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SPECIAL ISSUE

Virtual Reality–Assisted Heart Rate Variability Biofeedback as a Strategy to Improve Golf Performance: A Case Study

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Growing evidence suggests that Heart Rate Variability (HRV) biofeedback (BFB) may improve sport performance by helping athletes cope with the stress of competition. This study sought to identify whether HRV BFB procedure impacted psychological, physiological, and sport performance of a collegiate golfer. This individual volunteered to participate in 10 weeks of HRV BFB training according to the protocol developed by Leher, Vaschillo, and Vaschillo (2000). During the first, fourth, seventh, and tenth weeks of the study, the golfer and lead author met at a virtual reality golf center to practice skills for breathing at resonance frequency during golf performance. Golf performance and HR were recorded during nine holes of virtual reality golf before and after 10 weeks of HRV BFB training. Self-report questionnaires were administered also before and after HRV BFB training to measure symptoms of anxiety, stress, and sensation seeking. Physiological measures, including HRV and respiration rate, were recorded in the lab during the first, fourth, seventh, and tenth weeks of the study. Reduction in symptoms of anxiety, stress, and sensation seeking and increases in total HRV, low-frequency HRV, and amplitude of oscillation at .1 Hz and improved sport performance were observed. This effect became stronger across 10 weeks of HRV BFB training. A larger-scale study was conducted and is in the process of analysis to confirm these findings.

Introduction

For over a decade, sport researchers have examined the impact of Heart Rate Variability (HRV) biofeedback (BFB) with resonance frequency breathing on athletic performance. Vaschillo, Vysochin, and Rishe (1998) applied HRV BFB to 30 elite wrestlers with encouraging outcomes. The wrestlers trained in HRV BFB demonstrated a significant decrease in reaction time, as well as a decrease in the time of recovery in relaxation of quadriceps muscles, compared to no change in the control group. Strack (2003) examined the effects of HRV BFB on high school batting performance; they reported that baseball players trained in HRV BFB demonstrated a higher percent improvement in performance and significantly increased percentage of low frequency oscillations in the heart rate spectrum. Raymond, Sajid, Parkinson, and Gruzelier (2005) compared dance performances of 24 Latin and Ballroom dancers who were randomly assigned to either a neurofeedback, HRV BFB, or a no-treatment condition. Dancers in the HRV BFB condition improved dance performance as compared to those in the no-treatment condition and also improved the subscale of ''technique'' compared to those in the neurofeedback and the no-treatment condition. In sum, findings consistently highlighted the predictive validity of HRV, and that HRV BFB can enhance sport performance. Lagos et al. (2008) also reported that HRV BFB helped a 14-year-old elite athlete cope with competitive stress, potentially, by improving his neuromuscular functioning.

While preliminary HRV BFB data in the area of sport performance enhancement have yielded empirically robust results, there remains a strong need for understanding the physiological mechanisms through which this training improves athletic performance. No study has concomitantly examined the relationships between HRV BFB training effects, physiology during sport performance, and sport performance outcome.

Support for the notion that HRV BFB training may moderate the self-regulatory mechanisms that control anxiety comes from research suggesting that HRV is an index of autonomic tone. The term HRV refers to a measure of the beat-to-beat changes in duration of RR intervals in the electrocardiogram. Psychophysiological models consider HRV as a measure of the balance between sympathetic and parasympathetic influences on heart rate, rendering information about an individual's autonomic flexibility and ability to engage in regulated emotional responding (Applehands & Luecken, 2006). In general, high HRV represents a flexible autonomic nervous system

(ANS), responsive to both internal and external stimuli, and is related to fast reaction times and adaptability. Low HRV, on the other hand, suggests a less flexible ANS that is less able to respond to changing stimuli and/or modulate stress. Further, diminished HRV has been identified as a significant predictor of stress-related disorders and mortality of all sources (Lehrer et al., 2003).

The primary goal of this study, therefore, was to expand on previous findings regarding the impact of HRV BFB on athletic performance while examining the specific physiological mechanisms that may correlate with improved athletic performance. Specifically, this study addresses four main research areas. First, it examines the impact of HRV BFB on self-reported mood, stress, and sensation-seeking tendencies. Second, the effects of HRV BFB on physiological performance as defined by HRV, muscle tension, and respiration rate in the lab are measured. Third, this study explores whether an individual's physiology during athletic performance changes before and after HRV BFB. Last, this investigation examines whether HRV BFB enhances golf performance in the areas of total golf score, number of putts, number of pars, number of birdies, average driving distance, and longest driving distance. Consistent with prior literature, it is hypothesized that HRV BFB is positively associated with improvements in mood, reductions in stress, and decreases in sensation-seeking tendencies. With increases in HRV in the lab and during competition, the golfer is expected to improve his or her golf performance.

