Getting off the Bench: EEG and HRV Differences Between Starters and Nonstarters

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There is a strong interest in what separates top-level performers from those who have yet to achieve the same level, across all performance domains. Advances in psychophysiology give insight into where these differences may lie in the minds and bodies of athletes. The present study compared gymnasts who were selected for the competitive lineup to those who were considered part of the Division I gymnastics beam squad but did not compete. This study compared their initial baselines, their response to heart rate variability and neurofeedback training, and their posttraining levels. Baseline differences existed for self-perception of consistency and confidence. There were no pre or post differences in heart rate variability measures. Sensorimotor rhythm electroencephalography (EEG) biofeedback training was associated with a decline in busy brain waves for the competitors. The competitors also had a lower ratio of intensity (intensity/high alpha) in both the pre- and post-EEG measures.

Introduction

Research (Gould & Maynard, 2009) has outlined what skills are necessary for an athlete to succeed at the highest levels of competition. Included in these skills is the ability to be aware of and have control over one’s arousal level, which in the present study was assessed through the heart rate variability (HRV) measures. Other necessary skills include attentional focus and emotional control, which were assessed through neurofeedback (NF).

Using an intraindividual design, Garet et al. (2004) found a high positive correlation between HRV (measured through the standard deviation in milliseconds of the normalized interbeat interval of the heart [SDNN]) and how well the swimmer performed in a 400-m free-style race the following day. Other studies reported that HRV training is associated with increases in sport and dance skill performance. Strack (2003) assessed performance improvements in batting in high school baseball players after HRV biofeedback training. The results showed a 60% improvement in batting performance in the HRV training group compared with a 21% improvement in the control group; however, these results should be cautiously interpreted as the speed of the pitching machine was unintentionally set for 5 mph slower during posttesting as compared with pretesting. Raymond, Sajid, Parkinson, and Gruzelier (2005) trained HRV in Latin ballroom dancers and demonstrated improvement in technique. Lagos et al.’s (2008) case study of a 14-year-old golfer showed reduced season average strokes on an 18-hole course from 91 to 76 strokes after 10 weeks of HRV training. Tanis (2008), however, found no improvements following HRV training for college female volleyball players. Athletes reported positive benefits for both sport and school from the HRV training, but it is unknown if the lack of improvement in performance was the nature of the intervention or the nature of performance assessment, which was completed by the coaches during games. Although there is promise in HRV improving athletic performance, more research is required.

Some research has focused on measuring differences between elite and subelite athletes. In our earlier work using less sophisticated EEG equipment, university volleyball players, who were deemed by their coaches to be better under the stress of critical game situations, had lower resting frequencies at O1-T3 (cortical sites in the occipital and temporal regions, designated in the 10–20 international system) during baseline resting states than those who were not as competent under pressure (Wilson, Ainsworth, & Bird, 1985). An example of a more refined study was performed by Hauffler, Spalding, Santa Maria, and Hatfield (2000), who examined EEG differences between experts and novices in a shooting task. The expert marksmen showed increased alpha power across all regions, but particularly at T3, compared with novices. The authors suggested that the increased alpha may reflect a refinement in analytical or better self-talk strategies during the preshot time. An excellent review and discussion of EEG in athletes can be found in Hatfield, Hauffler, and Spalding (2006). A very simplified interpretation of their conclusions includes the...
following: The demands of the sport result in task-specific cortical resources being used in an efficient manner; that is, the same amount of work is accomplished but with less cortical activation or effort. Expert performance is associated with quieting of the left hemisphere and, in some cases, quieting of the right hemisphere; tasks are performed better if the person learns to become more “automatic” rather than engaging in “thinking.”

Only one study was found that conducted NF training with athletes. Landers et al. (1991) found that pre-elite archers receiving correct feedback during NF training (rewarding increased left hemisphere low-frequency activity) improved shooting performance, whereas the group given incorrect feedback (rewarding increased right hemisphere low-frequency activity) experienced a decline in performance. The effects of training were not examined in competition, and NF training was completed in 1 day.

