

Assessment and Learning of Self-Regulation in Olympic Athletes
Using Biofeedback and Neurofeedback

Margaret Dupee

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School of Human Kinetics
Faculty of Health Sciences
University of Ottawa

GENERAL ABSTRACT

It is understood that in order for athletes to perform to their potential consistently they must learn to optimally self-regulate their psychological and physiological states. Yet, the process by which this is accomplished is not well understood. The purpose of this doctoral dissertation was to explore the concept of self-regulation in the Olympic athlete population through the use of biofeedback and neurofeedback. To address this purpose, two studies were conducted. Study One (Article 1) used a quantitative methodology to explore the relationship between Olympic athletes' overall self-regulation ability and world ranking. Fifteen Olympic level athletes underwent a 9-stage psychophysiological stress assessment to determine each athlete's ability to return to baseline after a stress load was applied. Findings revealed that there was a significant correlation between the athletes' overall self-regulation ability and their ranking at the world level, meaning the better the overall self-regulation ability of the athlete the better the world ranking. Study Two (Articles 2 and 3) employed a qualitative methodology and explored what and how five Olympic level athletes learned from participating in a 20 session biofeedback and neurofeedback training intervention. Data was collected from post-intervention interviews with the athletes. In Study Two, Olympic athletes perceived that the biofeedback and neurofeedback training intervention assisted them in learning to improve self-awareness and self-regulation of their physical and mental states enabling them to feel more in control during sport performances. Engaging in active learning exercises, receiving real-time formative feedback, and utilization of the intervention exercises in training and competition environments were how athletes perceived they learned to self-regulate. Together, the findings from the two studies highlight the relevance and intricacies of self-regulation in high performance sport. Overall, the present dissertation makes a contribution to the sport psychology literature particularly with

regard to our understanding of the use of biofeedback and neurofeedback for enhancing self-regulation with Olympic athletes. Thus, learning to improve self-regulation skills using biofeedback and neurofeedback training should be an integral part of a comprehensive and holistic approach used by sport psychology practitioners in assisting athletes to perform to their potential.

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CHAPTER I
INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Self-regulation is a broad construct that has been conceptualized as the ability to flexibly modulate one's responses in order to meet the demands of the task at hand (Baumeister, Vohs, & Tice, 2007; Thayer & Lane, 2000, 2009). The idea of self-regulation is one of deliberate, effortful governance over one's self and research has shown that it has significant implications for both physical and psychological health (Baumeister & Vohs, 2004). Individuals engage in self-governing activities on a daily basis such as maintaining focus in the face of distraction, ignoring or correcting unwanted thoughts, and managing emotions as well as arousal levels. However, it should be recognized that individuals differ in their ability to self-regulate effectively (Baumeister & Vohs, 2007).

In the realm of sport, athletes who have developed self-awareness and self-regulation skills are able to bring their mental, emotional, and physical states to approximate what they know leads to their best performance (Anderson, Hanrahan, & Mallett, 2014; Krane & Williams, 2006; Harrison, 2011; Ravizza, 2006). However, even though it is believed that highly self-regulated mental and physical states consistently result in superior performance (Hanin, 2000), achieving one's own ideal internal psychological climate is not a simple task (Harrison, 2011; Krane & Williams, 2006). Thus, much of the research and applied work in the field of sport psychology has been driven by trying to understand the gap between an athlete's potential and his or her actual performance. In order to consistently help athletes perform to their potential, Gardner (2009) has suggested that more research is needed to examine the processes that lead to enhanced performance. Recent work by Anderson et al., (2014) responded to this identified gap by identifying the processes of self-regulation, control, and trust. And although this research has begun to address the gap related to understanding the processes that play a role in optimal

performance, more research is warranted. As Gardner asserts what is needed to further advance the field of sport psychology is to update the ‘toolbox’ with new theoretical models integrating emotional and cognitive science and new forms of performance enhancement interventions.

Biofeedback and neurofeedback training is one form of intervention that can be used to optimize one’s self-regulation ability (Edmonds & Tenenbaum, 2012; Hammond, 2011; Thompson & Thompson, 2015; Schwartz & Andrasik, 2016; Strack, Linden, & Wilson, 2011). Moreover, biofeedback and neurofeedback training has been shown to be beneficial to athletes in achieving optimal performance (Dekker, Van den Berg, Denissen, Sitskoorn, & Van Boxtel, 2014; Dupee & Werthner, 2011; Dupee, Werthner & Forneris, in press; Lagos, Vaschillo, Vaschillo, Lehrer, Bates, & Pandina, 2008, 2011; Paul & Garg, 2012; Shaw, Zaichowsky, & Wilson, 2012; Thompson, Steffert, Ros, Leach, & Gruzelier, 2008; Werthner, Christie, & Dupee, 2013). Biofeedback involves providing an individual with objective measurements concerning his or her physiological processes so that they can be brought under self-regulatory control (Schwartz & Andrasik, 2016). With commitment and practice, the athlete can be taught to consciously control physiological processes in order to optimize his or her bodily functions (Pepper, Tylova, Gibney, Harvey, & Cambatalade, 2008). In addition, the athlete can learn to maximize the brain’s efficiency using electroencephalography (EEG) biofeedback, also called neurofeedback (Wilson, Thompson, Thompson, & Peper, 2011). More specifically, neurofeedback training employs the analysis of EEG, a non-invasive method for monitoring bioelectrical activity of the brain. The brain’s electrical activity reflects an individual’s mental state and training with neurofeedback can be used to enhance one’s ability to self-regulate this mental state (Heinrich, Gevensleben, & Strehl, 2007; Thatcher, 2012; Thompson & Thompson,

2015). However, no research to date has examined the value of biofeedback and neurofeedback in helping athletes learn how to self-regulate.

The implementation of any form of sport psychology intervention comes with an assumption that learning will take place. Learning is recognized as a constructive process that involves building links between new information and experiences into one's existing knowledge base (Weimer, 2013). If the learner is unable to integrate new knowledge with prior knowledge they are unable to transfer what they have learned to new situations. It is this transfer process that fosters what is considered deep integrated learning (Weimer, 2013). One way to foster a deeper integrated level of learning, which is also equated with understanding as compared to memorizing, is to use a learner-centered approach (Doyle, 2011; Weimer, 2013). Within the learner-centered approach, a key component in achieving deep integrated learning is by engaging the learner in active learning. As Doyle (2011) states "the one who does the work, does the learning" (pg. 7). Furthermore, the learner-centered approach emphasizes the importance of having the learner receive formative feedback (Weimer, 2013). An example of formative feedback is when athletes receive ongoing feedback in real-time as they are learning a new skill. Both of these key components of the learner-centered approach are integral to biofeedback and neurofeedback interventions and therefore the learner-centered approach is useful in guiding an exploration of athletes' learning experiences within a biofeedback and neurofeedback intervention.

Research Purpose

The purpose of this doctoral dissertation was to explore self-regulation in the Olympic athlete population. Three broad research questions were proposed: (a) is the ability to self-regulate from a psychophysiological perspective related to performance outcomes?, (b) what

were the athletes perceived learning outcomes as a result of participating in a biofeedback and neurofeedback training intervention?, and (c) what were the athletes perceptions of how they learned during a biofeedback and neurofeedback training intervention? These three research questions were addressed in two separate studies. The aim of the first study (Article 1) was to assess whether Olympic athletes who were ranked higher in the world were indeed better self-regulators. The second study (Articles 2 and 3) was more exploratory in nature. Given no research has been conducted on athletes' experiences during a biofeedback and neurofeedback intervention the aim of the second study was to explore Olympic athletes' perceptions of what they learned and how they learned to self-regulate during a biofeedback and neurofeedback training intervention.

Organization of Dissertation

The following section of this first chapter reviews the literature in several relevant areas. First, key ideas, concepts, and research related to optimal performance in sport are highlighted. Second, the neurovisceral integration model of self-regulation, from the psychophysiology literature, is introduced to further articulate the aspects of self-regulation being considered. Third, as a tool to teach self-regulation skills, the biofeedback and neurofeedback literature is explored. Finally, the learner-centered approach, used as a guide in the second study, is presented.

Chapter II presents Article 1, which addresses the psychophysiological stress profiles of athletes and examines whether better baseline self-regulation of psychophysiological measures indicates better performance. Chapter III presents Article 2, which focuses on understanding Olympic athletes' perceptions of their learning outcomes as a result of participating in a 20 session biofeedback and neurofeedback intervention. Chapter IV presents Article 3, which

focuses on understanding how the athletes learned to self-regulate within the 20 session biofeedback and neurofeedback intervention. Finally, Chapter V presents a general discussion of the research, practical implications, limitations, suggestions for future research, and a final conclusion.

Review of Literature

Sport Psychology

Much of the sport psychology research over the past 35 years has examined specific aspects of athletic performance in an attempt to better understand the complex processes involved in producing optimal performance under stressful conditions (Harrison, 2011). Some of the psychological skills researchers have identified as being related to optimal performance include: arousal/activation level management, relaxation ability, focusing ability, distraction management, attentional control, automaticity, emotional control, thought control, and self-awareness. For example, a study by Gould, Dieffenbach, and Moffett (2002) administered a battery of psychological inventories to Olympic champions and found that these athletes were characterized by an ability to effectively cope with and control anxiety and to focus and block out distractions. More specifically, results from the Athletic Coping Skills Inventory–28 (ACSI-28) showed that these outstanding performers rated high on levels of concentration/focus. Similarly, the Test of Performance Strategies (TOPS) results indicated that these Olympians rated high on activation, relaxation, emotional control, and automaticity/attention focus.

In an extensive review of the literature, Krane and Williams (2006) identified a number of psychological characteristics of highly successful athletes as well as the mental skills required to achieve an optimal psychological state. The skills included arousal management, thought control strategies, well-developed pre-competition and competition plans, well-developed coping strategies, imagery, and goal setting. A second literature review was conducted by Gould and Maynard (2009) on the psychological characteristics associated specifically with Olympic performance success. Under the category of ‘psychological/emotional state’ they reported concentration/attention-focus, optimal zone of emotions/arousal/anxiety, emotional control,

automaticity, body awareness, and self-awareness as several of the attributes necessary for optimal performance. More recently, Anderson et al. (2014) identified that the development of the processes of self-regulation, control, and trust assisted Australian elite athletes in gaining an automatic state required for peak performance. The authors specifically emphasized the need for athletes to develop the ability to psychologically self-regulate all relevant aspects of their optimal performance states.

In terms of learning and maintaining these psychological skills, several authors have commented on the possible processes. For example, Krane and Williams (2006) argued that athletes can learn these psychological skills and strategies through education and practice. Orlick (2008) stated that mental skills must be continually practiced and refined for an athlete to perform to potential on a consistent basis, and Harrison (2011) argued that athletes can learn to achieve peak performance by becoming more self aware of their own ideal performance states. However, even with this understanding, it is still a challenge for athletes to learn to consistently self-regulate their individual optimal psychological states in order to perform to their potential (Harrison, 2011; Singer, 2002).

Psychophysiology and Self-Regulation

In considering the research in the field of sport psychology, many researchers appear to be in agreement that psychological skills training for achieving athletic excellence comprises both a psychological and a physiological component (Blumenstein, Bar-Eli, & Tenenbaum, 2002; Edmonds & Tenenbaum, 2012; Harrison, 2011; Jones, Hanton, & Connaughton, 2007; Landers & Arent, 2006; Mellalieu, Hanton, & Fletcher, 2006; Williams & Harris, 2006). Specifically, in high performance sport, it is crucial that an athlete develop the ability to effectively self-regulate physically and psychologically (Anderson et al., 2014; Dupee, Werthner,

& Forneris, 2015; Hanin, 2000; Ravizza, 2006). The combination of these two aspects has been discussed in the literature as the psychophysiology principle (Andreassi, 2007; Cacioppo & Tassinary, 1990).

Cacioppo and Tassinary (1990) define psychophysiology as “the scientific study of cognitive, emotional and behavioral phenomena as related to and revealed through physiological principles and events” (p. ix). Green, Green, and Walters (1970) formulated this psychophysiological principle as follows:

Every change in the physiological state is accompanied by an appropriate change in the mental emotional state, conscious or unconscious, and conversely, every change in the mental emotional state, conscious or unconscious, is accompanied by an appropriate change in the physiological state (p. 3).

This principle refers to the underlying connection between the brain and body; acknowledgment of this connection is also prevalent in the self-regulation literature.

The neurovisceral integration model of self-regulation (Thayer & Lane, 2000, 2009) is a comprehensive model that includes cognitive, affective, behavioral and physiological components. This model emphasises the “relationship between emotional regulation and attentional regulation and identifies a group of underlying physiological systems that serve to integrate these functions in the service of self-regulation and adaptability of the individual” (Thayer & Lane, 2000, p. 201). Thus, direct regulation of physiological systems (one’s physical and mental states---things like brainwaves, respiration, HR, HRV among others) impact emotional and attentional self-regulation and an individual’s overall ability to adapt to their environment. This direct regulation is achieved through inhibitory processes in the nervous system which ensure sympathetic-parasympathetic balance.

This model of self-regulation is particularly relevant with respect to optimal performance in sport. It is accepted that competitive stress is inherent in elite level sport (Davis, Sime, & Robertson, 2007; Paul & Garg, 2012). In the past, with respect to the management of stress, the focus has often been on the symptom, which is excessive sympathetic nervous system activation, and a focus on how to decrease that excessive activation (McEwen, 2004). The neurovisceral integration model suggests, using heart rate variability as a physiological index of self-regulation, that it is important to address the cause, which is parasympathetic deactivation (e.g. decreased cardiac vagal tone or withdrawal of the vagal brake on the heart) (Thayer & Lane, 2000, 2009). In reviewing the literature, Friedman & Thayer (1998) found that a decrease in vagally-mediated heart rate variability is consistent with poor attentional control, ineffective emotional regulation, and behavioral inflexibility. Thus, from the perspective of the neurovisceral integration model, the key to a healthy and adaptive nervous system and optimal self-regulation of physiological and psychological states is to ensure parasympathetic (vagal) activation. Importantly, the neurovisceral integration model attempts to provide the underpinnings of a comprehensive model of cognitive, affective, behavioral and physiological components inherent in regulation of both physical and mental states. One avenue available that utilizes physiological systems to pursue the learning of self-regulation is biofeedback and neurofeedback.

Biofeedback and Neurofeedback

Biofeedback and neurofeedback training techniques can facilitate the learning of effective self-regulatory control of the nervous system using self-observation and self-monitoring to control physiological and neurological functions with instrumentation (Bar-Eli & Blumenstein, 2004; Blumenstein et al., 2002; Dupee, 2008; Dupee & Werthner, 2011; Dupee et al., in press;

Edmonds & Tenenbaum, 2012; Lagos et al., 2008, 2011; Shaw et al., 2012; Strack et al., 2011; Thompson & Thompson, 2015; Werthner et al., 2013). Biofeedback and neurofeedback training requires attaching sensors to the body for the purpose of acquiring biological and neurological signals such as those produced by muscles, sweat glands, body temperature, respiration, heart rhythm (i.e., biofeedback modalities) and brainwaves (i.e., neurofeedback modality). Biological and neurological signals are fed to the individual being trained with the goal of gaining mental control over subconscious biological and neurological processes. More specifically, the trainee receives moment by moment information about changes from the sensors. Information may come in the form of auditory tones, digital or analog displays, or computer graphics. Biofeedback and neurofeedback training helps individuals learn how to regulate aspects of the central and autonomic nervous systems.

Biofeedback and neurofeedback training is based on the underlying principle that the nervous system is the command center of the body. The nervous system can be divided into two parts: the central nervous system (CNS) & the peripheral nervous system (PNS) (see Appendix A). Information travels within and among the two divisions via neural tissue. The CNS includes the brain and spinal cord. It is neurofeedback training, also known as EEG biofeedback, which is focused on cerebral functions, and more specifically, the brain's electrical activity. The PNS has two divisions: somatic (i.e. voluntary) and autonomic (i.e. involuntary). Biofeedback training targets the autonomic nervous system (ANS), which is further divided in two parts: the sympathetic, which activates the fight and flight response in the body (i.e. the stress response) and the parasympathetic which deactivates the fight and flight response in the body and allows the body to rest and regenerate (i.e. the relaxation response). Biofeedback, especially EMG biofeedback, also addresses the somatic nervous system that mediates muscle activity. The

following two sections provide a more comprehensive overview of biofeedback and neurofeedback.

Biofeedback. As mentioned above, biofeedback training focuses on developing voluntary control of the ANS division of the PNS with the goal of developing conscious regulation of one's physiology and the engagement of the parasympathetic nervous system or vagal brake, thereby decreasing the stress response. When one experiences anxiety or stress, the sympathetic nervous system becomes dominant. Biofeedback training improves the balance between sympathetic and parasympathetic nervous system activity, often referred to as ANS balance. Given that competitive stress and anxiety are inherent in sport, biofeedback training may be particularly useful for athletes as it can be used to learn how to optimally manage the ANS and the somatic nervous system (Davis et al., 2007; Paul & Garg, 2012).

The most common types of biofeedback training are muscle or electromyography (EMG), skin conductance/electro dermal activity (EDA), heart rate and heart rate variability (HRV), respiration rate and peripheral body temperature. During the training, individuals develop self-awareness and self-regulation of the various feedback modalities. Muscle feedback training enables the individual to become aware of tension in the muscles and trains the muscles to relax and release tension (Blumenstein et al., 2002; Pepper et al., 2008). Skin conductance feedback training is used to decrease activation/arousal level when an individual is feeling overwhelmed or anxious, or to increase activation/arousal level before an important event such as a competitive sport event (Blumenstein et al., 2002; Pepper et al., 2008). HRV biofeedback training induces a relaxation response by encouraging greater parasympathetic nervous system activity and ANS balance (Lagos et al., 2008, 2011; Lehrer & Gevirtz, 2014). Respiration feedback training reduces sympathetic arousal, encourages regeneration, releases tension, and

increases physical and mental relaxation (Elliott & Edmonson, 2006; Peper et al., 2008; Thompson & Thompsons, 2015). Finally, peripheral temperature feedback training is used to initiate a relaxation response in order to combat competition anxiety and to enhance recovery after a competitive event (Blumenstein et al., 2002; Peper & Schmid, 1983). A more in-depth explanation of each type of feedback modality follows.

Muscle or electromyography (EMG) feedback training. The principle of muscle feedback training is to provide an individual with enhanced information about his/her muscle tension in a particular area and to facilitate learning how to control tension in the muscle. Relaxation of excessive and inappropriate tension is the usual goal. To do this, sensors are attached to the skin on the muscle being targeted for change. Muscles may be targeted anywhere on the body including the forehead, neck, shoulders, back, jaws, arm, and legs. However, forehead (frontalis) and upper shoulder (trapezius) muscle activity are valid indicators of general arousal and muscle tension (Pepper et al., 2008).

