Biofeedback
Volume 39, Issue 1, pp. 000–000

SPECIAL ISSUE

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

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Keywords: biofeedback, heart rate variability, golf, sport performance

1 *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 was randomly selected 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 principal investigator met at a virtual reality golf center to practice skills for breathing at resonance frequency during golf performance. Results of the 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. Golf performance and HRV were recorded during nine holes of virtual reality golf. 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 sport performance improving were observed. This effect became stronger across 10 weeks of HRV BFB training, suggesting that HRV BFB may improve sport performance by helping athletes to cope with sport stress. A larger-scale study was conducted and is in the process of analysis to confirm these findings.*

Introduction

For over a decade, sport psychology 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 performance percent improvement and significantly increased the percentage of low frequency 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 (1) the predictive validity of HRV, (2) the stress response dampening impact of HRV BFB, and (3) 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 has 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, physiological state during sport performance, and sport performance outcome.

Support for the notion that HRV BFB training may moderate the self-regulatory mechanisms, which 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, 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 unable 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 possess a medical, psychiatric, or neurological condition that would contraindicate physiological assessment. 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 was 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 four 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. 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 (Stress Eraser, 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 Martin et al. (1983), the CSAI-2 consists of 2 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. Alpha coefficients ranged between .79 and .90 and demonstrated a high degree of internal consistency for the CSAI-2 subscales.

Stress inventory. To measure stress, the participant completed the Selby et al. (1990) Stress Scale. Stress was 3 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.'' An average stress score was calculated from the total number of indicated stressors (alpha = .80).

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 4 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''). An overall sensation seeking score, calculated by averaging the values of all items, was used in the analyses (alpha = .90).

Physiological Measures

Electrocardiogram (ECG). ECG was recorded in the University 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. Results were applied to create HR pattern for each golf shot.

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. Electrocardiogram and respiration were also recorded during four physiological recording sessions at the university lab. The recording sessions occurred during the first and tenth weeks of the study. Each session consisted of four 5-minute tasks: Task A—baseline, Task B—paced breathing task, Task C—second paced breathing task, and Task D—baseline after training.

HRV BFB Training

HRV BFB training followed the protocol set forth by Lehrer, Vaschillo, and Vaschillo (2000). The golfer met for 10 consecutive weekly sessions at a university lab. In the first session, the Resonance Frequency of her cardiovascular system was assessed. Initially she was trained for 10 minutes to breathe slowly, but not too deeply. The resonance frequency 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 tested frequency, at which the power of spectrum was found as maximal (in her case, .092 Hz or 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 how to transfer 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 and puts and in moments of stress.

Data Analysis

Beat-to-beat RR intervals (RRI) and HR were assessed from the ECG signal. A Fourier analysis of heart rate was used to estimate HRV. WinCPRS software (Absolute Alien Oy, Finland) was applied for ECG and respiration data analysis.

All self-report and paper and pencil measures were coded by the principal investigator. To facilitate error-free data, all coded instruments were input into electronic files twice, and then compared by SAS programs to identify inconsistencies. Inconsistencies were reviewed and corrected by reference to raw data. Corrected data sets were backed up and archived. A variable list/codebook that included each measure (e.g., SAS variable names, variable descriptions, and the range of values was assigned to each variable).

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 cumulative effects of systematic HRV BFB training results of analysis of physiological, psychological,

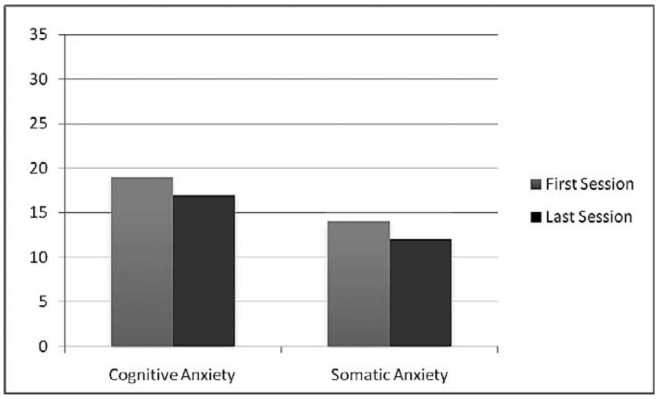

Figure 1. Competitive State Anxiety Inventory.

