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FEATURE ARTICLE

Clinical Use of a One Hertz Bin Electroencephalography Assessment to Distinguish Elite from Less Elite and Typical from Atypical Athlete Profiles

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The purpose of this paper was to highlight preliminary research into the use of one electroencephalography *(EEG) site (Cz) and 1 Hz bins to identify elite athletes during the assessment process. Eyes-open baseline data from several small groups of athletes (tennis, gymnastics) suggest that elite athletes have a dip in amplitude in very low frequencies and then an increased amplitude at 10 Hz in a single-site EEG spectral display, when compared with less successful teammates. Other clinical sites and research labs will need to replicate the reliability and value of this pattern. Three case studies demonstrate the potential for clinicians to use EEG information analyzed in 1 Hz bins to identify areas for clinical exploration. The authors suggest that the presentation of EEG data related to possible emotional issues makes it possible to discuss more quickly and directly any potential problem areas for athletes.*

Athletes Are Different

In our clinical work using biofeedback and neurofeedback, we began seeing an electroencephalography (EEG) pattern emerging that appears to distinguish elite athletes from those less skilled in several sports. The purpose of this paper is to highlight the preliminary research into the use of one EEG site (Cz) and 1 Hz bin EEG assessment to identify elite athletes. Cz refers to the central site or ''vertex'' on the human cortex in the international 10–20 EEG system, midway between the nasion and the inion, and midway between the left and right pre-auricular notch (Jasper, 1958). A bin is a 1 Hz–wide frequency range in electroencephalograph activity. Further, the potential for clinicians to use EEG information from 1 Hz bins to guide clinical questions in asking relevant questions is demonstrated.

Male and female athletes are more like each other than like their sex norms on many different psychophysiological variables, and thus comparisons when possible should be with their own sport group. Based on basic physiological and psychophysiological studies of athletes, aspects that are unique to elite performers should be considered when conducting biofeedback/neurofeedback (BF/NF) assessment and training within the sport setting. For example, the mental control of motor skills of elite athletes is different from that of less skilled athletes, which in turn differs from nonathletes (Vallacher, 1993; Wulf & Su, 2007). This has even been shown for how experts differ from less skilled individuals when they activate muscles performing the same skill (Janson, Archer, & Norlander, 2003). Even elite athletes in the same sport may be psychophysiologically different from each other to a greater degree than those investigated in a laboratory setting (Kamata, Tenenbaum, & Hanin 2002).

Decades ago, while using less sophisticated EEG equipment, we found that volleyball players (Wilson, Ainsworth, & Bird, 1985), orienteers (Wilson, Bird, & Hamilton, 1984), figure skaters (Wilson & Bird, 1983), rifle shooters (Bird, 1987), and track and field athletes (Cummings & Wilson, 1980; Wilson & Hamilton, 1983), who performed well under the stress of competition, had different physiological and EEG patterns than teammates who performed less well. Typically athletes whose coaches reported they coped well during the stress of competition had lower dominant frequencies in their eyes-closed resting EEG in alpha (8–12 Hz) in the area of O1-T3 than did athletes whom the coaches rated as coping less well during the stressful moments of competition. In a later study

(Wilson et al., 1999) of elite university and club competitive swimmers, the relative power of low alpha (8–10 Hz) was assessed at Cz in an eyes-closed condition. The fastest male and female swimmers had more relative alpha power in the low alpha range than their slower swimming counterparts after controlling for age and experience. The EEG equipment, electrode locations, and frequency bands were different in the various studies, but they highlighted that elite athletes have a different brain profile compared with less elite athletes, which may be interpreted as having a more efficient brain (Babiloni et al., 2010).

Ericsson, Krampe, and Tesch-Romer (1993) have suggested that the defining characteristics of expertise are primarily acquired through extensive involvement in relevant practice activities, rather than as a consequence of any innate ability. Smit and colleagues (2005), on the other hand, argue that genetics must also be considered because their research agrees with previous work that shows EEG power to be one of the most heritable complex traits in human subjects.

