conditions.

Measure	Reward condition					Punishment condition					Neutral condition				
	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot
Mean shooting score	$r(32) = 0.38*$	$r(32) = 0.36*$	$r(32) = 0.37*$	$r(32) = 0.36*$			$r(32) = 0.35*$	$r(32) = 0.36*$							
Standard deviation of shooting scores	$r(32) = -0.36*$	$r(32) = -0.36*$	$r(32) = -0.39*$	$r(32) = -0.39*$		$r(32) = -0.40*$	$r(32) = -0.40*$	$r(32) = -0.40*$							
Consecutive 10-point hits	$r(32) = 0.41*$	$r(32) = 0.35*$	$r(32) = 0.38*$	$r(32) = 0.37*$											
BAS Reward Responsiveness			$r(32) = 0.38*$	$r(32) = 0.35*$											
STAI trait scores											$r(32) = -0.35*$	$r(32) = -0.40*$	$r(32) = -0.35*$		
STAI state at the end of condition	$r(32) = -0.38*$		$r(32) = -0.35*$	$r(32) = -0.39*$	$r(32) = -0.36*$							$r(32) = -0.42*$	$r(32) = -0.36*$	$r(32) = -0.40*$	
Mental demand	$r(32) = -0.39*$	$r(32) = -0.39*$			$r(32) = -0.37*$	$r(32) = -0.41*$	$r(32) = -0.44*$	$r(32) = -0.43*$	$r(32) = -0.35*$	$r(32) = -0.44*$		$r(32) = -0.40*$	$r(32) = -0.38*$		$r(32) = -0.47**$
Physical demand	$r(32) = -0.49**$	$r(32) = -0.47**$	$r(32) = -0.37*$	$r(32) = -0.37*$	$r(32) = -0.42*$	$r(32) = -0.37*$	$r(32) = -0.36*$				$r(32) = -0.40*$		$r(32) = -0.35*$	$r(32) = -0.37*$	$r(32) = -0.43*$
Temporal demand	$r(32) = -0.49**$	$r(32) = -0.48**$	$r(32) = -0.42*$	$r(32) = -0.43*$	$r(32) = -0.47**$	$r(32) = -0.39*$	$r(32) = -0.44*$	$r(32) = -0.43*$	$r(32) = -0.41*$	$r(32) = -0.50**$					
Monetary balance at the end of experiment	$r(32) = 0.39*$					$r(32) = 0.39*$	$r(32) = 0.39*$	$r(32) = 0.40*$	$r(32) = 0.36*$						
Mean amount of jerking movements		$r(32) = -0.37*$	$r(32) = -0.35*$												
Mean distance of shots from one another												$r(32) = -0.36*$			

* correlation is significant at 0.05 level

** correlation is significant at 0.01 level

Table 12. Summary of correlation results for T3 Alpha power across different levels of stress.

Measure	Most stressful					Second most stressful					Least stressful				
	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot
Standard deviation of shooting scores	$r(31) = -0.46^{**}$	$r(31) = -0.43^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.40^{*}$											
BAS Reward Responsiveness									$r(31) = 0.39^{*}$	$r(31) = 0.38^{*}$					
STAI trait scores		$r(31) = -0.37^{*}$													
STAI state at the end of condition											$r(31) = -0.44^{*}$	$r(31) = -0.36^{*}$	$r(31) = -0.49^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.49^{**}$
Mental demand	$r(31) = -0.38^{*}$	$r(31) = -0.48^{**}$	$r(31) = -0.47^{**}$	$r(31) = -0.39^{*}$	$r(31) = -0.50^{**}$	$r(32) = -0.36^{*}$					$r(31) = -0.43^{*}$	$r(31) = -0.45^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.47^{**}$
Physical demand	$r(32) = -0.38^{*}$	$r(32) = -0.37^{*}$		$r(32) = -0.36^{*}$		$r(31) = -0.42^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.36^{*}$		$r(31) = -0.40^{*}$	$r(31) = -0.48^{**}$	$r(31) = -0.41^{*}$	$r(31) = -0.38^{*}$	$r(31) = -0.39^{*}$	$r(31) = -0.46^{**}$
Temporal demand	$r(31) = -0.43^{*}$	$r(31) = -0.49^{**}$	$r(31) = -0.49^{**}$	$r(31) = -0.52^{**}$	$r(31) = -0.47^{**}$	$r(31) = -0.49^{**}$	$r(31) = -0.48^{**}$	$r(31) = -0.45^{*}$	$r(31) = -0.44^{*}$	$r(31) = -0.51^{**}$	$r(31) = -0.42^{*}$	$r(31) = -0.43^{*}$	$r(31) = -0.49^{**}$	$r(31) = -0.47^{**}$	$r(31) = -0.51^{**}$
Monetary balance at the end of experiment						$r(31) = 0.36^{*}$		$r(31) = 0.36^{*}$			$r(31) = 0.36^{*}$	$r(31) = 0.36^{*}$	$r(31) = 0.37^{*}$		
Mean distance of shots from one another								$r(31) = -0.36^{*}$							
Mean distance of shots from center of target												$r(31) = -0.36^{*}$			
LF IBI											$r(29) = 0.437^{*}$	$r(29) = 0.38^{*}$	$r(29) = 0.41^{*}$	$r(29) = 0.37^{*}$	
Pz-T3 coherence 3 seconds before shot						$r(31) = 0.39^{*}$		$r(31) = 0.37^{*}$	$r(31) = 0.37^{*}$	$r(31) = 0.38^{*}$					

* correlation is significant at 0.05 level

** correlation is significant at 0.01 level

Table 13. Summary of correlation results for T3 Alpha power across different levels of enjoyment.

