7

From Investigation to Intervention

Biofeedback and Neurofeedback Biomarkers in Sport

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Sport neuroscience, lying at the intersection of applied neuroscience and sport psychology, includes among its hot topics the cognitive and affective processes and mechanisms that accompany the athletic performance.

This chapter focuses on present applications of psychophysiological and electrophysiological techniques, such as biofeedback and neurofeedback, to support or empower performance in sports. In particular, you will find an introduction to the mechanisms of action of most relevant techniques in the field, neural-bodily-behavioral modulations that are targeted by different intervention opportunities, and technical application notes.

We will discuss the value of self-awareness and of the ability to properly recognize bodily feedbacks, especially when athletes have to face competition, and the relevance of robust self-regulation skills to achieve maximum performance. Further, we will report a critical comparison between the efficacy and strong/weak points of bio/neurofeedback techniques and more traditional mental training techniques within the field of sport science. Finally, we will present and discuss different protocols applied to specific sports, such as baseball, golf, soccer, and gymnastics.

Biofeedback and Neurofeedback: Principles and Mechanisms of Action

The biofeedback technique aims at making practicers able to intentionally modulate their physiological activity and responses thanks based on real-time recording of such biosignals via non-invasive electronic sensors, in order to better their health status or to improve neurocognitive performance (Gilbert & Moss, 2003; Schwartz & Andrasik, 2003; Shaffer & Moss, 2006). Biometric sensors included in biofeedback devices are used to collect data about ongoing physiological processes and modulation of bodily activity and then provide a real-time feedback mirroring such modulations, thus helping the individual to increase awareness of such processes and to strengthen voluntary control over body and mind. Biofeedback applications are usually grounded on the measurement of muscle activity, electrodermal activity (commonly quantified as skin conductance), blood pressure, and cardiac activity. Because of that, the biofeedback technique has been described as a "psychophysiological mirror", which allows practicers to adaptively monitor and learn from physiological signals produced by their bodies (Peper, Harvey, & Takabayashi, 2009). On the other hand, neurofeedback is a technique that helps practicers to develop the ability to intentionally modulate their brain waves based on the accurate recording of patterns of cortical oscillatory activity via electroencephalography (Marzbani, Marateb, & Mansourian, 2016). Such information flow is used to reinforce and model neural behavior and, then, to increase awareness and to achieve self-regulation goals. Biofeedback and neurofeedback are now deemed as valuable

intervention tools, which are able to provide the kind of evidence-based practice the health care establishment is demanding (Geyman, Deyo, & Ramsey, 2000; Sackett, Strauss, Richardson, Rosenberg, & Haynes, 2000).

Both biofeedback and neurofeedback techniques have their roots deep into the operant conditioning paradigm, in which reinforcement and punishment are used to implicitly promote learning and to shape behavior, and apply its principles and techniques to help people to build a stronger bodily awareness and to learn how to influence the responses of their bodies and brains.

In general, the goal of biofeedback and neurofeedback protocols is to increase the voluntary control over physiological processes that otherwise lie outside awareness by translating information on their development and modification into external and easily-accessible feedbacks (Balconi & Crivelli, *in press*; Balconi, Fronda, Venturella, & Crivelli, 2017; Pop-Jordanova & Demerdzieva, 2010). At the beginning, biofeedback was developed as a research-based approach. Indeed, it directly stem from laboratory research on psychophysiology and behavior therapy, which forsook further understanding of neurophysiological mechanisms underlying psychological disorders. In particular, biofeedback therapies were born as non-pharmacologic treatments that use psychophysiological instruments to measure, amplify, and feedback physiological information to the patient being monitored. Psychophysiological self-regulation was – and currently is – a primary goal of biofeedback therapies. Feedbacks are provided to foster self- and bodily-control, just as they are used to facilitate learning of other skills in different training situations. Such real-time external feedback, which are typically visual and/or acoustic, guides the practicer during the training by making them learn, for example, to warm specific portions of their skin, to relax specific muscles, or to reduce blood pressure.

It has been proposed that these non-invasive intervention techniques also share further specific goals: (1) to give individuals a more active role in taking care of themselves and of their health; (2) to promote a holistic emphasis on body, mind, and spirit; and (3) to elicit the body's own healing and empowerment resources (Gilbert & Moss, 2003; Jonas & Levin, 1999).