Recently, using quantitative multisite EEG technology, Babiloni et al. (2010) found karate athletes differed from a normative population and also found that the karate athletes differed in their EEGs at different skill levels (elite vs. amateur). Their research focused on the various frequencies of eyes-closed resting-state EEG rhythms. The main topographical differences in elite karate athletes, as compared with nonathletes and amateur karate athletes, were the frontal preponderance of delta and theta, while parietal and occipital sources of alpha rhythms were higher in amplitude. A control study confirmed these results in elite rhythmic gymnasts. The authors interpreted the differences as follows: The elite athletes have brains that may be prewired to be more efficient. Yarrow, Brown, and Krakauer (2009) reviewed the neural processes that result in high achievement in sport. They conclude that elite athletes have not only increased precision in execution but also superior performance in perception, anticipation, and decision making. These advantages are traced to changes in underlying structural and physiological processes. Currently we were unable to identify any research that measures what proportion of the EEG differences between elite and less elite athletes are due to genetics or early learning.

Assessment Using 1 Hz Bin EEG Frequency Analysis at Cz

The use of a quantitative EEG involving a full cap, with a minimum of 19 electrode sites, using LORETA to identify underlying structures, is the gold standard for research to assess brain functioning because it provides increased spatial resolution. Alternatively, researchers may use evoked potentials, where the stimulus and the cortical response can be time linked. However, clinicians generally do not have the time or equipment to use these methods for assessment or training. Thus in our approach, the site Cz (International 10–20 System; Jasper, 1958), the central vertex of the head, was chosen for assessment of the athletes because it is believed to be a summation of the brain's activity and is least subject to movement or eye artifact (Thompson & Thompson, 2003; Ros et al., 2009). All measurements reported were collected on Infiniti™ equipment (Thought Technology) with impedances below 10,000 ohms, and with the data artifacted by automatic and visual inspection. The cleaned data averages were for 2–3 minutes in the eyes-open condition.

Electroencephalographic profiles have traditionally been reported by grouping several frequencies together, giving them names such as delta (1–3 Hz), theta (3–7 Hz), alpha (8–12), and beta (13–40) (Jasper, 1958). The exact frequency of the band depends on the practitioner and his or her judgment of which frequencies to include. Additionally, equipment can be a determinant in ideal bandwidth choices. For example, some equipment labels the 10 Hz frequency as consisting of all electrical activity from 9.5 to 10.5 Hz, while other equipment includes all activity from 10 to 10.9 Hz as the measure for 10 Hz.

Later studies have shown that various processes are occurring within the scope of the larger bands, and over time many researchers have subdivided the bands. For example, Klimesch (1996) found that low alpha (8–10 Hz) was more responsible for attentional processes, whereas high alpha (10–12 Hz) was more responsible for semantic memory. Newer studies have also begun to report the use of 1 Hz bins (Clark et al., 2004), and Thompson and Thompson (2006) recommend the use of the 1 Hz bins assessment as a guide for locating more specific atypical responses in an EEG pattern. They use this information to specifically train the single hertz activity that may be associated with the problem for which the individual sought treatment. They further suggest that the amplitude of a normal or typical EEG profile, using Cz as an example, will stair-step down with each increase in frequency. An example is shown in Figure 1.

In Figure 2 we show an example of the typical profile we have found for elite athletes, including male and female athletes from baseball, tennis, gymnastics, figure skating, sailing, orienteering, track, biathlon, and swimming.