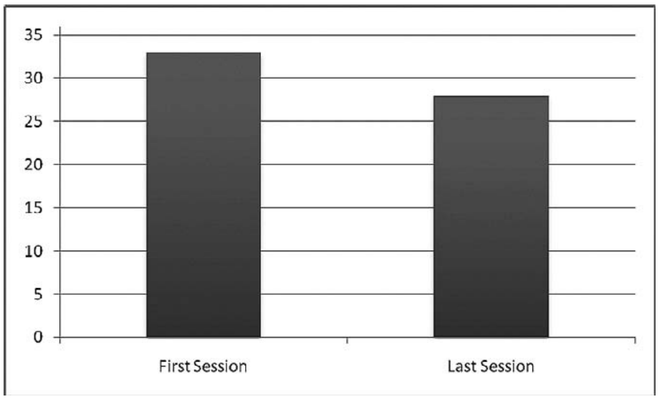

Figure 3. Sensation-seeking inventory.

and sport performance data collected before and after the 10 weeks of HRV BFB training were compared. Dynamics of HRV through 10 training sessions (during the first, fourth, seventh, and tenth weeks) was also estimated.

Psychological Performance

The golfer's cognitive and somatic anxiety, as measured by the CSAI-2, was reduced by 10 weeks of HRV BFB training. As demonstrated in Figure 1, cognitive and somatic anxiety scores prior to heart rate variability biofeedback training were 19 and 14, respectively. After the tenth week of training, the golfer reported cognitive anxiety as 17 and somatic anxiety as 12. The severity of the golfer's self-reported stress was reduced following HRV BFB. As indicated in Figure 2, the golfer's overall level reduced 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).

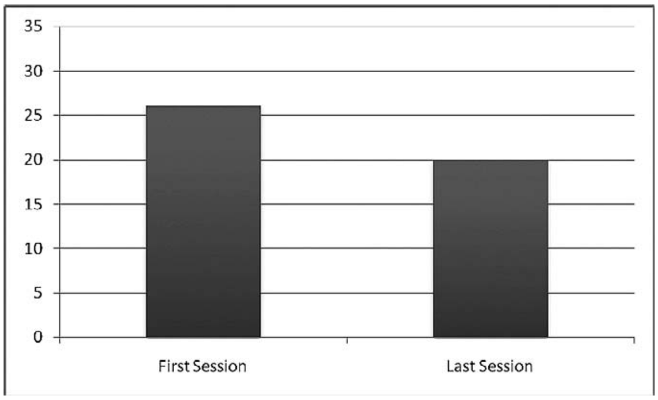

Figure 2. Stress scale.

Physiology at University Lab

Results of HR and HRV analyses revealed dramatic increase in parasympathetic system activity and normalizing sympathetic-parasympathetic balance after the fourth HRV BFB training session. Thus, the 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 toward ''0'' after session 4 (Figure 6). The decrease in this index means that the autonomic balance improved. Figure 7 shows that the golfer learned the needed type of breathing to decrease respiration volume at a rate of ~6 breaths per minute only after only four trainings.

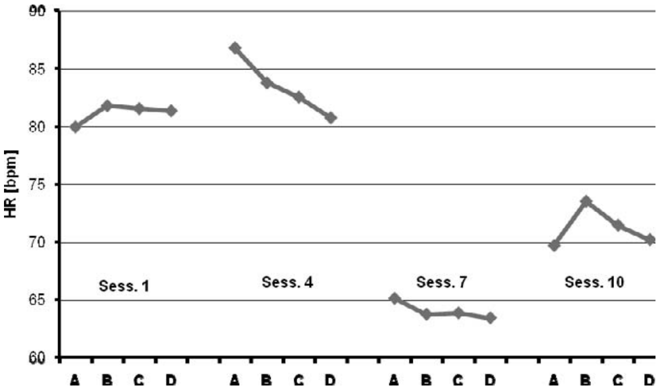

Figure 4. Change in mean HR following HRV BFB training.