Biofeedback and neurofeedback techniques have been widely used to intervene on many diseases and disorders, such as schizophrenia, autistic spectrum disorder, insomnia, drug addiction, attention disorders, altered stress response, and anxiety-related disturbances. Again, biofeedback and neurofeedback are used in a variety of applied settings:

1 assessment and treatment of clinical pictures, such as headache, attention-deficit hyperactivity disorder (ADHD), epilepsy, stress/anxiety, respiratory and sleep problems, pain, and many others;
2 empowerment and promotion of learning in education settings, e.g. reduction of learning anxiety, improvement of focusing skills, assessment of the learning processes;
3 enhancement of performance and optimal functioning for sports, business, and military activities;
4 promotion of self-exploration and self-enhancement, e.g. evaluation of the impact of life events on physiology, improvement of imagination and creativity, etc.

The use of peripheral biofeedback and central neurofeedback techniques is rapidly growing and, given the strong relationship between mental and physical performance in sport practice, sport neuroscience is a notably representative field with respect to novel applications of such techniques.

Brain Correlates of Bio/Neurofeedback Applications

Biofeedback and neurofeedback are procedures for self-regulation that, starting from the detection of peripheral biological signals, are intended to better the psychophysiological state of the practicer and thus foster the best level of performance. The scientific bases of those instruments are to be

found in neuroscience, a discipline that has highlighted the strict mutual bond between changes of the physiological and the mental status.

The relevance of biofeedback in athletes' training and sport interventions can be traced back to the very same "psychophysiological principle" that determines how every physiological change is associated to a parallel change in mind processes and emotional states (Green, Green, & Walters, 1970). Equally, every conscious or unconscious change of such processes and emotional states can be associated to a corresponding change of physiological states.

The process supporting bio/neurofeedback practice involves three methodological elements:

1 information about the physiological modifications, obtained by using sensing electrodes that collect specific signals;
2 amplification and transcription of those signals into easily-perceivable feedbacks by the bio/neurofeedback system;
3 feedbacks, advices, and instructions from the trainer or therapist, used by the practicer to try and increase (or decrease) the target physiological signal.

Specifically, the neurofeedback process involves training and learning self-regulation of brain activity associated to altered cognitive-affective states and central control of bodily responses. Such potential outcome has been deemed as a valuable help even in sports since, for example, the ability to develop a new adaptive response to situational stressors might change the life course of athletes and facilitate much more favorable athletic outcomes.

That, however, requires a gradual learning process. Neurofeedback training may be applied to any aspect of brain functioning that can be measured. Based on Skinner's theory of operant conditioning (1954), neurofeedback training grounds on the idea that learning is a function of change in overt behavior. Changes of conducts are the result of an individual's response to events (stimuli) that occur in the environment. The distinctive characteristic of operant conditioning with respect to previous behaviorist models of conditioning and learning is that the organism can actively produce responses instead of only generating elicited responses consequent to external stimuli. Reinforcements linked to such active responses are then the key element in Skinner's Stimulus-Response (S-R) theory. A reinforcer is anything that strengthens the desired response, i.e. the adaptive response that is intended to be trained. It could be a verbal praise, a good grade, or a feeling of increased accomplishment or satisfaction. The theory also covers negative reinforcers, defined as any stimulus that results in an increase of the frequency of a desired response when it is withdrawn. A great deal of attention was given to the investigation of schedules of reinforcement and of their effects on the promotion and maintenance of the desired behavior. The same principles are applied during a typical bio/neurofeedback training session. First, sensors are placed in correspondence to specific locations on the scalp or the body. Then, the sensors measure the pattern of autonomic responses or electrical activity generated by the neurons and such data are filtered and relayed to the computer and recorded. Finally, by using cutting edge technology, the practicer receives real-time visual and audio feedbacks about his/her bodily or brainwave activity, which are especially designed to reinforce the physiological activity that is intended to be trained.

Behavioral Correlates of Bio/Neurofeedback Applications

It's important, especially for athletes, to be able to recognize all the signs their body provides during exercise, and particularly to know how to control them adequately. Learning to maintain a specific balance between activation and relaxation supports the achievement of optimal performance, so that the athlete might be able to answer competition requests more effectively.