Measure	Most enjoyable					Second most enjoyable					Least enjoyable				
	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot	1 second after shot
Mean shooting score	$r(31) = 0.36^*$			$r(31) = 0.38^*$											
Standard deviation of shooting scores			$r(31) = -0.36^*$	$r(31) = -0.41^*$											
Consecutive 10-point hits	$r(31) = 0.40^*$			$r(31) = 0.41^*$											
STAI trait scores							$r(31) = -0.38^*$				$r(31) = -0.36^*$	$r(31) = -0.38^*$			
STAI state at the end of condition			$r(31) = -0.38^*$	$r(31) = -0.36^*$	$r(31) = -0.40^*$	$r(31) = -0.40^*$	$r(31) = -0.40^*$	$r(31) = -0.40^*$	$r(31) = -0.37^*$	$r(31) = -0.36^{**}$					
Mental demand	$r(31) = -0.52^{**}$	$r(31) = -0.54^{**}$	$r(31) = -0.52^{**}$	$r(31) = -0.51^{**}$	$r(31) = -0.54^{**}$						$r(31) = -0.41^*$	$r(31) = -0.42^*$			$r(31) = -0.42^*$
Physical demand	$r(31) = -0.49^{**}$	$r(31) = -0.45^*$	$r(31) = -0.44^*$	$r(31) = -0.41^*$	$r(31) = -0.46^{**}$	$r(31) = -0.45^*$	$r(31) = -0.41^*$		$r(31) = -0.36^*$	$r(31) = -0.44^*$					
Temporal demand	$r(31) = -0.51^{**}$	$r(31) = -0.49^{**}$	$r(31) = -0.55^{**}$	$r(31) = -0.52^{**}$	$r(31) = -0.58^{**}$	$r(31) = -0.42^*$	$r(31) = -0.41^*$	$r(31) = -0.36^*$	$r(31) = -0.37^*$	$r(31) = -0.44^*$	$r(31) = -0.42^*$	$r(31) = -0.50^{**}$	$r(31) = -0.52^{**}$	$r(31) = -0.54^{**}$	$r(31) = -0.47^{**}$
Monetary balance at the end of experiment	$r(31) = 0.45^*$	$r(31) = 0.36^*$	$r(31) = 0.43^*$	$r(31) = 0.41^*$							$r(31) = 0.36^*$	$r(31) = 0.37^*$			
Pz-T3 coherence 3 seconds before shot					$r(31) = 0.36^*$										

* correlation is significant at 0.05 level

** correlation is significant at 0.01 level

Heart rate variability

Heart rate variability was positively related to the mean shooting scores (SDNN: r (30) = 0.52, $p < 0.01$; RMSSD: r (30) = 0.40, $p < 0.05$; LF IBI: r (30) = 0.45, $p < 0.05$) and negatively related to the standard deviation of the shooting scores across shots in the reward condition (SDNN: r (30) = -0.57, $p < 0.01$; RMSSD: r (30) = -0.43, $p < 0.05$; LF IBI: r (30) = -0.46, $p < 0.05$). The same relationships were found for the most enjoyable condition (mean shooting scores – SDNN: r (29) = 0.57, $p < 0.01$; RMSSD: r (29) = 0.39, $p < 0.05$; LF IBI: r (29) = 0.48, $p < 0.01$; standard deviation of the shooting scores – SDNN: r (29) = -0.59, $p < 0.01$; RMSSD: r (29) = -0.40, $p < 0.05$; and LF IBI: r (29) = -0.49, $p < 0.01$).

HRV was positively related to alpha power recorded from the T3 electrode across all 4 epochs before the shot in the reward condition. The results are summarized in Table 14 below. The same relationship was found for LF IBI in the least stressful condition (4s: r (29) = 0.44, $p < 0.05$; 3s: r (29) = 0.38, $p < 0.05$; 2s: r (29) = 0.41, $p < 0.05$; 1s: r(29) = 0.37, $p < 0.05$) and SDNN and RMSSD in the most enjoyable condition (SDNN – 4s: r (29) = 0.39, $p < 0.05$; 3s: r (29) = 0.37, $p < 0.05$; 2s: r (29) = 0.37, $p < 0.05$; RMSSD – 3s: r(29) = 0.40, $p < 0.05$; and 2s: r (29) = 0.41, $p < 0.05$).

Table 14. Summary of correlation results for HRV against T3 alpha.

Measure	4 seconds before shot	3 seconds before shot	2 seconds before shot	1 second before shot
SDNN	r (30) = 0.40*	r (30) = 0.39*	r (30) = 0.45*	r (30) = 0.41*
RMSSD	r (30) = 0.36*	r (30) = 0.40*	r (30) = 0.44*	r (30) = 0.37*
LF IBI	r (30) = 0.42*	r (30) = 0.40*	r (30) = 0.46*	r (30) = 0.44*

* correlation is significant at 0.05 level

** correlation is significant at 0.01 level

In the punishment condition, the LF/HF ratio was positively related to the mean amount of jerking movements ($r(30) = 0.41$, $p < 0.05$), standard deviation of the amount of jerking movement across all shots in the condition ($r(30) = 0.43$, $p < 0.05$), standard deviation of the distance across all shots in the condition ($r(30) = 0.37$, $p < 0.05$) and standard deviation of the distance of all shots in the condition from the center of the target ($r(30) = 0.38$, $p < 0.05$). The same relationship was found in the most stressful condition (mean amount of jerking movements ($r(30) = 0.43$, $p < 0.05$), standard deviation of the amount of jerking movement across all shots in the condition ($r(30) = 0.41$, $p < 0.05$), mean distance of across all shots in the condition ($r(30) = 0.40$, $p < 0.05$) standard deviation of the distance across all shots in the condition ($r(30) = 0.39$, $p < 0.05$), mean distance of all shots in the condition from the center of the target ($r(30) = 0.38$, $p < 0.05$) and standard deviation of the distance of all shots in the condition from the center of the target ($r(30) = 0.40$, $p < 0.05$)).