Electromyography (EMG) measures, in microvolts, the electrical energy discharged by the motor nerve endings signaling a muscle to contract (Blumenstein et al., 2002). These tiny electrical signals emitted by the muscles, proportional to the degree of contraction, are amplified and fed to a visual display or audio signal. The visual display may be digits, polygraph-style lines, or changes in colors or patterns. The audio tone may indicate changes in muscle tension by a rising or falling tone or by a change in the frequency of a beep. One or more criteria are usually set as goals of EMG training. Muscle tension above 2 micro volts is considered not relaxed, between 1 and 2 micro volts is considered relaxed, and below 1 microvolt is considered deeply relaxed (Blumenstein et al., 2002). Speed of recovery from contraction is another common criterion, as well as keeping muscle tension lower during movement.

Skin conductance or electrodermal feedback training. This modality, known as electrodermal activity (EDA) or the more classic term, galvanic skin response (GSR), is related to the electrical activity of the skin. Sweat contains salt that makes it electrically conductive. A skin conductance device applies a very small electrical pressure (voltage) to the skin, typically on the volar surface of the fingers where there are many sweat glands, and measures the amount of electrical current that the skin will allow to pass. EDA is measured in micro-Siemans and is known to increase during stressful times and decrease during relaxation. Exact levels vary from 1 micro-Siemans for individuals with dry hands to 10 micro-Siemans for individuals with moist hands. EDA has been recognized as distinctly sensitive to transitory emotional states and mental events as well as being closely correlated with sympathetic nervous system activity (Blumenstein et al., 2002). Self-calming by physical or cognitive means tends to lower skin conductance while negative emotions such as fear, worry, or anger usually raise it. In learning to reliably regulate EDA, an individual learns to maintain a state of mind that is neutral or pleasant and resist distractions that disrupt attention. Thus, EDA training with athletes has been recommended for anxiety reduction (Blumenstein et al., 2002). In addition, EDA can also be utilized by athletes to increase arousal or activation levels prior to a competition if they feel they are not sufficiently activated.

Heart rate and heart rate variability biofeedback training. Using a photoplethysmograph monitor on the non-dominant thumb gives an indirect measure of heart rate. Under stress the number of beats per minute (bpm), or heart rate, increases. Typically elite athletes show much lower than average heart rates but genetics and conditioning determine the baseline. Athletes who are physically well trained often have heart rates of 45-60 bpm while the average non-conditioned individual is between 72-80 bpm (Wilson & Somers, 2011). Normally,

with activity, there are increases of 10-20 bpm and a return to baseline within a minute of activity completion.

Heart rate variability is a term that is predicated by the term 'Respiratory Sinus Arrhythmia' and refers to the rise and fall of the heart rate synchronized with each breath (i.e. increases on inhalation, decreases on exhalation). The magnitude of this systematic variability reflects a healthy alternation between two autonomic influences on the heart beat - the sympathetic and the parasympathetic (Schwartz & Andrasik, 2016). Lack of this variation reflects an imbalance between the two aspects of the ANS, most likely deficient parasympathetic influence. By calming one's emotional state and by making the breathing slower and more regular, the HRV can be increased (Lehrer et al., 2013). This involves the athlete learning to regulate breathing rate and rhythm in order to induce greater parasympathetic nervous system activity and improve sympathetic-parasympathetic balance. Although improved autonomic homeostasis, described above, is the most supported possible mechanism for the beneficial effects of HRV biofeedback training (Gevirtz, 2013), more expansive views that explore other mechanisms are now becoming prevalent in the literature (Brown & Gerbarg, 2005; Lehrer & Gevirtz, 2014). Another possible mechanism related to optimal performance explores the effect of the central nervous system (i.e., the brain) by way of the vagal afferent pathway in the parasympathetic nervous system (Brown & Gerbarg, 2005). This potential mechanism seeks to address how slow breathing during HRV training affects the brain.

The feedback for HRV involves monitoring heart rate, or heart rate plus respiration. Heart rate may be detected from a photoplethysmographic sensor on the finger or earlobe, or via an electrocardiogram (EKG) monitor. Most commonly, a trace reflecting cyclic variations in heart rate is displayed on a video screen. The variability of heart rate is what is of interest. An

individual observes the trace, or a derived graphic display, and uses it as feedback for regulating the breath and/or emotional state. The heart beat variability is maximized at a particular resonant frequency, which is breathing rate per minute, and this rate, usually around six breaths per minute, can be determined for each individual by observation and experimentation (Lehrer et al., 2013).

Respiration Rate Feedback Training. Respiration pattern, which is depth and frequency of breathing, is highly sensitive to changes of both arousal level and emotional factors (Mador & Tobin, 1991; Pack & McCool, 1992; Peper et al., 2008). It has rarely been used in biofeedback studies in the realm of sport and physical activity possibly due to methodological and technical difficulties (Blumenstein et al., 2002). However, Davis and Sime (2005) identified a shallow breathing pattern in athletes as one of the physiological indicators of stress.

Deregulation in breathing often happens during tasks and is usually indicated by one of three variations a) shallow breathing, with the shoulders doing most of the work rather than the abdominal region; b) breath holding during tasks; and/or c) increasing respiration rate (breaths per minute or brpm). All three of these variations are associated with poor performance in sport (Wilson & Somers, 2011). An ideal rate of breathing for most adults is 6 breaths per minute (Elliot & Edmonson, 2006; Thompson & Thompson, 2015). Breath rate can be retrained mechanically by use of biofeedback and/or a breath pacer. Effortless diaphragmatic breathing reduces sympathetic arousal encouraging regeneration, less tension, and increases in physical and mental relaxation (Elliot & Edmonson, 2006; Peper et al., 2008).

The instrument used to determine respiration rate is a strain gauge around the abdomen below the ribcage. Smooth continuous expansion of the abdominal region with inhalation is a sign of effortless breathing (Pepper et al., 2008). The surface EMG of the shoulders can also help

to determine whether the individual is overusing shoulder muscles during inhalation and if the shoulder muscle tension is released during exhalation.

Peripheral body temperature feedback training. Skin temperature changes of the fingers provide information about peripheral circulation. The cardiovascular mechanisms that regulate skin temperature in the hands are closely related to the activity of the sympathetic division of the autonomic nervous system (Schwartz & Andrasik, 2016). When this system is activated, the smooth muscles surrounding the blood vessels near the skin surface are likely to contract, resulting in vasoconstriction. This causes a decrease in the flow of blood in the area bringing about a drop in skin temperature. Low peripheral body temperature is a physiological sign of inner tension. Conversely, an increase in hand temperature is accompanied by vasodilation which is relaxation of the smooth muscles surrounding the peripheral blood vessels in the hands and results from relaxation of sympathetic activity.

A thermal sensor, called a thermistor, is taped to the skin, usually on the palmar surface of one of the fingers. The temperature of the skin changes the resistance of the thermistor, thereby altering the electrical signal in proportion to the temperature. The signal is displayed visually through a tone that changes in response to changes in temperature. The values of peripheral skin temperature fall into categories. For example, 18-21 degrees Celsius represents high sympathetic arousal and 32-35 degrees Celsius represents low sympathetic arousal (Wilson & Somers, 2011). During daily activity or during recovery the goal is to maintain peripheral body temperature at or above 32 degrees Celsius. It should be noted however that temperature training is typically combined with other biofeedback modalities to train general relaxation.

The time required to achieve improved self-regulation of the various biofeedback modalities varies based on the individual's physiology (Peper et al., 2008; Schwartz & Andrasik,

2016). Generalization to the everyday environment, away from the biofeedback monitor, can certainly take longer. However, practicing the various biofeedback modalities provides a model for real-life self-regulation. The goal is to develop awareness of one's breathing, emotional state, muscle tension, and peripheral body temperature, all of which interact and influence the ANS balance and aid in both recovery and ability to focus.

Neurofeedback. Neurofeedback, also known as EEG biofeedback can be used to help individuals learn self-regulatory control of their CNS, specifically their brainwaves, to optimize their brain's efficiency (Sherlin, Larson, & Sherlin, 2013; Thompson & Thompson, 2015). The focus is on optimizing brain wave patterns in specific regions of the brain that influence an individual's emotional state and cognitive performance by employing the analysis of EEG signals (Hammond, 2011; Schwartz & Andrasik, 2016). Specifically, neurofeedback training uses quantitative electroencephalographic (QEEG) feedback. The amount of electrical activity at different brainwave frequencies (i.e., the EEG signal) is amplified from the minute voltages and quantified. Starting in the 1950s, the EEG visual patterns were quantified (QEEG) and correlated with functions of the central nervous system (Lindsley, 1952). Basic types of waves present in EEG recordings include delta, theta, alpha, SMR, beta, high beta and these individual frequency bands are thought to represent different mental states (see Appendix B for a discussion on specific brainwave frequencies and corresponding mental states; Thompson & Thompson, 2015). During training, specific frequency bands are individually fine-tuned with respect to EEG and QEEG analysis as well as the needs of the individual being trained.

In essence, the brain waves reflect what a person is doing moment to moment and the overall goal of neurofeedback is to improve mental flexibility so that a person can produce a mental state appropriate to the demands of the task or the requirements of the situation (Schwartz

& Andrasik, 2016). Over a series of training sessions, an individual learns to (a) increase brain waves that are associated with focusing, staying in the present moment, remaining calm, and (b) quiet the mind; all by controlling the displays on the computer screen. The thresholds are slowly adjusted, helping to shape the behavior of an individual's brain into a more optimal pattern (Sherlin et al., 2011). This technique is used to help improve concentration, deal with distractions and negative thoughts, and help the brain recharge itself (Sime, 2003). Moreover, neurofeedback training enables an individual to become aware that attentional focus is a choice and to feel more in control of their mental state (Sime, 2003).

Details of the exact mechanisms at play during neurofeedback training (see Nunez & Srinivasan, 2006; Thatcher, 2012) are beyond the scope of this paper. A more general explanation is that exercising nerve pathways facilitates their growth and development and focuses on the underlying process of growth-through-utilization (Gunkelman & Johnstone, 2005). Similar to exercise to build muscle mass, the brain's dendritic connections are enhanced the more the brain is utilized. Neurofeedback training can be thought of as weight training for the brain to assist with better utilizing one's potential (Sime, 2003). With neurofeedback training, athletes are able to recognize both the state of focus and when they drift off into daydreams, ruminating thoughts, or negative self-talk (Wilson et al., 2011). The net result is that with neurofeedback training an athlete can become better at self-regulating his or her mental state, manage distractions, and sustain focus on the task at hand (Wilson et al. 2011; Schwartz & Andrasik, 2016).

Ultimately, biofeedback and neurofeedback training provides an individual with objective measurements concerning his or her physiological and neurological processes so that they can be brought under self-regulatory control in order to optimize central and autonomic nervous

systems' functions (Hammond, 2011; Moss & Wilson, 2012; Schwartz & Andrasik, 2016; Thompson & Thompson, 2015). Moreover, this training process has been shown to be beneficial to athletes in attaining optimal functioning and performance (Dekker et al., 2014; Dupee & Werthner, 2011; Dupee et al., in press; Gruzelier, 2014; Lagos et al., 2008, 2011; Paul & Garg, 2012; Shaw et al., 2012; Thompson et al., 2008; Werthner et al., 2013). To provide a framework to more deeply understand how learning may be achieved during a biofeedback and neurofeedback intervention, the following section presents an overview of the learner-centered approach (Barr & Tagg, 1996; Doyle 2011; Weimer, 2013).

Learning and the Learner-centered Approach

Over the past couple of decades there has been a considerable amount of research published on learning (Bransford, Brown, & Cocking, 2000; Dweck, 2006; Entwistle & Entwistle, 1991; Leamson, 1999; Sylwester, 1995; Zull, 2002). More is known than ever before about how people learn, what inhibits learning, and different kinds of learning (Harris & Cullen, 2010). One approach within the field of learning that has received considerable attention is the learner-centered approach (Barr & Tagg, 1996; Doyle, 2011; Weimer, 2013). The fundamental belief underlying the learner-centered approach is that the educational environment should be holistic, empowering, and optimize opportunities for the learner to learn (Doyle, 2011). Moreover, this approach draws on research from psychology, biology, cognitive neuroscience, and education to inform its understanding of how people learn. To help make the learner-centered approach more applicable for use Weimer (2013) developed five dimensions that encompass the fundamental components discussed within the larger context of the learner-centered approach. These dimensions include: function of the content, the purpose and process of evaluation, role of the instructor, responsibility for learning, and balance of power,

Function of the content. The function of the content dimension outlines the ways in which content can shift from something that is ‘covered’ by a teacher to something that can be ‘used’ by the learner. In addition, this dimension addresses the ways in which a learner can engage with the content. First, students must know why they need to learn the content and appreciate the value of the content. In order for students to then transfer what they learn in one discipline to another, they need to be able to link the new material being learned to their existing knowledge base and this link needs to be clear and explicit. Second, students must be assisted to acquire the learning skills that will work best for them (e.g., writing notes, discussing material, hands on activities). Third, students must understand the ways in which experts in their discipline successfully use the content. Fourth, students must learn to solve real-world problems through application of the content of a course.

Weimer (2013) strongly contends that the level to which students engage in the content matters. To remember and be able to use content presented, students must create their own meaning for such content through engagement. When students learn content by memorizing and not engaging with the material, they quickly forget it. As a result, researchers working with a learner-centered approach assert that it is this engagement in the learning process that fosters deep integrated learning (Doyle, 2011; Weimer, 2013). Active learning, where the learner practices skills, is seen as one of the best ways to create that engagement and foster deep-integrated learning (Barr & Tagg, 1996; Doyle 2011; Weimer, 2013). As Doyle (2011) states “the one who does the work, does the learning” (pg. 7).

The purpose and process of the evaluation. In the broader learner-centered approach, evaluation is integrated within the learning process rather than just being an outcome or final activity. For example, it is important to include opportunities for student learning during

evaluation activities or by having learning activities that incorporate evaluation components. One of the novel elements within the evaluation dimension that Weimer (2013) proposes is formative feedback. According to Weimer, formative feedback involves having the learner consistently receive feedback throughout the learning process to assess whether he or she is learning the content or improving a skill set. As a result, the purpose of evaluation is to foster learning and improvement and not only to assess learning. A specific example of formative feedback in sport is having a coach provide feedback at multiple times within and across training sessions prior to any form of final evaluation or test such as being asked to perform the skill in competition. For individuals to develop complex skills they need repeated opportunities to practice these skills with formative feedback provided and there needs to be a well-organized plan for the students to receive formative feedback as they are actively engaged in the learning (Weimer, 2013).

The role of the instructor. Weimer (2013) recognizes the critical role an instructor plays in the learning process and notes that an effective instructor is one who facilitates learning rather than directing and controlling the learning. In addition, to facilitate learning effectively, Weimer states that instructors need to be aware of and accommodate different learning styles, ensure that the learning methods integrated are congruent with the student's learning goals, and implement interactive learning activities.

Responsibility for learning. Weimer (2013) contends that responsibility for learning must rest with the student. In order for this to happen, students must be given regular opportunities to assume responsibility for their own learning. A key aspect of assuming responsibility for learning involves acquiring and practicing 'learning to learn skills' such as self-monitoring, time management, goal setting, and how to work independently (Blumberg, 2009; Candy, 1991).

Balance of power. Finally, Weimer (2013) discusses the balance of power between the instructor and the learner and its relationship to the motivation of the learner. Research in psychology has shown that intrinsic motivation to learn is affected by individuals' personal interests as well as their sense of choice and control (American Psychological Association, 2008). Within the learner-centered approach it is recognized that sharing power and control can promote engagement and subsequently facilitate learning (Harris & Cullen, 2010). Thus, Weimer advocates the emphasis should be on fostering empowerment which can be accomplished by incrementally increasing opportunities for decision making on the part of the learner.

The five dimensions developed by Weimer (2013) delineate how the main constructs discussed in the learner-centered approach can be put into practice. As a result, these five dimensions helped to guide this research given that one of aims of this research was to understand how deep integrated learning can be fostered within a biofeedback and neurofeedback intervention.

Summary

The literature reveals that optimal performance can be achieved by athletes becoming more aware of and learning to consistently self-regulate their ideal performance states. Specifically in high performance sport, it is crucial that athletes develop the ability to effectively self-regulate physically and psychologically. As well, self-regulation from a psychophysiological perspective, encompasses cognitive, affective, behavioral, and physiological aspects. Biofeedback and neurofeedback, embracing a learner-centered approach, can be utilized to train self-awareness and self-regulation ability.

CHAPTER II

**ARTICLE 1 – A PRELIMINARY STUDY ON THE RELATIONSHIP BETWEEN
ATHLETES' ABILITY TO SELF-REGULATE AND WORLD RANKING**

A preliminary study on the relationship between athletes' ability to self-regulate and
world ranking

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Abstract

This study was designed to explore the relationship between elite athletes' self-regulation ability and their ranking at the world level using psychophysiological stress assessment profiling. Fifteen elite level athletes' psychophysiological stress response patterns were recorded during a nine stage stress assessment. Respiration rate, heart rate, heart rate variability, skin conductance, peripheral body temperature, and electromyograph (trapezius and frontalis) were monitored. There was a significant correlation between elite athletes' overall self-regulation ability and their ranking at the world level, meaning that the better the overall self-regulation ability of the athlete the better the world ranking. In addition, a multiple regression analysis indicated that self-regulation accounted for 76% of the variance in world ranking. Our results suggest the existence of a relationship between elite athletes' overall self-regulation ability and their ranking at the world level. Therefore, the results of this study have important implications for training of optimal psychophysiological self-regulation in athletes.

Keywords: Elite athletes, self-regulation, psychophysiological stress response profiling

Introduction

The ability to manage one's level of stress and anxiety, in the high-pressure situations of national championships, selections, world championships, and the Olympic Games, is a key skill that athletes need to develop in order to excel at the highest levels of sport. This elite sport environment is stressful and many talented athletes struggle and sometimes fail to achieve their performance potential (Davis, Sime, & Robertson, 2007; Paul & Garg, 2012). Accordingly, much of the research and applied work in the field of sport psychology has been driven by an interest in exploring the gap between an athlete's potential and his or her actual performance (Bortoli, Bertollo, Hanin, & Robazza, 2012; Boutcher, 2008; Davis & Sime, 2005; Davis et al., 2007; Gould & Maynard, 2009; Gould, Dieffenbach, & Moffett, 2002; Jones, Hanton, & Connaughton, 2007). One major factor that has been shown to influence successful performance under pressure is an athlete's ability to manage him or herself physiologically (Babiloni et al., 2011; Davis et al., 2007; Lagos, Vaschillo, Vaschillo, Lehrer, Bates, & Pandina, 2008; Robazza, Pellizzari, & Hanin, 2004). While the key variables that cause stress in the competitive setting (e.g., expectations, self-presentation, opponents, fans, weather, mental errors) have been well documented (Didymus & Fletcher, 2014; Hanton, Fletcher & Coughlan, 2005; Janelle, 2002; Kristiansen & Roberts, 2010; Mellalieu, Neil, Hanton, & Fletcher, 2009; Nicholls, Jones, Polman, Borkoles, 2009; Wilson & Pritchard, 2005), minimal research has reported on the psychophysiological stress response profile of elite athletes.