Method
The present study examined the HRV and electroencephalography (EEG) activity of 6 university-level gymnasts who were consistently in the competitive lineup for balance beam (labeled competitors) and 5 gymnasts who were not selected to perform in competitions (labeled bench).

Eleven female gymnasts from a Division 1 university completed consent forms approved by the Board of Review, Department of Athletics and Gymnastics head coach. Balance beam performance in a competitive setting was assessed by a nationally certified, independent judge who was hired for the study. In addition, scores from the four competitions during which the NF/HRV training was conducted (January) were examined in relationship to scores earned in the following four competitions when there was no NF/HRV training (February). Subjective assessments of the degree of consistency of beam routines and level of confidence in practice and competition were obtained in the preassessment period. Ratings were from low (1) consistency or confidence to (10) high on balance beam performance.

Psychophysiological Measures
HRV assessment and training used a Thought Technology (TT; Montreal, Quebec, Canada) Biograph Infiniti™ blood volume pulse sensor on the underside of the left index finger and a respiration belt secured around the lower ribcage. The decision to place the belt on the ribcage of the gymnasts was made because gymnasts typically keep their stomach still and tend to breathe more into their ribcage.

HRV was assessed by examining the time domain of SDNN (Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996) and also the frequency domain using a fast Fourier transformation with the CardioPro (TT) software program to separate activity into spectral bands of high, low, and very low activity. The low-frequency (LF) range of HRV is considered to reflect the influence of the baroreflex response and is representative of an optimal state for health and performance (Vaschillo, Vaschillo, & Lehrer, 2006).

For EEG assessment and training, the Cz site (the vertex or center of the cortex in the 10–20 international system) was prepared, such that impedances were always below 10 Kohms with the reference on the right ear and the ground electrode on the left ear. Cz has been used as a training site in previous performance enhancement protocols as it is believed to provide a measurement of the activity in both hemispheres and in the frontal lobes. In addition, training this area of the sensorimotor strip is associated with training a calm state of reflection, which precedes action (Thompson & Thompson, 2003) and has been shown to produce performance enhancement (Ros et al., 2009). The training parameters for each NF session were to decrease theta and increase the sensorimotor rhythm (SMR). The EEG measures included Thompson and Thompson’s (2006) suggested ratios of theta/beta (4–8 Hz/16–20 Hz), intensity/high alpha (19–22 Hz/11–12 Hz), and busy brain/SMR (23–34 Hz/12–15 Hz).

The timeline for data collections was as follows: premeasures in December, HRV and SMR training from December through January, and postmeasures at the end of January. Competitions continued through February, but there was no researcher contact during this time.

All participants were assessed in pre- and postbiofeedback measures and then received 10 sessions of biofeedback HRV and SMR training two times a week for 5 weeks. The pre- and postbaseline assessments included a recording of 3 minutes with the eyes open, followed by gymnastics tasks such as rehearsing one’s preperformance routine for balance beam in practice and competition. Only baseline measurements are reported here, with full details provided by Shaw (2010). Training was conducted in the following format: three cycles of 90 seconds of HRV training, a 5-second break, followed by 90 seconds of SMR training. A 10-second break was given between the first and second, and second and third cycle. The 90-second HRV and SMR duration was chosen as this is the length of a balance beam routine.

Keeping with the Wingate Five-Step Approach to Mental Training (Blumenstein, Bar-Eli, & Tennenbaum, 1997), the biofeedback training was designed to be transferred from the lab to a field setting. To enhance the transfer, Sessions 1 through 5 were conducted in a...
classroom, whereas Sessions 6 through 10 were conducted in the gymnasium with gymnasts standing near the balance beam (Figure 1).

**Results**

The total group of 6 competitor gymnasts showed improvement on their balance beam scores in competition and also on artistry and execution scores from the independent judge from preassessment to the end of biofeedback training (6 weeks). However, rather than continuing to improve in the next 4 weeks, when the HRV and SMR training was withdrawn, the competition scores decreased.

