Observational Report of the Effects of Performance Brain Training in Collegiate Golfers

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Keywords: neurofeedback, golf, QEEG, brain training, performance

There has been a recent interest in the use of neurofeedback to enhance sports performance. Our goal is to report the effects of performance brain training (a specific neurofeedback training paradigm with protocols based on the NeuroPerformance Assessment) on specific measures of golf performance in a group of Division I National Collegiate Athletic Association (NCAA) golfers. Participants included 16 golfers. Baseline performance data was collected prior to grouping athletes (Time Point 1). Initially, both groups continued as normal with team practice, tournament play, and sport-related coaching, while only Group 1 completed performance brain training (Time Point 2) due to limited athlete availability. Subsequently, only Group 2 completed while both groups maintained normal team activities (time point 3). Performance data was collected at each time point. Paired t-test analyses were completed for five performance variables from Time Point 1 to Time Point 2 and from Time Point 2 to Time Point 3 for each group. When comparing Time Point 1 to 2, Group 1 showed significant improvements in several golf performance indices: with increases in greens in regulation, decreases in the putting average, and decreases in the average number of three putts per round. Between Time Points 2 and 3, Group 2 demonstrated statistically significant improvements in greens in regulation, fairways in regulation, putting average, and average of three putts per round. It appears that Performance Brain Training may contribute to improvement in sport measures. Broadly, these findings lend support to previous studies illustrating that brain training improves performance outcomes, yet replication in a large sample size is required for further conclusions to be drawn.

Introduction
In recent years there has been an awareness of the potential for neurofeedback training to enhance sport performance (e.g., Hammond, 2007; Vernon, 2005). The previous research illustrating differences between amateur and expert performers suggests that opportunities for modulating brain wave activity may have a positive impact on performance. Despite this potential, the evidence is very limited with regard to direct improvements from neurofeedback training on objective performance measures. We analyzed data collected from a small group of top-ranked collegiate golfers where neurofeedback was implemented at two time points because of team schedules. Our goal in these post-hoc evaluations was to discover if completing neurofeedback training would correlate to sport performance improvements and if those improvements would be sustained once neurofeedback training ceased.

Electro-Cortical Differences Between Elite and Novice Performers

Advances in our understanding of the cortical differences between highly skilled and amateur performers indicate that there are differences in brain states during performance for these two groups (e.g., Deeny, Hillman, Janelle, & Hatfield, 2003; Milton, Solodkin, Hustik, & Small, 2007). Many studies have identified that more skilled individuals who perform better tend to present with more economical cortical activity, that is, greater theta and alpha power diffusely as well as less beta power, particularly in the cortical areas unrelated to the task (e.g., Baumeister, Reinecke, Liesen, & Weiss, 2008; Del Percio et al., 2009; Harung et al., 2011; Hund-Georgiadis & von Cramon, 1999; Kim et al., 2008; Lotze, Scheler, Tan, Braun & Birbaumer, 2003). It has been suggested that this economical cortical activation is the result of extensive training and demonstrates the ability to filter out unnecessary stimuli (Milton et al., 2007).

Given the evidence that neurofeedback training results in cortical changes reflected through electroencephalographic (EEG) activity (Fernández, et al., 2007; Gevensleben, et al., 2009), it is interesting to consider how...
neurofeedback may be used as a tool in training the brain activity of an amateur to function more like that of an elite performer. There have been some early indications that this training would contribute to performance improvements (Thompson, Steffert, Ros, Leach, & Gruzelier, 2008). Despite this expectation, the literature is weak in supporting neurofeedback training to enhance performance changes, specifically improvements where dependent variables are performance metrics of sport.