Background of Participant

The participant in this applied case study was a 21-year-old competitive golfer in her senior year of college at a NCAA Division I University. Her eligibility for the study was determined by her current participation on the university golf team, fluency in English, and 20/20 or corrected vision. In addition, the golfer did not report a history of medical, psychiatric, or neurological conditions that would interfere with interpretations of physiological data. She provided written consent prior to participating in the study. Upon completion of the study, the golfer was paid a total of $200 for her participation in the approximately 16 hours of physiological monitoring.

Method

Location

The study was completed in two locations. The 10 sessions of HRV BFB training were conducted at the Cognitive Neuroscience Laboratory at the Center of Alcohol Studies (Rutgers University lab). The golfer was taught how to implement resonance frequency breathing skills during two sessions of training at a virtual reality golf center (Somerset, NJ).

Instrumentation

A Procomp Infiniti™ (Thought Technology, Montreal, Canada) System was used in the laboratory to collect electrocardiogram (ECG) and respiration data and to provide biofeedback. ECG data were digitalized at a rate of 1000 samples per second. Beat-to-beat RR intervals (RRI) of the ECG signal were measured. Respiration strain gauge belts were used for collecting respiration data. Further, the golfer used a portable heart rate variability biofeedback device (StressEraser™, New York, NY) to practice resonance frequency breathing for two 20-minute sessions of at-home breathing practice each day for a period of 10 weeks. A heart rate monitor watch (PolarUSA™, New York, New York) was worn by each golfer and used for recording HR data during golf performance in a virtual reality golf center.

Psychometric Measures

Competitive State Anxiety Inventory (CSAI-2). Cognitive and somatic anxiety about competition was assessed using the Competitive State Anxiety Inventory (CSAI-2). Developed by Martens et al. (1982), the CSAI-2 consists of 27 items, each rated on a Likert scale from 1 (''not at all'') to 4 (''very much so''). The 27 items represented three nine-item subscales, including somatic anxiety, cognitive anxiety, and self-confidence. Each scale yielded a separate score ranging between 9 and 37.

Stress inventory. To measure stress, the participant completed the Selby et al. (1990) Stress Scale. Stress was measured using 11 items. Each item was measured on a five-point Likert scale, ranging from ''not stressful at all'' to ''highly stressful'' with an additional category labeled ''does not apply.''

Sensation-seeking inventory. To measure sensation-seeking tendencies, the participant completed a nine-item scale developed by Schafer, Blanchard, and Fals-Stewart (1994). The golfer responded to how often she acted or felt like the item (e.g., ''act on the spur of the moment without stopping to think,'' ''get a kick out of doing things that are a little dangerous'') using a five-point Likert scale (ranging from ''never'' to ''always'').

Physiological Measures

Electrocardiogram (ECG). ECG was recorded in the lab and in the virtual reality golf center. In the lab, ECG was measured with electrodes attached to the upper part of the right arm (negative), lower part of the left leg (positive), and the upper part of the left arm (ground). ECG record was used for HRV analysis. In the golf center, ECG was measured by a in-chest led. Heart rate calculated from ECG was averaged over 10-second epochs. The HR pattern for each golf shot was considered.

Respiration. Respiration data were collected in the lab only. To record respiration, a strain gauged belt was placed around the navel section of the abdomen.

Heart rate. A heart-rate–monitoring watch recorded the golfer's heart rate during golf performance.

Golf Performance Measures

Total score. The number of strokes to complete nine holes of golf.

Putts. The number of strokes when the ball is on the green.

Driving average. The average distance of the first shot toward a hole hit from the teeing ground, recorded in yards.

Longest drive. The longest distance of any drive on any hole when using a driver.