The concept of psychophysiological response to high-stress environments, as in elite sport, is not new. In fact, the stress response is an adaptive biological mechanism that has evolved over time to ensure survival of the human species (Karatsoreos & McEwen, 2011; McEwen, 1998). The term stress can be defined as a threat (real or implied) to the body's ability

to maintain homeostasis through the stability of physiological systems that maintain life (e.g., pH, body temperature, glucose levels, and oxygen tension) (McEwen & Wingfield, 2003). Humans, upon sensing an impending threat to their safety, react by either fighting back or fleeing the stressful situation. This behavioural response to stress has been described as the “fight-or-flight” reaction of the sympathetic nervous system (Cannon, 1967; McEwen, 1998). Associated physiological reactions can include cool moist palms, elevated HR, increased respiration rate, muscle tension, and reduced brain functioning (attention) (e.g., Andreassi, 2007; Bundy, Lane, Murray, & Fisher, 2002; Janelle, 2002). A contemporary theory of stress, namely allostasis theory, can be used to better understand these psychophysiological mechanisms of stress (McGrady, 2007).

Allostasis theory (McEwen & Wingfield 2003; McEwen & Seeman, 1999; Schulkin, 2003; Sterling, 2012) defines *allostasis* as the optimal operation of regulatory systems linking the nervous system with the endocrine and immune systems. It is the body’s continuous adaptive attempt to maintain stability (homeostasis) through change (i.e., stress). When too much stress accumulates in the physiological system, it can manifest as less than optimal functioning of that system, referred to as “allostatic load” (McEwen & Wingfield 2003). Allostatic load, according to McEwen and Stellar (1993), develops as a result of excessive “wear and tear” on the body due to chronic stress or poor recovery. As a result, the sympathetic nervous system loses its capacity to return to baseline. There is clear evidence from allostatic load studies that failure to regularly shut off the sympathetic nervous system (the stress response) can have serious consequences, such as lower baseline functioning, poorer cognitive performance, weaker physical performance, augmented risk of incident cardiovascular disease, and increased risk of all cause mortality (Juster, McEwen, & Lupien, 2010; Seeman, McEwen, Rowe, & Singer, 2001; Seeman, Singer,

Rowe, Horwitz, & McEwen, 1997).

Psychophysiological stress profiling is useful for identifying patterns of reactions to stressful circumstances and for identifying and analysing any atypical responses that may occur outside of normal ranges (Gevirtz, 2007; Kanbara, Mitani, Fukunaga, Ishino, Takebayashi, & Nakai, 2004; Wilson & Somers, 2011). Psychophysiological stress profiles are conducted by utilizing various modalities, e.g., respiration rate (RR), heart rate (HR), temperature (TEMP), skin conductance (SC), and electromyography (EMG), to measure the body's response to stressful events applied in the lab (Gevirtz, 2007; Kanbara, et al., 2004). Measures are taken before and after stressors based on the concept of autonomic response specificity (Lacey, Bateman, & VanLehn, 1953) that later became known as individual response specificity (Andreassi, 2007; Marwitz & Stemmler, 1998; Simon & Bueno, 2009). This concept states that the autonomic nervous systems' response to stress has a stable and reproducible reaction profile meaning that an individual will respond with the same physiological response (e.g., skin conductance response) under different stress conditions (e.g., whether the athlete is faced with stress in a competitive setting or in a practice setting).

Moreover, the field of sport psychophysiology has developed over the last two and a half decades. Research has evolved with multiple studies validating the physiological effects of psychological stress states in sports (Blumenstein, Bar-Eli, & Tenenbaum, 2002; Carlstedt, 2001; Davis & Sime, 2005; Edmonds, Tenenbaum, Mann, Johnson, & Kamata, 2008; Janelle, 1999; Hatfield & Hillman, 2001; Paul & Garg, 2012; Shaw, Zaichowsky, & Wilson, 2012). Davis, Sime, and Robertson (2007) have noted that the psychophysiological effects of stress on athletes can lead to deterioration in overall performance. For example, negative emotions can result in narrowed or inefficient attention states (Janelle, Singer, & Williams, 1999; Wilson & Prichard,

2005), impaired motor performance (Eysenck, Derakshan, Santos, & Calvo, 2007), and reduced peripheral blood flow to the fingers, affecting an athlete's dexterity (Davis et al., 2007).

In an attempt to counteract these psychophysiological effects of stress, various research studies have explored the effect of biofeedback training interventions on performance. For example, Blumenstein and colleagues (2002) focused their research efforts on the improvement of athletes' self-regulation skills, through biofeedback training, specifically EMG, HR and SC, and psychological skills training to enhance athletic performance. Their research with adolescent swimmers and runners reported increases in performance in the intervention group (i.e., consistent decrease in running and swimming times) compared to the relatively stable performances of the control groups (Bar-Eli & Blumenstein, 2004a; Bar-Eli & Blumenstein, 2004b; Bar-Eli, Dreshman, Blumenstein, & Weinstein, 2002).

Although numerous studies have demonstrated enhanced performance with biofeedback training (e.g. Blumenstein, Bar-Eli, & Tenenbaum, 1995; Beauchamp, Harvey, & Beauchamp, 2012; Caird, McKenzie, & Sleivert, 1999; Dupee & Werthner, 2011; Edmonds et al., 2008; Edmonds & Tenenbaum, 2012; Galloway, 2011; Kavussanu, Crews, & Gills, 1998; Lagos, 2011; Lagos et al., 2008; Landers, Petruzzello, Crews, Kubitz, Gannon, & Han, 1991; Paul & Garg, 2012; Peper & Schmid, 1983; Raymond, Sajid, Parkinson, & Gruzelier, 2005; Shaw et al. 2012), few studies have addressed the psychophysiological stress profiles of athletes and whether better baseline self-regulation of psychophysiological measures indicate better performance. Thus the purpose of this paper is twofold, (a) to explore whether the ability to self-regulate from a psychophysiological perspective is related to world ranking in elite athletes, and (b) to examine if any of the specific individual psychophysiological measures (e.g., respiration rate (RR), heart rate (HR), heart rate variability (HRV), skin conductance (SC), peripheral body temperature

(TEMP), and electromyography (EMG-Trapezius and EMG-Frontalis)) are significant in relationship to their world ranking.

Method

Participants

Fifteen elite level athletes underwent a psychophysiological stress profile assessment to identify their self-regulation ability. The 7 female and 8 male athletes ranged in age from 20-29 years old (mean \pm standard deviation: 25.1 ± 2.7), had all been competing at the international level for at least six years, and were from different disciplines in the sport of freestyle ski. Ethics approval for this study was obtained from the University's Ethics Review Board and written informed consent was obtained from each athlete in line with the University's ethical research guidelines.

Procedure

Each athlete completed an informed consent form and demographic questionnaire and was seated in a cushioned recliner facing a computer monitor. Psychophysiological data were recorded using the ProComp Infiniti™ version 3.1.5, (Thought Technology Ltd., Montreal, Quebec, Canada). This eight-channel research grade device acquires 256 samples/second. To record respiration rate (RR), a belt containing a strain gauge was secured around the abdomen below the ribcage. An indirect measure of HR was recorded using a photoplethysmograph sensor, which was secured to the volar surface of the distal phalange of the non-dominant thumb. Heart rate variability (HRV) was computed using the formula $HR \text{ Max} - HR \text{ Min}$ (that is, the mean of the difference between maximal HR and minimal HR in each breath cycle). Skin conductance response (SCR) was recorded using the SC sensor. SC electrodes were secured on the volar surface of the proximal phalanges on the second and fourth fingers of the dominant

hand. A thermal sensor was secured to the skin on the palmar surface, at the base of the second finger on the non-dominant hand, to measure peripheral body temperature. Surface Electromyography (SEMG) was monitored using a Myoscan Pro sensor with a bandpass filter set between 100 and 200 Hz. Three EMG electrodes were placed on the participant's forehead, to measure frontalis EMG and on the participant's non-dominant shoulder to measure trapezius EMG.

Stress Assessment. Psychophysiological recordings began and the athlete was asked to relax and remain still while the clinician checked to make sure that each sensor was accurately recording data. The psychophysiological stress profile testing started with a baseline measurement and then subjected the athlete to different stressors while monitoring the psychophysiological parameters. After each stressor there was a recovery period. The goal was to identify the psychophysiological response patterns that occurred. A modified version of a structured stress assessment protocol for athletes was used (Wilson, 2006). The assessment was divided into nine sections, with the initial baseline 2 minutes in length and each successive section of 1 minute in duration. The recorded psychophysiological data was reviewed for movement artifacts and only artifact-free segments of the data were analyzed.

Measures

World Ranking. Each athlete's world ranking was recorded at the time of the assessment. For the purpose of this article, higher world ranking refers to a top ranked athlete, such as one who is first or second in the world in their event, and a lower world ranking refers to an athlete who might, for example, be ranked 24th in their event.

Self-Regulation Ability. Data gathered, for each athlete, on the seven criteria (RR, HR, HRV, SC, TEMP, EMG-Frontalis, and EMG-Trapezius) were categorized as either poor,

moderate, or good self-regulation ability in reference to whether the athlete returned to baseline after each stressor (Wilson & Somers, 2011). A poor rating (1) was given if during the recovery phase the athlete either stayed at the same activation level as during the stressor or went in the opposite direction expected (i.e., respiration rate increased or temperature decreased during recovery). A moderate rating (2) was assigned if the athlete recovered up to half way to baseline. A good rating (3) was given if recovery was either back to baseline or greater than half of the way back to baseline. An overall self-regulation ability score (minimum of 7 and maximum of 21) was computed for each athlete by summing his or her scores on the seven criteria. Each athlete was then assigned an overall self-regulation ability score.

Data Analysis. The psychophysiological data and world rankings were statistically analysed using SPSS 18.0. First, a spearman Rho correlation was conducted to examine the association between overall self-regulation ability and world ranking. Second, a multiple regression was conducted to examine if any of the specific individual psychophysiological measures (e.g., respiration rate (RR), heart rate (HR), heart rate variability (HRV), skin conductance (SC), peripheral body temperature (TEMP), and electromyography (EMG-Trapezius and EMG-Frontalis)) were significant in predicting world ranking. The athlete's actual numerical world ranking and his or her overall self-regulation ability score were used in the data analysis.

Results

As depicted in Figure 1, the overall self-regulation ability was significantly associated with world ranking ($r_s = -0.848$, $p=0.01$), meaning that the better the overall self-regulation ability of the athlete the better the world ranking.

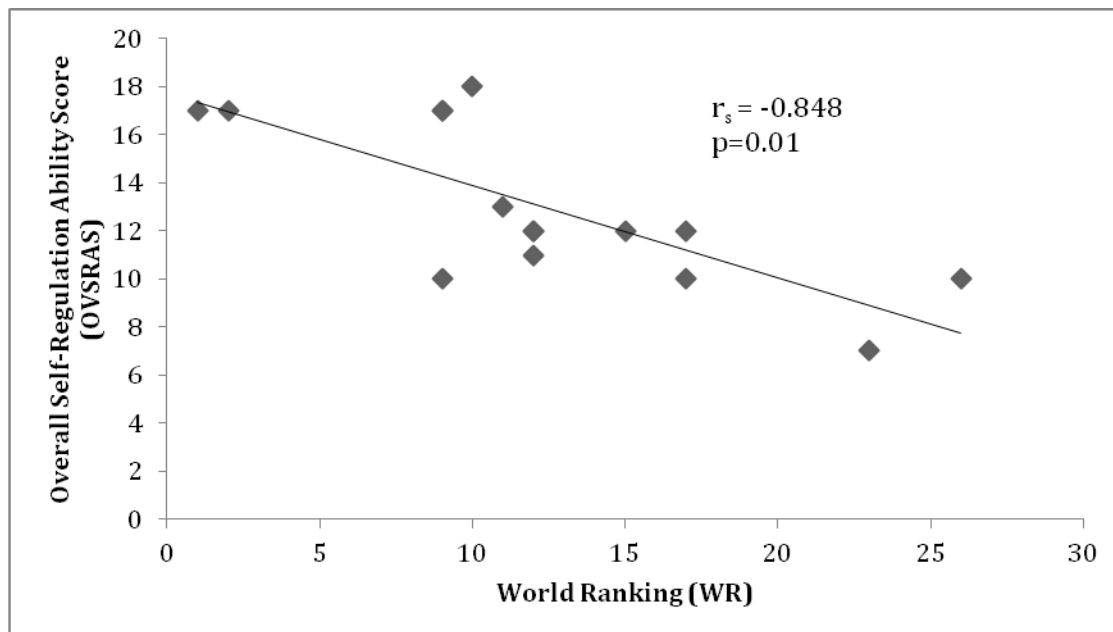


Figure 1. Association between overall self-regulation ability and world ranking in 15 athletes. Two data points do not appear because they are duplicated (i.e., two athletes with a world ranking of 9th had a self-regulation score of 17 and 2 athletes with a world ranking of 12th had a self-regulation score of 12)

The multiple regression analyses with all measures of self-regulation predicting world ranking indicated that all seven measures of self-regulation accounted for 76% of the variance in world ranking (Adjusted $R^2 = .525$). Examination of the individual measures of self-regulation indicated that only the EMG-Trapezius self-regulation score (beta = $-.708$, $p = .012$) significantly contributed to the model and accounted for 58% of the variance of world ranking.

Table 1.

Multiple Regression Examining Predictors of Athletes' World Ranking

	Beta	p value
Respiration Rate	-.419	.198
Heart Rate	-.432	.134
Heart Rate Variability	-.464	.109
Skin Conductance	-.223	.395
Peripheral Body Temperature	-.285	.339
EMG-Trapezius	-.708	.012

EMG-Frontalis	.116	.608
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Discussion

The purpose of this paper was twofold: (a) to explore whether the ability to self-regulate from a psychophysiological perspective was related to world ranking in elite athletes, and (b) to examine if any of the specific individual psychophysiological measures (e.g., respiration rate (RR), heart rate (HR), heart rate variability (HRV), skin conductance (SC), peripheral body temperature (TEMP), and electromyography (EMG-T and EMG-F) are significant in relationship to their world ranking. Results from this research showed that overall self-regulation ability was significantly associated with world ranking. Taken together all seven measures of self-regulation accounted for 76% of the variance in world ranking; however, only the EMG-Trapezius self-regulation score significantly contributed to the model. The results of this research lend support to McEwen's allostatic load model (McEwen & Wingfield 2003; McEwen & Seeman, 1999). The athletes who were less effective at turning off the stress response and returning their physiological state to baseline after a stress load (poor self-regulators) had poorer world rankings. Conversely, those who were ranked higher in the world demonstrated the ability to recover after a stress load was applied.

The results of this study also indirectly support research in the field of sport psychology. For example, Bois, Sarrazin, Southon, and Boiche (2009), studying the emotional management skills of professional golfers, found three predictors of superior performance: (1) slightly elevated levels of cognitive anxiety that were perceived by the golfers as facilitating performance, (2) frequent use of relaxation strategies, and (3) use of emotional control strategies. In that study, the regression accounted for 59% of the variance of players' ranking. Although

cognitive anxiety was not a direct measure in this particular study, self-regulation was obtained through both relaxation and emotional regulation strategies. In addition, Krane and Williams' (2006) review of the sport psychology literature found that arousal management techniques were key to attaining peak performance. Similarly, a study by Gould, Dieffenbach, and Moffett (2002) showed that Olympic champions rated high on activation, relaxation, and emotional control abilities.

The second objective of the study was to examine if any of the specific individual psychophysiological measures (e.g., RR, HR, HRV, SC, TEMP, EMG-T and EMG-F) were significant in relationship to an athlete's world ranking. Sime (2003) has suggested classic symptoms of stress in competitive sport are demonstrated in muscle bracing and residual tension and that optimal control of muscle tension assists not only in enhanced skill execution but also in the conservation of energy. This concept was supported in the current study, which indicated that EMG-Trapezius was the one psychophysiological measure that was found to be significant in terms of overall world ranking and the ability to self-regulate.

Overall the results of this study are congruent with Blumenstein and colleagues' research (2002, 2004a, 2004b) that has shown increases in athletic performance through the improvement of athletes' self-regulation skills, specifically EMG, HR and SC. Thus, it follows that there is a need for self-regulation training for elite athletes in order to help them foster optimal performance. Based on this research it is recommended that athletes be assessed to determine their psychophysiological stress response profile and identify their patterns of reactions. Once this is complete, self-regulation training can then be undertaken for any identified atypical psychophysiological responses. It is important that sport psychologists assisting athletes in achieving optimal self-awareness and self-regulation of their psychophysiological state recognize

that each athlete's path will be idiosyncratic and that any self-regulation training or interventions are adapted to the individual athlete's needs.

Although the findings from this research have important implications there are a number of limitations. One of the limitations is the sample size (N=15). Given such a small number of subjects the results must be interpreted with caution. As well, the subjects were restricted to one winter sport. Future research should seek to explore psychophysiological stress profiling with a greater number of athletes in a variety of sports to determine whether or not there is a *specific* profile or whether particular psychophysiological measures predict self-regulation ability and optimal sport performance. A third limitation is the ecological validity of the study. Ecological validity is limited due to the inability to evaluate baseline self-regulation ability under real life competitive field settings (Collins & McPherson, 2006). Due to the limitations of the current technology (e.g., equipment portability, wires and electrodes attached to the athlete that may impede movement) it is difficult to capture psychophysiological data within the actual sport environment. As such, future research should seek to create protocols that closely mimic performance conditions (Davis & Sime, 2005; Linden, Strack, & Sideroff, 2011).

In conclusion, although several studies in sport have demonstrated enhanced performance with BNFK training, few studies, to date, have addressed the psychophysiological stress profiles of elite athletes and whether better self-regulation ability correlates to better performance. The results of this study indicated that elite level athletes with higher world ranking can be discriminated from lower world ranking athletes on the basis of their ability to self-regulate and, in particular, the EMG trapezius. Therefore, it is recommended that coaches consider biofeedback training to enhance an athlete's ability to become first more self-aware and second optimize the management of their stress response. Developing ways of helping athletes manage

the stress inherent in competitive sport would be advantageous in narrowing the gap between potential and actual performance.