To see if this pattern of an increase in 10 Hz was unique to our clinic, we obtained profiles from an attention disorders clinic in another location, which reported having

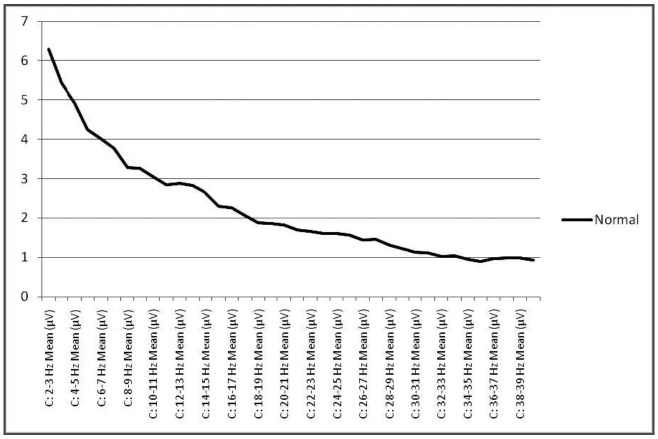

Figure 1. The 1 Hz profile at the Cz site of a “normal” 20-year-old nonathlete. The amplitude measured in micro volts (*x* axis) stair-steps down with each increase in the EEG frequency (*y* axis).

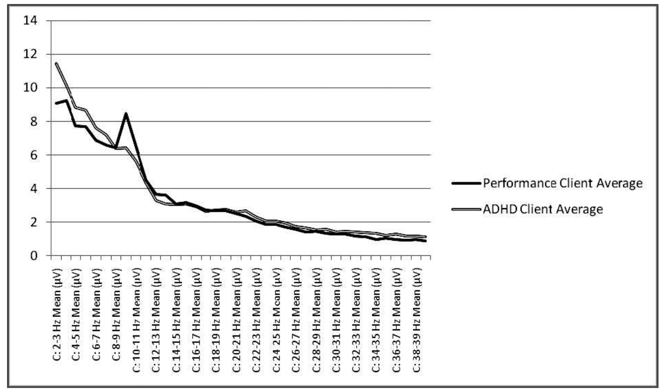

Figure 3. The 1 Hz bins profile averages for six individuals diagnosed with attention deficit disorder are shown in the double black line, and the three athletes who were attending for performance enhancement are shown in the solid black line. All clients are female between 16 and 26 years of age. The athletes had elevated 10 Hz at rest with the eyes open.

three elite athletes, and, for comparison, six nonathletes from the same age range (ADD Centre, Toronto), Figure 3 shows the data from the attention disorders clinic.

To further investigate the increase in alpha seen in individual athletes, at approximately 10 Hz, we reanalyzed data collected in a study (Shaw, 2010) that used EEG training to enhance the performance of university (age 18–22) gymnasts. The gymnasts were separated into a group of six with the highest rankings from competition, compared with six on the same team but of lower ranking. The gymnasts were of similar competitive background and years of coaching. The results are shown in Figure 4.

Further, we then assessed EEG activity in young gymnasts (age 9–15 years) from a gymnastics club in another country, who had 7.5 (SD 2.3) years of competitive experience but whose best competitor’s highest ranking was a provincial level. Two coaches independently ranked the gymnasts, because all gymnasts did not compete in all events and thus could not be compared by competition scores. The two gymnastics coaches had unanimous agreement except for one athlete; thus, her data were not included. In Figure 5 we show the data for the six better gymnasts compared with the six less skilled gymnasts. The young gymnasts show a peak at about 9 Hz rather than 10 Hz. This may be due to their young age, because brain maturation is believed to occur in the early 20s.

Finally, we analyzed the data of young women (15–18 years) who participated in tennis in a large metropolitan region. The provincial rankings for women under 18 were used to divide the women into an elite group ($n = 8$) and a less successful group ($n = 7$). Information on their experience was not available, but a comparison of their EEGs by 1 Hz bins is shown in Figure 6.