Hit/Miss Comparison

In order to investigate differences between 10-point shots and non-10-point shots, a 2 x 3 x 5 x 2 (Hit/Miss x Condition x Epoch x Performance Group) repeated measures ANOVA was conducted for EEG measures. One subject did not have enough segments of misses for analysis in the reward condition and another subject did not have enough segments of hits for analysis in the neutral condition. A 2 x 3 x 2 (Hit/Miss x Condition x Performance Group) repeated measures ANOVA was conducted for aiming behavior. This included the amount of jerking movements, precision (i.e. distance of shots from one another) and accuracy (i.e. distance of shots from the center of the bullseye target).

T3 High alpha power (11-13 Hz)

As before, a significant main effect of Epoch was found (F (4, 112) = 3.90, p < 0.01; see Figure 11). Post-hoc analysis with Bonferroni correction revealed higher high-alpha power in the aiming period 1 s before the shot relative to that observed 4 s before the shot.

Additionally, there was a significant main effect of Performance Group (F (1, 28) = 8.00, p < 0.01). The better performing group showed significantly lower high-alpha power as compared to the worse performing group.

There was also a significant interaction effect of Condition x Epoch x Performance Group (F (8, 240) = 2.31, p < 0.05). Post-hoc tests revealed that the worse performing group did not show the varying main effect of Epoch while only the better performing group did. The better performing group showed significantly greater high-alpha values 1 to 3s than 4s before the shot while the worse performing group did not show any significant differences across the aiming period. This effect was found to be present only in the neutral condition (F (4, 60) = 5.72, p < 0.01).
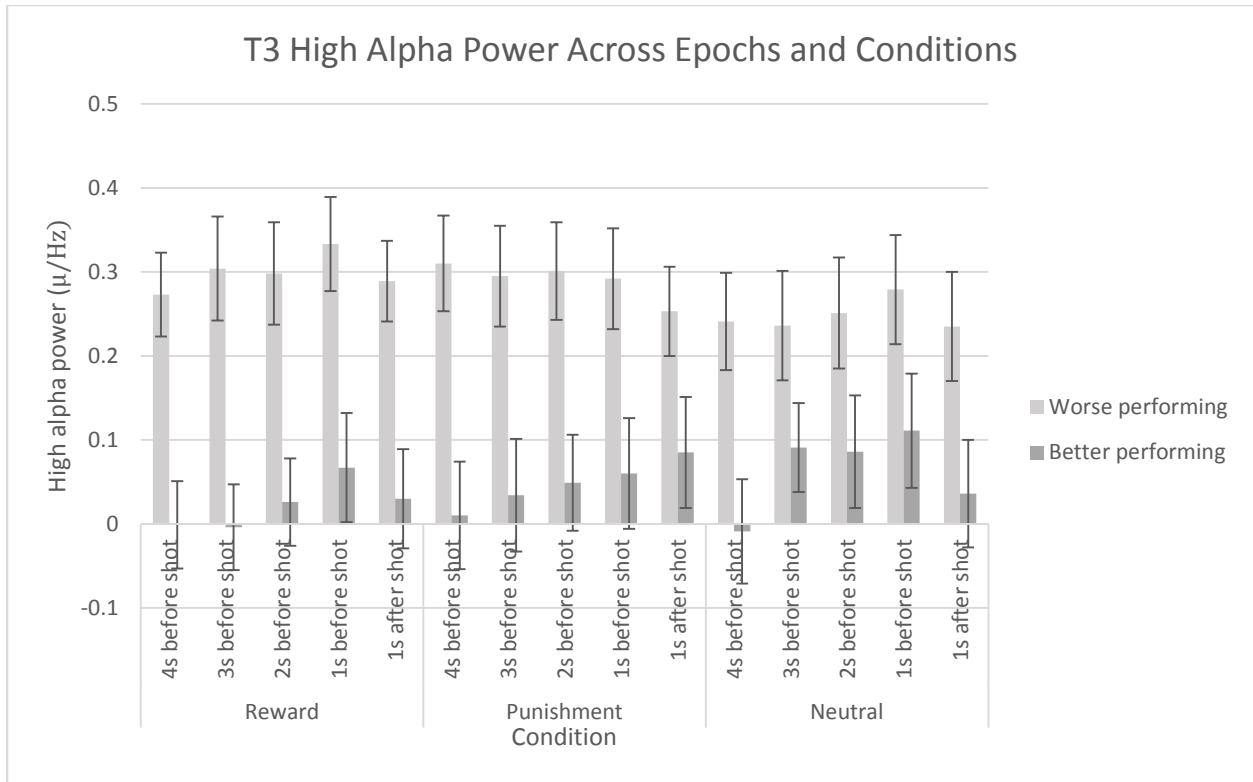
Figure 11. T3 High Alpha-Power across Epochs and Conditions. Errors bars denote 1 S.E..