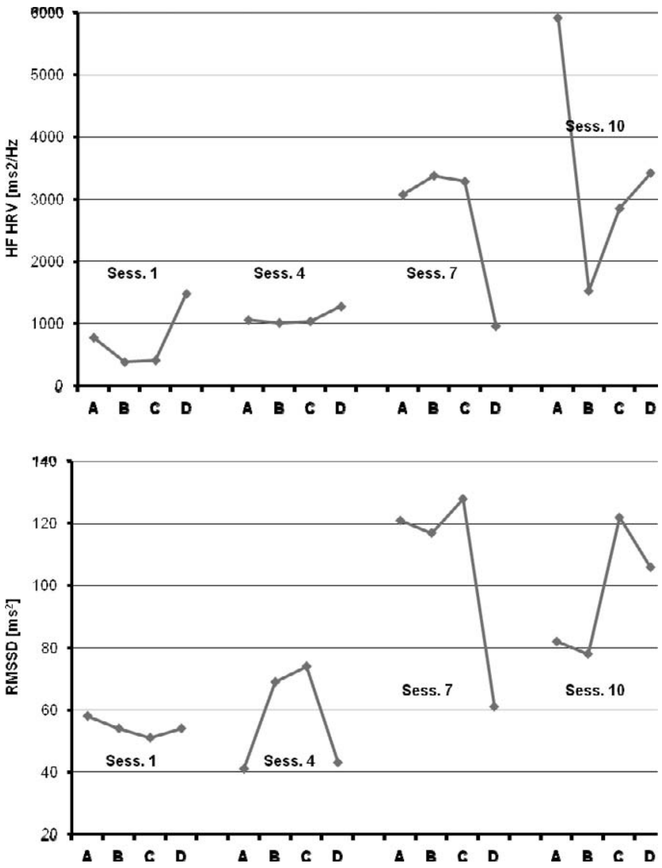

Figure 5. Dynamics of HRV indices that reflected level of parasympathetic system activity.

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 data of 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.

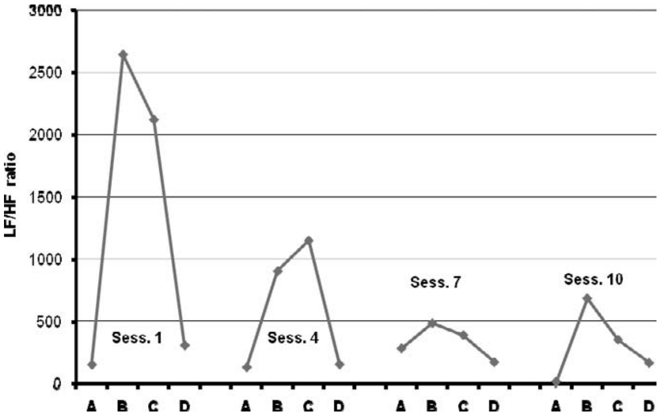

Figure 6. Dynamics of HRV index that reflected sympathetic-parasympathetic balance.

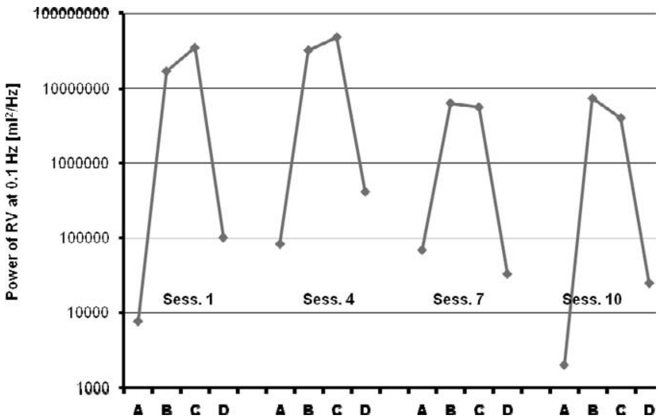

Figure 7. Change in respiration volume following HRV BFB training. *y* axis has logarithmic scale.

