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Examining the Effects of an Interspersed Biofeedback Training Intervention on Physiological Indices

Abstract

The study aimed to determine whether athletes who practice biofeedback are able to self-regulate by reaching resonance frequency and gaining physiological control quicker than if practice time integrates imagery or a rest period. Intervention effectiveness (e.g., intervention length, time spent training) was also explored. Twenty-seven university athletes were assigned to one of three groups: (1) biofeedback (i.e., continuous training), (2) biofeedback/imagery (i.e., interspersed with imagery), and (3) biofeedback/rest (i.e., interspersed with a rest period). Five biofeedback sessions, training respiration rate (RR), heart rate variability (HRV), and skin conductance (SC) were conducted. A repeated measure ANOVA showed a significant interaction between groups over time ($p \leq 0.05$) for RR, HRV, and SC, indicating that resonance frequency and physiological control was regained following imagery or a rest period. Post-manipulation check data found intervention length and training time to be sufficient. Combining imagery with biofeedback may optimize management of psychophysiological processes.

Keywords: high performance athlete, biofeedback, imagery, sport psychology, performance optimization

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Introduction

Involvement in high performance sport (i.e., university sport) can often be associated with increased performance demands, and the athlete's ability to cope with such demands can have a direct influence on sport performance (Gorgulu, Cooke & Woodman, 2019; Woodman & Hardy, 2003). It is essential that high performance athletes have the self-regulation strategies to manage both the positive (e.g., success) and negative (e.g., pressure, anxiety) effects of sport. Biofeedback is a technique that provides psychophysiological assessments in real-time to provide an athlete with the necessary self-awareness and self-regulation skills to manage physiological, psychological, attentional, and behavioural responses that could be detrimental to performance (Bar-Eli & Blumenstein, 2004; Dupee, Werthner, & Forneris, 2015; Morgan & Mora, 2017; Paul & Garg, 2012; Perry, 2018).

When applied, biofeedback training can teach an athlete how to voluntarily control anatomic responses such as respiration rate, heart rate, skin conductance, electromyography, and temperature. The intuitive feedback that biofeedback provides about physiological activity could have a direct impact on an athlete's ability to recover from the inherent stress, anxiety, and/or pressure during competition (Blumenstein, Bar-Eli, & Tenenbaum, 2002). With biofeedback, athletes can learn how to control and alter the physiological responses (e.g., respiration rate) that are best suited for optimal performance (Blumenstein et al., 2002; Dupee et al., 2015; Perry, 2018). The various modalities of biofeedback can serve multiple purposes and researchers have used a combination of these modalities (e.g., Dupee et al., 2015) depending on the purpose of the intervention. Although various anatomic responses can be trained with the use of biofeedback, the current study examined the combination of respiration rate, heart rate variability, and skin conductance training with the use of biofeedback.

Respiration rate, the process of inhaling and exhaling, is a source of rhythmical stimulation and has a direct impact on heart rate (Lagos et al., 2011; Lehrer, Vaschillo, & Vaschillo, 2000; Paul & Garg, 2012). Research indicates that breathing at about six breaths per minute or a resonance frequency in heart rate close to 0.1 Hz, can optimize performance (Dupee et al., 2015; Lehrer et al., 2000; Meuret, Wilhelm, & Roth, 2001). Resonance frequency exists at a specific frequency for each individual and can be detected as the frequency at which maximum heart rate variability is produced (Lehrer et al., 2000). Thus, resonance frequency is generated by paced breathing and can be achieved by the breathing tools created within the biofeedback software.

When an individual breathes at their resonant frequency, their heart rate and breath rate begin to cohere, producing a smooth sinusoidal wave. As an individual inhales, their heart rate will increase and as they exhale, their heart rate will decrease (Lagos et al., 2008; Lehrer et al., 2000). This then expands the amplitude of heart rate oscillations, increasing heart rate variability. Heart rate variability measures changes in heart rate patterns and refers to the beat-to-beat changes in the electrocardiogram (Lagos et al., 2008; 2011). Changes in heart rate can be triggered by emotions, breathing patterns, and changes in physical behaviours. High heart rate variability can be associated with faster reaction times and a better ability to manage emotions as well as changes in internal and external stimuli (Dupee et al., 2015; Lagos et al., 2008; 2011; Lehrer et al., 2000; Meuret et al., 2001; Paul & Garg, 2012). With biofeedback, an athlete has the capacity to learn strategies to increase heart rate variability, enhancing their ability to regulate emotions and perform at full potential (Lagos et al., 2008; 2011).