During the last decades, the analysis of the psychological, physiological, kinematic, and behavioral mechanisms underlying the performance of élite athletes has received increasing attention,

especially in precision sports (Goodman, Haufler, Shim, & Hatfield, 2009; Hatfield & Landers, 1983). At present, the measurement of performance-related emotional experiences is also taken in great consideration and it is evaluated by multimodal and multidimensional assessment procedures derived from the integration of different fields of investigation – such as motor behavior, sport psychology, and affective psychophysiology. Monitoring the entire spectrum of psychophysiological and behavioral correlates related to the athletic performance is important in order to develop and implement biofeedback and neurofeedback protocols for sports. The principal aims of such protocols are, indeed, to support athletes in identifying their subjective zones of optimal functioning, in enhancing their performance, and in strengthening their ability to self-regulate and regulate emotions, so to prevent choking under competitive pressure.

Furthermore, besides improving subjective control of central and autonomic nervous system, stress responses, and affective reactions to trying situations, biofeedback and, in particular, neurofeedback practice leads to additional advantages including:

1 improved depth and quality of sleep, which is known to directly correlate to performance;
2 increased neural plasticity, which helps the central nervous system to learn more efficiently and to better cope with stress due to pressure on performance;
3 greater focusing and attention skills, which are essential for athletes;
4 maintenance of clarity of mind and cognitive efficiency over time and in spite of fatigue;
5 helping to avert one-way, negative thinking, athletes are indeed subject to downturns in sports not only because of potential inefficiency of their bodies, but also because of what is happening into their brains and minds.

What's New in Sport Neuroscience? Bio/Neurofeedback as Biological Markers of Physical and Mental Activity

The integration of neurosciences and sport psychology fueled the study of cognitive and emotional mechanisms for the achievement of peak athletic performance. In high-performance sports, in fact, many cognitive functions are concurrently involved in modulating athletic outcomes, such as the information-processing speed and readiness to respond to stimuli, the storage capacity in short and long term memory, the ability to conceive and implement effective strategies, and the ability to quickly change mindset and action plans on the basis of environmental changes and needs.

Biofeedback and neurofeedback can be used to support the learning process during training of such cognitive and psychomotor skills. Indeed, in the field of applied sport research, biofeedback and neurofeedback already have a quite well-established tradition with regard to three primary practical implications (Zaichkowsky & Fuchs, 1988):

1 as techniques for teaching athletes to deal with general and specific anxiety;
2 as a mean of restoring function after muscle injury;
3 as a mean for providing biomechanical and muscle feedback to athletes so that they could perfect highly-skilled movements and enhance performance.

The efficacy of different training protocols designed to foster cognitive and emotional self-regulation and to improve athlete performance with regard to sport-specific tasks has been tested in many studies. Additionally, sport-specific performance measures proved to be enhanced following bio/neurofeedback interventions. For example, it was shown that, by using the skills learned during bio/neurofeedback training, athletes may become able to regulate their breathing and arousal levels so to increase their performance in their sport (Perry, Shaw, & Zaichkowsky, 2011).

A Comparison Between Visual, Kinesthetic and Mental Imagery Performance and Psychophysiological Techniques (Biofeedback and Neurofeedback)

There are several techniques used in sports for the evaluation of the processes that allow us to mentally simulate a sequence of movements and actions to be implemented in a context that, consequently, may help to achieve a deeper knowledge about the functional organization of the cognitive engine system and the use of this potential. In particular, among the various approaches, visual imagination, kinesthetic motor imagery, and mental images have also been used in combination with psychophysiological techniques.

Conditions that promote the formation of mental images are: vividness and controllability, practice, attitude and expectations of athletes, influence of past experience, attention, and a relaxed stance (Corbin, 1972). A vivid image is one in which the imagined events are as realistic as possible and involve connected sensory and emotional experiences. The more realistic the image is, the more the current task will be facilitated in its execution. The principle of specificity of the formation of mental images is based on the assumption that individuals can benefit from imagination in so far as such condition is similar to a past experience, and that such similarity contributes to better learning.

In addition to the visual imagery, kinesthetic images – e.g. the mental focusing on the bodily correlates of a sequence of complex movements – are also often used. Instructions that are typically given when using that kind of imagery technique – namely, kinesthetic imagery or sensorimotor imagination – initially include the actual repetition of a target movement several times and then require the practicer to keep repeating it internally via mental simulation while focusing on its kinesthetic correlates. The rationale underlying the use of such mental images is that focusing on kinesthetic aspects of a gesture, after the actual experience of the target movement, allows for developing a greater awareness of the motor act and of specific movements that was initially carried out unconsciously (Jeannerod, 1995).