Procedures

Recording

This 10-week study occurred during the spring 2008 golf season. Psychological questionnaires, muscle tension assessments, and sport performance measures were obtained before and after HRV BFB training. An electrocardiogram and a respiration tracing were also recorded during four physiological recording sessions at the lab. The recording sessions occurred during the first, fourth, seventh, and tenth weeks of the study. Each session consisted of four 5-minute tasks: Task A—baseline, Task B—first breathing task using a breath pacer, Task C—second breathing task where the golfer attempted to increase peak-to-trough heart rate swings with each breath on the cardiotachometer tracing, and Task D—baseline after training.

HRV BFB Training

HRV BFB training followed the protocol described by Lehrer, Vaschillo, and Vaschillo (2000). The golfer met for 10 consecutive weekly sessions at the lab. In the first session, the resonance frequency of her cardiovascular system was determined after a 10-minute training to breathe slowly, but not too deeply. The determination assessment procedure consisted of 2-minute paced breathing tasks at five tested frequencies, in a range close to .1 Hz (Vaschillo, Vaschillo, & Lehrer, 2006). The interbeat interval spectra were calculated for each tested task. The frequency at which the amplitude of the spectral power peak was highest was found to be at .092 Hz (5.5 times per minute), was defined as her resonance frequency. In the next nine sessions, the golfer performed BFB training at this resonance frequency. She was also asked to practice breathing at her resonance frequency for two 20-minute sessions per day using the portable Stress Eraser device. During the fourth and seventh weeks of the study, the golfer was provided with instructions for transfering breathing skills to competitive sport. These instructions took place at a virtual reality golf center. Each virtual reality session lasted approximately 60 minutes. During this time, she was taught to implement resonance frequency breathing before tee shots, putts, and moments of stress.

Data Analysis

Beat-to-beat RR intervals (RRIs) and HR were from the ECG signal and the respiration tracing analyzed. WinCPRS software (Absolute Alien Oy, Finland), which calculated both time and frequency domain measures from both signals (Bernston et al, 1997).

For each dependent variable, data were graphed and visually analyzed to evaluate the effects of the intervention (Barlow & Hersen, 1984). These graphs were interpreted with respect to immediacy and level of change pre- and postintervention, amount of overlapping data points across phases, and changes in slope and/or variability across phases (Hrycaiko & Martin, 1996; Thelwell, Greenlees, & Weston, 2006).

Results

To evaluate the cumulative effects of systematic HRV BFB training, physiological, psychological, and sport performance data collected before and after the 10 weeks of HRV BFB training were compared. The dynamics of HRV through 10 training sessions (during the first, fourth, seventh, and tenth weeks) was also assessed.

Psychological Performance

The golfer's cognitive and somatic anxiety, as measured by the CSAI-2, was reduced after 10 weeks of HRV BFB training. As demonstrated in Figure 1, cognitive and somatic

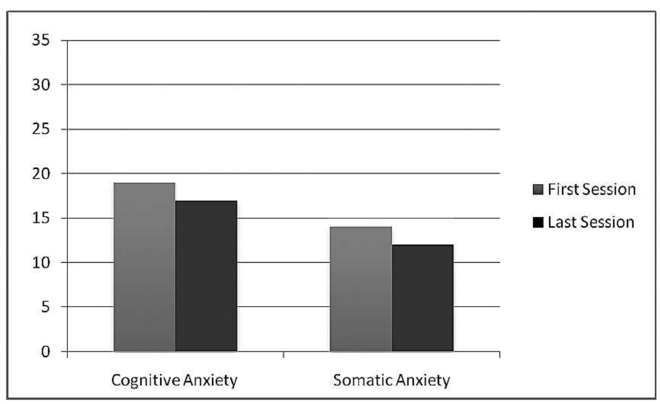

Figure 1. Competitive State Anxiety Inventory.

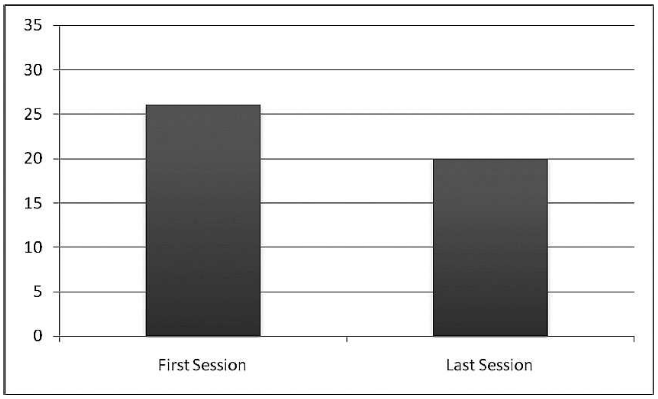

Figure 2. Stress scale.