Lastly, skin conductance measures the skin's ability to conduct electricity (Blumenstein, Bar-Eli, & Tenenbaum, 1997; 2002). Physiological activation caused by psychological stress states (i.e., increased somatic anxiety) can have an immediate influence on skin conductance (i.e., increased skin conductance; Sime, 2003). Previous research has shown that increases in skin conductance due to heightened emotions could have a negative impact on sport performance (Blumenstein et al., 2002; Dupee et al., 2015; Paul & Garg, 2012). For an athlete to reach maximal performance levels, they must be able to self-regulate and cope with various performance demands and outcomes (Dupee et al., 2015). Research suggests that training these variables (i.e., respiration rate, heart rate variability, skin conductance) can teach athletes to regulate competitive anxiety (Lagos et al., 2008; 2011; Lehrer et al., 2000; Meuret et al., 2001; Sime, 2003), cope with emotions (Lagos et al., 2008; 2011; Lehrer et al., 2000; Meuret et al., 2001; Paul & Garg, 2012; Sime, 2003), optimize self-regulation ability (Dupee et al., 2015; Lagos et al., 2008; Nelson Ferguson & Hall, 2020; Paul & Garg, 2012), and enhance performance (Bar-Eli & Blumenstein, 2004; Bar-Eli, Dreshman, Blumenstein, & Weinstein, 2002; Galloway, 2011).

Therefore, pairing and training these three functions (i.e., respiration rate, heart rate variability, skin conductance) with the use of biofeedback should help counteract the negative psychophysiological effects that athletes may experience and provide them with additional self-regulation strategies to improve performance. In addition, many sport biofeedback researchers couple respiration rate and heart rate variability training (see Dupee et al., 2015; Lagos et al., 2008; 2011; Paul & Garg, 2012), as respiration has a direct impact on heart rate through rhythmical stimulation. Incorporating measures of skin conductance (i.e., emotion detector) can determine an individual's emotional response to the additional variables included in the current study.

Research has shown the positive effects of biofeedback training on sport performance, however it lacks investigation into the effects of combining additional regulation strategies, such as imagery, with biofeedback. In the sport and performance literature, imagery is a well-researched topic with previous research demonstrating the positive effects it can have on sport performance (Morris, Spittle, & Watt, 2005). Imagery can be described as "an experience generated from memorial information, involving quasi-sensorial, quasi-perceptual, and quasi-affective characteristics, that is under the volitional control of the imager, and which may occur in the absence of real stimulus antecedents normally associated with the actual experience" (Morris et al., 2005, p. 19). Imagery is a multisensory construct where an athlete can incorporate all relevant modalities (i.e., kinesthetic, visual, auditory, tactile, olfactory, and gustatory) when practicing the skill. Imagery that encompasses all of the senses can lead to a more effective imagery experience (Moran, 2013; Vealey & Greenleaf, 2010).

Much of the imagery research has stemmed from Paivio's (1985) framework, which suggests imagery has both cognitive and motivational functions. These functions operate at both a specific and general level. Based on Paivio's analytic framework, Hall et al. (1998) identified five different functions of imagery: (1) cognitive specific (e.g., images of sport specific skills), (2) cognitive general (e.g., images of sport specific strategies and/or routines), (3) motivational specific (e.g., images related to an individual's goals), (4) motivational general-arousal (e.g., images related to regulating arousal, stress, and anxiety), and (5) motivational general-mastery (e.g., images of being self-confident, focused, and mentally tough). While athletes report using all of these functions, researchers have focused primarily on cognitive specific and motivational general-mastery functions as these functions are typically employed most frequently (Cumming

& Hall, 2002; Hall, Mack, Paivio, & Hausenblas, 1998; Munroe-Chandler, Hall, Fishburne, Murphy, & Hall, 2012; Vadocz, Hall, & Moritz, 1997).

For the purposes of the current research, cognitive specific, motivational general-arousal, and motivational general-mastery were emphasized. Cognitive specific imagery interventions have demonstrated a positive effect on sport performance (Munroe-Chandler et al., 2002). Motivational general-arousal interventions have indicated that this function of imagery is effective in controlling emotions, as well as creating more facilitative interpretations of symptoms associated with competitive anxiety (see Jones, Mace, Bray, MacRae, & Stockbridge, 2002; Mellalieu, Hanton, & Thomas, 2009). Similarly, motivational general-mastery imagery interventions have shown that athletes have the ability to enhance levels of self-confidence and self-efficacy (e.g., Callow, Hardy, & Hall, 2001; O, Munroe-Chandler, Hall, & Hall, 2014).

It is evident that research indicates the positive effects that both biofeedback interventions and imagery interventions can have on sport performance. Sport and performance researchers have investigated the effects of multi-modal mental skills interventions that utilize the grouping of concentration, relaxation, imagery, and biofeedback (see Bar-Eli & Blumenstein, 2004; Bar-Eli et al., 2002; Galloway, 2011). However, there is a large gap in the sport and performance literature that examines the effectiveness of coupling imagery and biofeedback training and whether this type of intervention can generate more control over the physiological and psychological stress states within sport performance (Paul & Garg, 2012). Further, if biofeedback training is disrupted with imagery training or a rest period, it is undetermined if athletes will reach resonance frequency and gain physiological control as quickly as those who have continuous biofeedback training.

Therefore, the purpose of this study was to determine if athletes who practice biofeedback are able to self-regulate by reaching resonance frequency and gain physiological control quicker than if practice time integrates imagery training or a rest period. Further, the study aimed to explore athletes' perceptions of intervention effectiveness by determining if the number of sessions (i.e., 5 sessions) and the practice time (i.e., 10-15 minutes) of each session were adequate in aiding in the development of self-awareness and self-regulation of physiological indices (i.e., respiration rate, heart rate variability, skin conductance).