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CHAPTER III

**ARTICLE 2 – PERCEIVED OUTCOMES OF A BIOFEEDBACK AND
NEUROFEEDBACK TRAINING INTERVENTION FOR OPTIMAL PERFORMANCE:
LEARNING TO ENHANCE SELF-AWARENESS AND SELF-REGULATION WITH
OLYMPIC ATHLETES**

Perceived outcomes of a biofeedback and neurofeedback training intervention for optimal performance: Learning to enhance self-awareness and self-regulation with Olympic athletes

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Abstract

The purpose of this study was to explore the perceived outcomes of a biofeedback and neurofeedback training intervention with high performance athletes. Five Olympic level athletes preparing for world championships and the 2012 Olympic Games took part in a 20 session intervention over the period of one year. At the completion of the intervention, a semi-structured interview was conducted with each athlete. The athletes indicated that they became more self-aware, were better able to self-regulate both their physiological and psychological states, developed a greater sense of personal control, and a greater understanding of skills inherent in the field of sport psychology. Three of the athletes made the Canadian Olympic team for the 2012 Olympic Games and two of those athletes won bronze medals. The present study suggests that biofeedback and neurofeedback training may be useful in enabling athletes to perform optimally, in both training and competition, on a consistent basis.

Keywords: Olympic athletes, biofeedback, neurofeedback, self-awareness, self-regulation, optimal performance

Introduction

What does it take to perform optimally in high performance sport? One perspective suggests consistent optimal sport performance stems from the ability to self-regulate one's physiological and psychological states. If one shares such a perspective, and many researchers and recent studies appear to be in agreement (e.g., Anderson, Hanrahan, & Mallett, 2014; Dupee, Werthner, & Forneris, 2015; Hanin, 2000; Jones, Hanton, & Connaughton, 2007; Ravizza, 2006), it follows that learning to improve the ability to effectively manage these two states should lead to optimal performance. Much of the research in the field of sport psychology is descriptive and only identifies the characteristics necessary for optimal performance. For a more complete understanding of optimal performance, interventions that target critical change processes such as self-regulation are needed (Gardner, 2009). Thus, this qualitative exploratory research was designed to examine the perceived outcomes of participating in a biofeedback and neurofeedback training intervention designed to increase self-awareness and self-regulation of athletes' physical and mental states.

The range of factors contributing to peak performance highlight the need for athletes to have a highly developed ability to psychologically self-regulate all relevant aspects of their optimal performance states (Anderson et al., 2014). Key psychophysiological components that high performance and Olympic athletes must learn to optimally regulate in order to achieve athletic excellence have been recognized in numerous studies conducted over the last 15 years (Anderson et al., 2014; Golby & Sheard, 2004; Gould & Maynard, 2009; Gould, Dieffenbach, & Moffett, 2002; Harrison, 2011; Jones et al., 2007; Krane & Williams, 2006; Orlick, 2008; Thelwell, Such, Weston, Such, & Greenlees, 2010). More specifically, psychophysiological attributes and mental skills that these researchers have identified as being related to the ability to

self-regulate in highly successful athletes include: arousal/activation management, relaxation ability, focusing ability, distraction management, attentional control, automaticity, emotional control, and self-awareness including body awareness. In addition, the ability to engage in honest self-appraisal to enhance self-awareness has been identified as an important mental skill by elite athletes (Bull, Shambrook, James, & Brooks, 2005; Calmels, d'Arripe-Longueville, Fournier, & Soulard, 2003; Gould & Maynard, 2009). Self-awareness is the ability to engage in introspection and retrospection to understand one's thoughts, feelings, and behaviors (Vealey, 2007) and is seen as a critical precursor to effective self-regulation and success in sport (Anderson et al., 2014; Chen & Singer, 1992).

Also recognized as important is an athlete's ability to create and manage an ideal level of arousal of the nervous system. This notion of self-regulation encompasses both a psychological and physiological component (Blumenstein, Bar-Eli, & Tenenbaum, 2002; Crews, Lochbaum, & Karoly, 2001; Landers & Arent, 2006; Williams & Harris, 2006). The combination of the physiological and psychological aspects has been discussed in the literature as the psychophysiology principle (Andreassi, 2007; Cacioppo & Tassinary, 1990). Cacioppo and Tassinary (1990) define psychophysiology as "the scientific study of cognitive, emotional and behavioral phenomena as related to and revealed through physiological principles and events" (p. ix). Green, Green, and Walters (1970) formulated this psychophysiological principle as follows:

Every change in the physiological state is accompanied by an appropriate change in the mental emotional state, conscious or unconscious, and conversely, every change in the mental emotional state, conscious or unconscious, is accompanied by an appropriate change in the physiological state (p. 3).

One technique for facilitating the learning of effective self-regulation of the activation levels of the nervous system is biofeedback and neurofeedback training which uses self-observation and self-monitoring with instruments to control physiological (autonomic nervous system) and neurological (central nervous system) functions (Bar-Eli & Blumenstein, 2004; Dekker, Van den Berg, Denissen, Sitskoorn, & Van Boxtel, 2014; Dupee & Werthner, 2011; Lagos, Vaschillo, Vaschillo, Lehrer, Bates, & Pandina, 2011; Paul & Garg, 2012; Raymond, Sajid, Parkinson, & Gruzelier, 2005; Shaw, Zaichowsky, & Wilson, 2012; Werthner, Christie, & Dupee, 2013). Biofeedback and neurofeedback training requires attaching sensors to the body for the purpose of acquiring biological and neurological signals such as those produced by muscles, sweat glands, body temperature, respiration, and heart rhythm (i.e. biofeedback modalities) and brainwaves (i.e. neurofeedback modality). Biological and neurological signals are fed to the athlete being trained with the goal of gaining mental control over subconscious biological and neurological processes. More specifically, the athlete receives moment by moment information about changes from the sensors. Information may come in the form of auditory tones, digital or analog displays, or computer graphics. Therefore, the training is designed to enable individuals to learn how to regulate aspects of their central and autonomic nervous systems (Schwartz & Andrasik, 2003; Thompson & Thompson, 2003).

In addition, the neurovisceral integration model of self-regulation (Thayer & Lane, 2000, 2009), also stemming from the field of psychophysiology, can be used to enhance our understanding of how to integrate the various components of optimal performance to help athletes improve their ability to self-regulate. It recognizes that a comprehensive model of self-regulation must account for the complex mix of cognitive (attentional), affective (emotional), behavioral, and physiological components. An emphasis is placed on the relationship between

attentional regulation and emotional processes and a group of underlying physiological systems that serve to integrate these functions in the service of self-regulation and adaptability.

There are numerous research studies in both the field of biofeedback and in sport psychology that argue the benefits of an athlete's ability to self-regulate and optimal performance. Most recently, Dupee et al. (2015) noted a relationship between overall physiological self-regulation ability and world ranking in 15 elite athletes preparing for the Vancouver 2010 Olympics. Athletes who ranked higher in the world had a better ability to return their physiological indicators to base line levels after a stressor ended. As well, in the sport psychology literature, Anderson et al. (2014) argues that the range of factors contributing to peak performance highlights the need for athletes to have a highly developed ability to psychologically self-regulate all relevant aspects of their optimal performance states. More specifically, research on mental toughness has found that best performers have the ability to switch focus on and off and to remain fully focused, when needed, on the task despite personal or competitive distracters (Jones et al., 2007; Thelwell et al., 2010).

In sum, it is believed that highly self-regulated mental and physical states result in superior performance (Anderson et al. 2014; Dupee et al., 2015; Hanin, 2000; Jones et al., 2007; Ravizza, 2006); however, learning to consistently achieve one's own ideal internal psychological climate is not a simple task (Harrison, 2011; Krane & Williams, 2006). Moss and Wilson (2012) suggest that biofeedback and neurofeedback when used as complementary tools provide enhanced awareness of the complexity of the mind-body connection, increased control over physiological and neurological mechanisms, and increased access to self-regulation strategies. Also, there is an accumulating body of knowledge regarding the attributes and mental skills related to self-awareness and self-regulation that help athletes consistently perform close to their

optimal level (Anderson et al., 2014; Golby & Sheard, 2004; Gould & Maynard, 2009; Gould et al., 2002; Harrison, 2011; Jones et al., 2007; Krane & Williams, 2006; Orlick, 2008; Thelwell et al., 2010). However, there is a paucity of research on the athlete's experience learning these skills. Thus, the purpose of this research was to explore the perceived outcomes of participating in a biofeedback and neurofeedback training intervention designed to increase self-awareness and self-regulation of athletes' physical and mental states. The research questions that guided this study were as follows: (a) What did athletes learn as a result of participating in a biofeedback and neurofeedback training intervention? (b) What were the perceived benefits of participating in the intervention? This qualitative exploratory study can be used as a starting point for researchers wishing to gain further insight into athletes' perceived outcomes of what they learned and the benefits gained from participating in a biofeedback and neurofeedback training intervention in the pursuit of optimal performance.

Method

Design

A case study protocol (Stake, 2005) was used to examine a biofeedback and neurofeedback training intervention conducted with Canadian elite athletes preparing for international competition and in particular, the 2012 summer Olympic Games. Yin (2009) stated that case study protocol allows for an extensive description of the unique features of the studied object and Stake (2006) recognized that when researchers provide rich descriptions of the cases, 'naturalistic' generalizations can emerge. A case study is therefore of value in an exploration of the learning experiences of athletes taking part in a biofeedback and neurofeedback training intervention.

This research was guided by a constructivist epistemology. This worldview recognizes that each individual will understand and interpret the world from his or her point of view (Sparkes & Smith, 2014). Given that the overall purpose of this study was to gain understanding of the athletes' perceived outcomes from participating in a biofeedback and neurofeedback training intervention this epistemological approach was appropriate.

Participants

The participants in this research study were five elite athletes from one summer Olympic sport who were preparing for world championships and an Olympic Games. The three male athletes and two female athletes had a mean age of 25.2 years ($M \pm SD$ 2.9) and had participated in the sport for an average of 10.2 ($M \pm SD$ 3.1) years. A purposeful sampling protocol was used to select athletes. The national team coaches and administration identified athletes who had potential to win medals at the 2012 London summer Olympics Games and all athletes identified were given the opportunity to participate in the biofeedback and neurofeedback training intervention. Presented in this research are the five athletes that completed the full biofeedback and neurofeedback training program.

Intervention/Procedures

The goal of the biofeedback and neurofeedback training sessions was to enable the athletes to learn to identify and exercise control over the activation levels of their autonomic nervous system (ANS) and central nervous system (CNS), first in the lab and, ultimately, when competing at various international competitions and the Olympic Games. The intervention consisted of an initial and final assessment as well as 20 training sessions. Training sessions were conducted over a one year time period with variations in the exact frequency of sessions in order to accommodate the training and competition schedules of each individual athlete. In addition, a

9-stage psychophysiological stress assessment (Dupee et al., 2015; Gevirtz, 2007; Wilson & Sommers, 2011) was used to gain insight into each athlete's ANS and CNS activation levels and patterns under stress and in recovery. ProComp Infinity equipment from Thought Technology Ltd., was used to gather measures in seven areas: electroencephalography (EEG), surface electromyography (SEMG), respiration rate, heart rate, heart rate variability, skin conductance, and peripheral body temperature. This information was then used to optimize the training sessions for each of the athletes.

Each of the 20 one-hour training sessions included three components (Dupee & Werthner, 2011). The first component was biofeedback training or quieting the ANS. This component was identified as brief physical recovery exercises. Self-awareness and self-regulation of muscle tension, respiration rate, heart rate, skin conductance activity, and peripheral body temperature were trained both with eyes open and eyes closed. Target training criteria for the biofeedback training are listed in Table 1 along with the range of the athletes' data on these measures pre- and post- intervention. The second component was neurofeedback training or managing the CNS. The EEG modality was used for the three aspects of this component: (a) brief mental recovery (wide focus), (b) narrow focus, and (c) switching states between narrow focus and brief recovery (narrow and wide focus; Thompson & Thompson, 2003). Refer to Table 1 for the training criteria ratios used during the neurofeedback component, as well as, the range of the athletes' data on the ratios pre- and post- intervention. The third and final component included biofeedback and neurofeedback training, in tandem, and specifically involved decreasing activation in both the ANS and CNS. All seven measures, (EEG, SEMG, respiration rate, heart rate, heart rate variability, skin conductance, and peripheral body temperature) were monitored for the physical and mental deep recovery component. Paced

breathing (Lehrer, Vaschillo, & Vaschillo, 2000) was used to help the athletes decrease activation in both systems. In addition, each training session was broken down into 20 minutes quieting the ANS, 20 minutes managing the CNS, and 20 minutes deep recovery. Initial training sessions focused more on self-regulation of the ANS. These skills were then used to assist with regulation of the CNS. Deep recovery work began as a six minute exercise and over time was increased to 20 minutes.

Table 1.

A Sample of the Range of the Athletes' Biofeedback and Neurofeedback Data for Training Parameters Pre- and Post- Intervention

	Training Parameters	Target Range	Pre- Intervention	Post- Intervention
Biofeedback Data				
(during recovery)	respiration rate (brpm)	5-7	10-15	6-8
	heart rate (bpm)	45-60	48-67	45-62
	heart rate variability (hrmax-hrmin)	> 10	12-25	18-30
	muscle tension (micro-volts)	< 2.0	1.5-4.3	0.9-2.5
	skin conductance (micro-siemens)	< 5	1.7-8.8	1.3-6.4
	hand temperature (degrees Celsius)	32-35	27-35	32-35
Neurofeedback Data				
(during focus)	focusing ratio (theta/beta)	< 2.0	1.5-2.5	1.3-2.2
(recovery & focus)	intensity ratio (high alpha/intensity)	< 1.0	1.2-1.5	0.8-1.3
(recovery & focus)	ruminantion ratio (busy brain/SMR)	< 1.5	1.6-2.8	1.2-1.9

Note. For a further description of the training parameters for biofeedback refer to Blumenstein et al., 2002 and Wilson & Somers, 2011 and for neurofeedback refer to Thompson & Thompson, 2003 and Wilson, Thompson, Thompson & Peper, 2011.

As well, within each of the 20 sessions, discussion was encouraged with each athlete about how the learning in the lab could be transferred to the training and competition setting. For example, when the athlete was working on narrow focus, questions were asked by the researcher about how might the learning be utilized at up-coming competitions. When working on shifting states between a narrow focus and a brief recovery, how might that learning be utilized in training sessions or on competition day. Upon agreeing to participate in the research study, each

athlete provided written informed consent. In addition, approval to conduct the study was granted by the researchers' University Ethics Board.

Data Collection

Interviews. Each athlete participated in an open-ended, semi-structured interview at the end of the intervention (Rubin & Rubin, 2005). An interview guide was developed that asked questions in three main areas: experience of the biofeedback and neurofeedback training intervention, transfer of skills learned in the lab to the sport environment, and overall learning about the self. During interviews, probes were used to ensure the participants elaborated on or clarified certain responses using actual events (Patton, 2002). Given potential social desirability issues in interpretive research (Alvesson, 2011), all participants were assured that only the researchers would have access to the interview transcripts to ensure the athletes did not feel participation in the study could compromise their involvement on the national team. All of the interviews were conducted in person and ranged from 67-104 minutes ($M=85$). All of the interviews were digitally audio-recorded and then subsequently transcribed verbatim.

Data Analysis

Before coding, the purpose of the research was revisited in order to guide the data analysis. The data was then transcribed verbatim. The software NVivo 10 (Qualitative Solution and Research, 2010) was used to organize the data from the interview transcripts. A thematic analysis was performed whereby the data were broken into meaning units and submitted to descriptive treatment (Braun & Clarke, 2006). A thematic analysis was used as it is a flexible method for analyzing and reporting data from a variety of participants. First, the lead author reviewed the data several times to identify preliminary themes. After preliminary analysis, the lead author created initial codes for the meaning units identified from the data. These meaning

units (see Table 2) were then combined to form overarching themes and sub-themes. Once all of the coding was complete all of the authors reviewed the overarching themes and subthemes to refine them. Whenever differences arose the authors discussed until consensus was met and there was agreement that the findings provided a comprehensive representation of the data. Finally, the first author selected the most relevant quotes and consulted with the second and third authors multiple times to ensure the quotes supported the themes as well as the athletes' experiences of the intervention. To protect confidentiality codes were used to represent participants (i.e. Athlete 1=A1).

Trustworthiness

Several measures were taken to increase the trustworthiness of findings and interpretations. Before collecting the data, the researcher participated in a bracketing interview (Rolls & Reif, 2006). Bracketing interviews help a researcher reflect on his or her assumptions and how assumptions might influence the construction of knowledge. Two pilot interviews with two elite athletes who were not involved in the study were also conducted to ensure that the questions were clear. Only slight wording modifications were made to a select number of questions. Prior to analysis the interview transcripts were sent to participants via e-mail for a member check to confirm the accuracy of the responses shared with the researcher and no changes were requested. Once the initial analysis was completed by the first author, the second and third authors examined the initial meaning units to ensure the subthemes depicted were truly data driven. The researchers discussed any issues raised as a result of the review process until agreement was reached concerning the appropriateness of each established subtheme. Several major themes emerged from the data. Each theme consisted of data that belonged together in a meaningful way (i.e., internal homogeneity) yet were sufficiently distinct from information

contained in other themes (i.e., external homogeneity; Patton, 2002). In addition, throughout the analysis, all three authors worked together and discussed how to organize the themes until a consensus was reached, thereby offering greater assurance that the analyzed data offered an accurate portrait of the case. Finally, during the writing phase, member-checking was performed by having one of the athletes verify the accuracy of the researcher's interpretations.

Results

The analysis of the results (see Table 2) revealed three main themes: Greater self-awareness, enhanced self-regulation, and perceived benefits. These three main themes are made up of numerous subthemes which are outlined below under each of the main themes.

Table 2.
Summary of Findings

Themes	Sub-themes
Greater Self-Awareness	<ul style="list-style-type: none"> Recognition that physical & mental states can be managed Ability to identify and differentiate between physical and mental states Understanding the mind-body connection
Enhanced Self-Regulation	<ul style="list-style-type: none"> Sustaining a state Managing distractions Shifting between states Breathing as a key component Feeling 'in control' when performing
Perceived Benefits	<ul style="list-style-type: none"> Greater understanding and appreciation for sport psychology In depth understanding of techniques for stress management

Greater Self-Awareness

All five of the athletes felt that the biofeedback and neurofeedback training helped them develop a greater level of self-awareness. Three sub-themes emerged: (a) recognition that

physical and mental states can be managed, (b) ability to identify and differentiate between states, and (c) understanding of the mind-body connection.