anxiety scores prior to heart rate variability biofeedback training were 19 and 14, respectively. After the tenth week of training, the golfer scored 17 on cognitive anxiety and 12 on somatic anxiety. The severity of the golfer's self-reported stress was reduced following HRV BFB. As indicated in Figure 2, the golfer's overall levels of stress decreased from a score of 26 to 20. Notably, the individual reported reductions in 6 out of 11 areas of stress including meeting academic demands, controlling eating, social life, having or getting an injury, academic competition, and sport participation time demands. There were no increases in stress in any of the 11 areas. There were also no reported changes in 5 out of 11 areas of stress, which include controlling weight, general health concerns, maintaining athletic scholarship, maintaining academic scholarship, or sports competition. There was also a reduction in sensation-seeking tendencies after 10 weeks of training. Prior to training, the golfer reported a score of 33; during the tenth week of training, the golfer reported a score of 28 (Figure 3).

Physiology at University Lab

Results of HR and HRV analyses revealed a dramatic increase in parasympathetic system activity and a consequent increase

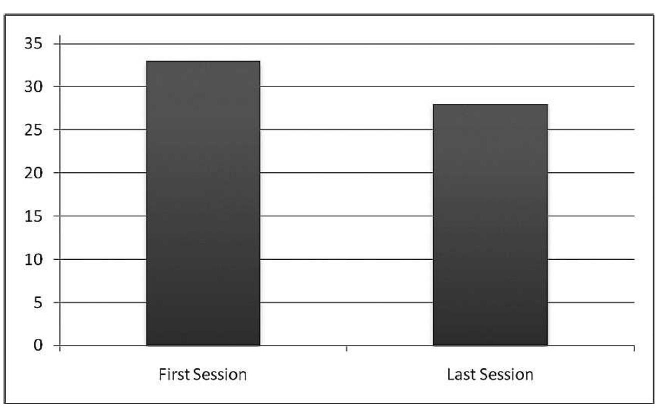

Figure 3. Sensation-seeking inventory.

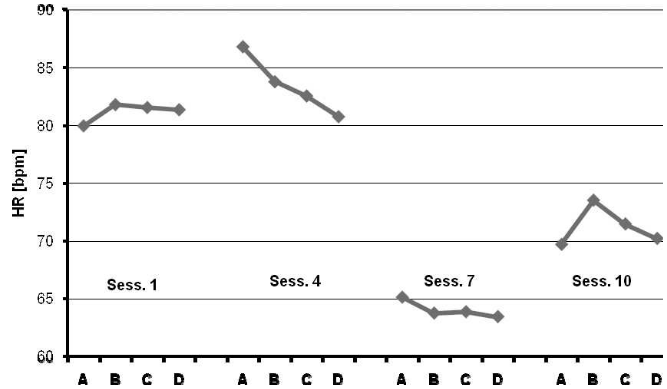

Figure 4. Change in mean HR following HRV BFB training.

in the ratio of sympathetic to parasympathetic activity after the fourth HRV BFB training session both during baseline and biofeedback periods. Mean HR was considerably lower in sessions 7 and 10 than in sessions 1 and 4 (Figure 4), while RMSSD and HF HRV indices of HRV, which reflect vagus activity, were considerably higher in sessions 7 and 10 than in sessions 1 and 4 (Figure 5). The HRV LF/HF ratio index was also shifted to lower levels after session 4 (Figure 6), suggesting a lower sympathetic to parasympathetic ratio in