Compared to the effect of the mere kinesthetic image formation, it has been shown that mental practice improves the performance of athletes with regard to learning motor skills in a variety of situations (Driskell, Copper, & Moran, 1994). Motor imagery is indeed an active process, in which an action is represented and mentally reproduced, taking into account even specific cognitive components such as attention and working memory. Those internal representations of motor acts are centrally organized and, just as any other representation, they are stored, can be modified by practice, and can be retrieved through specific cognitive processes.

A quite long tradition of experimental studies suggests that there are limited differences between neural and functional correlates of actual execution of an action and of its mental simulation. In fact, the areas that are activated within the planning and execution sensorimotor networks (medial supplementary motor area, the premotor cortex, dorsolateral prefrontal cortex, and posterior parietal cortex) are often the same (see Balconi, Cortesi, & Crivelli, 2017; Balconi, Crivelli, & Cortesi, 2017; Balconi, Crivelli, & Bove, 2018). Furthermore, mental images that are used in sport-related training do not necessarily involve just a motor, somatosensory, auditory, or visual experience, but can be an integration of all these elements (Balconi & Caldiroli, 2011; Balconi, Caldiroli & Vitaloni, 2011; Balconi & Cortesi, 2016). Given that such shared physiological modulations, though not easily-accessible by the consciousness, are directly associated with executed and imagined movements, the use of psychophysiological techniques is a valuable opportunity to help athletes to access such internal source of information even in combination to imagery techniques and to monitor and control the variations observed in autonomic parameters, such as heart rate, respiratory rate, and skin conductance responses (Decety, Jeannerod, Germain, & Pastene, 1991; Guillot & Collet, 2008).

The Contribution of Mental Training and Biofeedback

The contribution of both the peripheral and the central nervous system to the coordination of movement, as well as its efficiency, are mediated in various ways by psychological factors. Since mental training can help to build attention towards psychological processes involved in sport practice and, in particular, to build awareness of how they influence athletic outcomes, it is an opportunity for all athletes who want to improve their sports performance. Through mental training and the use of related techniques, the athlete can increase self-knowledge, become more aware of his/her resources, improve self-confidence, and understand how his/her body and mind interact, thus allowing the realization of his/her potential.

The main techniques that are traditionally included among mental training practices are relaxation, self-talk, and biofeedback.

Relaxation refers to a physiological status characterized by the reduction of the overall level of activation of the organism, which corresponds to calmness, harmony, and minimized anxiety and tension. In sports, relaxation techniques are used to become aware of muscle tension at rest and to manage anxiety or stressful situations that can adversely affect the performance.

Another important mental training technique is self-talk. This technique consists in an "internal" dialogue that the athlete sustains with him/herself, through which it is possible to act upon concentration, to arouse positive emotions, and to increase self-confidence. Thoughts that do often automatically show up into the athlete's mind can affect performance both positively and negatively. A typical internal dialogue of an athlete can be constituted by statements like "I can do it!", "Hang in there a few more minutes!", and "It happens to everyone to make a mistake, and then it can happen to me!". On the one side, positive thoughts promote feelings of adequacy to the task and facilitate therefore a good performance. On the other, inappropriate and negative thoughts of inadequacy arouse apprehension and adversely affect the outcome of the performance.

Again, in sport psychology, biofeedback is one of the most effective techniques to facilitate the learning of self-regulation of the level of arousal. Indeed, biofeedback is advisable for the promotion of relaxation even in those individuals who have difficulty with other techniques such as hypnosis or mental imagery. In fact, the immediate feedback regarding physiological states allows the athlete for more easily perceiving and modulating his/her level of activation than alternative techniques. To train such skills is peculiarly important since, when we are faced with a trying challenge (affecting, for example our social or working life) or, even more specifically, with a sport competition, our mind-body system prepares to deal with it through a complex set of responses that support psychophysiological activation. A series of relevant processes and mechanisms are then set in motion, including increase of vigilance and attention (activation of the central nervous system), preparation of the muscles to endure the expected amount of effort (activation of the musculoskeletal system), and increase of cardiovascular and respiratory activity to optimize the distribution of resources (sympathetic autonomic system). Research in sport psychology has shown that there is a very close relationship between psychophysiological activation and psychomotor performance, and that learning to optimize such form of activation positively influences performance outcomes. When the mind-body system presents a low level of activation (underactivation), the athlete may feel detached and may find it hard to concentrate and enter the race because of a lack of motivation and because he/she feels not challenged enough. As the activation grows, the performance improves, until reaching its optimal maximum corresponding to the vertex of an inverted U curve (such point is often related to the state of flow). Then, if activation grows too much (hyperactivation), the athlete may experience feelings of excessive fatigue, anxiety, and helplessness that undermine performance outcomes.