Fz-T3 Coherence

A significant interaction effect of Hit/Miss x Performance Group was found (F (1, 30) = 51.98, $p < 0.01$; see Figure 12). Post-hoc tests revealed that the better performing group showed greater Fz-T3 coherence during missed shots than hit shots while the worse performing group showed greater Fz-T3 coherence during hit shots than missed shots. Within Hits, there was a significant main effect of Performance Group (F (1, 30) = 22.66, $p < 0.01$). The better performing group showed significantly lower coherence than the worse performing group. Within Misses, there was a significant main effect of Performance Group as well (F (1, 30) = 7.60, $p < 0.05$). The better performing group showed significantly higher coherence than the worse performing group.
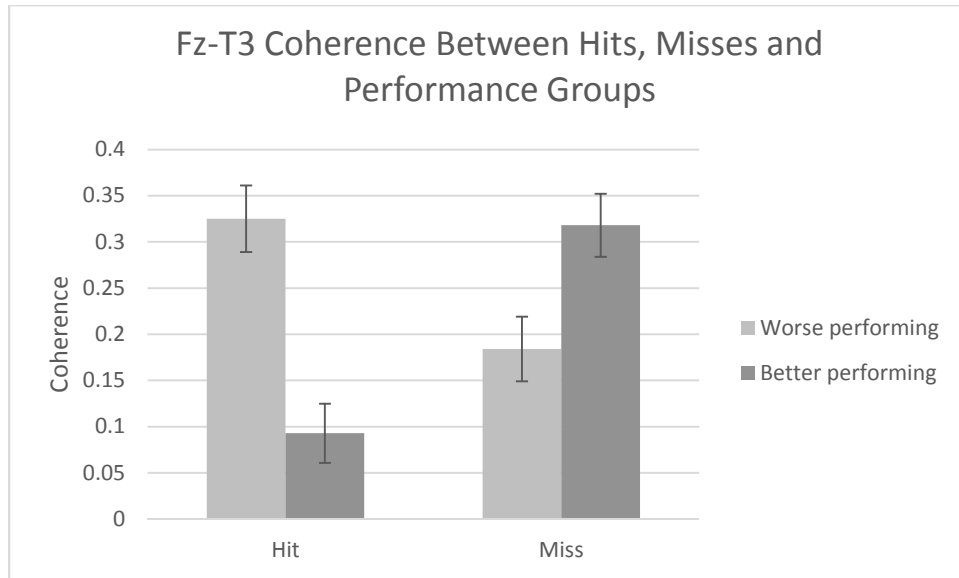
Figure 12. Fz-T3 Coherence between Hits, Misses and Performance Groups. Error bars denote 1 S.E..

Pz-T3 Coherence

A significant main effect of Hit/Miss was found (F (1, 30) = 4.33, $p < 0.05$; see Figure 13). Post-hoc analysis with Bonferroni correction revealed higher Pz-T3 coherence when participants missed the 10-point mark than if they hit the 10-point mark.

A significant interaction effect of Hit/Miss x Group was also found ((F (1, 30) = 78.15, $p < 0.01$). Post-hoc tests revealed that the better performing group showed greater Pz-T3 coherence during missed shots than hit shots while the worse performing group showed greater Pz-T3 coherence during hit shots than missed shots. Within Hits, there was a significant main effect of Performance Group (F (1, 30) = 24.80, $p < 0.01$). The better performing group showed significantly lower coherence than the worse performing group. Within Misses, there was a significant main effect of Performance Group as well (F (1, 30) = 13.23, $p < 0.01$). The better performing group showed significantly higher coherence than the worse performing group.
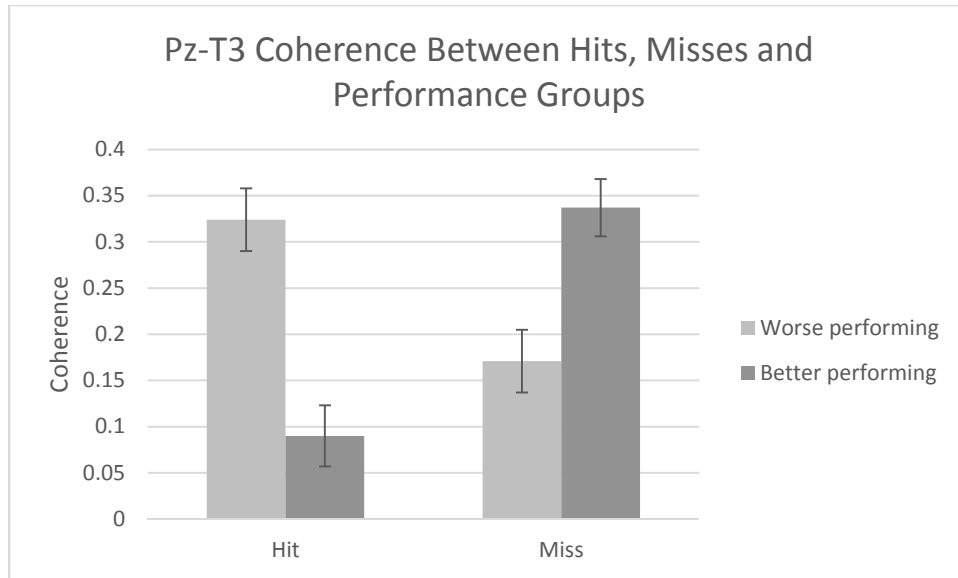
92

Figure 13. Pz-T3 Coherence between Hits, Misses and Performance Groups. Error bars denote 1 S.E..