Method

Participants

Twenty-seven high performance athletes from university athletics teams (i.e., varsity sports teams; 7 male, 20 female) representing a post-secondary school in Southwestern Ontario, Canada agreed to participate ($M_{age} = 21.04$, $SD = 2.85$). Athletes ranged from having one to seven years' experience at the varsity level and spent an average of 10 hours per week training. The sports represented include: rowing ($N = 13$), rugby ($N = 7$), swimming ($N = 4$), cheerleading ($N = 1$), basketball ($N = 1$), and dance ($N = 1$).

Measures

Physiological data were recorded using the Biograph Procomp Infiniti™ T7500M Biofeedback System manufactured by Thought Technology (Montreal, Quebec, Canada). This device is a valid research grade device that acquires 256 samples per second (Thought Technology Ltd., n.d.). For the purposes of this research, respiration rate, heart rate variability, and skin conductance were measured. To measure respiration rate, a strain-gauged belt was placed around the mid-section of the abdomen. Heart rate variability was measured through an indirect measure of heart rate. A blood volume pulse detection sensor was placed around the participant's thumb and heart rate variability was computed using the formula HR Max – HR Min (i.e., the mean difference between heart rate maximum and heart rate minimum during each breath). Based on previous sport biofeedback research (Dupee et al., 2015), heart rate variability was measured using this formula. Lastly, skin conductance was measured by connecting two separate sensors to the index and ring finger. Once connected to the encoder, participants were able to monitor the three physiological variables through real-time, visual feedback on a computer screen. All three measures were recorded into a computer and analyzed by the aforementioned specialized biofeedback software program (i.e., Biograph Procomp Infiniti™ T7500M Thought Technology Ltd., Canada).

Protocol

Ethics approval for this study was obtained from the university's human research ethics board. Coaches from various university sports teams were contacted by the primary investigator via email with a letter of information outlining the purpose of the study. In addition, coaches were asked if there was a suitable time for the primary investigator to come to a practice to discuss the study in person and to recruit athletes who were interested in participating. Written informed consent was obtained from each athlete prior to the start of the intervention. Once consent forms were provided, participants were grouped based on the sport they represented (e.g., all rugby players were placed in one pile, all swimmers were placed in another pile). Since this study consisted of 3 groups, the primary investigator assigned a number (e.g., 1, 2, or 3) to each athlete per sport. This method was chosen to ensure that one group did not have an over representation of one sport. Therefore, participants were assigned to one of three equal groups (i.e., 9 athletes per group): (1) biofeedback group (2 male, 7 female; rowing [$N = 5$], rugby [$N = 2$], swimming [$N = 2$]), (2) biofeedback/imagery group (2 male, 7 female; rowing [$N = 4$], rugby

[*N* = 2], swimming [*N* = 1], cheerleading [*N* = 1], basketball [*N* = 4]), and (3) biofeedback/rest group (3 male, 6 female; rowing [*N* = 4], rugby [*N* = 3], swimming [*N* = 1], dance [*N* = 1]).

The intervention was conducted over two months. Each participant met with the primary investigator on a weekly basis until they completed the intervention. Most participants were able to complete the intervention in two and a half weeks. Sessions were conducted on weekdays and were scheduled every other day. Therefore, some participants had two sessions scheduled per week (e.g., Tuesday/Thursday) and others had three scheduled in one week (e.g., Monday, Wednesday, Friday).

All groups completed five training sessions. The rationale for this experimental design (i.e., five training sessions) was based on previous pilot research (Nelson Ferguson & Hall, 2020) where athletes perceived five training sessions to be an adequate amount of time to attain the self-regulation strategies intended for optimal performance. Based on the pilot research, a five-session biofeedback intervention seemed appropriate with the exploratory nature of this study. The primary investigator created a biofeedback training screen to measure breathing patterns, resonance frequency, heart rate, and skin conductance. This training screen was also used in the pilot study (Nelson Ferguson & Hall, 2020). Particularly, participants were able to view their respiration rate, beat-to-beat heart rate, and skin conductance (measured in micro Siemens) on the screen. The same screen was used for each training session. Participants were connected to the aforementioned sensors and respiration strap prior to the start of each session.

It should be noted that before the first session began, the researcher leading the intervention spent approximately 10 minutes with each participant explaining the use of biofeedback and what each sensor measured. Detailed descriptions of each variable shown on the biofeedback training screen (i.e., respiration rate, heart rate, skin conductance) were provided and participants were made aware that each session would be guided by instructions on proper breathing techniques. During the first session, the protocol designed to increase heart rate variability with biofeedback by Lehrer, Vaschillo, and Vaschillo (2000) was implemented with each group. Each participant was asked to breathe at variable respiration rates (e.g., 7.5, 7, 6.5, 6, 5.5 breaths/minute) while following a pacing stimulus (e.g., a line that moved up and down, instructing the participant when to inhale and exhale) for two minutes. Resonance frequency can be detected at the frequency at which maximum heart rate variability is produced, which was detected through the biofeedback device. The paced stimulus was set for each participant (e.g., 6 breaths/minute) and participants were instructed for natural and shallow abdominal breathing in accordance to his or her resonance frequency. The idea of balloon imagery (i.e., trying to fill the balloon with each inhale, and deflate the balloon with each exhale) was introduced to participants to facilitate abdominal breathing (Khazan, 2013; Perry, 2018). It is important for athletes to learn diaphragmatic breathing and to minimize thoracic movement to maintain control over physiological functions (Khazan, 2013; Perry, 2018).