Recognition that physical and mental states can be managed. The athletes reported that participating in the intervention helped them recognize that they could develop the ability to manage both their physical state and mental state. As one athlete stated “the more biofeedback and neurofeedback training I did the more I understood that you can actually control your physical and mental state” (A5). Another athlete shared:

I learned that things are not definite, that you can change your physical and mental state midway, that you can turn things around if you stick with it (maintain your focus and/or refocus when you get off), even though (at the start of the intervention) it feels like you can't in that moment (A3)

Similarly, another athlete expressed how, prior to starting the intervention training, he had not recognized what was possible, “I learned that you can control a lot more with your mind than what I thought you could” (A2). As well, this athlete shared how valuable it was to learn that she could begin to manage her anxiety level:

About half way through the training I realized that I had been living in the purple zone (busy brain). Good thing you guys came and brought me back. I was on the edge of going to the other side. It was just a good reminder, wow, you don't have to live there. You can control this (A1).

Ability to identify and differentiate between physical and mental states. The athletes also reported becoming more aware of the state of their body and mind at any point in time and differentiating between states. One of the athletes felt that he “learned to be more aware of what is happening inside my body and mind...I feel like I have improved my awareness of what state I

am in” (A4). Another athlete discovered that she lived in a highly activated state a lot, saying “it made me aware that I was on all the time” (A1). More, specifically, the athletes shared that the training helped them to become more aware of different aspects of their physical and mental state. One athlete commented “by doing exercises in the lab I learnt what it feels like to have no tension in my muscles. It made me realize that I have tension in my shoulders a lot during the day” (A2). Another athlete described becoming more aware of the tension in her jaw, “when we started I had no clue that I was always clenching my jaw. I remember the first time I came I was like ‘yeah, I am relaxed’ even though I now know I wasn’t” (A1).

Several athletes commented that the training also allowed them to increase their awareness of their mental state by observing their thoughts. As one athlete explained “I started to observe the thoughts that were going through my head” (A4). Another athlete stated “the training made me aware that I was thinking all the time. I noticed that even when I was off the water my brain was still thinking about paddling” (A5). Similarly, when observing her thoughts another athlete recognized that “I am an over thinker...I am thinking all the time...I never shut it down” (A3).

The athletes also discussed learning to identify when both their body and mind were in a relaxed state. “I learned how to physically relax and not think about anything. Before I would always be thinking even when I wasn’t on the water so I was never really fully relaxed in the past” (A5). Two athletes shared that it was a new experience to quiet their thoughts. One athlete said “I learned to trust that it was ok to let my brain relax and quiet down” (A2) while another athlete shared “...to be relaxed and to not think about everything...to me that was a brand new thing... before I couldn’t do that” (A3).

Furthermore, the athletes also identified what it meant to be in a focused state. One athlete explained, “it has helped me to learn exactly what focus is and also how to focus in training and in racing instead of just sort of going through the motions” (A2). Similarly, another athlete stated, “the training helped me learn what it feels like to be focused. It was on the bowling ball screen that I was able to figure out what I need to think and how I need to feel to stay focused” (A5). Having some awareness on breathing helped another athlete to focus, “I learned what it felt like to be physically relaxed but mentally really intensely focused. To do this I always now keep a little bit of awareness on my breathing” (A4).

The athletes not only talked about how they learned to identify their current state but also spoke about beginning to understand how to differentiate between two states or when they are moving from one state to another. As one athlete shared “from the training, you learn what is a good focusing zone and what is a good recovery zone for you” (A5). Similarly two other athletes explained, “the training gave me the tools to understand what it means to be in different states and how to recognize the state that you are in” (A4); “I became totally more aware of when I am relaxed and when I am tense” (A2). The athletes also discussed how learning to differentiate between the states or when they are moving from one state to the next was helpful as it allowed them to intervene earlier to help maintain the state they wanted to be in to perform optimally. One athlete said:

For me it was a really helpful tool [the intervention] to just understand what it means to be in different states and how it felt. Now I can actually feel when I am getting out of a relaxed state and when I am getting over anxious...and I am able to do something about it earlier...the more training I did the more I understood the difference(s) between being focused and being in recovery (A3).

Understanding the mind-body connection. The athletes also discussed gaining a better understanding of the mind-body connection. One athlete identified the link between negative thoughts and muscle tension. “I learned that when I think negative thoughts or worry, my muscles tighten up. I saw that on the screen in the lab and I noticed it on the water in competition” (A5). Another athlete reported noticing, “both in the lab and on the water, when I was in a really aggressive mood or feeling too intense, that my jaw was always tight and relaxing my jaw helped me bring down the intensity” (A1). A third athlete felt “that when I am just aware of my breathing, I can let all my other thoughts go” (A3). Lastly, an athlete said, “in World Cup races at the beginning of the year, if I thought about getting tired, my shoulders would go up. With the training I learned to be aware of keeping my shoulders down especially when I was tired” (A2).

Enhanced Self-Regulation

The second main theme was enhanced self-regulation. The athletes discussed in a number of ways how the biofeedback and neurofeedback training sessions helped them learn to effectively self-regulate and manage themselves. There were five sub-themes: (a) sustaining a state, (b) managing distractions, (c) shifting states, (d) breathing as a key component (e) feeling ‘in control’ when performing.

Sustaining a state. All five athletes spoke of developing the ability to sustain a desired state, psychologically and physiologically. For example one of the athletes spoke of learning how to sustain a focused state, “the [neurofeedback] training helped me to learn how to keep my focus on myself, my plan, and my key words during training and competition” (A4). The ability to sustain a relaxed state was also reported by the athletes. One of the athletes shared “I learned

how to calm myself down by focusing on my breathing and relaxing my face, shoulders, and hands...it was really helpful in learning how to stay in a relaxed state” (A5).

Managing distractions. Athletes identified managing negative distractions as a skill that they improved due to the training. They knew it was a skill that is intimately connected to sustaining a good focusing state. One athlete shared, “I learned that I have to have something very specific to focus on otherwise I get distracted really easily” (A4). Another athlete simply stated, “I learned just to stick to what I have to do more than focusing on what other people are doing, in order to not get distracted” (A2). In addition, the athletes commented on how they transferred this skill to competition. One athlete explained, “I have learned how to not be distracted by the other competitors around me. In the past, if there were things going on beside me on the water, I would easily get distracted but now it is no big deal” (A1).

Shifting between states. Being able to switch their physical and mental states on demand, based on the task being asked, is another skill that athletes identified as important. One athlete stated:

The training gave me the tools to change my physical and mental state when I need and want to...for example...like when I needed to take a rest in between exercises in training or when I needed to get more intense for racing. What I learned helped for everyday training as well as for competition (A2).

Another athlete identified the importance of being able to flexibly shift mental states between focus and recovery, “once I understood how much energy it takes to be focused it gave me a better appreciation for how important recovery is, how important letting things go is” (A5). A third athlete explained “it gave me the tools to switch it up when I need to...now when I notice I

am physically tense I actually take a few seconds and relax because now I know what it means to be relaxed” (A4).

Breathing as a key component. The athletes discussed how breathing training helped self-regulate their mental state. One athlete stated, “having some awareness on my breathing definitely helps me be able to stay focused on the present moment. The breathing helps because it is simple and I know exactly what I am supposed to be doing” (A2). Another athlete shared that breathing was a tool that was very helpful for effective self-regulation. He said, “for me the breathing clearly proved to be a new tool that I can really use to stay in the state I want to be in...I use it to help me when I am both getting prepared to focus and for recovery” (A5).

Similarly, one of the athletes commented on the skill of breathing for re-focusing:

I know I have something to go back to if my mind wanders to other thoughts...I just go back to being aware of my breathing. I know exactly how to do it and I know if I do it some kind of positive effect is going to happen. Having something prescribed and concrete like the breathing to help you sustain your focus and to help you get back to focusing if you lose it...having a very clear way to do it is helpful. (A3).

Feeling ‘in control’ when performing. The athletes shared that the training helped them to feel more ‘in control’ when competing. One athlete commented, “when I think about my Olympic races the one thing that sticks out is that I was able to be ‘in control’ before and during my race...(and I) was in a pretty solid place which helped me to perform my best” (A5).

Similarly, another athlete shared that he was able to race better because he was able to control his focus. He stated:

The reason I made it to the Olympics is because I was able to control my focus. I was able to control it on the water and also during my race, but also when I was off the water

and before going in, like in the boat bay and stuff like that. I was able to just see and take what I needed and let go of all the other things which made me able to race better (A4).

As well, this athlete talked about how the training really helped her feel more 'in control' compared to previous races:

The training really helped me if I compare to races before we started the training. Back then, I was really tense and I was really shaky and I was really on the edge all the time and I took things really personal. At the Olympics, I was more able to enjoy what I was doing and be aware of what I was doing instead of living in the stress zone all the time...it helped me to feel more in control (A1).

Perceived Benefits

Along with increased self-awareness and an enhanced ability to self-regulate the five athletes described a number of benefits gained from participating in the intervention. These benefits comprised two subthemes: (a) greater appreciation for sport psychology and (b) in depth understanding of techniques for stress management.

Greater understanding and appreciation for sport psychology. The athletes acknowledged that the training intervention provided objective measures for the concepts in sport psychology and helped to make the concepts more concrete. One athlete explained as follows:

I think the big thing I learned was that what you hear in sport psych...the zone and things like that...even like kind of cheesy words that I didn't have much respect for before and then to see it all in objective measures...it kind of showed me that things are not just baloney...they (sport psychology concepts) actually translate into real things and the

biofeedback training gave me a better appreciation of how important sport psychology is and how it fits into every part of the training year and the racing. I think that the training intervention just made me a lot more aware of that and that there are specific skills like focus and recovery that I need to be good at (A4).

A second athlete summarized how the training had helped him. “For sure, it gave me a better understanding of the sport psychology terms and the sport psychology field. Words like focus and mental states were always really abstract concepts for me. This training makes those concepts way more concrete” (A5).

In depth understanding of the techniques for stress management. The athletes recognized that the training provided them with an opportunity to learn techniques that helped them to be better aware of and more effectively manage stress. One athlete stated:

I have more tools now to manage stress... I am definitely more able to identify why am I feeling a certain way and what I can do to change it... it doesn't make it always easy but I think before I would feel more like it was the end of the world when something not so good happened...but now I am more able to recognize that this feels like the end of the world but it is not. It is a cycle and it will go away. I just have to wait it out. I can acknowledge it more now (A1).

Similarly, another athlete was able to recognize the signs of stress more easily after completing the training. She stated:

I think now I am better at understanding red flags and acknowledging that I am stressed.

Yeah, I am more aware of what makes me stressed or why I am feeling a certain way like

fatigue and irritability and things like that where I think before it would kind of happen really quickly and then I would only deal with it after I was overwhelmed (A3).

A third athlete explained that “not only am I more aware of when I am stressed but now I am better at catching myself and doing something about it” (A2).

Discussion

The purpose of this study was to explore the perceived outcomes of a biofeedback and neurofeedback training intervention with elite athletes. The overall findings are encouraging and suggest that further exploration of interventions utilizing a biofeedback and neurofeedback intervention are warranted for those interested in enabling optimal performance in sport. After completing a 20 session biofeedback and neurofeedback training intervention, the five athletes in this study perceived that they improved both their self-awareness and their ability to self-regulate both physiologically and psychologically which, in turn, assisted them in feeling ‘in control’ when competing at major competitions and the 2012 Olympic Games. The specific results are discussed in greater detail below in relation to previous research.

In the sport psychology literature, Anderson et al. (2014) identified self-awareness as a crucial skill that allows athletes to recognize the necessary elements of the psychological state required for peak performance. The development of self-awareness that the athletes report in this study has been described in the literature as ‘making covert processes overt’ (Schwartz & Andrasik, 2003). This entails bringing processes into conscious awareness that previously were happening below the level of conscious awareness. During biofeedback and neurofeedback training, sensors record the athlete’s physiological and neurological signals and display them back to the athlete being recorded. Often athletes are not initially consciously aware that they are, for example, holding tension in their shoulders or that they have excessive high beta (i.e.,

rumination, worry) brainwaves and the feedback from the indicators, as the athletes in this study highlighted, brings this into the athlete's conscious awareness.

In this study the athletes discussed how the intervention improved their awareness of their physical and mental states through developing an ability to identify and differentiate between various states. The training intervention provided each athlete with techniques to recognize the state that they were in and with a better understanding of what it means to be in different states. This finding supports previous research. In the biofeedback and neurofeedback literature, an in depth explanation of different physical and mental states and identifying characteristics has been documented (Thompson & Thompson, 2003; Wilson & Somers, 2011). Specifically, it has been recognized that different mental states correspond with well-defined brain wave frequency ranges (Lindsley, 1952) and individuals are able to learn to recognize the state that they are in (Sterman, 1996, 2000).

In addition, athletes identified that the training helped them to gain a greater awareness & understanding of the connection between their mind and body. This has been recognized in the literature as the psychophysiological principle (Green et al., 1970). In the present study, the athletes recognized how intimately their bodies and minds were connected and as the covert processes were brought into their awareness during the sessions, recognition of the link between the mind and body strengthened. Importantly, Harrison (2011) suggested that each athlete's ideal mind-body state is highly idiosyncratic. Thus, improved self-awareness in the present study provided each athlete with the opportunity to choose how to self-regulate their own individual physical and mental state.

The neurovisceral integration model (Thayer & Lane, 2000, 2009) recognizes self-regulation as a complex mix of cognitive, affective, behavioral, and physiological components.

The findings in the present study add support to the neurovisceral integration model of self-regulation as athletes spoke of a variety of ways that the biofeedback and neurofeedback training intervention contributed to their increased ability to self-regulate their physical and mental states. Athletes reported learning to effectively sustain a desired state (both physiologically and psychologically), improve their ability to shift their physical and mental states on demand, and develop an enhanced capacity to select meaningful information and disregard irrelevant information from their environment. Noteworthy is the fact that both the neurovisceral integration model and biofeedback and neurofeedback training utilize the central autonomic network (Benarroch, 1993) as the structural basis for self-regulation.

Anderson et al. (2014) highlighted the link between self-awareness and self-regulation by emphasizing that without self-awareness, athletes would fail to effectively self-regulate their thoughts, emotions, and behaviors when required. With respect to learning to perform optimally, results from the present study clearly demonstrate that athletes believe they can learn to improve self-awareness and self-regulation by participating in a biofeedback and neurofeedback intervention. Moreover, the present study provides an example of a training technique that can help athletes learn to develop their mental skills (such as focus, recovery from a sustained focus, relaxation, and distraction control) and coping strategies (i.e., stress management strategies) in order to feel in control during performances. Support for this can be found in the literature as Anderson et al.'s (2014) research identified psychological processes such as self-regulation and control that can assist athletes in consistently finding the state that results in best performances. As well, research in the area of mental toughness reported that best performers have the ability to switch focus on and off and to remain fully focused even in the face of distractions (Jones et al., 2007; Thelwell et al., 2010).

It is important to acknowledge the limitations of the study. The sample was relatively small and all of the athletes were from the same sport and were all elite level athletes which may limit generalizability of the findings. Therefore, future research will need to examine other sports and perhaps larger numbers of athletes at varying competitive levels, although it should be noted that running a lengthy biofeedback and neurofeedback intervention with a large number of athletes will require numerous researchers and technicians. Second, this study focused on the perceptions of the athletes with regards to the impact of the intervention. Future research that incorporates observations, interviews with others working with the athletes (e.g. coaches), and/or some form of performance measure before and after the intervention is needed to provide further support to the findings from this qualitative exploratory study.

For sport psychology practitioners, the results of the present study provide insight into another tool that can be used to help athletes (especially those that underperform) to optimally regulate their physical and mental states, assisting them in performing to their potential more consistently. By engaging in biofeedback and neurofeedback training, the athlete and practitioner receive feedback in the form of quantified data about the athlete's internal mental and physical state that can supplement a discussion about what the athlete should be thinking and feeling in order to perform optimally. In preparation for engaging in biofeedback and neurofeedback training, the practitioner can help athletes begin to develop greater self-awareness of their physical and mental states under stressful conditions by asking the question, "What do you notice when you are feeling stressed (e.g., do you experience an increased heart rate, is your breathing shallow, do you sweat excessively, are your hands colder than your neck, what are you thinking about)?" Moreover, given that psychological skills have been identified in the literature (Anderson et al., 2014; Gould et al., 2002; Gould & Maynard, 2009; Harrison, 2011; Krane &

Williams, 2006) as facilitating optimal performance, it is fitting that athletes in this study stated that one of the benefits of the biofeedback and neurofeedback training was that it made sport psychology concepts more concrete.

In conclusion, the present study demonstrated that participating in a 20 session biofeedback and neurofeedback training intervention enabled athletes to become more self-aware and to improve their ability to self-regulate their physiological and psychological states, assisting them to feel 'in control' when performing. Importantly, all five athletes indicated that the training intervention enabled them to begin to effectively manage various states that, in turn, resulted in better preparation for the stress of competition. It is suggested that biofeedback and neurofeedback training may well be a useful technique for developing skills required for optimal performance in high performance sport.

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CHAPTER IV**OLYMPIC ATHLETES' PERCEPTIONS OF HOW THEY LEARNED DURING A
BIOFEEDBACK AND NEUROFEEDBACK INTERVENTION FOR OPTIMAL
PERFORMANCE**

Olympic athletes' perceptions of how they learned during a biofeedback and neurofeedback
intervention for optimal performance

Dupee, M., Werthner, P., & Forneris, T. (submitted). Olympic athletes' perceptions of how they
learned during a biofeedback and neurofeedback intervention. *International Journal of
Sport and Exercise Psychology*.

Abstract

To perform to potential, athletes must learn to regulate their optimal performance states. However, the exact process to achieve this is not well understood. This research explores how Olympic athletes perceived they learned while participating in a 20 session biofeedback and neurofeedback training intervention designed to improve self-awareness and self-regulation of their physical and mental states. A semi-structured interview was conducted with each athlete following the intervention. The athletes indicated they learned to self-regulate by engaging in active learning exercises, receiving real-time formative feedback, and utilizing the exercises learned during the intervention in both their training and competition environments.