The data presented here suggest that elite athletes have enhanced amplitude at 10 Hz with the eyes open at Cz, but further replication in other labs and with other athletes is needed. However, our findings are similar to those of Bablioni et al. (2010), in that elite athletes can be distinguished from less elite athletes, but our work was done by a clinician using one electrode site. Yarrow et al. (2009)

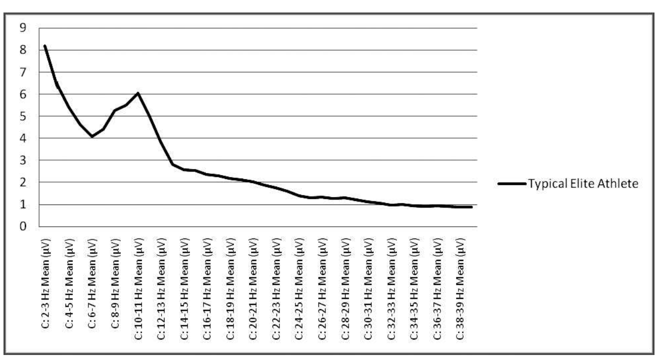

Figure 2. Typical elite athlete 1 Hz profile at Cz with eyes open shows an initial dip in amplitude in very low frequencies and a peak or increase at about 10 Hz.

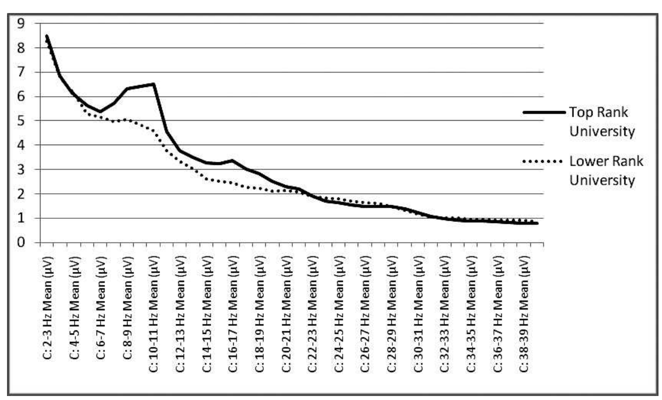

Figure 4. Six university gymnasts in the highest ranking group are represented by the solid line and are compared to the five in the lower ranking group in 1 Hz bins at Cz with the eyes open.

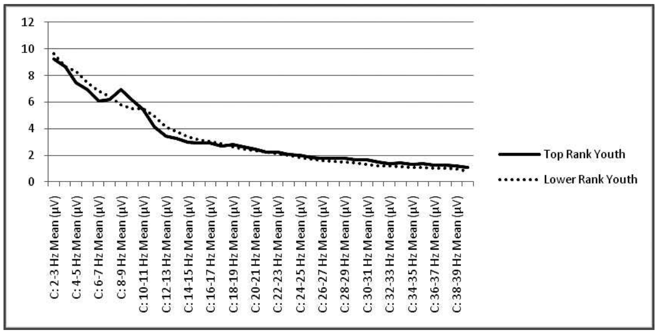

Figure 5. The 1 Hz EEG bins for six young competitive gymnasts classified as better skilled and six less skilled gymnasts at the Cz site with eyes open.

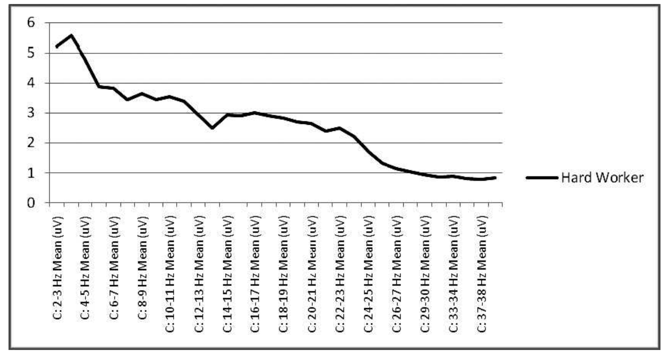

Figure 7. The profile is that of a national caliber athlete who is defined by the coach as not gifted, but the hardest working athlete in the country.

would suggest that the elite athletes have a more efficient brain that predisposes them to be ready to perform at a superior level. But caution is necessary in the interpretation of this finding as other interpretations are possible. For example, one study was located that suggested that high amplitudes at 10 Hz are associated with a higher IQ (Doppelmeyer, Klimesch, Stadler, Pöllhuber, & Heine, 2002).