The primary investigator continued to guide athletes by reminding them about using their abdomen to breathe while attempting to produce large, rolling peaks on the screen. For sessions two through five, all participants closed their eyes for the last three minutes of biofeedback training to practice breathing at resonance frequency without the pacer stimulus. The feedback was provided to the participant in the form of respiration rate, beat-to-beat heart rate, and skin conductance rate over the span of 30 seconds on the screen. At the end of each 15-minute session, the biofeedback training screen was paused to allow for all participants to review their final physiological measures after opening their eyes. If participants had questions about their final measures, they were addressed at this time. This usually took about five minutes per participant per session.

Group 1: Biofeedback group. Participants in the biofeedback group completed five biofeedback training sessions, with each session lasting 15 minutes. The resonance frequency for biofeedback group participants ranged from 0.1 to 0.12 Hz, or about six to seven breaths per minute. Physiological measures (i.e., respiration rate, heart rate variability, skin conductance) were recorded during each 15-minute session. This protocol was adhered to for all five sessions.

Group 2: Biofeedback/imagery group. Participants in the imagery group completed five training sessions, with each session lasting 15 minutes. However, participants in the imagery group followed a time sensitive protocol. For the first five minutes, participants practiced biofeedback. This was then followed by a five-minute imagery script. During the five-minute imagery script, participants were instructed to close their eyes and imagine the script that was read to them by the primary investigator. The imagery script was created around cognitive specific (e.g., imaging sport specific skills), motivational general-arousal (e.g., regulating emotions using imagery), and motivational general-mastery (e.g., imagery to build self-confidence, focus) situations in accordance to Paivio's (1985) model. Imagery scripts with response propositions (e.g., imagine being in control and confident during a difficult sport situation) are more likely to produce vivid images (Lang, Kozak, Miller, Levin, & McLean, 1980). The imagery script was based on previous imagery scripts (e.g., Callow et al., 2001; Cumming & Ste-Marie, 2001; Vealey & Greenleaf, 2010) as a foundation and was adapted from work done by Leslie-Toogood, Hammond, and Gregg (n.d.) on developing a suitable imagery script. Therefore, with athletes being recruited from a variety of sports, the script was general and focused on being in control and confident during performance mistakes and outcomes (e.g., Imagine yourself refocusing and remaining confident… You refocus on your process and fully commit to each skill you make… Now see yourself at the competition totally focused, having a great performance) to ensure that it was meaningful for each athlete. The same imagery script was read each training session. Following the imagery script, participants resumed biofeedback training for the remaining five minutes. The resonance frequency for imagery group participants ranged from 0.09 to 0.13 Hz, or about five and a half to eight breaths per minute. This protocol was adhered to for all five sessions.

Group 3: Biofeedback/rest group. Participants in the biofeedback/rest group completed five training sessions, with each session lasting 15 minutes. Similar to the time sensitive biofeedback/imagery group, participants in the biofeedback/rest group practiced biofeedback for the first five minutes. This was then followed by a five-minute rest period where participants were instructed to rotate their chair to ensure their attention was not directed at the biofeedback screen. All participants chose to use their mobile device for each rest period. To finish, participants resumed biofeedback training for the remaining five minutes. The resonance frequency for biofeedback/rest group participants ranged from 0.1 to 0.12 Hz, or about six to seven breaths per minute. This protocol was adhered to for all five sessions.

Post-manipulation check. Following the intervention, each participant completed a post-manipulation check questionnaire developed by the primary investigator to explore athletes' perceptions of intervention. The questionnaire varied by group and consisted of six items for the biofeedback and biofeedback/rest group and seven items for the biofeedback/imagery group. The questionnaire for the biofeedback group aimed to examine intervention effectiveness (e.g., "the biofeedback intervention was effective, the length of the intervention was appropriate") as well as the impact it may have elicited on sport performance (e.g., "this training will have a positive impact on my sport performance”). The questionnaire for the biofeedback/imagery group examined perceptions of imagery ability during training (e.g., “I was able to image during the imagery script”), the effectiveness of combining imagery and biofeedback (e.g., “I found the combination of imagery and biofeedback to be effective”), if the length of the intervention was appropriate, whether participants found 10 minutes of biofeedback to be adequate (e.g., “10 minutes of biofeedback was an adequate amount of time each session”), and the impact it may have elicited on sport performance. The biofeedback/rest group had a similar questionnaire to the biofeedback group with exception to training time and whether participants found 10 minutes of biofeedback to be sufficient (e.g., “10 minutes of biofeedback was an adequate amount of time each session”). Each item was rated on a five-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*).