Keywords: biofeedback, neurofeedback, Olympic athletes, learner-centered approach, self-regulation

Introduction

Sport psychology research suggests that athletes must learn how to establish their individual optimal psychological states in order to perform their best on a consistent basis (Anderson, Hanrahan, & Mallett, 2014; Harrison, 2011; Martin, Vause, & Schwartzman, 2005). Researchers contend that this can be accomplished through improving self-awareness of individual ideal performance states as well as developing the necessary psychological skills, such as focus and relaxation, to effectively regulate internal states (Gould & Maynard, 2009; Gould, Dieffenbach, & Moffet, 2002; Hardy, Jones, & Gould, 1996; Harrison, 2011; Jackson, Thomas, Marsh, & Smethurst, 2001; Jones, Hanton, & Connaughton, 2007; Krane & Williams, 2006). Sport psychology interventions that utilize biofeedback and neurofeedback training can facilitate the learning of effective self-regulation of physical and mental states (Edmonds & Tenenbaum, 2012; Strack, Linden, & Wilson, 2011). What is less well understood in the research literature is how athletes learn to self-regulate. Certainly, several researchers have identified a need for more studies that examine the learning processes involved in sport psychology interventions (Gardner, 2009; Harrison, 2011). The purpose of the present exploratory qualitative research was to understand Olympic athletes' perceptions of how they learned to self-regulate within a biofeedback and neurofeedback intervention using the theoretical lens of the learner-centered approach (Doyle, 2011; Weimer 2013).

Biofeedback and Neurofeedback

Biofeedback and neurofeedback training is designed to enable individuals to learn to regulate physiological states; improve cognitive flexibility; and achieve states of alertness, relaxation, and focused attention (Edmonds & Tenenbaum, 2012; Hammond, 2011; Thompson & Thompson, 2015; Schwartz & Andrasik, 2016; Strack, et al., 2011). This training has been

shown to be beneficial in attaining optimal functioning and performance (Dekker, Van den Berg, Denissen, Sitskoorn, & Van Boxtel, 2014; Dupee & Werthner, 2011; Dupee, Werthner, & Forneris, in press; Lagos, Vaschillo, Vaschillo, Lehrer, Bates, & Pandina, 2011; Paul & Garg, 2012; Shaw, Zaichowsky, & Wilson, 2012; Thompson, Steffert, Ros, Leach, & Gruzelier, 2008; Werthner, Christie, & Dupee, 2013).

Biofeedback is a training tool that focuses on developing voluntary control of the autonomic nervous system. It provides an individual with objective measurements concerning his or her physiological processes so that they can be brought under self-regulatory control (Schwartz & Andrasik, 2016). The physiological measurements include peripheral skin temperature, skin conduction (electrodermal response or EDR), muscle tension (surface electromyogram or SEMG), respiration rate, heart rate, and heart rate variability (HRV). With sufficient commitment and active exercise, an individual can learn to consciously control these physiological processes in order to optimize his or her bodily functions (Peper, Tylova, Gibney, Harvey, & Cambatalade, 2008).

Neurofeedback training is essentially a form of biofeedback that employs the analysis of electroencephalogram (EEG) signals (Gruzelier, 2014; Heinrich, Gevensleben, & Strehl, 2007; Thatcher, 2012). EEG is a non-invasive method for monitoring bioelectrical activity of the brain that was originally developed to analyze mental processes. Starting in the 1950s, the EEG visual patterns were quantified (QEEG) and correlated with functions of the central nervous system (Lindsley, 1952). By monitoring bioelectrical activity of neurons using EEG measurements, an individual is provided with feedback regarding the brain's functioning in order to improve it (Hammond, 2011; Heinrich et al., 2007). Neurofeedback training assumes the brain's electrical activity reflects the individual's mental states and that it can be trained (Thompson & Thompson,

2015). As mental states change, so do the amplitudes of different brain wave frequencies. The information about the brain wave activity of interest is displayed in real-time on a computer screen. While observing the feedback, an individual learns how to influence the brain waves in order to complete specific exercises and achieve the set goal, thus developing the ability of self-regulation of various mental states, including attention, remaining calm, and quieting the mind (Heinrich et al., 2007; Thompson & Thompson, 2015; Wilson, Thompson, Thompson & Peper, 2011).

Learner-centered Approach

Learning is a constructive, on-going process that involves individuals linking new information and experiences with their existing knowledge base (Weimer, 2013). If the learner does not integrate new knowledge with prior knowledge they are unable to transfer what they have learned to new situations, even if they are just slightly different than the original situation (Alexander & Murphy, 2000). It is this integration of new knowledge with existing knowledge that facilitates transfer and leads to what is recognized as deep integrated learning (Weimer, 2013). One way to foster deep integrated learning is to use a learner-centered approach (Doyle, 2011; Weimer, 2013). Within the learner-centered approach, one key component is active learning. As Doyle (2011) states “the one who does the work, does the learning” (pg. 7). Thus, one of the best ways to enhance deep integrated learning is to actively engage the learner by providing opportunities to use and practice the content and/or skills for a significant period of time (Doyle, 2011).

A second key component of the learner-centered approach is formative feedback (Weimer, 2013). An example of formative feedback in a sport situation would be a coach providing feedback to an athlete at multiple times within and across training sessions prior to the

athlete using the skill in competition. It is well known that developing complex skills (e.g., self-regulation skills) require repeated opportunities to practice with adequate feedback and that there needs to be a well-organized plan for formative feedback opportunities to occur (Blumberg, 2009; Weimer, 2013). It is of note that both active learning and formative feedback are inherently built into biofeedback and neurofeedback training. For example, within a biofeedback and neurofeedback intervention, when athletes are working on a skill (e.g., relaxation), they engage in multiple training tasks, practice the skills, and obtain continuous objective real-time feedback on a computer screen.

Given that the focus of this study was to explore athletes' perceptions of how they learned, a learner-centered approach was used to help guide this research. This approach is a strong fit for two reasons. First, a learner centered approach is recognized as fostering deep integrated learning by ensuring the learner is actively engaged with the material, has time to practice what he or she is learning, and receives formative feedback (Doyle, 2011; Weimer, 2013). Second, this approach parallels what has been recognized as an essential process for learning psychological skills within sport. For example, Harrison (2011) asserts that for athletes to learn psychological skills there needs to be a systematic approach that includes a) education about the required skills, b) acquisition of the skills via a structured training program, and c) integration of the skills into practice and competition until the skill becomes automatic.

Purpose

As mentioned above, sport psychologists have recognized that athletes need to learn to self-regulate to perform optimally (Anderson et al., 2014; Krane & Williams, 2006). A biofeedback and neurofeedback training intervention can facilitate the learning of effective self-regulation (Edmonds & Tenenbaum, 2012). However, very little research has been conducted to

examine how athletes learn to self-regulate. As a result, the purpose of this study was to understand Olympic athletes' perceptions of how they learned to self-regulate within a biofeedback and neurofeedback intervention.

Method

Epistemology & Ontology

Constructivism guides the proposed research both epistemologically and ontologically. Constructivism challenges the dualistic division of mind from body, learner from learned, and subject from object (Light, 2008). Hoskins (2002) states that constructivists look at *how* people come to know what they know, as well as *what* they know. This fundamental constructivist assumption fits well with the purpose of the present study as participants are considered experts on how they learn and their knowledge of this may change throughout the study (Guba & Lincoln, 1994). Constructivism focuses on the meaning-making activity of the mind (Crotty, 1998) and this fits well with the learner-centered approach (Doyle, 2011; Weimer, 2013). In the learner-centered approach knowledge is constructed by learners experiencing the world through their own subjective lens. In this study, each participant's individual experiences, interpretations, and constructed meaning play a critical role in better understanding the phenomenon being studied – athletes' perceptions of how they learn during a biofeedback and neurofeedback training intervention.

Participants & Procedures

The participants were five elite athletes (three males and two females) competing at world and Olympic level competition within one summer Olympic sport. The athletes had a mean age of 25.2 years (M+/-SD 2.9) and had participated in their sport for an average of 10.2 (M+/-SD 3.1) years. Purposeful sampling was used to select athletes. It is a strategy that involves

selecting rich cases that provide in-depth knowledge about the phenomena of interest (Patton 2002). National team coaches identified athletes who had potential to win medals at the 2012 London summer Olympics. The biofeedback and neurofeedback training intervention was made available to all identified athletes. This research reports on five of the athletes that completed the full program. All of the athletes provided written consent and all procedures were approved by the Ethics office at the lead researcher's institution.

Intervention

The role of the instructor, during an intervention embracing a learner-centered approach, is that of a facilitator or guide (Weimer, 2013). The instructor's primary task is to support the learning efforts of the athletes, by creating conditions that foster growth and learning. However, in the end, it is the responsibility of the learner (the athlete) to master the material and develop the learning skills. Weimer (2013) suggests that this is done by the athlete connecting what they already know to the new concepts and skills presented---in order to make sense of it. Also, as learning progresses, a shift takes place in the balance of power between the instructor and the athlete. Initially, the instructor suggests strategies that can help the athlete break through to understanding but as the training progresses the athletes takes control of their learning by assuming more and more responsibility for deciding on what strategies work best for themselves.

More specifically, the purpose of the biofeedback and neurofeedback training sessions was twofold: (a) to enable the athletes to identify and exercise control over the activation levels of their autonomic nervous system (ANS) and central nervous system (CNS) in the lab and (b) to transfer that learning to training and competition settings. The intervention consisted of 20 training sessions spread over a one year time period. The frequency of sessions for each athlete varied due training and competition schedules. Measures were gathered during a

psychophysiological stress assessment (Dupee, Werthner, & Forneris, 2015; Wilson & Somers, 2011), prior to the intervention, in seven areas: EEG, SEMG, respiration rate, heart rate, HRV, skin conductance, and peripheral body temperature. Data on how athletes responded to stress and their activation levels were identified and used to optimize the training sessions for each of the athletes. The equipment used in the research was a ProComp Infinity unit from Thought Technology Ltd.

The following in-depth description of the biofeedback and neurofeedback training intervention also appears in Dupee et al. (in press). Each of the 20 one-hour training sessions included 3 components (Dupee & Werthner, 2011). The first component was biofeedback or quieting the ANS. This component was identified as brief physical recovery exercises. Self-awareness and self-regulation of muscle tension, respiration rate, heart rate, skin conductance activity, and peripheral body temperature were trained both with eyes open and eyes closed. Training parameters for the biofeedback modalities can be found in Wilson and Somers (2011). Neurofeedback training, or managing the CNS, was the second component. The EEG modality was used for the three aspects of this component: (a) brief mental recovery (wide focus), (b) narrow focus, and (c) switching states between narrow focus and brief recovery (narrow and wide focus; Thompson & Thompson, 2015). For the parameters used in the neurofeedback training refer to Wilson et al. (2011). The third component involved both biofeedback and neurofeedback training, specifically decreasing activation in both the ANS and CNS. All seven measures (EEG, SEMG, respiration rate, heart rate, heart rate variability, skin conductance, and peripheral body temperature) were monitored for this physical and mental deep recovery component. Paced breathing (Lehrer et al., 2013; Lehrer, Vaschillo, & Vaschillo, 2000) was used to help the athletes decrease activation in both systems. Overall, each training session was

broken down into 20 minutes quieting the ANS, 20 minutes managing the CNS, and 20 minutes deep recovery. Initial training sessions focused more on self-regulation of the ANS and more time was spent on this aspect of training. These skills were then used to assist with regulation of the CNS. Deep recovery work began as a six minute exercise and over time was increased to 20 minutes. Each athlete was asked to do the paced breathing as ‘homework’ outside of the formal training sessions.

Measures

Interviews. At the completion of the intervention, an open-ended, semi-structured interview (Rubin & Rubin, 2005) was conducted with each athlete. An interview guide was developed and composed of questions such as: “Tell me about your overall experience with the training”? “What did you find most useful”? “What was most difficult to learn”? “Were you able to transfer the skills learned in the lab to your training and competition environment? If yes, tell me about that”? Probes were used during the interviews to encourage athletes to elaborate on their responses (Patton, 2002). Interviews with athletes were performed in person, were digitally audio recorded, and ranged from 67-104 minutes. All interviews were transcribed verbatim.

Data Analysis

Electronic formats of interview transcripts were downloaded into the software NVivo 10 (Qualitative Solution and Research, 2010) allowing for all sources of data to be organized and easily accessed. Using computer assisted qualitative data analysis software offers a number of advantages as it facilitates the coding of information, allows for the construction of hierarchical categories and visual maps, and makes it possible to write and link memos to important themes (Davis & Meyer, 2009). Furthermore, systematic organization of information in a database allows other researchers the opportunity to review the data, increasing the reliability of the study

(Yin, 2009). An inductive-deductive thematic analysis was performed with the deductive analysis guided by the learner-centered approach. The data were broken into smaller units, placed into categories, and submitted to descriptive treatment (Braun & Clarke, 2006).

A thematic analysis was employed for two reasons. First, a thematic analysis is not inherently linked to any one world-view and therefore, it can be used with the underlying principles and assumptions of different paradigms (Braun & Clarke, 2006). Thus, the thematic analysis conducted was congruent with the constructivist worldview used to guide the study. Second, thematic analysis enables researchers to examine specific contexts and the manner in which those contexts can shape people's experiences (Sparkes & Smith, 2014).

The thematic analysis was conducted in six phases (Braun & Clarke, 2006). Phase one consisted reading and reviewing the data on numerous occasions in order to get familiarized with the content and to identify preliminary themes. In phase two, generated initial codes and organized the data into meaningful groups. Analytical memos were written and preliminary connections to theoretical concepts were made. The third phase consisted of combining some initial codes to form higher-order categories. Phases one through three were conducted by the first author. Phase four of the analysis consisted of reviewing the entire database as well as the categories. Careful consideration was taken to ensure that the categories exhaustively covered the data gathered in both phase one and two and helped answer the main research question. Phase five defined the orientation of the article and the categories to be used. The sixth and final phase of analysis consisted of writing the article. All three of the authors participated in phases four through six of data analysis. Efforts were made to insure that all participants were included in the results and codes were used to represent participants (i.e. Athlete 1=A1). Finally, multiple revisions, involving input from all authors, were made for the article in order to tell the athletes'

story in a concise and logical manner. The article provides a preliminary portrait of Olympic athletes' perceptions of 'how' they learned to self-regulate within a biofeedback and neurofeedback intervention.

It is noteworthy to mention that other dimensions in these interviews, specifically 'what' the athletes perceived they learned from participating in the biofeedback and neurofeedback intervention, were previously analyzed and prepared for publication elsewhere (Dupee, et al., in press).

Trustworthiness

The methods used in this study take a relativist approach in determining the accuracy of the data (Sparkes & Smith, 2009). To judge the quality of research, relativists view criteria as a list of open-ended traits that are subject to reinterpretation as times, conditions and purposes change (Sparkes & Smith, 2009, 2014). Criteria that strengthen this study's design include (a) commitment and rigour, (b) transparency and coherence, (c) credibility, and (d) accuracy (Stake, 2006; Tracy, 2010; Yardley, 2008). To ensure commitment and rigour athletes were carefully selected based on criteria relevant to the research question (Yardley, 2008).

Transparency and coherence were established by providing a detailed account of the procedures undertaken during data collection and analysis (Yardley 2008). Credibility was achieved through the thick descriptions provided in the results (Tracy, 2010). The complexity and detail clearly describe the subtleties of a participant's experiences and perceptions of learning. Accuracy of the gathered data was established by sending the transcripts back to the athletes and asking each of them to verify the accuracy of their answers and perspective (Stake, 2006). Additionally, member checking (Creswell, 1998) with athletes were conducted to verify the authors' interpretations. These serve to improve interpretation of the reporting. However, it must be

remembered that although every effort was made to ensure trustworthiness in the study during the analysis phase, other equally valid interpretations are possible.

Results

The analysis of the results revealed three main themes related to athletes' perceptions of how they learned to self-regulate in a biofeedback and neurofeedback training intervention: the intervention engaged the athletes through active learning, receiving real-time formative feedback was vital, and utilization of the exercises, learned during the intervention, in both training and competition environments. It should be noted that within the first theme two subthemes emerged and are described below.

The Intervention Engaged the Athlete Through Active Learning

All five of the athletes felt the intervention created an environment of active learning which, in turn, allowed them to learn to effectively manage themselves psychologically and physiologically. As one athlete stated "I know what I have to do to perform well but I can't always do it...actually getting hooked up [attached] and practicing is what helps the most. To get better, I just need to keep working on it" (A2). A second athlete stated "during the training I have an opportunity to practice my words and thoughts and to recreate the feeling I want to have to race well" (A1).

Related to active learning, two subthemes emerged: Developing the ability to effectively focus as well as relax requires active learning and deep integrated learning takes time and responsibility.

Developing the ability to effectively focus and relax requires active learning. The athletes expressed that it was being able to engage in the active learning exercises that allowed them to learn how to focus effectively and how to relax. Related to focus one athlete stated:

During the [intervention] training, I practiced putting myself into my ideal focusing zone by making myself focus narrowly and stay there...it was a systematic thing...I was consciously aware of letting other thoughts go and on keeping my focus on what was happening at that moment (A4).

Similarly, a second athlete shared that the biofeedback intervention enabled him to develop a good focusing state through practice. “It is such a small band that I need to be in...I need to feel activated while suppressing other thoughts...the training gave me the opportunity to recognize this and to practice it” (A3). This athlete also discussed the need to practice in order to learn how to relax, “if you practice relaxing you get better at relaxing...so I practice my breathing to help me relax. Then later when I start to feel stressed it is just good to be able to go to something I’ve practiced” (A3). Another athlete also described learning to relax as an active task:

When I started doing the training, I started thinking about resting as a part of my training and that resting is just as important as the other aspects of training...you can’t just rest without putting some effort into it or mentally doing it (A5).

Deep integrated learning takes time and responsibility. The athletes also identified that in order to develop the skills to effectively focus and relax, they needed to have time to practice as well as take responsibility for their learning. As one athlete said “it took a while for me to learn how to allow myself to relax and not think about anything...to realize this state exists. Just sitting here and letting everything go is not easy and took a lot of practice” (A1). Another athlete shared “day after day just practicing the skills and doing them allowed me to better understand what is going on in my head and in my body” (A3). Similarly, a third athlete stated:

It was after much practice on the computer that I really learned how to focus...eventually I felt like if I came to one of the training sessions I was just going to kill it because I

totally got it. That is when my training (in the boat) really went to the next level as far as being focused and just being in the moment – and I could now do it (focus optimally)—I could do it on the computer screen and I could do it in my boat (A5).

In terms of taking responsibility, the athletes noted that even though they were supported through the intervention they had to take responsibility for deep learning to occur. As one athlete explained “I had help figuring out “what” to do but then I figured out “how” I can do it, by myself” (A4). Another athlete shared:

At first, each training screen felt like a test. I felt uncomfortable with it...once I said ‘well this is just helping me to get better, this is helping me to achieve my goal, that this is for me’ - I just kind of took ownership of it. It doesn’t matter if I have a bad session or if I do one of the exercises poorly because I just have to use it to make myself better (A5).