Amount of Jerking Movements, Precision, Accuracy

A significant main effect of Hit/Miss was found (F (1, 30) = 16.06, $p < 0.01$; see Figure 14). Post-hoc analysis with Bonferroni correction revealed significantly reduced amount of jerking movements for hits than misses. The same was found for precision (F (1, 30) = 30.00, $p < 0.01$; see Figure 15) and accuracy (F (1, 30) = 12.14, $p < 0.01$; see Figure 16). Post-hoc analysis with Bonferroni correction revealed significantly shorter distance between shots and to the center of the target for hits than misses. No significant main effects were found for the standard deviations of these measures.
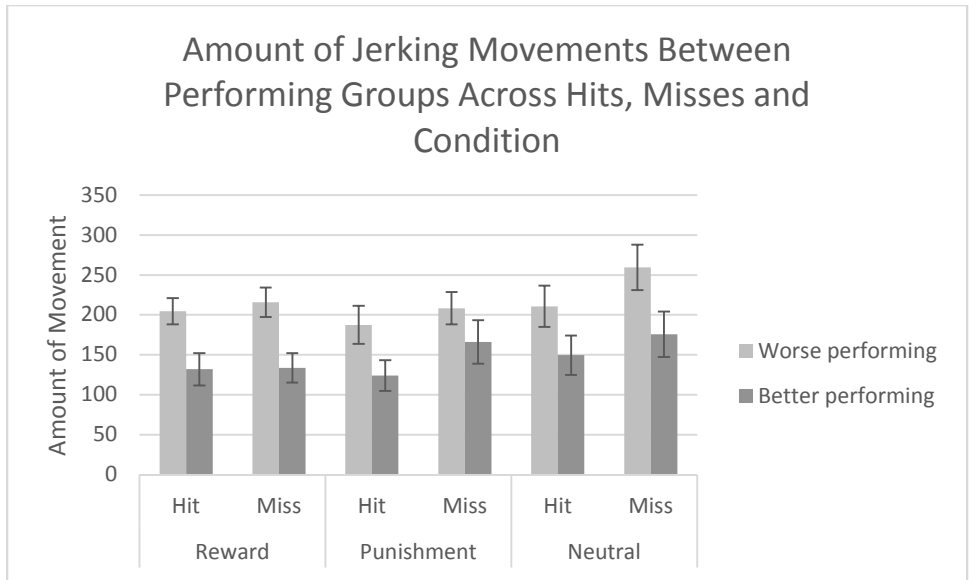
Figure 14. Amount of Jerking Movements between Performance Groups across Hits, Misses and Condition. Error Bars denote 1 S.E..
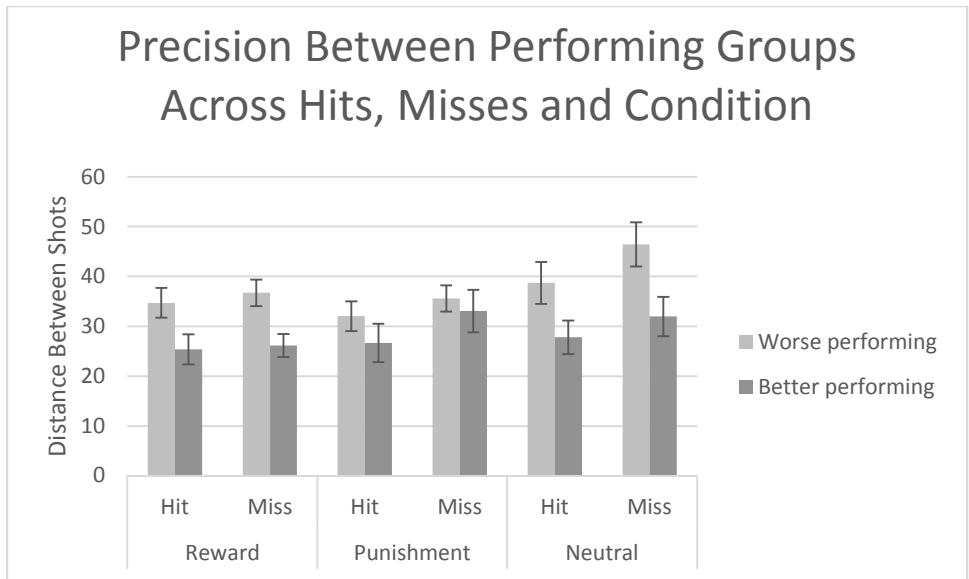

Figure 15. Precision between Performance Groups across Hits, Misses and Condition. Error Bars denote 1 S.E..
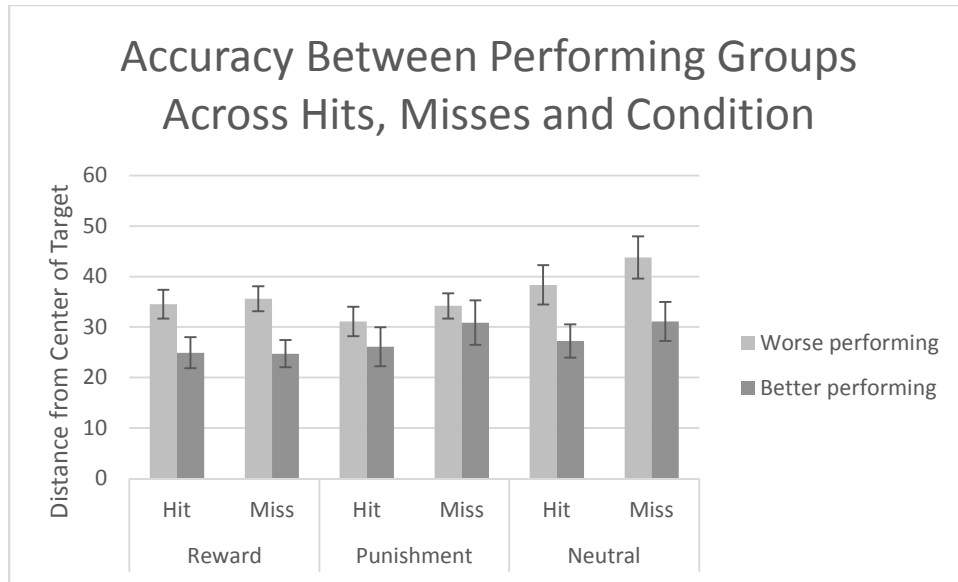
Figure 16. Accuracy between Performance Groups across Hits, Misses and Condition. Error Bars denote 1 S.E..

Other Measures

No significant main effects or interaction effects were found for frontal asymmetry score and Cz-T3 coherence.

Discussion

The proposed neuroaffective model states that the amygdala transmits emotional and motivational value to the ventral striatum, which then sends signals to the PFC to generate approach or withdrawal responses. The ventral striatum, as the limbic-motor interface, also exerts influence on the motor cortex to produce coordinated motor responses based on commands dictated by the PFC. The ACC, which monitors conflicts and errors between planned and executed behaviors communicates with the PFC and the amygdala to generate relevant ANS responses.