Biofeedback, unlike other mental training techniques, provides an immediate feedback on the achievement of training goals, allowing the athlete for real-time continuous monitoring of his/her psychophysiological state. Therefore, the integration of such approach with adequate mental

preparation techniques offers the athlete the opportunity to make more appropriate interpretations of his/her bodily sensations and affective reactions, to gain deeper knowledge of his/her self-regulation skills, and to strengthen such self-acquired abilities. Since biofeedback practice is actually devised as a training process (as opposed to a passive treatment), individuals undergoing biofeedback training must take an active role, self-experiment, and keep practicing in order to develop the desired skills and to reach the goals that have been planned. As is the case with other mental training techniques, the practicer is an active learner rather than a passive beneficiary of some kind of treatment. However, unlike other mental training technique, biofeedback also directly informs practicers on how their bodily systems react to mental tasks and particularly stressful situations and, thus, adds a relevant source of information to the learning process. Trainers and therapists can indeed pause the recording and show to the athlete the correlates of his/her physiological reactivity, as well as the extent to which and the speed with which his/her physiological activity returns to baseline values. Then, trainers and therapists may use those pieces of evidence to explain what the optimal values for each of the physiological variables being measured are, as well as how they relate to the athlete's health. Another important aspect of biofeedback practice is the reinforcement given by the trainer/therapist to the practicer with regard to his/her advancements, to the goals that he/she has achieved, to his/her increased awareness and control, and to the benefits in terms of mental and physical wellness (Frank, Khorshid, Kiffer, Moravec, & McKee, 2010).

The Contribution of Mental Training and Neurofeedback

Recently, there has been a relevant increase of interest and awareness of the potential of neurofeedback training for the improvement of sports performance (Hammond, 2007). The latest research suggests that opportunities to modulate brain activity can have a positive impact on performance. Nonetheless, despite the potential of the technique, systematic investigations of the effect of neurofeedback training on objective measures of performance are still very limited.

Through an integrated approach to mental training and neurofeedback, it may be possible to increase awareness of specific central correlates of athletic performance and sport practice. Further, an athlete undergoing neurofeedback training might learn to optimize brain activity and central control over athletic gestures, by strengthening neural connections, improving coherence across the activity of neural structures, and empowering core cognitive abilities, such as focusing, attention, and memory.

Among the advantages of integrating mental training practice with specific neuroscience techniques, there might be the possibility to reach desired training goals in a much shorter time due to the opportunity to more directly work on inherent plasticity of the brain. Neurofeedback training may act as a compass, showing the way into physical and mental states that are difficult to reach without guidance and then, after some practice, allowing the practicer to get there autonomously. You might think of neurofeedback as a personal training session for the brain, where the brain eventually becomes its own trainer. Training the brain to function at its maximum potential is conceptually similar to the way the body is trained, toned, and maintained. Namely, brain training uses repeated practice to exercise the neural networks supporting core cognitive functions such as concentration and focusing, just as muscle training uses exercise to strengthen and optimize the functioning of effectors enacting a movement.

With respect to mental preparation in sports, neurofeedback practice has also been combined with the goal setting, or training objectives, approach. As for the goal setting approach, it has been shown that a good understanding of what you want to achieve, with which strategy you may get there, and how long will it take increases performance more than having no goals or simply setting the aspecific goal to give the best of ourselves. If implemented in the right way, goal setting allows you to avoid some typical mistakes, like defining goals that are too ambitious or too uninspiring

with respect to our resources and skills. Helping an athlete to set achievable and challenging goals affects his/her cognitive performance and attention, and increases his/her motivation. Integrating such practice with neurofeedback training fosters the optimization of neural responses to environmental requests, may improve neurocognitive efficiency, and helps the athlete to define adaptive individual strategies to manage stress and workload.