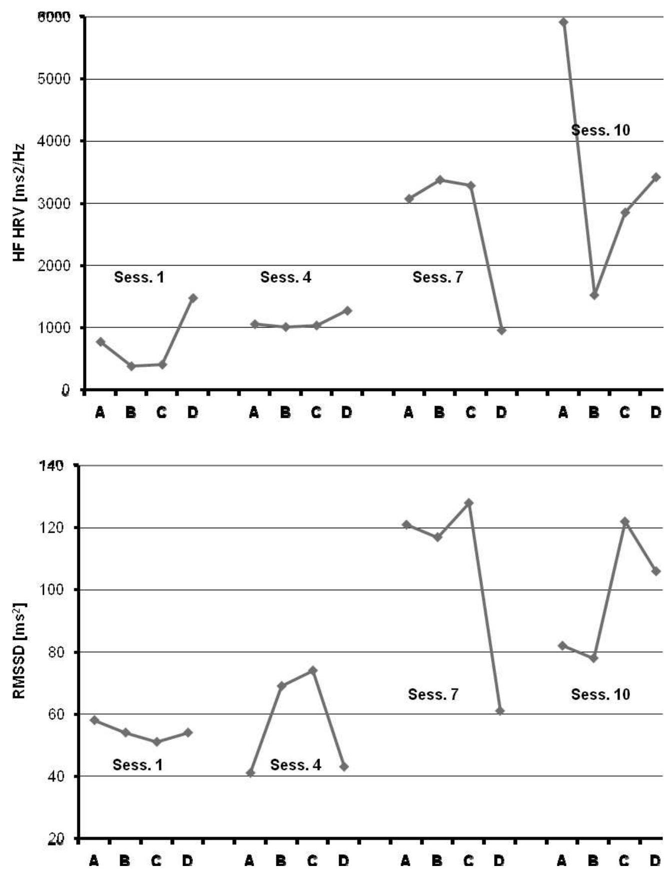

Figure 5. Dynamics of HRV indices that reflected level of parasympathetic system activity.

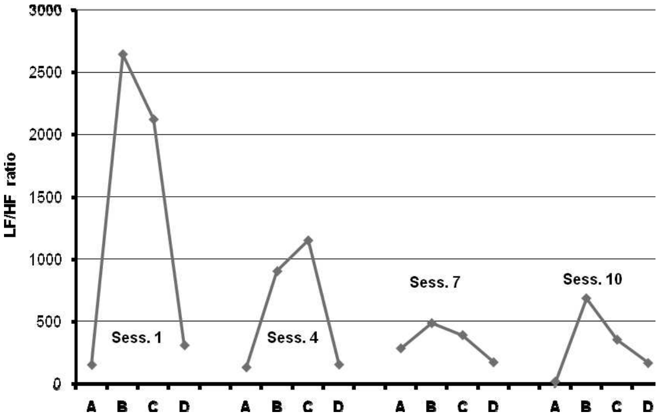

Figure 6. Dynamics of HRV index that reflected sympathetic-parasympathetic balance.

autonomic balance. Figure 7 shows that the golfer learned breathing (at a rate of ~6 breaths per minute) only after the fourth week of training.

Physiology during Virtual Golf Sessions

HR was continually recorded when the golfer was performing golf tasks in the virtual reality golf center. The HR pattern, based on 3 minutes of HR record before and 3 minutes after the shot, was calculated for each shot. Average HR patterns across all shots for before and after 10-week HRV BFB training are presented in Figure 8. Comparison of HR patterns indicates that systematic HRV BFB training reduced HR acceleration prior to the shot, possibly due to an increased ability to cope with stress. Figure 8 also shows that after 10 weeks of training, the golfer's heart rate returned to baseline rate in a shorter amount of time (e.g., faster recovery) after the shot than prior to HRV BFB training.

Sport Performance

The golfer's sport performance during 18 holes of virtual reality golf improved across several domains after 10 weeks

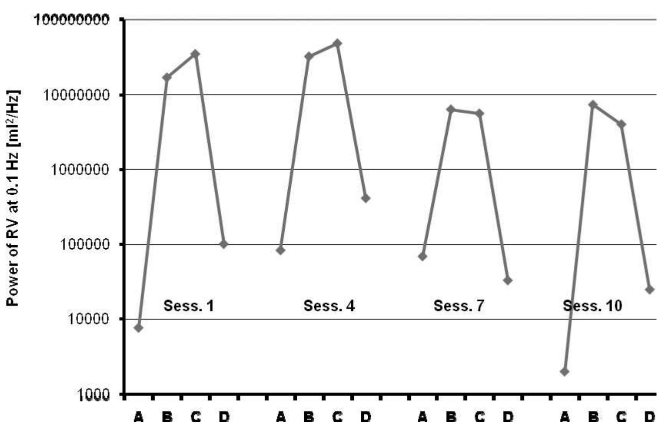

Figure 7. Change in respiration volume following HRV BFB training. *y* axis has logarithmic scale.