**Performance Changes After Neurofeedback Training**

Beyond anecdotal reports of performance improvements following neurofeedback training, only a few experimental studies have been conducted with the goal to determine if neurofeedback can improve performance (Thompson et al., 2008). Rather than actual performance measures, some studies have considered how neurofeedback training affects assessments like a continuous performance task (CPT). This was recently reported among minor league baseball developmental players, where it was shown that neurofeedback training was correlated to quantitative electroencephalogram (QEEG) changes, CPT improvements, and subjective reports of enhanced attention control and sleep quality (Sherlin, Larson, & Sherlin, 2012). In the performing arts, the work of Gruzelier, Egner, and Vernon (2006) has gone to great lengths over multiple years to demonstrate that neurofeedback is a viable training tool by showing beneficial and reproducible changes among performing artists identified as responders to neurofeedback training. In 2001, Gruzelier and colleagues demonstrated that augmenting sensory motor rhythm at C4 or beta 1 (15–20 Hz) at C3 in conservatoire students significantly reduced commission errors on a CPT (Gruzelier et al., 2006: C3 and C4 are cortical sites in the International 10–20 EEG placement system, representing left and right central cortical sites). It should be noted that they also found that those who were able to enhance the amplitude of sensory motor rhythm were also those who had the most significant improvements in impulsivity (i.e., reduced commission errors). Evidence of increases in P300 amplitude was also detected with regard to the beta 1 training. The authors replicated their work in 2003 and 2004 and in addition to a standard CPT they added a more complex test of divided attention. In both studies they found similar results to the initial study, errors were decreased, less reaction time variability, greater perceptual sensitivity, and finally increase of the P300 amplitude when comparing pre- to postneurofeedback training data (Gruzelier et al., 2006). Unfortunately, no studies have demonstrated that improvements on a CPT are predictive of improvements in competitive performance; therefore, with these results we cannot definitively state that neurofeedback improved performance.

In 2005, Raymond, Sajid, Parkinson, and Gruzelier published the results of a more direct test of the relationship between neurofeedback and performance by comparing the effects of alpha/theta neurofeedback training to a heart rate variability (HRV) training group as well as a control group (no training). The three groups were comprised of 24 dance students from the Imperial College Dance Sport Team. Changes were based on the evaluations of two expert dance judges and demonstrated that after an average of nine sessions of alpha/theta neurofeedback training and HRV training, the students in the intervention group significantly improved overall execution, while the control group made no significant changes. Additionally, neurofeedback training significantly improved the timing subscale, and HRV training was associated with significant improvements in the technique subscale compared to the controls. No significant differences were found between these biofeedback training groups, which may be related to the limited number of sessions or the likelihood that both protocols would have had a calming effect. More tailored neurofeedback protocols based on QEEG may lead to better outcomes than generic alpha/theta training.

Taken together, the improvements in CPT assessments and performance ratings lend support to the notion that competitive performance can be improved with neurofeedback training. However, the assessment of performance improvements should be based on a more objective scoring program, such as competition or even a pre–post neurofeedback training sport performance assessment. To date, there are only two studies to utilize measurable sport data to determine improvements after neurofeedback training.

The first analysis of sport performance changes due to neurofeedback appears to have been conducted by Landers et al. (1991). The authors randomly assigned 24 pre–elite archers (female = 8) to either a correct feedback, incorrect feedback, or control (no training) group, labels that were based on theoretical hypotheses of which protocols would improve performance. The results of neurofeedback training demonstrated that enhancements in left hemisphere alpha power at the electrode site T3 on the International 10–20 Electrode Placement System, which was deemed the “correct” feedback, were significantly correlated to better posttraining performance. Furthermore, increases in right hemisphere (T4) alpha synchrony, hypothesized to be the incorrect feedback protocol, were significantly correlated with poorer performance after training (T4 is a right temporal site in the international 10–20 electrode system).
A more recent investigation was conducted with six average golfers among amateur golfers in 2008 (Arns, Kleinnijenhuis, Fallahpour, & Breteler, 2008). By first determining a personalized event-locked EEG assessment from the electrode site FPz (the midline point in the prefrontal area in the international 10–20 system) during successful puts for each golfer, the authors were able to train each golfer to reproduce their respective successful EEG assessment while putting. During training segments with EEG feedback, the putting success rate was significantly higher. Interestingly, when feedback was withheld, performance did not improve. While these results are promising, the most apparent limitation is that the golfers did not learn to reproduce their successful EEG assessment when the feedback was not offered. This is likely due to the small number and short time frame of the training sessions.