The competitors self-reported performing more consistently on the balance beam in practice ($t_{10} = 3.64, p < .01$) and in competition ($t_{10} = 2.6, p < .05$) than the bench group. Both groups reported more consistency in practice after training. The competitors reported more confidence on the beam in practice ($t_{10} = 2.71, p < .05$) and in competition ($t_{10} = 6.17, p < .01$). Both groups reported more confidence in practice after training.

In assessing HRV, the measure of SDNN for the competitors and the bench group showed no differences for either the pre- or postassessments; however, there was an upward trend for both groups. There were no significant differences for the %LF between the competitors and the bench group on the pretests and posttests. When the data from both groups are combined, there was an improvement only in SDNN ascribed to HRV training.

There was a significant difference between the competitors and the bench group for the intensity/high alpha ratio for pre- ($t_{10} = 2.24, p < .05$) and postassessment ($t_{10} = 2.32, p < .05$). The only difference found after SMR training was that the competitors had less busy brain in the postassessment (Figure 2). Differences noted were not associated with changes in electromyography activity in the EEG recording as both groups had similar readings.

To determine if the ratio differences were due to changes in intensity or high alpha, we analyzed these bands separately by competitors and bench group. The results are shown in Figure 3 and suggest that the differences were probably in the high alpha band as the competitors had

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**Figure 1.** Note the gymnast standing in the bottom right corner. Later training sessions of gymnasts mirrored the competitor preparing in the same place as she would be prior to performing on the balance beam.
significantly increased high alpha ($t_{10} = 1.96, p < .05$) in the postassessment.

**Discussion**

The subjective experiences regarding higher reported levels of consistency and confidence in the competitors are reasonable and were not due to age. The differences are likely associated with the competitors’ having started gymnastics one year earlier and having spent more time in high-level competition. Another possibility is that the competitors were successful early, and in sport, success tends to bring on more confidence and perhaps more attention from coaches. Two take-home messages for those working with athletes are (a) given success begets success, set your athletes up to achieve; and (b) high-level experience counts!

The failure to see differences in the SDNN baseline measures may be due to the small number of gymnasts, as when the two groups’ data were combined, there was a significant increase in SDNN after HRV training. It is also possible that there is no difference in SDNN as both groups have similar physiological training. Why there are changes in SDNN in the total group due to training but no significant change in %LF is not known; however, conflicting results are also noted in Aubert, Seps, and Becker’s (2003) review of HRV with athletes. The SDNN measure is also less reliable when based on brief measurements, as opposed to 24-hour Holter monitoring. Other indices of HRV might be considered for future studies, such as the pNN50% or the HR Maximum-HR Minimum measures.

The only EEG measure that distinguished the competitors from the bench group was the intensity/high alpha ratio, where the competitors had a lower ratio in the pre- and postassessment. Athletes have suggested to us in clinical work that this ratio corresponds to their “trying too hard” when this ratio is high. The intensity measure in the ratio is the high Beta frequency range of anxious and effortful thinking. Gymnastics requires ultimate precision, and if the bench athletes were trying too hard, it might be enough to create wobbles and point deductions and lead the coaches to exclude them from the competitive lineup. One would wonder if the differences are innate or if the competitors have learned to develop a better self-control strategy.

The only effect from the 10 sessions of SMR training was that the competitors had a pre- to post decrease in the busy brain/SMR ratio. Because the SMR did not change, the differences are probably due to a decrease in the busy brain band. Changes in beta are reported in previous sport literature and suggest that performance is enhanced when the inner chatter or self-talk is attenuated.

Overall, despite having very similar experience, training, and background, there were differences between competitors and those on the bench in both self-perception and EEG. This study needs replication with more elite-level athletes in various sports to see if natural advantages can be found between the competitors and the bench athletes.

**References**


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