Receiving Real-time Formative Feedback was Vital

The athletes referred to the real-time formative feedback they were seeing on the screen as a vital aspect of the intervention. It was this feedback that enabled the athletes to learn how to self-regulate their internal states. One athlete stated “seeing it all in objective measures taught me that what you feel inside can be quantified...that it can actually be translated into real numbers (A4).” Another athlete shared “seeing the feedback made me realize that the ideas I have about how my body functions are correct...it showed that in the data... it gave me a really good understanding of just how my brain and body works” (A2). Finally, another athlete stated “what I liked best about the training is the immediate feedback. It is very helpful and reassuring to me because sometimes I tend to over think things” (A3). Interestingly, the athletes shared that this intervention represented the first time they had been able to receive objective feedback about

their internal states. As one athlete said “I have never had an opportunity to observe myself before...to observe what I was thinking and what I was feeling” (A3).

Importantly, the feedback also helped the athletes become aware of a good focusing state. One athlete commented “it was pretty clear during the neurofeedback training when you were in a good focusing state...the boat or the mouse kept moving...the feedback re-enforced that what I was doing and feeling was right” (A4). Another athlete used the feedback to test his focusing strategy. He stated “first I decided on a strategy...the feedback showed me right away if the strategy worked...then I would use it when I raced” (A2).

As well, the formative nature of the feedback helped the athletes learn that by maintaining some awareness on their physiological state made it easier to sustain focus. One athlete stated “for me, when I can control the biofeedback indicators on the screen like breathing, relaxing my muscles, and letting the blood flow to my hands, it is way easier to hold a good focusing state” (A4). A second athlete commented, “having some awareness on my breathing definitely helps me be able to stay focused and keep the dart going. It helps me stay in the present moment” (A3). In terms of learning how to sustain a focused state for the demand of their sport event, one athlete stated that “with the mouse screen, I learned to just focus on his ear...to keep my focus on one thing...then I could hold a good focusing state...it would keep going” (A2). Similarly, another athlete spoke of his learning process:

At first I had a lot of trouble with the bowling ball training screen but then once I just started focusing on the ball and not the pins, not the ball moving, just the black hole in the ball on the screen then that made it move ---no matter what was happening I was just focused on one thing (A5).

Finally, another athlete commented, “the feedback I received with each additional training session seemed to help me learn to concentrate on one thing for longer and longer periods of time” (A1).

The feedback the athletes received during the intervention training sessions, with paced abdominal breathing, also helped them develop the skill of relaxation. One athlete stated “I do breathing where my heart rate tracks my breathing...when I see by the feedback on the screen, where they are going up and down together, I can feel my whole body relax” (A4). Similarly, a second athlete stated “How I learned to relax was by observing how the feedback changed on the screen as my thoughts quieted down and my body became more relaxed” (A5). Another athlete also stated:

The feedback that shows breathing making a physical change in my body...that feedback made it easier to learn how to relax. You can feel the sensations in your body and you can see the results or the changes on the screen...so you can find what works for you. (A3)

More specifically, the real-time formative feedback helped the athletes understand that it took time to quiet down their internal state. One athlete noted that observing the feedback “helped me learn how long I need to stick with it to bring my activation level down...especially seeing how quickly my skin conductance measure goes up and how slowly it comes down” (A2). Another athlete noted that getting feedback on her hand temperature helped her learn to relax when she was stressed, “my hands get cold and doing the breathing exercises and visualizing the blood flowing helps warm them up...and observing that feedback really helped me learn how long I need to stick with it to fully relax” (A1).

Utilization of the Exercises, Learned During the Intervention, in Both Training and Competition Environments

The athletes discussed how the skills practiced and learned in the biofeedback and neurofeedback training intervention, were able to be utilized in both training and competition. One athlete discussed practicing the skills in training in order to be able to be successful when racing:

In order to have control over my body and my thoughts when racing, I practice it every day in training. It has helped me to become more aware of the way I paddle and of the state I am in before and after each piece of work (A1).

Similarly, another athlete described how he utilized what he had learned in the lab:

In my boat I imagine that the blade of my paddle is the black big square on the bowling ball. I just zone everything else out and just move my boat with my paddle...once I applied that same focus (that I learned with the training screen) to my paddling... it was almost easier than doing it on the computer...now during training or racing any time negative thoughts come I notice them and then bring my focus back to my stroke (A5).

More specific to the training environment, the athletes spoke of the importance of the breathing exercises and how they utilized the breathing. As one athlete said "I use the breathing for recovery especially between training intervals. I always try to calm myself down and allow myself to recover each time" (A2). Another athlete commented "one thing that has really helped me is doing breathing exercises to recover after I do a workout" (A4). Finally, an athlete spoke of the usefulness of the breathing exercises, practiced in the lab and as homework, to his training:

I use the breathing exercises all the time in training...I can just throw it in even if it is just 10 breaths here or there just to relax...even when I am on the water...I specifically use it if I am having a hard training session and am breathing really hard and need to calm back down (A5).

The athletes also spoke of using the EMG training and the breathing training in their racing environments. One athlete stated “the most important thing I use from the training [intervention] is awareness of muscle tension in my shoulders. I focus on keeping my shoulders down...so I can get off the start line really fast” (A4). Similarly, an athlete shared:

From the exercises in the lab I learned what it feels like to have no tension in my muscles and I was able to use this in my races. I would be half a boat ahead of the other guys and I would start to feel myself tighten up, and then immediately one guy would catch up. I needed to really focus on relaxing my muscles in order to stay with him (A2).

This athlete expressed that the breathing exercises were also helpful just prior to a race, “the breathe training helps me a lot especially when I get nervous before a race...I use it the day before the race, and minutes before a race, too...like when warming-up and when sitting in the start blocks” (A1).

Additionally, the athletes commented that the more they practiced the skills in the field the more automatic they became. One athlete stated “the more I use the skills on a daily basis in training the more automatic they became” (A3). Similarly, another athlete commented “after doing all the training and using the skills in training and competition they have now become part of what I do automatically everyday” (A4).

Discussion

The purpose of the present study was to understand Olympic athletes’ perceptions of how they learned to self-regulate within a biofeedback and neurofeedback intervention. To achieve this, in-depth interviews were conducted with five elite athletes following a 20 session training intervention. The overall findings suggest that the athletes perceived they learned through active

learning, use of real-time formative feedback, and by being able to utilize the skills learned in the biofeedback and neurofeedback intervention in both their training and competition environments.

One of the key findings of the present study was the importance of active learning. Within the learner-centered approach, active learning is a process of ensuring individuals engage in activities that allow them to practice the skills (Doyle, 2011; Weimer 2013). The active learning environment inherent in the design of the biofeedback and neurofeedback intervention helped all five of the athletes become more self-aware and hone their skills of focus, relaxation, and overall self-regulation. The athletes appreciated the opportunity to observe their internal states and practice regulating them. They mentioned that at times they knew what they needed to do to perform their best but could not do it consistently. The athletes also recognized that development of the skills took time and required taking responsibility for their own learning. The biofeedback and neurofeedback training intervention in the present study provided the athletes with an extended opportunity to actively engage in learning how to self-regulate physiologically and psychologically.

A second key finding was in relation to the value of formative feedback. Weimer (2013) emphasizes the importance of feedback throughout the learning process and the biofeedback and neurofeedback intervention provided real-time feedback within each session. Each training screen was designed to enable the athletes to see, begin to understand and recognize, and eventually learn how to more effectively self-regulate - whether that was in learning to sustain an effective focus or develop the ability to relax and recover from a stressful event. The real-time formative feedback they received helped them to recognize the time it took to quiet down their internal states and created the opportunity to practice sticking with it so they could more deeply learn.

A third key finding was that exercises learned and practiced in the intervention were able to be utilized by the athletes in both their training and competition environments. This again speaks to the design of the intervention. The discussions between the athlete and the researcher during each of the training sessions focused on both what was being learned in the lab and how that learning might be utilized in training and competition. For example, the athletes spoke at length about the transference of the breathing exercises learned, within the lab setting, to training and race situations.

Research has shown that it is developing a high level of proficiency in psychological skills such as focus and relaxation that allows athletes to perform optimally on a consistent basis (Anderson et al., 2014; Golby & Sheard, 2004; Gould & Maynard, 2009; Gould, Dieffenbach, & Moffet, 2002; Harrison, 2011; Jackson, Thomas, Marsh, & Smethurst, 2001; Jones, Hanton, & Connaughton, 2007; Krane & Williams, 2006). Harrison (2011) suggests that ideally the learning of psychological skills should embrace a systematic approach that includes acquiring skills through a structured training program and integrating these skills into practice and competition. The 20 session biofeedback and neurofeedback intervention in the present study created a systematic approach to learning and was consistent with main tenets of the learner-centered approach. Thus, sport psychologists may want to consider integrating biofeedback and neurofeedback training to provide a more comprehensive approach to helping athletes learn how to optimize performance in both training and competition. Moreover, the findings from this research may also be used to advocate for and support the integration of self-regulation training using biofeedback and neurofeedback into sport psychology interventions.

Limitations and Future Research

Despite the insights gained into how Olympic athletes learn during a biofeedback and neurofeedback intervention, this study has several limitations. First, the retrospective nature of the interviews limits our ability to fully understand how the athletes learned. In future research it is suggested that interviews could be conducted at multiple points throughout the training to allow for 'real-time' accounts of each athlete's experience as it occurs. Second, the small sample of athletes within a single sport is a limitation. It is suggested that future research consider other sports and a larger numbers of athletes at varying levels of expertise to provide a more complete picture of how athletes learn within such an intervention. In terms of examining learning processes of athletes, a third limitation is the present study's inability to investigate the process of athlete learning in its entirety. This study was only able to speak to athletes' perceptions of how they learned to self-regulate their physical and mental states during a biofeedback and neurofeedback intervention. A fourth and final limitation is that the intervention was designed from a holistic perspective to address athletes' overall self-regulation ability and thus integrated several modalities both physiologically and psychologically. In doing this, each individual modality was not explored independently. Future research could more deeply explore individual modalities.

Conclusion

The present study highlighted Olympic athletes' perceptions of how they learned to self-regulate during a 20 session biofeedback and neurofeedback training intervention. Active learning exercises, receiving real-time formative feedback, and utilization of the exercises, learned in the biofeedback and neurofeedback intervention, in both their training and competition environments were identified as ways that helped the five athletes learn to improve self-

regulation of their internal states. Overall the present research targeted the process rather than the outcome of such an intervention, helping to further our understanding of the factors involved in learning to improve self-regulation skills for optimal performance. Gardner (2009) has suggested that what is needed to better understand optimal performance and move the field of sport psychology forward is an updating of the 'toolbox' with the integration of emotional and cognitive science and a different way of providing performance enhancement interventions. The contribution the present research makes to the extant literature is that a biofeedback and neurofeedback training intervention grounded in a learner-centered approach may offer an innovative and holistic way to help athletes learn to self-regulate their internal states for optimal performance.

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CHAPTER V
GENERAL DISCUSSION & CONCLUSION

General Discussion

The general purpose of this doctoral dissertation was to explore self-regulation in the Olympic athlete population. To address this purpose, two studies were conducted. Study One (Article 1), using a quantitative methodology, explored the relationship between elite athletes overall self-regulation ability and world ranking. Fifteen elite level athletes underwent a 9-stage psychophysiological stress assessment to determine each athlete's ability to return to baseline after a stress load was applied. Study Two (Articles 2 and 3), using a qualitative methodology, explored what and how five Olympic level athletes learned during a 20 session biofeedback and neurofeedback training intervention. Together, findings from the two studies highlight the relevance and intricacies of self-regulation in high performance sport. Study One revealed that there was a significant correlation between elite athletes' overall self-regulation ability and their ranking at the world level. In Study Two, Olympic athletes perceived that the biofeedback and neurofeedback training intervention assisted them in learning to improve self-awareness and self-regulation of their physical and mental states enabling them to feel more in control during sport performances. With regards to athletes' perceptions of how they learned, athletes highlighted that it was the active learning exercises, real-time formative feedback, and being able to utilize the skills in the field that facilitated their learning. Below is a broader discussion of these findings in terms of how they relate to the current literature and implications for the field of sport psychology.

The findings of the present research make a number of important contributions to the literature. First and foremost, in Study One (Article 1), the link between athletes' ability to self-regulate and optimal performance was supported. Although previous literature has suggested that self-regulation is a key process in optimal performance (Anderson et al., 2014; Gardner, 2009;

Hanin, 2000; Ravizza, 2006) this dissertation provides initial objective evidence that an athlete's ability to physiologically self-regulate, through returning to baseline after a stress load is applied, was linked to their world ranking. This demonstrates that the better the athlete's ability to self-regulate, the better their world ranking.

Second, the results from Study One also suggest that shoulder tension (EMG-trapezius) may be an important factor in the relationship between ability to self-regulate and ability to perform to potential. However, given that this was the first study to explore the relative importance of the individual psychophysiological indicators in self-regulation further research is needed to substantiate these findings. Based on the results from Study One it is suggested that training to improve self-regulation should assist athletes to perform to their potential more consistently.

Third, the results of Study Two (Articles 2 and 3), demonstrated that the biofeedback and neurofeedback training intervention created a learning environment that enabled the five athletes to become more self-aware and enhance their ability to self-regulate. Within this larger study three key aspects that warrant further discussion in relation to advancing the literature on biofeedback and neurofeedback and sport psychology are state management, abdominal paced breathing using HRV biofeedback, and the recognition that inherent in a biofeedback and neurofeedback training intervention are the main tenets of the learner-centered approach.

With regards to state management the findings illustrated that athletes perceived, as a result of participating in the intervention, that they were able to effectively learn how to sustain and shift their states when needed. The neurovisceral integration model of self-regulation recognizes that mental-emotional state spaces can be sustained and shifted seamlessly (Thayer & Lane, 2000). This is particularly true when individuals are able to activate their PNS, specifically

activation of the vagal nerve. When an individual can sustain and shift their physical and mental states seamlessly she or he can flexibly adapt to changing environmental demands. When the ability to sustain and/or shift is compromised, the individual is 'stuck' in a behavioral pattern that is not responsive to the demands placed upon it by the environment (Stormark, Laberg, Norby, & Hugdahl, 1998). To relate this to athletes' optimal performance, if they are unable to effectively self-regulate, meaning sustain and shift states as needed, they could remain stuck in a state that inhibits optimal performance.

Abdominal paced breathing using HRV biofeedback also emerged as a key concept. All of the athletes discussed on numerous occasions that awareness and utilization of breathing at their resonant frequency, which is trained during HRV biofeedback (Gevirtz, 2013; Lehrer & Gevirtz, 2014), helped them sustain and shift both their physical state (through the ANS) and their mental state (through their CNS). The athletes reported that awareness of their breathing helped them be physically relaxed but mentally focused, sustain their focus when required, and quiet their thoughts. This finding supports previous studies that have shown a positive relationship between HRV biofeedback training and performance in golf, baseball, gymnastics, and basketball (Lagos et al., 2011; Paul & Garg, 2012; Shaw et al., 2012; Strack, 2003). At this point in time, the literature suggests that the benefits of HRV biofeedback training stem from the convergence of a number of mechanisms (Gevirtz, 2013; Lehrer & Gevirtz, 2014). Two of these mechanisms can help us better understand how HRV biofeedback breathing training can be useful for optimal performance. The first mechanism is strengthening ANS homeostasis or balance (Lehrer et al., 2013). This restoration of autonomic balance is a balancing of sympathetic and parasympathetic nervous system activity that increases flexibility and recovery from fight/flight situations and allows the parasympathetic nervous system to govern the

sympathetic nervous system in nonemergency situations (Gervirtz, 2013). As well, Shaffer and Venner (2013) contend that HRV biofeedback teaches individuals to restore autonomic balance by decreasing sympathetic nervous system arousal while simultaneously increasing parasympathetic nervous system activity. Overall, it is thought that HRV biofeedback may be effective by blocking excessive sympathetic activation. Moreover, the neurovisceral integration model (Thayer & Lane, 2000) identifies this same mechanism and describes it as inhibition of the nervous system which controls over-activation of the sympathetic nervous system.

The second mechanism attempts to explain how slow breathing stimulates the vagal nerve of the PNS and the ultimate effects on the brain in the CNS. Specifically, the effect on the vagal afferent pathway to the frontal cortical areas has been proposed (Gervirtz, 2013; Lehrer & Gervirtz, 2014). It is known that HRV biofeedback promotes slow diaphragmatic breathing that, in turn, stimulates subdiaphragmatic vagal afferents that can have central nervous system effects (Porges, 2011). As well, Brown and Gerbarg (2005) suggest that ANS functions, specifically vagal afferents to the brainstem, can be affected by voluntary control of breathing. Brown and Gerbarg's neurophysiological model postulates that vagal afferents of the parasympathetic nervous system enhance attention as well as alertness, quiet frontal activity, and reduce rumination.

The two above mentioned mechanisms, detailing the workings of the ANS and CNS, provide insight to explain the finding that the athletes perceived paced abdominal breathing as helping to improve their self-regulation ability and improve their psychological skills. Thus, it is possible that HRV biofeedback paced breathing may assist athletes in learning to self-regulate their physical and mental states and improve their sport psychology skills of focus and recovery. Since there is an absence of research on the mechanisms related to performance enhancement in

sport (Callow & Hardy, 2005; Gardner, 2009; Hardy, Jones, & Gould, 1996; Moore, 2007) the present research also fills a gap by identifying possible mechanisms involved in self-regulation.

Finally, a fourth contribution of the present doctoral dissertation is the recognition that a learner-centered approach is inherent in the design of a biofeedback and neurofeedback training intervention. The athletes felt strongly that the active learning exercises they participated in, receiving real-time formative feedback about their internal states, and being able to utilize the exercises practiced in the intervention in both training and competition environments allowed them to learn to self-regulate. More specifically, the training intervention provided the athletes with the opportunity to actively observe their mental and physical states and practice skills to regulate these states. In addition, the athletes reported that receiving feedback on the training screens helped them recognize how their learning was progressing and to identify changes they needed to make for the next training screen or exercise. Finally, the athletes highly valued that they could utilize the skills practiced in the intervention when they were training and competing. As Dolye (2011) suggests, such an active learning approach fosters deep integrated learning. Thus it can be argued that biofeedback and neurofeedback training can provide a practical, innovative, and effective means for athletes to improve self-regulation skills within an intervention and then use the learned skills to perform optimally in training and competition.

Anderson et al. (2014) conclude that a comprehensive and holistic approach is required for athletes to consistently perform at their best. As well, Friesen and Orlick (2010) emphasized the importance of incorporating the holistic development of the athlete into an applied psychology intervention that involves recognizing the dynamic relationship between an athlete's thoughts, feelings, physiology and behavior. The biofeedback and neurofeedback training intervention utilized in the present research embraces such a holistic approach. Using several

indicators of the activation levels of the CNS and ANS, biofeedback and neurofeedback training provides feedback to athletes with respect to their physical and mental states, moment to moment. This information can assist athletes in regulating their internal states in order to create their optimal psychological states for sport performance. Thus, sport psychology consultants who aspire to develop the athlete from a holistic perspective could benefit from integrating biofeedback and neurofeedback training techniques into their practice.