Data Analysis

Physiological data was extracted from the specialized biofeedback software program, which were then statistically analyzed using the Statistical Package for Social Sciences (SPSS)/25.0 (Copyright© SPSS Inc.). For examining changes in the dependent variables between groups, a 3 (Group: biofeedback, imagery, rest) x 3 (Time: first five minutes, second five minutes, third five minutes) x 5 (Session: 1, 2, 3, 4, 5) repeated measures ANOVA was applied to analyze differences between groups over times and sessions. Statistical significance was accepted at $p \leq 0.05$. To analyze the post-manipulation check questionnaire for each group, participant responses per group were inputted in SPSS to reveal descriptive statistics in the form of means, standard deviations, and range of response.

Results

Physiological Measures

Respiration rate. The ANOVA revealed a significant main effect of Time, $F(6, 19) = 15.876$, $p = .000$, $\eta^2 = .834$, as well as a significant Group x Time interaction, $F(12, 40) = 3.139$, $p = .003$, $\eta^2 = .485$ across all groups. Figure 1 depicts the estimated marginal means for heart rate variability across each group (i.e., biofeedback, imagery, rest) over time.

Heart rate variability. The ANOVA revealed a significant main effect of Time, $F(6, 19) = 15.876$, $p = .000$, $\eta^2 = .834$, as well as a significant Group x Time interaction, $F(12, 40) = 3.139$, $p = .003$, $\eta^2 = .485$ across all groups. Figure 2 depicts the estimated marginal means for heart rate variability across each group (i.e., biofeedback, imagery, rest) over time.

Skin conductance. The ANOVA revealed a significant main effect of Time, $F(6, 19) = 15.876$, $p = .000$, $\eta^2 = .834$, as well as a significant Group x Time interaction, $F(12, 40) = 3.139$, $p = .003$, $\eta^2 = .485$ across all groups. Figure 3 depicts the estimated marginal means for heart rate variability across each group (i.e., biofeedback, imagery, rest) over time.

Post-Manipulation Check: Descriptive Statistics

A post-manipulation check data in the form of means, standard deviations, and range of responses are presented in Table 1.

Discussion

The purpose of this study was to examine the practice effect of biofeedback in high performance varsity athletes. More specifically, this research aimed to determine whether athletes who practice biofeedback are able to self-regulate by reaching resonance frequency and gaining physiological control quicker than if practice time integrates imagery training or a rest period. It also explored athletes' perceptions of intervention effectiveness by determining if the number of sessions (i.e., 5 sessions) and the time spent training each session (i.e., 10-15 minutes) aided in the development of self-awareness and self-regulation of the physiological variables trained (i.e., respiration rate, heart rate variability, skin conductance).

Each group (biofeedback, imagery, rest) was provided with the same instructions and biofeedback training screen, measuring respiration rate, heart rate variability, and skin conductance. The primary objective of this study can be explained through the Group x Time interaction. With Figure 1, 2, and 3 representing the marginal means of respiration rate, heart rate variability, and skin conductance, respectively, it is evident that this significant interaction can be attributed to the procedure followed within each group. As seen in Figure 1, the biofeedback group maintained a consistent respiratory rate across time. Each participant in this group had instruction to breathe at the pace best suited for their heart rate oscillations. In the biofeedback/imagery and biofeedback/rest group, coherence (i.e., smooth sinusoidal wave between heart rate and respiration) was reached at Time 1 and Time 3 as participants maintained resonance frequency. Participants in the biofeedback/imagery group had a slight increase in their respiration rate during Time 2 (i.e., while imaging). This was expected as participants were instructed to close their eyes and follow along with the imagery script as opposed to the pacer stimulus. Further, the biofeedback/rest group had a significant increase in their respiration rate during Time 2, which was anticipated as their attention was away from the biofeedback screen. During Time 3, participants in the biofeedback/imagery and biofeedback/rest groups were able to bring respiration rate down to their determined breathing pace.

As seen in Figure 2, the marginal mean for heart rate variability for the biofeedback group presented a relatively stable trend across each time point. There is a slight increase at Time 3, indicating that as participants continued to breathe at their resonance frequency, they were able to expand the amplitude of their heart rate oscillations. Participants in both the biofeedback/imagery and biofeedback/rest group displayed high amplitude oscillations in heart rate for Time 1 and Time 3. During Time 2, attention was taken off of the biofeedback screen (i.e., imagery training or rest period) and heart rate variability began to decrease. Therefore, high amplitude heart rate oscillations were not being achieved. With a decrease in heart rate variability, an athlete's ability to regulate emotions is reduced (Lagos et al., 2008). Based on previous research, it is apparent that during Time 2, the ability to manage physiological, psychological, attentional, and behavioral fluctuations started to diminish (Lagos et al., 2008; Paul & Garg, 2012; Perry, 2018).

When examining marginal means for skin conductance among each group (see Figure 3), the biofeedback group maintained a relatively stable emotional response during all time points. This can be attributed to paced and controlled breathing (i.e., resonance frequency breathing), which elicited a relaxed physiological state and in turn emotional regulation (Lagos et al., 2011; Lehrer et al., 2000; Paul & Garg, 2012). For the biofeedback/imagery group, skin conductance levels increased during the five-minute imagery script. The imagery script focused on athletic performance mistakes and outcomes, which could have heightened the athlete's emotional responses. Although participants in the biofeedback/imagery group were able to reach and maintain coherence during Time 3 (i.e., biofeedback training), skin conductance slightly climbed indicating that athletes may not have had the chance to regulate the emotions associated with their imaging. Interestingly, the biofeedback/rest group's skin conductance continued to increase throughout each time point. For Time 2, participants used their mobile devices during each session. However, for Time 3 (i.e., biofeedback training), skin conductance levels continued to rise even once coherence was met. As anxiety and arousal levels increase, skin conductance begins to follow this pattern through psychophysiological activation (Sime, 2003). Therefore, participants' psychophysiological activation during their rest period may not have been regulated during Time 3.