Clearly, there are different methodological approaches between the work of Landers et al. (1991) and Arns et al. (2008). Most importantly, Landers et al. (1991) conducted in vitro training with theoretically driven neurofeedback protocols established from the EEG patterns of experts, while Arns et al. (2008) conducted in vivo training with neurofeedback protocols based on individualized EEG assessments. Together these studies suggest first, that neurofeedback training will likely lead to improvements in performance, and second, that neurofeedback training protocols derived from a combination of theory and the distinct cortical patterns of the trainee probably present the most effective approach.

In total, there are fairly consistent EEG patterns that distinguish expert from novice performers and better from worse performance. Additionally, there is evidence, although limited, suggesting that appropriate neurofeedback training can positively impact performance. A direct comparison of pre-post performance outcomes after a sufficient amount of neurofeedback sessions is warranted based on the previously described literature. The remaining question then, relates to what protocols will be most effective for performance enhancement.

**Neurofeedback Protocols for Performance Enhancement**

To date, there are no standardized neurofeedback training protocols evidenced to enhance performance due to the limited research published in this area. As reviewed earlier, most reports thus far have utilized theoretical neurofeedback protocols, with the exception of Arns et al. (2008). Yet, Vernon (2005) suggested that performance will likely be most improved by neurofeedback protocols based on identified cortical patterns that are associated with better performance in experts. Additionally, Sterman (2000) reported that regardless of the goal, neurofeedback training is twice as effective when the protocols are selected based on the individual’s QEEG. In line with both points, the authors chose to use the recently described NeuroPerformance Assessment (Sherlin et al., 2012), which offers a reference range for comparison to other expert performers, but more importantly quantifies the cortical activity of the athlete during baseline and challenge task (i.e., CPT). These aspects allow for greater insight into EEG patterns that might influence performance.

The goal of the current report was to determine if neurofeedback conducted with the training protocols developed from the NeuroPerformance Assessment were able to effectively enhance the performance of Division I NCAA golfers.

**Methodology**

**Participants**

Participants were Division I collegiate level golfers (N = 16; male = 10), ranging in age from 18 to 20 years (mean age = 19.25 years). These student athletes voluntarily participated in services that were offered for possible mental training enhancement. The process, potential benefits, and potential negative side effects of Performance Brain Training (neurofeedback) were explained to the student athletes, and written consent was obtained prior to the evaluation and receipt of services. This sample of convenience was the result of the encouragement from both the men and women’s coaches; again, participation was not required.

At the conclusion of the services provided, the student athletes voluntarily gave written permission allowing Neurotopia (DBA SenseLabs, San Francisco, CA) to utilize the collected EEG and golf performance data once all personally identifying information was removed for the purpose of examining the efficacy of the neurofeedback training on golf performance measures. Players were informed that there was no obligation or consequence if they declined. Although this project did not have Institutional Review Board (IRB) oversight at the time of service, company policies for providing services include the highest ethical standards equivalent to those required by an IRB for a priori research protocols during the entire process of providing services including client confidentiality, considerations for potential client harm, efficacy-to-risk ratio considerations, and client-informed consent. Subsequently, and prior to this submission, IRB approval was obtained to analyze data from this project from Western IRB protocol 20141247.
Procedure
During the initial visit, the athletes gave written informed consent, all questions regarding participation were answered, and finally, the student athletes were randomly assigned into two groups. This randomization was done because the number of time slots available to the participants for training would not allow all athletes to participate during the same time frame. The first half, Group 1, received services during the fall semester, and the other half, Group 2, waited until the spring semester. Starting with Time Point 1, a baseline QEEG/CPT assessment was conducted for each player, which was combined to produce the respective baseline NeuroPerformance Assessment. Following this initial testing, Group 1 began Performance Brain Training, in addition to the usual required training for the golf team, while Group 2 only had practice as usual, with no Performance Brain Training. Once Group 1 had completed Performance Brain Training (M = 20.7 sessions), both groups underwent another QEEG/CPT assessment, generating another NeuroPerformance Assessment at Time Point 2. Next, the groups were switched (i.e., Group 1 proceeded with only practice as usual, while Group 2 began Performance Brain Training sessions along with regular practice). At Time Point 3, Group 2 had completed the Performance Brain Training and both groups were assessed in a final QEEG/CPT producing a final NeuroPerformance Assessment.