Perhaps future research will be able to determine if the athletes with ''neural efficiency'' should be trained in a different manner from those without this advantage.

Assessing Atypical Profiles Using 1 Hz Bins from Cz

Clinically the 1 Hz bin assessment also helps to identify questions that may be relevant to attentional/emotional issues that the athlete may be experiencing, which may influence performance. In almost all clinical cases where a finding is ''atypical,'' the profile is repeated in another session. A few case studies will be used to illustrate a rational, but not the only, interpretation of the profile. We once again suggest caution in our conclusions and propose that these findings should be used to develop ''good questions'' to pursue in the assessment of the athlete.

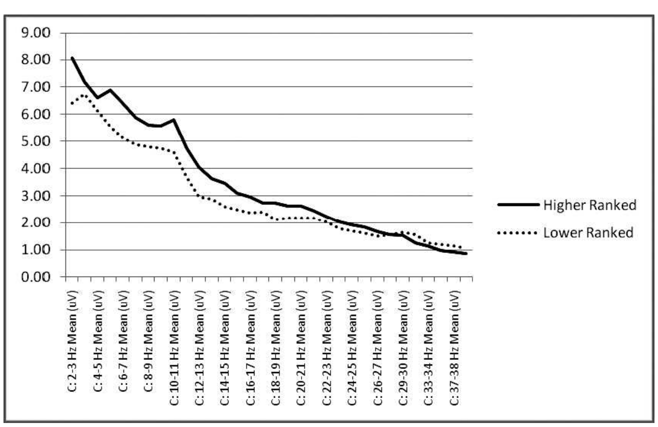

Figure 6. Provincially ranked female singles tennis players with higher rankings (n = 8) and lower ranked (n = 7). The players who rank higher show a higher 10 Hz frequency with their eyes open at Cz.

A Hard-Working Athlete Without the 10 Hz Peak

The first case study is a 1 Hz bin assessment of a nationally ranked athlete whom the coach reported as ''not being a natural athlete, but the hardest worker in the sport.'' The athlete had no medical or psychological complaints, and the coach merely wanted to see if we could enhance the athlete's performance. Figure 7 is presented as a normal athlete with a potential atypical pattern.

This profile shows an elevation for the ''anxiety/try too hard'' frequencies of 18–22 Hz, which he labels as being always on the edge in a ''push for perfection''; he expresses that he wishes to maintain that feeling and reports controlling the stress through participation in martial arts. He does not show the marker of the ''efficient'' brain of many elite athletes. This profile shows no elevation at 10 Hz, and this matches the coach's comments that this man has to work for every inch of performance he gains. Seeing the profile confirmed for the athlete that he was ''normal, i.e., not dumb,'' but that he was not gifted in picking things up quickly and permanently. Similar to his motor sport skill training, his BF/NF training included concise, specific skill targets with a lot of repetition for retaining the thoughts and feelings to obtain his pre-performance states. In each session, he repeats the training procedures quickly until he is able to show control over all the systems (breathing, muscles, sweat response, and neurofeedback for focus, calm, quiet mind) to what he believes is his best pre-performance state. He then practices imagery of his skills, once he has the performance state. If the imagery shows a degradation of brain responses, that is, either his EEG shows he gets a busy brain (enhanced high beta) or his attention wanders (enhanced theta), he is stopped by the clinician and encouraged to refocus to

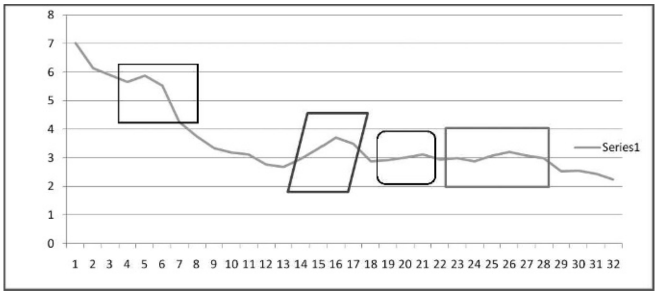

Figure 8. A profile of a national caliber athlete who has atypical responses in several areas of the 1 Hz profile that are associated with attentional disorders, anxiety, and rumination.