Although the biofeedback group trained continuously and maintained relatively stable physiological responses during each intervention session, the biofeedback/imagery and biofeedback/rest group were able to reach resonance frequency and control their physiological responses during Time 3 (i.e., once biofeedback training resumed). In Figure 2 (i.e., margin means for heart rate variability), both the biofeedback/imagery and biofeedback/rest groups were able to increase their heart rate variability during Time 3. The marginal means for these groups were in fact higher than the biofeedback group (about three beats for the biofeedback/rest group and five beats for the biofeedback/imagery group). Therefore, the time spent training with biofeedback and the positive outcomes associated with reaching resonance frequency did not differ if biofeedback training was continuous or interspersed.

To date, researchers have not examined the integration of imagery during biofeedback training while measuring physiological variables and how those variables respond. Each imagery session utilized cognitive specific (e.g., images of sport specific skills), motivational general-arousal (e.g., images related to regulating arousal, stress, and anxiety), and motivational general-mastery (e.g., images of being self-confident, focused, and mentally tough) imagery functions. With research highlighting the positive effects these functions can have on sport performance (see Munroe-Chandler et al., 2002; Jones et al., 2002; Mellalieu et al., 2009; Callow et al., 2001; O et al., 2014), the integration of imagery could generate cognitive (i.e., psychological) and somatic (i.e., physiological) self-regulation, enhancing the outcome of biofeedback training (Paul & Garg, 2012). Although imagery participants increased their respiration rate and decreased heart rate variability during each five-minute imagery script, they were able to quickly regain physiological control during Time 3 (see Figure 1 and 2).

The role of imagery on skin conductance (i.e., the emotion detector) may need further investigation as well. As seen in Figure 3, skin conductance continued to rise during Time 2 (imagery script) and Time 3 (biofeedback training) for the biofeedback/imagery group. As emotions, such as anxiety, stress, and pressure increase, skin conductance begins to follow this pattern through psychophysiological activation (Sime, 2003). Even though participants reached resonance frequency and increased heart rate variability for Time 3 (see Figure 1 and 2), the emotions associated with each imagery session may have had a direct impact on the continued rise in skin conductance. The relationship between imagery and skin conductance has received very limited empirical investigation (e.g., Haney & Euse, 1976).

Further, an overall examination of participants' perceptions of the intervention indicated that participants were highly satisfied with its effectiveness. As noted on the post-manipulation check (see Table 1), investigation into the biofeedback group showed the intervention to be effective, the length of the intervention appropriate, the training relatively easy, 15 minutes of training to be adequate, and the training to have a positive impact on sport performance. The biofeedback/imagery group indicated a relatively high imagery ability, the combination of imagery and biofeedback to be effective, the training relatively easy, the length of the intervention appropriate, 10 minutes of training to be adequate, and the training to have a positive impact on sport performance. Lastly, the biofeedback/rest group showed the intervention to be effective, the length of the intervention appropriate, the training relatively easy, 10 minutes of training to be adequate, and the training to have a positive impact on sport performance.

Therefore participants regardless of the group they were assigned to, found that the length of the intervention was sufficient for acquiring self-awareness and self-regulation strategies.

Future research regarding the use of biofeedback could benefit from including post-intervention follow-ups (e.g., 1-month and 6-month post-intervention) to evaluate adherence and perceived effectiveness. In addition, it would be useful to conduct a biofeedback training intervention similar to the current study during the competitive season. This could evaluate an athlete's ability to transfer the acquired skills from the lab to the sport setting. It could also be helpful to employ the same intervention using group-training sessions with participants involved in team sports (Blumenstein & Orbach, 2014). It may be easier for athletes to implement the acquired skills if they are learning the self-regulation skills as a group. This could contribute to team cohesion as well as performance enhancement across the team (Blumenstein & Orbach, 2014). Continued research examining the combination of imagery and biofeedback training effects on sport performance is necessary as this combined intervention could generate the management of both cognitive (psychological) and somatic (physiological) responses, contributing to positive performance outcomes. Lastly, future research examining participants' physiological variables over varied intervention lengths would be valuable (e.g., five sessions, seven sessions, and ten sessions) to determine if results differ between groups over time.

While findings from the current study have important implications there are a number of limitations. A better understanding of intervention effects could have been determined through a post-intervention interview rather than a post-manipulation check. This could have offered valuable suggestions for future interventions. The transfer effect from the laboratory setting to the sport environment is undetermined, which poses a major limitation to the study. As previously mentioned, conducting this intervention during competition season and/or the inclusion of a post-intervention follow-up could have averted this limitation. As with many skills, a learning curve could have occurred after the initial session. This can be considered a methodological weakness of the study because participants were not provided with a practice session before the intervention began. Therefore, results should be interpreted with caution. To add, there is an evident imbalance in the number of male and female participants. Results do not give an accurate representation of intervention effectiveness, as findings cannot be generalized to athletes beyond this sample. Lastly, running a biofeedback training intervention with high performance athletes can be difficult due to the length and time required. Even though the sample size ($N = 27$) was relatively large for a study of this nature, the results should be interpreted with caution until these results are replicated and extended.