In this study, the reward and punishment scenarios were designed to create differential motivational values so as to compare their effects on prefrontal regulatory functions on the other

95

parts of the brain. In accord with the proposed neuroaffective model, the frontal regions of the brain were observed to have an effect on the other regions and processes mainly in the reward and neutral conditions. The beneficial effects of greater left frontal activation (or approach motivation), as shown in Figure 17, of higher heart rate variability, higher alpha power in the left temporal region, lower PZ-T3 coherence, lower fERN amplitude and reduced variability in jerking movements during aiming was only seen in the reward, neutral and most enjoyable conditions. This constellation of findings coincides with the positive relationship of reward-seeking behavior as seen in the BAS reward responsiveness measurement. Frontal activation effects, as previously reported (Pizzagalli et al., 2005), was once again observed only in reward seeking or neutral scenarios. It is possible that maybe a shooting task, where inhibition is not required, could be unsuitable to produce withdrawal tendencies.
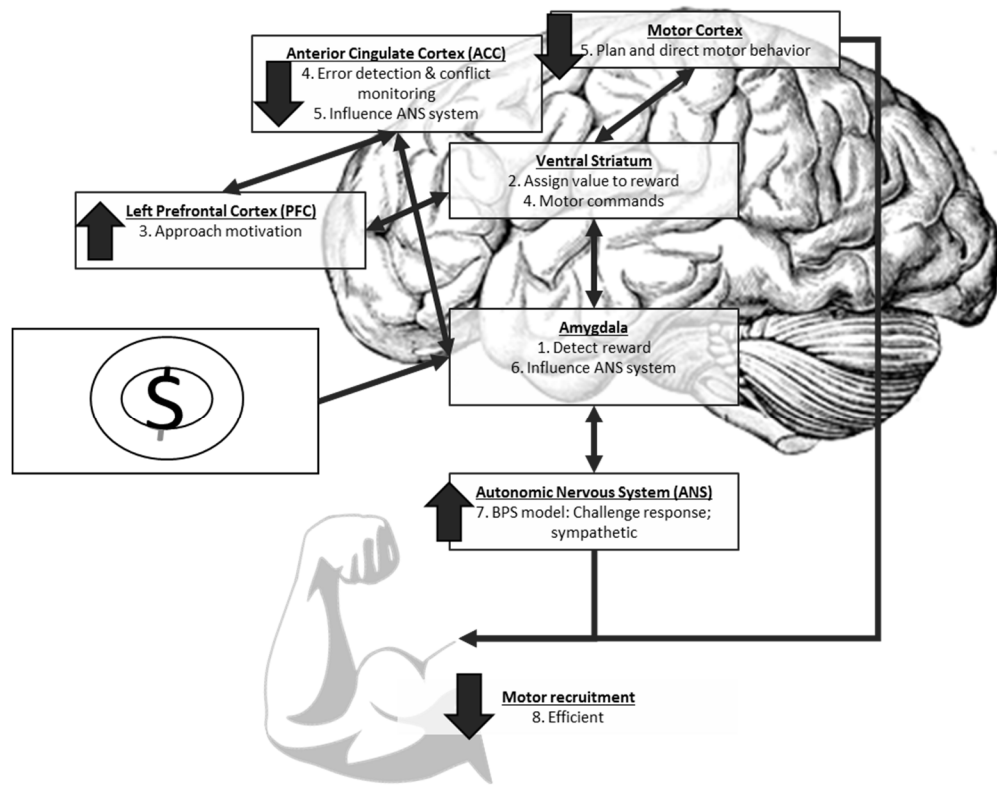
Figure 17. Updated relationships, as observed in this study, of when left frontal activation increases with reward. Notably, the effect on the amygdala is removed.

In the updated model above (see Figure 17), the effect of the PFC on the activity of the amygdala has been removed. EBS amplitude, which is related to amygdala reactivity and anxiety (Cuthbert et al., 1996), seems to only be activated and mainly positively linked to STAI state scores in the punishment, most stressful and least enjoyable conditions – negative affective states. It was also observed that an increase in EBS amplitude was related to a decrease in Pz-T3 coherence in those same conditions. This was contrary to the expectation that the increase in amygdala reactivity would lead to more (i.e., non-essential) communication between the verbal-analytical left temporal region and the visual-spatial motor planning regions of the brain. Instead, the response appears to be an adaptive one as other investigators have reported that EEG coherence that is negatively related to expertise in skilled marksmen (Deeny et al., 2003). However, the participants in the

97

present study were not highly skilled so the negative relationship between the EBS and cortico-cortical communication could be indicative of an earlier stage of learning where brain areas are making associative links.

One of the significant effects elicited by the different conditions was that observed on the STAI state scores, which were higher at the end of the punishment and, surprisingly, the neutral condition than at the beginning of the experiment. The reward condition did not effect a significant change. This finding could be due to the observation that most of the participants rated the reward condition less stressful and most enjoyable. These factors were found to result in lower reported anxiety levels as well. Even though the neutral condition played no part in monetary incentives or the result of the competition between the participants, many of them reported at the end-of-experiment interview that the anxiety came from not performing as well as they would like to during the condition.

Another physiological response influenced by the three different conditions was that of mean heart rate. Mean heart rate was found to be higher in the reward and punishment conditions than in the neutral condition, reflecting that the monetary incentives created increased arousal. According to Blascovich and colleagues (2004) who described the biopsychosocial model of arousal regulation, increased heart rate is also an adaptive coping mechanism to deal with challenge and threat. Heart rate variability in the reward and punishment conditions was related mainly to shooting performance and cortical activation. When in the reward condition, which was most enjoyable and least stressful of the conditions, heart rate variability was positively related to shooting scores, inversely related to variability in shooting performance and positively related to alpha power (i.e. less activation) in the left temporal region. In the punishment (and most stressful) condition, an increase in sympathetic response (i.e. increased LF/HF ratio) was positively related

to jerking movements as well as variability of placement (on the target) in the shots taken. This finding is congruent with the challenge and threat hypothesis where distinct cardiac profiles can predict motor performance. In the case of a perceived challenge (i.e. reward and enjoyment), increases in heart rate variability led to better performance. Conversely, in the case of a threat (i.e. punishment or overwhelming stress), the sympathetic nervous system is activated and could lead to extraneous motions that could be detrimental to shooting performance.