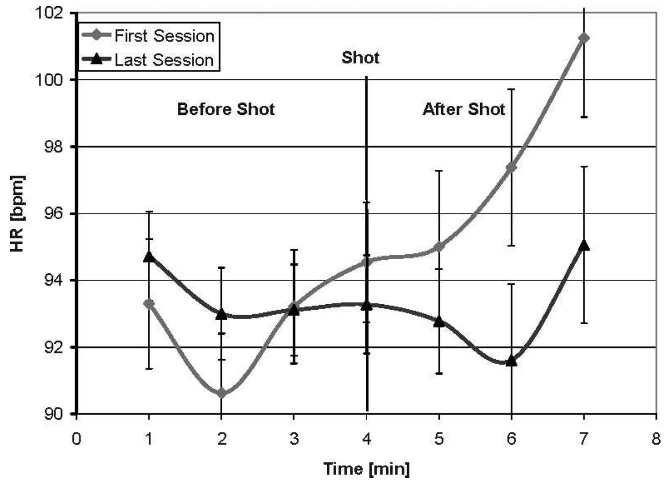

Figure 8. HR patterns averaged across 18 shot for the virtual golf session. Errors bars represent 1.96 standard errors.

of HRV BFB training. As demonstrated in Figure 9, she scored 46 strokes on 18 holes of virtual reality golf prior to HRV BRB. Post HRV BFB, she reduced her golf score to 30 strokes. Relatedly, her putting performance improved from 15 to 14 putts. The golfer's birdie score also improved from zero to one, while her par score increased from two to three. Her average driving distance increased from 170 to 184 yards through training and longest driving distance increased from 219 to 221 yards (Figure 10).

Discussion

These results are consistent with previous findings on athletic performance suggesting that HRV BRB may enhance athletic performance. Biofeedback effects on cardiovascular measures occurred after four sessions of training. The same finding was described in Lehrer et al. (2003, 2004), where therapeutic effects of HRV BFB procedures started after the fourth session. Four sessions of training were necessary for the participants to develop skills to breathe slowly, but not too deeply. These results

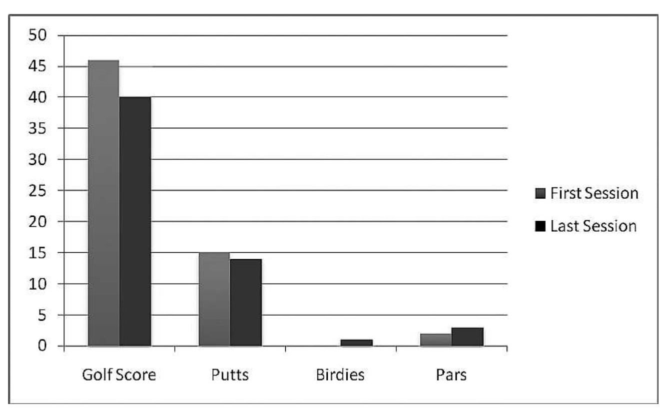

Figure 9. Golf performance.

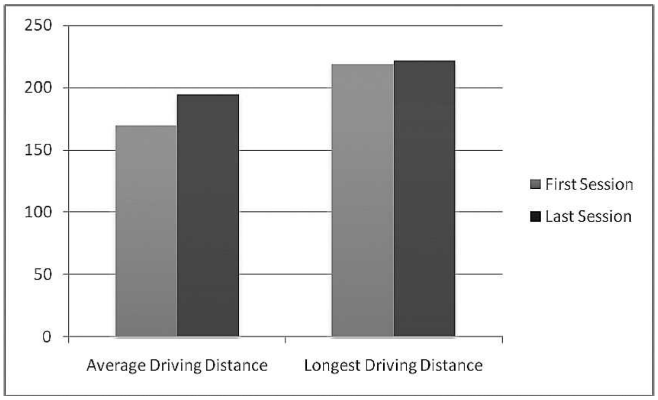

Figure 10. Golf driving distances.

suggest that the skills for HRV BFB may be acquired as early as the fourth session and that the greatest effects of HRV BRB on physiology and sport performance appear through extended time and practice.

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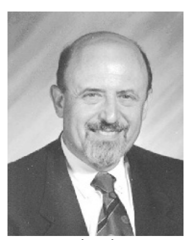

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