Neurofeedback Training: Performance Brain Training
Assessments and neurofeedback sessions were conducted in a small campus facility adjacent to the teams’ practice area and accessed exclusively by the university’s golf athletes and staff. Two separate neurofeedback stations were set up, allowing two athletes to train simultaneously. Distractions were minimized with Beats® headsets (Beats Electronics, LLC, Culver City, CA) with zero gravity chairs for comfort, and the feedback was played on a 47-in. television, taking up most of the athlete’s field of vision. BioExplorer software (CyberEvolution, Inc., www.cyberevolution.com) was used in conjunction with a variety of games, such as Dual Drive Xtreme, Inner Tube, or Particle Editor software (Somatic Vision, Inc., www.SomaticVision.com), that consist of different audio and visual feedback responses to reward the desired brain states.

During the training, the athletes were asked to focus on the changes in the game and to attempt to make associations with their mind and body when they were succeeding or failing. Additionally, they were encouraged to relax as much as possible without falling asleep while also maintaining alertness and interest in the feedback. As a tip for succeeding in the game, every athlete was told that typically a calm body, clear mind, and focused attention on the game without frustration or intense emotion is the best strategy. To increase standardization of the training process, the technician gave minimal or no verbal feedback during the session except to answer questions or to remind the athlete to relax or attend to the feedback. Athletes were able to ask questions as needed during the session, and when necessary, the training was paused to answer questions and talk about goals of training. At the conclusion of the training program, both groups were debriefed and asked to complete a paper-and-pencil satisfaction survey, where they had an opportunity to express how the Performance Brain Training had affected them, both personally and in the sport of golf.

The Performance Brain Training sessions ranged from zero to five sessions per week with the average of 1.48 over 15 weeks for Group 1 and 2.05 in 8 weeks for Group 2. Although the goal was a minimum of 25 sessions and 30 min each session for every player in both groups, the athletes’ golf schedules and school workload prohibited that number of sessions. Ultimately, every session was at least 20 min. The project was completed over a 15-month period from March 28, 2011, to June 8, 2012.

EEG Data Collection
For each subject EEG data was collected continuously in the previously mentioned facility with only the technician and client present. The EEG was sampled with 19 electrodes in the standard 10–20 International placements referenced to linked ears. Impedances were all below 5 kOhms and within 1.5 kOhm difference between sites. Data was collected using the Mitsar 201M amplifier, WinEEG software (Mitsar Ltd, St. Petersburg, Russia), and electrode caps (Electro-Cap International, Inc., Eaton, OH) for 10 min of eyes-closed baseline, 10 min of eyes-open baseline, and approximately 21 min of the QIKtest CPT (BEE Medic GmbH, Kirchberg, Switzerland) sampled and stored at 250 samples per second.

Measures
Quantitative Electroencephalography
Data was plotted and carefully inspected using manual artifact-rejection for all tasks. All episodic artifacts including eye blinks, eye movements, teeth clenching, body movements, or EKG artifact was removed from the stream of EEG. All recorded participants had acceptable quality data after the researchers performed the artifacting procedure. Edited QEEG data were exported and submitted to the NeuroPerformance Assessment.
**Continuous Performance Test**

The QIKtest CPT was used to provide two stimuli (target and nontarget) to record participant response time, response time variability, errors of omission, and errors of commission. The QIKtest CPT is a battery-powered stand-alone device that presents visual stimulus in an LED array and auditory stimulus. This study utilized only the visual stimuli to track measures with a time measurement resolution of 0.1 ms. The test challenges the participant under both high-demand and low-demand conditions in five segments (low, low, high, high, and low demand; Sherlin et al., 2012). These data analysis were additionally submitted for analysis as part of the NeuroPerformance Assessment.