In conclusion, it is apparent that athletes who practice imagery or take rest periods between biofeedback training are typically able to regain resonance frequency and increase heart rate variability, but may have difficulty in regaining physiological control. Therefore, it may be worth interspersing biofeedback with additional self-regulation strategies, such as imagery. Further, results indicate that the athletes perceived five training sessions at 10-15 minutes per session to be adequate in providing the self-awareness and self-regulation skills required to optimize performance. From an applied standpoint, the delivery of biofeedback could be optimized with the integration of imagery training and pairing the two mental strategies together to generate the management of both cognitive (psychological) and somatic (physiological) processes.

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Figures

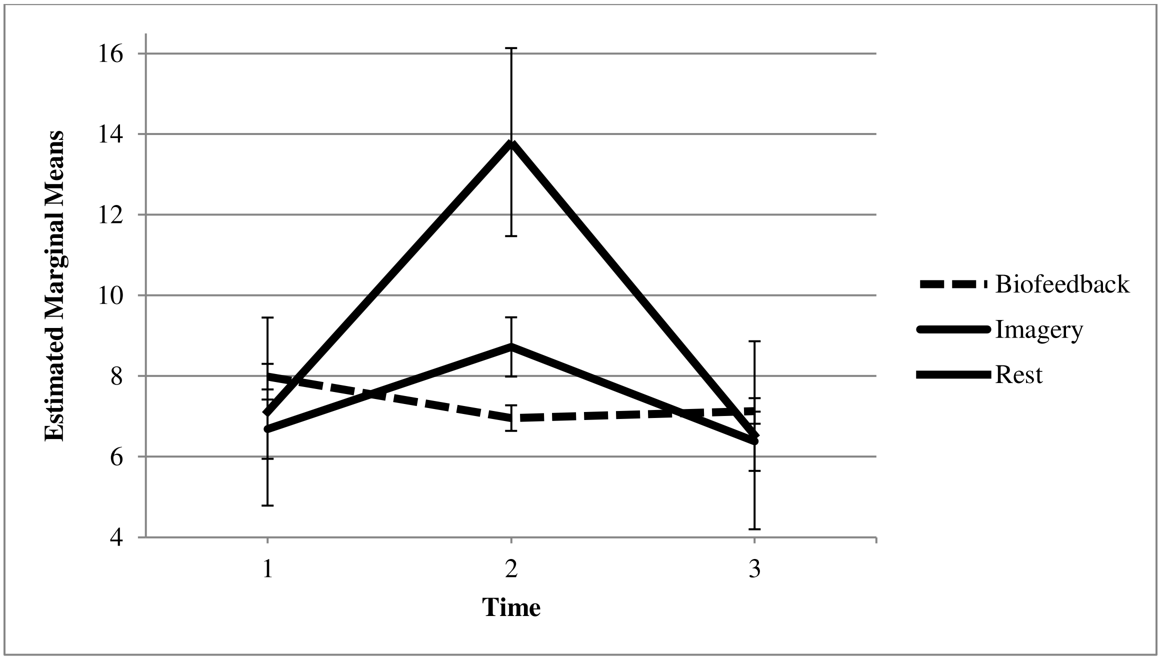

Figure 1. Estimated margin means for respiration rate for each group across time.