Sport Performance

The golfer's sport performance during 18 holes of virtual reality golf improved across several domains after 10 weeks of HRV BFB training. As demonstrated in Figure 9, she scored 46 strokes on 18 holes of virtual reality golf. 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).

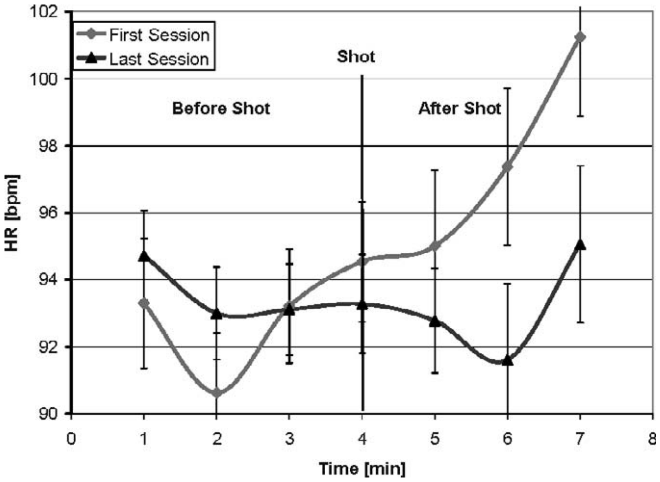

Figure 8. HR patterns averaged across 18 shot for the virtual golf session. Errors bars represent 1.96 standard errors.

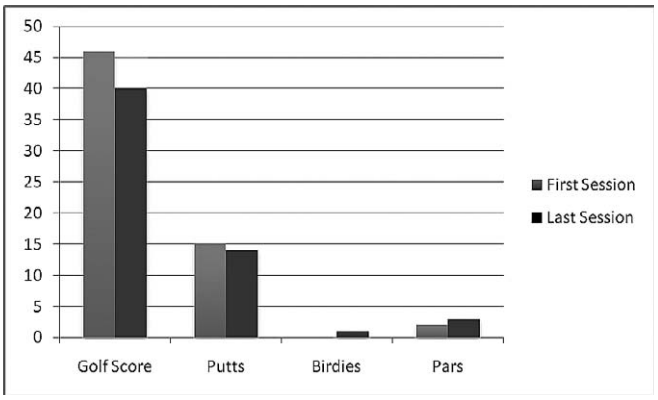

Figure 9. Golf performance.

Discussion

Biofeedback effects on cardiovascular measures occurred after four sessions of training. The same finding was described in Lehrer et al. (2003, 2004): that is, 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, producing an increase in parasympathetic system activity and normalizing sympathetic-parasympathetic balance. However, the greatest changes in psychological, physiological, and sport performance in the current study did not appear until after the tenth session of training. These results suggest that the skills for HRV BFB may be acquired as early as the fourth session and that the most optimal effects of HRV BFB on psychological and sport performance appear through extended time and practice.

Acknowledgments

This study was supported, in part, by NIDA grant P20 DAO 17552. The authors would like to thank Andrea Rydel and Georgia Kouzoukas for their assistance with data collection.

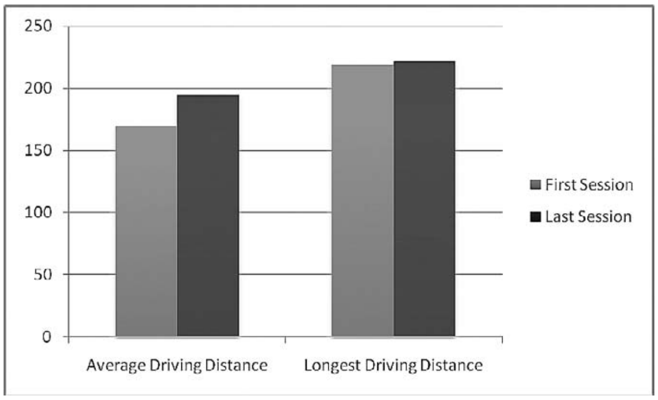

Figure 10. Golf driving distances.

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Journal: **Biofeedback**
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