In this case, the relationship that was predicted to promote emotion regulation could possibly be explained by the participants' perceptions of the required demands to execute a task. This notion is consistent with the biopsychosocial model of arousal regulation, which states that individuals will react according to how well equipped they believe they are to meet the demands of the task. Furthermore, the model would also explain why left temporal alpha power was related to heart rate variability measures.

The observed increase in alpha power in the left temporal region across the epochs leading up to the trigger pull, as reported for skilled marksmen (Hatfield et al., 1984), appears to be associated consistently with the mental, physical and temporal demands that participants reported feeling when they were completing the task. It should be noted that in this study, higher alpha power in the left temporal region was positively related to shooting performance, particularly in reward, punishment, as well as the most stressful and the most enjoyable conditions (i.e., those high in emotional arousal).

Between better and worse performers, other than differences in their shooting performance, worse performers reported feeling significantly more frustration than better performers. Of note, worse performers also displayed higher fERN amplitudes than better performers. Although a significant correlation between reported frustration and fERN amplitude was reported only in the

99

reward condition, the finding is consistent with Luu and colleagues' (2000) report that higher negative emotionality results in larger ERN amplitudes. Larger fERN amplitudes, as mentioned earlier in Chapter 4, is related to participants paying greater emphasis on the negative feedback of their results. Consequently, this observation was negatively related to shooting performance, positively related to variability of performance, negatively related to 10-point hits and positively related to variability in the aiming trajectory behavior (where there are increased jerking movements), shots are fired further from one another and further from the center of the target. In this manner, the error monitoring and conflict management function of the ACC appears to be over-correcting bad shots making them worse and more variable. This results in the activity in this area, as inferred by fERN amplitude, to be affecting shooting performance through corrective mechanisms based on performance feedback. This finding is in accord with the model where the ACC sends feedback to the PFC and ventral striatum to affect the motor cortex. In reward or neutral scenarios, as mentioned earlier, the effect of extraneous movements can be mitigated with prefrontal control.

In addition to the effect hits and misses have on fERN, they seem to have an effect on cortical activation as well. After removing the participants who did not score any misses in the reward condition or hits in the neutral condition, respectively, better performers showed increasing high-alpha power leading up to the shot while worse performers did not. The latter group showed a consistently greater, but stable, unchanging levels of high-alpha power that could be indicative of a disengaged state or lack of concentration. Hatfield and Kerick (2007) suggested an inverted-U relationship between T3 activation and performance where too much or too little cortical engagement can cause a degradation in performance. Better performers showed an optimal activation in cognitive activity followed by progressive relaxation approaching the shot which

suggests an adaptive level of arousal. This could indicate conscious effort and strategic thinking to improve performance which is inhibited or "turned off" at the right time so that it does not interfere with shooting performance. On the other hand, worse performers who show a constant relaxed state may lack the conscious planning and control needed to score more hits.

Better performers also showed lower Fz-T3 and Pz-T3 coherence during hits than misses while worse performers showed the opposite. The elevated communication needed to achieve the hits in worse performers is indicative of an inefficient use of neural resources. On top of that, worse performers seem to be unable to attain hits without this elevated communication. Linking back to Fitts and Posner's (1968) theory of motor learning, the performers appear to be in the associative stage while the better performers are closer to the automatic stage as they do not require constant feedback between cognitive regions and motor planning and execution regions. The increase in cortico-cortical communication in the poorer performers could also be a byproduct of over-correcting for their mistakes, as shown by worse performers' higher fERN amplitudes and closer attention to their errors. The pattern of cortical activation suggests worse performers could be trying to relearn their shooting skills in order to correct for mistakes.

It was expected, with evidence from previous studies, that showed increased alpha power and decreased coherence should lead to less extraneous movements and better performance (Deeny et al., 2003, Hatfield et al., 2013). This could only be said for the better performers where lower coherence during hits and higher coherence during misses corresponded with less extraneous movements and more consistent shots during hits and more extraneous movements and less consistent shots during misses, respectively. Poorer performers may be using excessive neural effort in cortico-cortical communication to stabilize their aim trajectory and achieve hits. There was no evidence to show that alpha power played a role in interfering with motor control as the

statistical analysis of high alpha power failed to reveal any differentiation between hit and missed shots. Given that the experience level between the two groups of participants was not vastly different, and combining these results with those found from fERN, the evidence seems to show that the strategy to correct for errors plays a bigger part in interfering with motor control. If errors are overemphasized, participants would revert to an associative stage and spend more effort (i.e., excessive) when performing the motor task. Ironically, if participants were less explicitly concerned with error monitoring, they hypothetically perform the motor task in the automatic stage with less effort likely resulting in higher quality.

The neuroaffective model also predicted that ACC is capable of driving autonomic changes through the amygdala. The biopsychosocial model of arousal regulation and internal interpretations of self-efficacy could be driven primarily by the ACC that is monitoring internal resources and the demands of the task at hand so that it could direct the most appropriate ANS response. Focusing on negative feedback could reflect feelings of inadequacy to handle a task which leads to maladaptive responses such as heightened arousal and increase in sympathetic nervous system response. This could be the other reason why fERN was found to be related to performance measures.

Although the three conditions of reward, punishment and neutral that were employed to produce differential motivation and frontal effects did not influence behavior and physiology as neatly as expected, the predicted relationships between different brain areas, the autonomic system and motor behavior were observed in at least one of the conditions. A possible reason that the intended differential motivation did not work could be that participants attach different values of stress and enjoyment to the scenario as seen in Table 7. In order to communicate the pattern of

results in a concise manner the hypothesized and observed correlation results are presented in

Table 15 and illustrated in Figure 18 below.

Table 15. Hypothesized and observed statistically significant correlation analysis results. '+' denotes predicted positive relationship. '−' denotes predicted negative relationship.