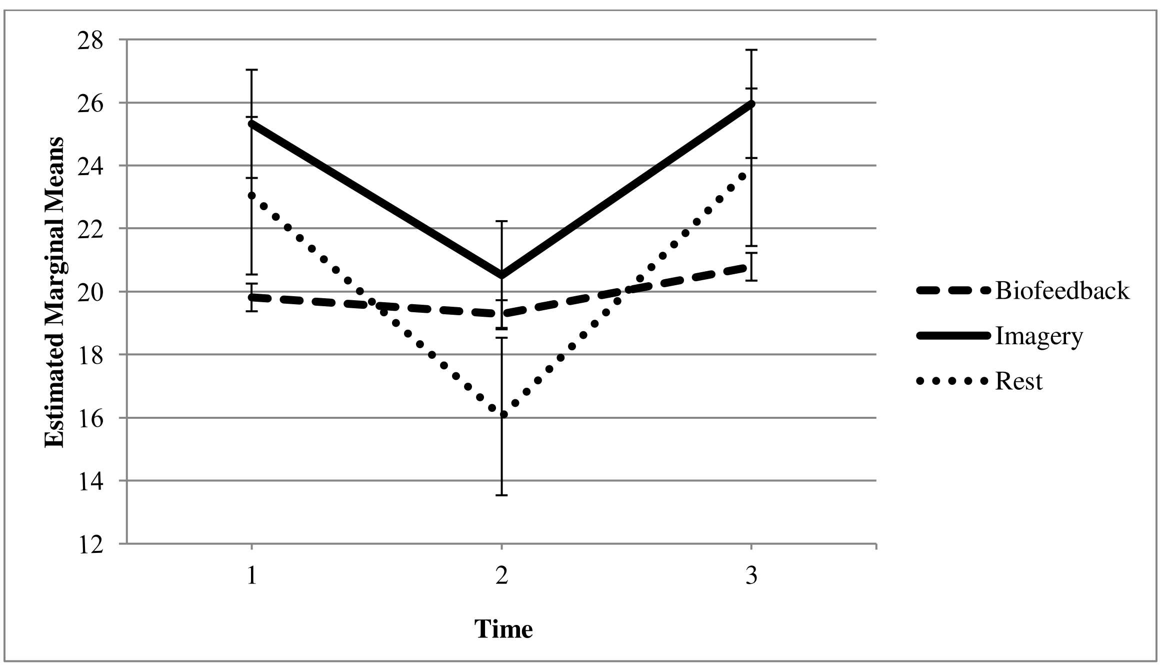

Figure 2. Estimated margin means for heart rate variability for each group across time.

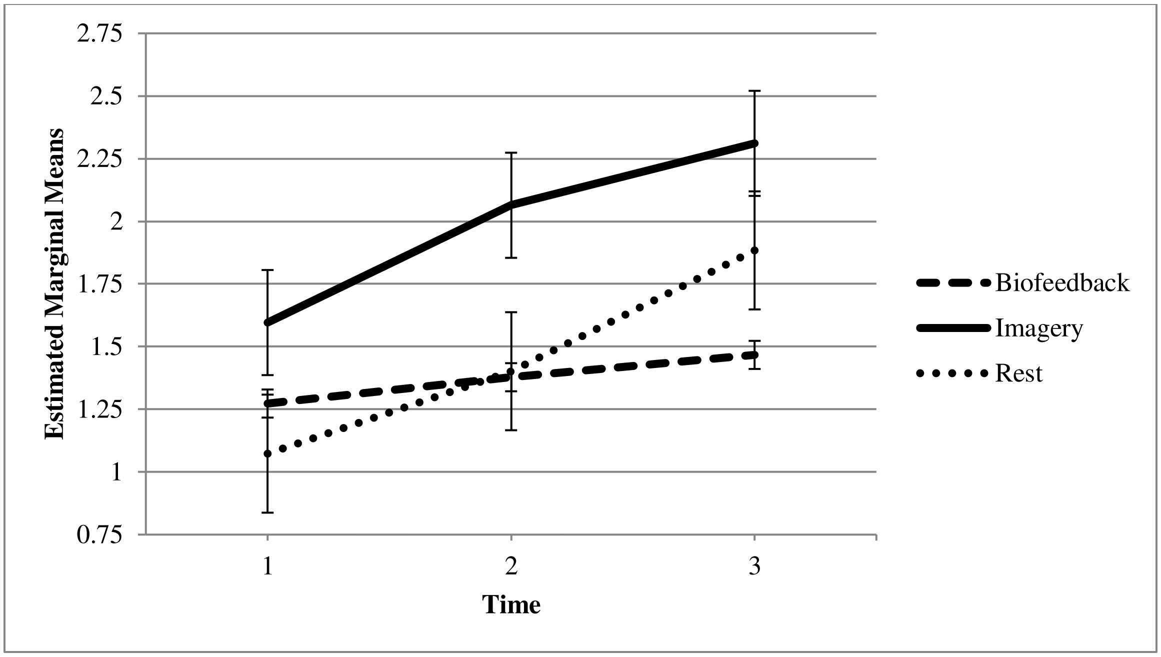

Figure 3. Estimated margin means for skin conductance across each group.

Tables

Table 1

Descriptive statistics: Post-manipulation check responses from participants

Item	Mean ± SD	Range
Biofeedback Group (*N* = 9)		
The biofeedback intervention was effective.	4.89 ± 0.33	1.0
The length of the intervention was appropriate.	4.78 ± 0.44	1.0
The training was easy.	4.33 ± 0.71	2.0
15 minutes of biofeedback was an adequate amount of time each session.	4.67 ± 0.50	1.0
The training will have a positive impact on my sport performance.	4.78 ± 0.44	1.0
Biofeedback/Imagery Group (*N* = 9)		
I was able to image during the imagery script.	4.56 ± 0.73	2.0
I found the combination of imagery and biofeedback to be effective.	4.67 ± 0.50	1.0
The training was easy.	4.11 ± 0.78	2.0
The length of the intervention was appropriate.	4.78 ± 0.44	1.0
10 minutes of biofeedback was an adequate amount of time each session.	4.89 ± 0.33	1.0
The training will have a positive impact on my sport performance.	4.67 ± 0.71	2.0
Biofeedback/Rest Group (*N* = 9)		
The biofeedback intervention was effective.	4.67 ± 0.50	1.0
The length of the intervention was appropriate.	4.78 ± 0.44	1.0
The training was easy.	4.44 ± 0.53	1.0

10 minutes of biofeedback was an adequate amount of time each session.	4.44 ± 0.53	1.0
The training will have a positive impact on my sport performance.	4.22 ± 0.67	2.0

Note. Each item was rated on a five-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*)