Practical Implications

There are also a number of practical implications of the current research. First, this research provides support for the relationship between overall self-regulation ability of elite athletes and their ability to perform consistently well. Thus, as standard protocol, each athlete could undergo a stress assessment in order to identify patterns in their nervous system that may be inhibiting them from consistently performing their best. Following that, a biofeedback and neurofeedback training intervention, based on the strengths and weaknesses identified in the assessment, could be implemented to assist in optimizing an athlete's self-regulation ability.

Second, this research provides support for the neurovisceral integration model in that athletes found that breathing at their resonant frequency enabled activation of the parasympathetic branch of nervous system (vagal brake) which assisted with attentional control during both focused and relaxed states. Breathing at one's resonant frequency (maximal HRV) is a concrete tool that athletes can learn to use. It is recommended that athletes first learn to breathe at their resonant frequency and then integrate the breathing exercises into their daily training routine to ensure activation of the vagal brake and sympathetic/parasympathetic balance in their autonomic nervous system.

Third, this research provides support for using a learner-centered approach in sport psychology interventions. Integrating active learning exercises into psychological training for athletes can help athletes learn to optimally regulate their physical and mental states as well as specifically practice focus and recovery exercises in order to improve those skills. As well, athletes perceived that formative feedback and the ability to utilize the exercises practiced in the intervention was how they learned to self-regulate. Therefore, it is recommended that practitioners involved in designing and implementing interventions for athletes consider integrating active learning tasks into the athletes' training that can be utilized outside of the intervention.

Finally, sport psychologists, coaches, high performance directors, sport administrators, and optimal performance researchers can use the findings at the macro and the micro level. At the macro level, findings can inform high performance directors and sport administrators on the importance of self-regulation in the elite athlete population. They can use this information to justify the need to support standard use of sport psychology training for athletes. At the micro level, sport psychologists and coaches can use the findings to support the integration of self-regulation training, using biofeedback and neurofeedback, into the programs and training sessions delivered to the athletes. This dissertation provides an initial template for implementation of a biofeedback and neurofeedback intervention in sport.

Limitations

It is essential to address some of the limitations of the research conducted for this doctoral dissertation. The general limitations of this research represent those that are often inherent in interventions: regularity of training, small N, variety of sports, subjective aspect of interviews, and the researcher's expertise. When doing an intervention, regularity of training is

always an important consideration. Given the population chosen, Olympic athletes, the structuring of the intervention sessions had to accommodate their busy schedules of training and competing. Ideally, the biofeedback and neurofeedback training would take place at regular intervals i.e. weekly or biweekly. In our case, training was scheduled around training sessions, competition travel schedules, and school. Another limitation is the small number of participants involved in the research. The time demands of biofeedback and neurofeedback assessment and training as well as the accessibility and availability of Olympic athletes makes recruiting more participants challenging and costly. However, it is recognized that the small numbers may limit the generalizability of the results.

As well, the research project is limited to participants from two sports, and so potentially rich or unique experiences of athletes from other sports will remain untold. Consequently, readers should be careful not to conclude that athletes, from other sports, taking part in biofeedback and neurofeedback training will result in the same findings. It is also important to recognize that the experiences of the athletes and the benefits gained will be highly dependent upon the needs of the athletes.

The subjective aspect of interviews from only one perspective is also a limitation. The research was limited to the information offered by the athletes in the interviews and training sessions, as mediated by their honesty and memory, as well as the interviewer's skills as a conversational partner. As a result, it is recommended that the reader should make his or her judgement on the applicability of the findings to other athletes. In other words, the biofeedback and neurofeedback training, may well provide different benefits for other athlete populations based on each athlete's individual needs.

Future Research

In addition to the suggestions for future research noted above, there are a number of other potential directions based on the findings of this thesis. These include employing a quasi-experiment or experimental design with a wait-list control group that would allow for the examination of causal relationships between intervention and outcomes. Ideally, pre-post testing and true comparison groups with random assignment would be used. The relative absence of this type of study utilizing competitive performers within sport psychology has been noted (Callow & Hardy, 2005; Gardner & Moore, 2006). However, it has been suggested that experimental control designs are problematic in that they may not generalize to true field conditions (Gardner, 2009).

In contrast, there is also value in attempting to utilize multiple individual case studies to further understand biofeedback and neurofeedback training. More specifically, case studies documenting the experience of individual participants as they learn to improve self-awareness and self-regulation of their physical and mental states and how they utilize these skills in the field to perform to their potential more consistently is warranted. A potential benefit of case study research might include further understanding successful and unsuccessful experiences with the intervention that may in turn help to suggest future variations of the biofeedback and neurofeedback training. Another potential benefit of individual case studies or a multiple case study design would be the possibility of more easily integrating the findings into a sport psychology practice that utilizes biofeedback and neurofeedback training.

Conclusion

It is known that self-regulatory abilities predict successful life outcomes and help to maintain healthy psychological functioning (Baumeister & Vohs, 2004). The development of

physiological and psychological self-regulation skills ensure the athletes understand and develop the abilities required to perform optimally (Anderson et al., 2014; Hanin, 2000; Ravizza, 2006). The present study found a relationship between overall self-regulation ability and world ranking of elite athletes. In addition, Olympic athletes reported that the biofeedback and neurofeedback training helped them recognize and manage their physical and mental states, allowed them to feel more in control, provided tools for stress management, and made sport psychology concepts more concrete. Biofeedback and neurofeedback training may be particularly effective as it involves active learning, provides real-time formative feedback and the exercises practiced in the lab can be utilized in training and competition which, according to the learner-centered approach, fosters deep integrated learning. Thus, learning to improve self-regulation skills using biofeedback and neurofeedback training should be an integral part of the comprehensive and holistic approach used by sport psychology practitioners to help athletes perform to their potential.

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Statement of Contributions

I, Margaret Dupee, was responsible for the development and implementation of the biofeedback and neurofeedback assessment and training intervention as well as for gathering and analysing data in the two phases of data collection. Furthermore, I was entirely responsible for writing the three articles of this doctoral dissertation. Dr. Penny Werthner and Dr. Tanya Forneris reviewed all three articles on numerous occasions and provided valuable feedback at a conceptual and organisational level, as well as ensuring that there were no grammatical mistakes, and that the articles respected journal guidelines.

Appendices

Appendix A

Figure 1.1 Biofeedback, Neurofeedback, And Branches Of Nervous System

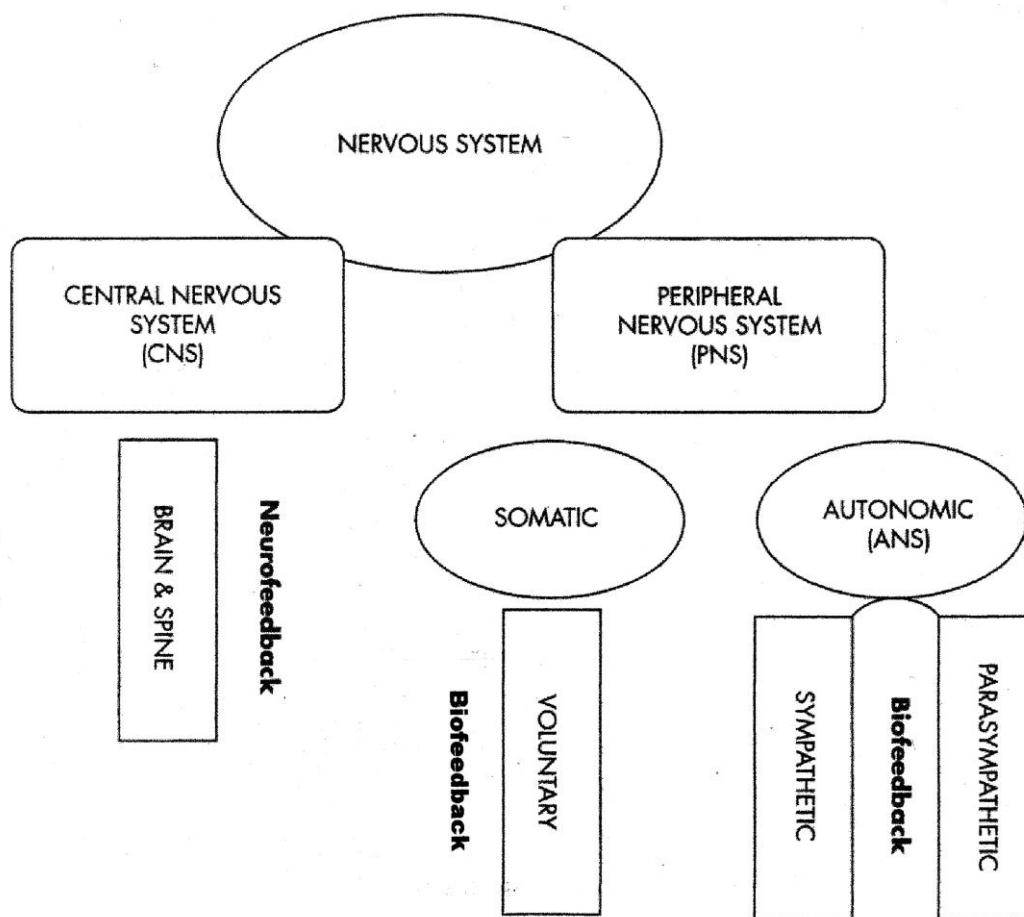


Figure 1 Adapted with modifications from “Brain Basics and Body Anatomy and Physiology” by J. N. Demos 2005 in Getting Started with Neurofeedback, p. 23., New York: Norton. Copyright 2005 by John N. Demos.

Appendix B

Brainwave Frequencies and Corresponding Mental States

Delta. .05-3 Hz waves are called delta (.05-3 cycles or waves in one second). They are the slowest yet highest amplitude waves. Delta waves normally occur during sleep. These waves are dominant in normal infants in the waking state up to about six months of age. They may be seen in people with brain damage, and in some learning disabled children (Thompson & Thompson, 2015).

Theta. 3-7 Hz waves are called theta (3-7 cycles or waves in one second). They represent the day dreaming, “spacey” state of mind associated with mental inefficiency. At very slow levels, theta represents a relaxed state and the twilight zone between waking and sleep. When we are drowsy or inattentive to external things and our mind is wandering more, theta is dominant (Thompson & Thompson, 2015).

Alpha. 8-12 Hz waves are called alpha (8-12 cycles or waves in one second). They are associated with a state of relaxation, representing the brain shifting into an idling gear, relaxed, and a bit disengaged waiting to respond when needed. When our eyes are closed and picturing something peaceful, there begins to be a large increase in alpha waves. Alpha is especially pre-dominant in the back third of the head. People who feel anxious and stressed may show a decrease in alpha waves (Thompson & Thompson, 2015).

SMR. 13-15 Hz waves are called Sensori-Motor Rhythm, which is shortened to SMR (13-15 cycles or waves in one second). These waves are called SMR only across the sensori-motor strip of the cortex. They are called beta when found elsewhere. “SMR appears to be associated with a calm mental state with increased reflecting-before-acting. It is thus important to train up (increase) SMR in those who have problems with hyperactivity and/or impulsivity” (Thompson & Thompson, 2015).

Beta. Waves above 12 Hz are called beta. These waves represent awake, alert, externally-focused, logical, problem solving, and attentive states. They may also indicate anxious and tense states (Thompson & Thompson, 2015).

Low Beta. 16-20 Hz waves are called low beta. It is referred to as “problem-solving beta” (Thompson & Thompson, 2015).

19-21 or 20-23 Hz Beta. These waves are often dominant in anxious people. They may correlate with emotional intensity. “They may correlate with productive cognitive work, productive but too intense work, or unproductive intense or anxious thinking” (Thompson & Thompson, 2015).

High Beta. 22-36 Hz waves are called high beta. These waves are seen in worried and anxious people, who often feel stressed-out, hyper-vigilant, are ruminating excessively or have negative self-talk. (Thompson & Thompson, 2015).

Appendix C

Post-Intervention Interview Questions

BNFK Training Experience

1. Tell me about your experience with BNFK
 - *What part did you like the most?
 - *What helped you the most?
 - *What part did you like the least? Was there anything that wasn't helpful?

2. Did you find any biofeedback modality/modalities useful in self-regulating your activation level i.e. breathing training, temperature training, muscle relaxation training or skin conductance training?
 - *Can you give me an example?
 - *Which training screens were your most/least favorite? Why?
 - *Which training screens were the hardest/most fun? Why?
 - *What helped you the most or the least? Why?

3. Was the neurofeedback training useful in improving your focusing or recovery ability?
 - *Can you give me an example?
 - *Which training screens were your most/least favourite? Why?
 - *Which training screens were the hardest/most fun? Why?
 - *What helped you the most or the least? Why? Examples

Transfer of Skills Learned to Sport (practice and competition)

4. Do you use any of the skills that were taught in the BNFK training in practice? If yes, what?
 - *Do you think it helps you? If yes, how?
 - *How much did you work on these skills outside of the lab training i.e in practice?

5. Do you use any of the skills that were taught in the BNFK training in competition? If yes, what?
 - * Do you think it helps you? If yes, how?

6. Specifically, has the training helped you with your ability to focus and/or recover in practice or competition?

Performance

7. Have you reached your personal performance goals this season?
 - *Do you think the BNFK training helped in reaching any of these goals?
If yes, how? If no, why not?

8. What were you doing in your best performances this year? And in disappointing performances?

Overall Learning About Yourself

9. What did you learn about yourself or your abilities during the training?

10. Did you learn anything from the BNFK training that you use/used in your life outside sport?
If yes, give an example.

General

11. Do you have any thoughts, comments, or recommendations about the BNFK training? (i.e., number of hours, modalities used, how the sessions were run, frequency, too much, not enough)

Appendix D

Consent Form Athletes

Bioneurofeedback Training and Testing in Sport

Name of researcher:	Penny Werthner, Ph.D.	Margaret Dupee, Research Assistant
Institution:	University of Ottawa Faculty of Health Sciences School of Human Kinetics.	University of Ottawa Faculty of Health Sciences School of Human Kinetics

I, _____, agree to participate in the research project conducted by Dr. Penny Werthner and Margaret Dupee, of the School of Human Kinetics from the Faculty of Health Sciences at the University of Ottawa. The purpose of the research is to determine: 1) whether bioneurofeedback training improves stress control, relaxation and concentration skills for athletes and 2) whether these specific psychological skills lead to improvements in performance for athletes.

My participation will consist of twenty sessions of bioneurofeedback training, each one hour in length. I have been informed and I understand that bioneurofeedback training is non-invasive and entails the attachment of sensors to monitor a variety of physiological changes in my body. During biofeedback training I will be asked to relax and to observe feedback on the computer screen regarding my respiration rate, heart rate, body temperature, skin conductance levels and muscle tension. I will be encouraged to voluntarily control all of the biofeedback variables i.e. decrease muscle tension to 2mV or below. During neurofeedback training I will be asked to observe feedback on the computer screen regarding my brainwave activity. I will be encouraged to decrease theta (emotion) and beta 2 (negative self-talk) brainwaves using biofeedback techniques i.e. decreasing muscle tension and deep breathing, in order to increase my concentration (beta 1). I will also be required to answer questions during pre and post training interviews. All research and interviews will take place in the Biofeedback Lab, Room 414, Montpetit Building, 125 University Road, University of Ottawa.

I understand that all data collected and recorded will be used only for the purposes of research and that my confidentiality will be respected. I have received assurance from the researcher that the information that I will produce and share will remain strictly confidential. Anonymity will be assured in a number of ways. A code number will identify me so my name will not appear on any documentation. I also expect that only Dr. Penny Werthner and Margaret Dupee will have access to the code numbers. I have been informed that all data produced and collected will be stored in Dr. Penny Werthner's office to which only her research team have access. As well, the list identifying the participants will be kept in a separate, locked file cabinet in Dr. Werthner's office so that no association between a code number and a participant's identity will be possible.

I understand that this activity deals with personal information about my athletic experiences and my physiology and that the risks involved are very minimal. If I agree to be part of the study I

will be asked to meet with the researcher for twenty sessions each two hours long. If I so choose below, I will have the opportunity to review my transcript of the interviews one week after they take place. A copy of the transcript will be sent to me by email and I will have a two week period during which I will be allowed to respond either by email or telephone requesting that the researcher remove, add and/or modify any information that I feel is necessary. If I regret disclosing something about myself or my athletic experiences, the information will be excluded from the data base and will not be reported in any form of communication. If I do not respond within two weeks, the researcher will contact me either by email or telephone on the 14th day after contacting me with the transcript to confirm that I am waiving my right to amend it.

Benefits of this study are two-fold: The first is that if bioneurofeedback training, is shown to enhance an individual's ability to regulate their relaxation and concentration skills, this could benefit not only the athlete, but all individuals in the management of daily tasks as well as performance demands. Enhancement of the quality of life, for the individual and society, is one of the possible benefits of development and use of bioneurofeedback training. Secondly, this study will begin to build research in the area of bioneurofeedback training and athletic performance enhancement, which is currently quite sparse.

The goal of the researcher is to use the information from many athletes to determine whether bioneurofeedback training enhances athletic performance and to draw a general assessment of the effects of bioneurofeedback training on athletic performance. Thus the results of this study will be presented at conferences and/or in sport journals. The data from this study will be conserved for a period of 5 years and after that time period, all electronic data will be deleted and the written documents will be destroyed by shredding.

I am free to withdraw from the project at any time, before or during the training, refuse to participate and refuse to answer questions without prejudice. If I withdraw from the study the data collected from me up to that point will be destroyed.

Any information requests about my rights as a research participant may be addressed to the Protocol Officer for Ethics in Research, , University of Ottawa, 550 Cumberland Street, Tabaret Hall, Room 154, Ottawa, Ontario, Canada, K1N 6N5, 613-562-5387 or ethics@uottawa.ca.

There are two copies of the consent form, one of which I may keep.

If I have any questions about the conduct of the research project, I may contact the researcher at: Dr. Penny Werthner, School of Human Kinetics, University of Ottawa, K1N 6N5 or Margaret Dupee, Research Assistant, School of Human Kinetics, University of Ottawa.

I want to review the transcript of my interview.

Yes _____ No _____

I understand that data collected will be referred to throughout the study. I prefer:

____ Not to be quoted at all

____ To be anonymously quoted and only referred to by number

Researcher's signature: _____ Date: _____

Research Subject's signature: _____ Date: _____