**NeuroPerformance Assessment**

The NeuroPerformance Assessment is designed to measure key elements that contribute to the mental/cognitive aspects of performance, particularly in athletes. The NeuroPerformance Assessment is based on a combination of both behavioral and physiological data. It includes QEEG spectral information from the eyes closed, eyes open, and the varying time periods of the CPT, as well as the resultant behavioral analysis of the CPT performance (see Sherlin et al., 2012, for a more detailed description of the Neuro-performance Assessment).

**Statistical Analyses**

The golf statistics for the men’s team were collected from an online database (www.golfimprovementplan.com) that was kept current by the men’s assistant golf coach. The women’s golf statistics were entered by the team’s statistician and sent to a different online database (www.golfstat.com). Once both groups had completed Performance Brain Training (Time Point 3), the golf performance data was collected for analysis from the entire time period.

Our goal was to complete the most direct test evaluating the program efficacy of Performance Brain Training and how it may have impacted the performance measures; therefore, we chose to employ a paired-groups t test to compare Time Points 1 and 2 and Time Points 2 and 3 for both groups at a .05 alpha level. To control for multiple comparisons, we implemented the use of false discovery rate (FDR) analysis. We computed FDR estimates directly from the p values using the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995). The false discovery rate estimation, summarized in a q value, controls the error rate among a set of tests. We defined the q value as the minimum FDR attained score at a threshold of t based upon our p values at .05. Therefore the q value associated with t is expected proportion of false positives among all of the scores above the threshold (Storey, 2002). Thus our q value for this data was set at q = 0.05. No QEEG analysis comparisons are included in this paper but will follow independently.

**Results**

After randomization, Group 1 (n = 9) consisted of four females and five males with a mean age of 19.25 (SD = 0.83) and Group 2 (n = 7) consisted of two females and five males with a mean age of 19.29 (SD = 1.1). Originally, Group 2 included another female golfer, but just after group assignments she decided to pursue her professional career on the Ladies Professional Golf Association (LPGA) Tour;

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>Mean T1</th>
<th>Mean T2</th>
<th>t</th>
<th>p</th>
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<td>.075</td>
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<tr>
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</tr>
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<td>5.228</td>
<td>.007*</td>
</tr>
<tr>
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<td>3.361</td>
<td>.022</td>
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<td>1</td>
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<td>71.3</td>
<td>.517</td>
<td>.311</td>
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<tr>
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<tr>
<td>2</td>
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<td>2.231</td>
<td>.078</td>
</tr>
<tr>
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<td>1.174</td>
<td>.181</td>
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<td>72.6</td>
<td>.290</td>
<td>.391</td>
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</table>

*Note.* Significant p values are in bold. *Significant p values when adjusted for multiple comparisons (False Discovery Rate).
all data collected from her was excluded from the current study. The participating student athletes represented a variety of nationalities including White, not of Hispanic origin \(n=6\), Hispanic \(n=4\), Asian or Pacific Islander \(n=5\), and American Indian \(n=1\). There were no significant differences between the groups at baseline (Time Point 1) with regard to performance measures.

When comparing Time Points 1 and 2, Group 1 significantly increased the number of greens in regulation, \(t=10.44, p<.01\), while also significantly decreasing the average number of putts per round, \(t=5.23, p<.01\), and average number of three putts per round, \(t=3.36, p<.05\), after Performance Brain Training. There were no significant changes to the average score, yet the increase in number of fairways in regulation approached statistical significance, \(t=1.93, p=.07\). Importantly, Group 2 did not significantly change in any of the performance measures between Time Points 1 and 2. After controlling for multiple comparisons with the FDR, the significant improvements for number of greens in regulation, FDR\((p) = .01\), and putting average, FDR\((p) = .03\), were both retained (see Table 1 and Figures 1 through 4 for detailed results of the comparisons between Time Points 1 and 2).