Furthermore, recent technological innovations lead to the development of a novel integrated approach that combines mindfulness-based mental training and wearable neurofeedback devices for the empowerment of stress management, neurocognitive efficiency, and mental focus skills (Balconi & Crivelli, *in press*; Balconi et al., 2017). First available efficacy data depict such novel technology-supported mindfulness-based protocol as a promising training approach (Crivelli, Fronda, Venturella, & Balconi, 2018); nonetheless its potential still needs to be further tested in different applied contexts.

Investigating the Efficacy of Neurofeedback and Biofeedback Training for Expertise and Excellence in Sport

Neurofeedback is a tool by which the athlete learns to change the amplitude, frequency, and coherence of the electrophysiological correlates of brain activity, thus allowing him/her to achieve a specific improvement of associated mental states. Neurofeedback practice may train athletes to be aware of their own mental states under different conditions and to modify them adaptively so to face performance requests. Indeed, while practicing neurofeedback, athletes can picture their mindset and its modulations by using visual and acoustic feedbacks provided by a computer on the basis of recorded transient patterns of neural activity, and can then identify specific states that are mostly functional with regard to their training goals and the needs of their sport specialty. In this way, it is possible to train to achieve the individual "optimal zone" for performance.

Currently, no universally-recognized and standardized practice exists for training athletes with neurofeedback. Further, it is still unclear whether there are particular athletes that respond better to that kind of training, which training protocol is the best to achieve optimal performance goals, or which is the minimum number of training sessions for improvement to occur.

Neurofeedback and Biofeedback Training for Peak Performance

Peak experience in sport is defined as a state of exceptional functioning of an athlete's psychological and physical systems, which determines optimal performance (Berger & Tobar, 2007).

Csikszentmihalyi (1975) has conceptualized the term flow as the subjective psychological state of maximum optimism and gratification that can be experienced when carrying out activities for which our resources optimally meet the requests and challenges posed by the activity and that corresponds to a complete immersion in the task. The state of flow is not a stable condition, but a transient experience that depends on the continuous adaptation to external (opponent unanticipated move, weather changes, etc.) and internal (increase of lactic acid, variation of heartbeats, etc.) conditions. One of the methods that are commonly used in sport psychology to work on the flow and on the ability to voluntarily enter in such state is mental imagery, which can be used to mentally evoke an athletic episode that went particularly well together with the associated mindset and affective states.

In order to improve the ability to experience flow and to reach peak performance, it is however important also to recognize and be aware of bodily functioning before, during, and after training or competition (brain activity, heart rate, respiration, muscle tension, and many other quantifiable measures of human performance). By recording, analyzing, and identifying individual ideal levels of bodily functions, it is possible to help an athlete to reach his/her peak in terms of performance, to improve stress management, to contain performance anxiety, and to decrease pre-competition

tension. The pressure associated to sport performance can be generated by both internal and external factors but, whatever the cause, it may have harmful effects on the athlete and on the team as a whole. Often, athletes can be their worst enemies. Indeed, focusing on past failures undermines athletes' confidence, making easier for them to fail again as long as they remain unfocused and self-critical (Wilson et al, 2006).

Specifically, by practicing neurofeedback, an athlete can reach a deeper understanding of his/her own mind-brain activity and, above all, to modify it by developing individual mental strategies with the help of experts. Besides relieving psychological symptoms (e.g. anxiety, depression) and supporting the recovery from sport-related injuries (e.g. concussion, headache, muscle tension) that may interfere with sports performance, neurofeedback training may aim at improving different abilities that are necessary to maximize performance, such as relaxation, focusing, agility, and timing, as well as the maintenance or increase of motivation (Wilson, Peper, & Moss, 2006). The most frequently-cited benefits of bio\neurofeedback training for sport practice are: better concentration, better attention, optimized decision-making processes, reduced number of errors, shorter response times, enhanced creativity, more efficient memory, accelerated learning, increased resilience to stress, increased productivity, lowered susceptibility to burn-out, quicker and deeper relaxation, better mind/body integration, enhanced well-being, reduced anxiety and stage fright, increased self-confidence and assertiveness, enhanced self-control and self-awareness, and improved emotional intelligence.