	Eyeblink startle amplitude	ERN amplitude	High alpha band power	EEG coherence scores	HR variability	Shooting performance	Displacement	Additional
Frontal asymmetry score	− Not observed	− Observed only in most enjoyable condition	+ Observed only in reward condition	− Observed only in neutral condition	+ Observed only in reward and least stressful condition	+ Observed only in neutral condition	− Observed only in reward condition	BAS Reward Responsiveness, STAI Trait, STAI start, STAI end
Eyeblink startle amplitude		+ Not observed	− Not observed	+ Contrary to expectations. Observed only in punishment, most stressful and least enjoyable condition	− Contrary to expectations. Observed only in second most stressful condition	− Not observed	+ Not observed	STAI start
ERN amplitude			− Not observed	+ Not observed	− Not observed	− Observed only in reward, punishment, most stressful, least stressful, most enjoyable and least enjoyable condition	+ Observed only in reward, punishment, most stressful, least stressful and most enjoyable condition	Frustration, Mental, Physical & Temporal demand, STAI Trait, STAI end

104

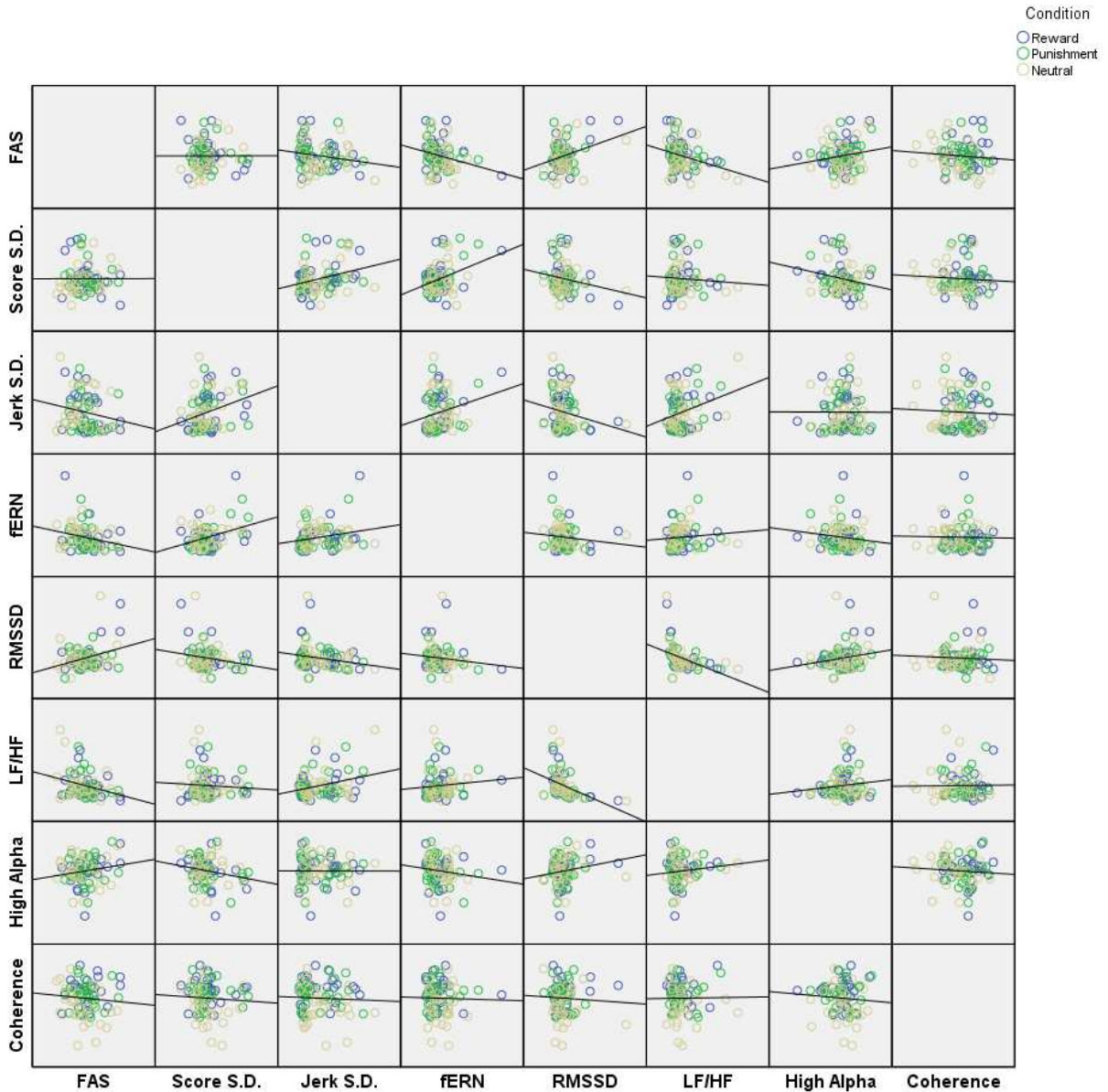|					
High alpha band power	**−** Contrary to expectations. Observed only in second most stressful and most enjoyable condition	**+** Observed only in reward and least stressful condition	**+** Observed in reward, punishment, most stressful and most enjoyable condition	**−** Observed in reward, neutral, second most stressful and least stressful condition	STAI Trait, STAI end, BAS Reward Responsiveness, Mental, Physical, Temporal demand
EEG coherence scores		**−** Not observed	**−** Not observed	**+** Not observed	
HR variability			**+** Observed in reward and most enjoyable condition	**−** Observed in punishment and most stressful condition	
Shooting score				**−** Not observed	

Figure 18. Scatterplot of selected variables. High Alpha and Coherence values are taken from the aiming period 1s before shot.

Conclusion

The cascade of the neuroaffective model was best seen in the reward and neutral conditions where frontal asymmetry influenced various emotion regulatory areas. The brain areas are playing

the functions as they have been reported, but appear to be working independently in different scenarios and conditions, as needed, based on the parameters of this study. Different scenarios may require different coping strategies and as such, not all brain areas have to be activated or play a part in regulation all the time. They may play distinctive roles and there could be a mediating or modulating structure or mechanism that is controlling their timely and adaptive activation. However, this is outside the premise of this study.

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