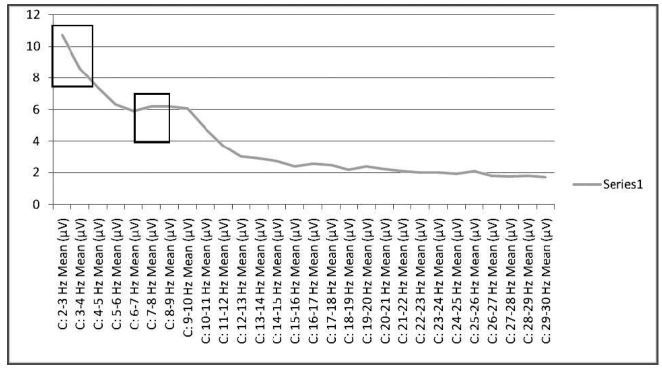

Figure 9. Profile for a national caliber athlete who is facing academic warning and, according to the coach, has more ability than is showing in his sport results.

enhance the images. This training has worked for him because he reports he feels confident and on track, and his performance has improved to his being a national champion and world class competition. He requests BF/NF ''booster'' sessions when he is not traveling to ''stay tuned.''

Atypical Profiles

One hertz bin EEG assessments, along with ratios designed by Thompson and Thompson (2006) to identify attentional deficits/learning disorders, problem-solving abilities, anxiety or trying too hard, and busy brains, are used to explore athletes' strengths and weaknesses. The information may also guide the clinician in what skills and/or neurofeedback training may be most beneficial for individuals.

Three case studies will be presented to demonstrate the value of 1 Hz bin assessments in sport psychology. The first young woman was referred by the coach because he felt that she was too anxious and ''tied up'' in her competitions. She is a university student who reports, compared with her teammates, having to consistently work long and hard to stay up with school work and stay on a national level in her sport. There were no outstanding medical or psychological issues initially reported by the athlete (see Figure 8). Four patterns are noted that suggest that the clinician should conduct further assessment.

The first box on the left indicates a rise in slow hertz activity (theta) which is associated with attentional problems. Initially her theta/beta ratio was assessed following the guidance of Monastra et al. (1999), who proposed that the theta/beta ratio serve as an index for potential attention deficit disorder. Her theta/beta ratio was found to be almost two standard deviations above age-related norms. Additionally her theta/beta ratio increased during tasks, which further suggests attentional problems. When probed further about her school work, she reported that academic requirements were difficult for her, and she constantly had to study harder than classmates. She declined a referral for a full assessment into a possible learning disability (money was an issue). She was provided with a summary of learning strategies similar to those used for individuals with attentional disorders (Thompson & Thompson, 2003).

The second box shows an increase in the problem-solving frequencies (15–18 Hz), when she is supposed to be at rest. She self-reports that she is unable to do ''nothing'' and that her brain is always busy. Starting her on meditation or ''do nothing'' relaxation would not be immediately effective. She was introduced to the Stress Eraser™, a home training biofeedback device that guides the individual to increase heart rate variability, so that she had a target to focus upon and a strategy to improve her heart/brain performance.

The third box highlights the 19–22 Hz range, which typically goes down unless the athlete reports either being anxious or highly intense or trying too hard. She agreed that all of these characteristics describe her, especially during her sports activities. The last box (23–32 Hz) also fails to continue the normal downward trend and is associated with busy brain, evaluation, rumination, and worry. Again she laughed and said, ''You got me.'' These independent results led to her acknowledging and confirming that she had personal/family problems that needed to be addressed. It is our experience that when athletes see an independent confirmation of atypical responses, and learn that these patterns can be eliminated or improved, they are more likely and more quickly willing to discuss the root of these self-defeating thoughts, feelings, and behaviors. Neurofeedback can also be used to track the progress on the busy-brain pattern during clinical interventions.