Brain-Training for Physical Performance, Neurofeedback Applications and Relaxation Training in Athletes

In recent years, the integration of EEG-based neurofeedback and relaxation techniques have been more and more used to optimize athletes' brain functioning and performance, as a valuable training opportunity for coach and trainers in professional sports training centers.

EEG investigations within the field of sport research largely focused on the alpha rhythm (8–12.5 Hz). The alpha rhythm is easily distinguishable from other brain rhythms (for example, theta 4–7.5 Hz, and beta at 13–30 Hz). Alpha is a dominant frequency band in the EEG of adults and it is also the most widely studied neural oscillatory activity. A wealth of contemporary studies supports the view that alpha plays an active role in cognitive processing and that it modulation marks the shift between cortical idling, relaxed wakefulness, and active information-processing (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, Sauseng, & Hanslmayr, 2007).

Alpha oscillations are thought to mirror active inhibition of unnecessary cortical activity and control mechanisms that prevent processing of information that is not relevant for the task (Klimesch, Doppelmayr, Schwaiger, Winkler, & Gruber, 2000; Pfurtscheller & Da Silva, 1999). Thus, the modification of alpha activity can be detected in a wide range of tasks and can be considered as a marker of the modulation of information-processing linked to a number of different functions. Support for this view comes from empirical findings that show how distinct sub-alpha bands are associated with multiple operations – many of which are very important for sport practice – including the modulation of global arousal and attention processes (Pfurtscheller & Da Silva, 1999; Thut, Nietzel, Brandt, & Pascual-Leone, 2006), processing of sensorimotor and semantic information (Klimesch, Doppelmayr, Pachinger, & Ripper, 1997; Klimesch, Doppelmayr, Pachinger, & Russegger, 1997), maintenance of pieces of information within the working memory buffers (Jensen & Tesche, 2002; Tuladhar et al., 2007), inhibition of motor programs (Hummel, Andres, Altenmüller, Dichgans, & Gerloff, 2002), and motor learning (Koeneke, Lutz, Herwig, Ziemann, & Jäncke, 2006).

For example, in the EEG literature on sports correlates, variations of alpha power during a task or an exercise with respect to resting-state baseline levels (often measures during eye-closed idling conditions) are often used as a marker of task-related or exercise-related cortical activation/

deactivation. Because alpha frequency components are always present in the cortical activity to a certain extent, the choice of the baseline has a significant impact on the pattern of brain activation that can be reported. Variations of the power of EEG frequency bands reflect the presence or the release of cortical inhibition. The constructs of inhibition and neural efficiency are pervasive in the sport literature based on EEG investigations and they are consistent with different models of learning and motor skills proficiency that have been very influential in the field of sports science.

As an example, Mikicin and colleagues (2015) devised a study to specifically test the impact of neurofeedback training for physical performance on physiological (EEG) and behavioral measures in a sample of semi-professional athletes. The neurofeedback protocol was designed to increase the amplitude of the sensorimotor rhythm (12–15 Hz, a set of frequency components encompassing the highest portion of the alpha band) and of the lower beta frequency components (13–20 Hz), and to concurrently reduce the amplitude of the theta band (4–7.5 Hz) and of the highest beta frequency components (20–30 Hz). The training program increased alpha and beta power in trained participants when measured at rest with eyes-closed. In addition, during eyes-open recording, trained participants presented similar levels of activity across all frequency bands in contrast to control subjects, who showed a decrease of the power of the lower portion of the beta band. Again, with respect to the control group, the trained group improved the response time during a visual attention test and showed an improvement in the speed, efficiency, and accuracy of performance. These results hint at the potential of neurofeedback training for sports training.

Biofeedback and Neurofeedback and Sport Disciplines

The advancement of biofeedback and neurofeedback applications holds great promise for sport psychology and specifically for psychological skills training. Sport achievement is the result of well-planned hard training with progressively growing demands and challenges over a long time period. The main goal of the training process is to increase the athlete's work capacity, skill, and capabilities as well as to develop strong psychological qualities for successful performance (Bompa & Carrera, 2003; Bompa & Haff, 2009).

As above noted, one of the applications of the neurofeedback methodology is the achievement of peak performance in sport. Neurofeedback holds potential for retraining brainwave activity to enhance optimal performance in athletes in various sports (Hammond, 2007). It has been shown to have the potential for quieting the mind and improving performance in archery, for example. It can also be used to improve concentration and focus, cognitive functions, and emotional control following concussions and mild head injuries. Furthermore, it has untapped potential for increasing physical balance in gymnastics, ice skating, skiing, and other areas of performance (Ziółkowski et al., 2014).