In comparing Time Points 2 and 3, Group 2 significantly increased fairways in regulation, \(t=54.51, p<.01\), greens in regulation, \(t=3.10, p<.05\), and significantly decreased putting average, \(t=24.13, p<.01\), and average number of three putts per round, \(t=3.20, p<.05\), after completing Performance Brain Training. Again, there was no significant change in scoring average for Group 2 between Time Points 2 and 3. Interestingly, Group 1 did significantly decrease the number of greens in regulation, \(t=5.93, p<.05\), during this time period where they were no longer participating in Performance Brain Training, but there were
no other significant diminishments of performance improvements observed for this time period. When controlling for multiple comparisons, the significant improvements made by Group 2 after completing Performance Brain Training on number of fairways in regulation, $FDR(p) < .01$, and putting average, $FDR(p) < .01$, were retained (see Table 2 and Figures 5 through 8 for detailed results of the comparisons between Time Points 2 and 3).

**Discussion**

These results demonstrate that after completing the Performance Brain Training, the athletes were able to significantly improve on a number of golf performance metrics. Furthermore, the 8-week follow-up data available for Group 1 following the completion of Performance Brain Training suggests that the improvements measured at Time Point 2 were maintained, with the exception of greens in regulation that returned to the baseline level. Additionally, the effects of Performance Brain Training were highlighted by the lack of significant changes during the training as usual periods of this study. Specifically, if Group 2 had improved between Time Points 1 and 2, the improvements for Group 1 would be less impressive as they would more likely be the influence of some other covariate; furthermore, if Group 1 had continued to make significant progress along with Group 2 between Time Points 2 and 3, it would likely be the result of a covariate. Ultimately, the results here support the hypothesis that Performance Brain Training would contribute to significant improvements and

<table>
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<th>Group</th>
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*Note. Significant $p$ values are in bold. *Significant $p$ values when adjusted for multiple comparisons (False Discovery Rate).
that those improvements would be additive and beyond the improvements that might be made during training as usual periods.

Interestingly, the average score did not change much for both groups, but there are many factors that we simply could not consider in these analyses such as the varying difficulty of the courses and the competition that these golfers faced. Additionally, there was some variation in the type of rounds played that lead to sport statistic reporting; some athletes played in more tournaments while others played in noncompetition rounds. The mental strategies and intensity of these two types of playing conditions are drastically different and would likely contribute distinctively to the golf statistics reported by the athletes. The number of rounds per player also varied because not all players qualified to compete in every tournament; a greater and more consistent number of golf rounds may also influence the scoring average. We find it intriguing that Performance Brain Training seemed to positively affect all aspects of golf performance except the average total score posted by the players. Given the improvements of smaller scale, it may be that more Performance Brain Training sessions would have improved the average score.

Another possible limitation of studies such as this is the lack of standardization in collecting golf performance data. These two teams collected information but the data entry and systematic input can be a challenging task and not all data points were gathered. The coaching staff has a long list of responsibilities, none of which is the standardized collection and reporting of performance data to an outside entity. This study also was a post hoc analysis of archived data for evaluating the service modality provided and not an a priori research study. Future studies should develop more standardized methods of tracking performance as well as require that the golf statistics are from similar types of performances (i.e., either all practice or all competition).

In order for neurofeedback to be considered a legitimate and valuable service to athlete populations, performance data must be directly correlated with improvements generated by neurofeedback alone. A crossover design, which this study inadvertently became, controls for the continuous coaching and practice of elite performers. The results reported here, despite the various limitations acknowledged, offer a model for future studies to design a priori tests of the effectiveness of neurofeedback paradigms in improving sport performance.

References