The second case is represented in Figure 9 and illustrates a male national-level athlete who was struggling with maintaining workouts and juggling school work. According to the coach, the athlete was not meeting his potential in the sport and was also nearing an academic warning, which is why he was referred.

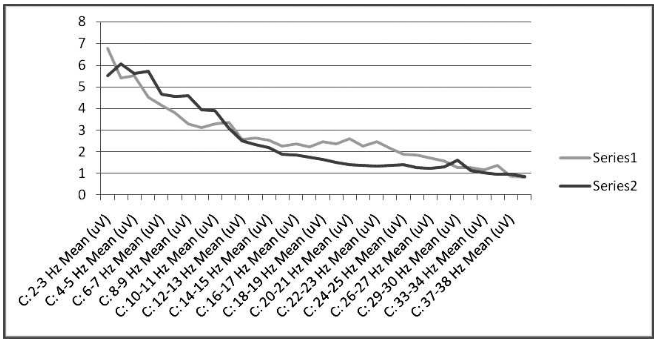

Figure 10. Both profiles show increases in upper level frequencies, which are not typical of athletes. The one athlete also has high frequencies in anxiety area (19–22 Hz). Both athletes report significant problems in their personal lives unrelated to sport. One athlete was referred for counseling following suicide ideation, and the other had several coach-initiated interventions because of the parents' "over-involvement" in the athlete's life.

The athlete is showing too much slow wave activity at 2–4 Hz and again at 6–8 Hz relative to the normative database, and his theta/beta ratio (Monastra et al., 1999) was two standard deviations from his age norm, suggesting attentional disorders. He does show the pattern of having an efficient elite athlete brain (higher amplitude around 10 Hz). Although there are small amplitude increases in areas that suggest both anxiety/''trying too hard'' (20 Hz) and worry (25 Hz), he does not confirm either. He accepted the referral for a professional assessment for attentional deficit disorder and reported that this diagnosis was confirmed. Regrettably, he dropped out of school to focus on his goal of going to the Olympics. He has not returned, and it is not known whether he is receiving EEG training or other treatment for attention deficit disorder. He told teammates that he particularly liked the few EEG training sessions he had in which autogenic standard exercises were combined with alpha (calming) and sensory motor rhythm (''zone'' or preperformance state) enhancement. He did not place as high as he or the coach expected during the national trials.

In case study three, we show the profiles of two athletes (representing two different sports) who had serious family issues (see Figure 10). We seldom see replicable increases in the upper 20 or 30 Hz frequencies with athletes (these elevations are more common in individuals seeking treatment for serious anxiety/personal issues). Neither athlete reported serious emotional issues in the intake or in paper-and-pencil assessments. Only after being asked about possible ''issues'' that might cause elevation in the ''evaluation, judgment, busy brain'' frequencies of the profile did both athletes disclose personal problems not related to sport. In one case, the coach had to intervene with the parents, and in the other case the athlete attempted suicide after her parents revealed an impending divorce.

The ability to see and track the immediate changes in the brain provides the clinician with the opportunity to explore emotional responses, to note mind-body changes based on the skills training, and to create another communication channel for the athlete. It is now possible to actually and permanently change the brain. We suggest that when clinicians integrate their clinical expertise and the sport psychology skills with BF/NF monitoring, athletes will learn and perform at their maximum level more quickly and reliably. Yarrow et al. (2009) go even further than suggesting the clinical potential of psychophysiological profiling. They suggest that in addition to refining future training strategies, physiological profiling may become predictive, and genotyping may predict future success. Elite athletes are different! At the very least, our data and experience suggest that a carefully controlled database of the elite athlete population would be helpful in assessing the strengths and weaknesses of each athlete as well as for tracking training changes.

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