The integration of biofeedback and neurofeedback into the common training routine of athletes can support assessment and can teach the athletes to maintain appropriate breathing, relaxed muscles, coherent heart rhythms, and dominant alpha brain states even under pressure.

Neurofeedback Training in Soccer Athletes

Soccer performance depends on several basic skills. Achieving optimal performance is not an easy or automatic process, since lots of environmental disturbances and contextual factors may induce dysfunctional stress in the player. Athletes need to deal with many aspects, such as their emotional stability and focus of attention notwithstanding adverse environmental conditions.

People's ability to influence their own psychological states mostly rely on cognitive-emotional control (Wegner & Pennebaker, 1993), which involves the deliberate use of strategies to change or maintain thoughts, feelings, or actions (Totterdell, 2000). Coping with stressful competitive situations is deemed as a natural ability of the players, yet without effective stress management skills

the effect of stress on emotional response and performance for the player may be severe (Eubank & Gilbourne, 2003). Many of the psychological techniques used with athletes require them to intentionally regulate their moods or emotions, in order to check out the counterproductive emotions such as tension (Totterdell, 2000). For that purpose, neurofeedback training can help to regulate heightened emotionality. The rationale underlying the use of emotion regulation techniques to empower athletes is that there is a relationship between emotion and performance, which can then be enhanced by them via adaptive control of their mood states. More specifically, emotional regulation is thought to influence performance because it enables people to get into the sort of positive mood that facilitates certain cognitive processes (Matthews, 1992), which in turn increase effort and persistence on tasks (George & Brief, 1996).

A recent study on the Italian soccer team, which won the World Championship in 2006, describes the use of neurofeedback as a "secret weapon" to achieve that success. In fact, they attributed their win in part to that very training. This result shows that biofeedback and neurofeedback training in professional soccer players reflects the increasing acceptance and application of such training with professionals whose performance must be optimal during times of extreme stress (Wilson et al., 2006).

Building Performance: Brain Training for Baseball Players

The idea behind the application of neurofeedback training with baseball players is that it can be used to increase attention orientation and focusing, thus helping athletes to force their focus only on the most relevant anticipatory cues and to identify the signs in body position and movements that anticipate which action will be enacted next.

A study with a Major League baseball team has evaluated the feasibility of conducting a brain training and neurofeedback protocol within a professional organization and the effects of such training on quantitative EEG (qEEG) and qualitative self-report data (Sherlin, Larson, & Sherlin, 2013). The brain training protocol proved to be able to significantly change physiological levels and to reduce commission errors at a specific performance test. The significant reduction of commission errors likely mirrors the improvement of executive functions and impulse control. Future investigation should examine to what extent this improvement can be transferred to other domains and affect actual athletic performance in baseball. Again, participants reported increased attention and ability to focus, and they noted that those improvements may be critical for their sport. Baseball players who were training to decrease excessive cortical activity linked to the generation of intrusive thoughts (by enhancing slower EEG frequency bands and inhibiting faster ones) have shown a significant modulation of related EEG indices. Although it was not a primary target of the training, many participants also noted improvements in sleep quality. That outcome is rather valuable because it is well-known that sleep is especially important for the recovery period of a high performance athlete.

Sensorimotor Rhythm Neurofeedback and Golf Performance

Efficient and well-balanced mental processes can differentiate standard and superior performance in precision sports, such as golf. For example, "pitch & putt" is a particular part of golf practice that favors skill and clarity of mind in the short game on the greens and that is one of the most important elements of the game (Pelz & Frank, 2000).

Such part of the game is the most stressful one, since it put precision skills under strong test while relying on automatized athletic gestures. The complexity of such situations, which combines controlled and automated processes, is well represented by neuroimaging evidence. Indeed, it was shown that players who are involved in an automated process present altered activity within bilateral cerebellum, motor areas, and pre-supplementary, premotor, parietal, and prefrontal

cortices (Wu, Chan, & Hallett, 2008). Again, it has been shown that high-frequency alpha power in correspondence to those cortical areas reflects attention processes related to the task (Klimesch, Doppelmayr, Pachinger, & Ripper, 1997). In parallel, frontal midline theta power seems to mirror top-down sustained attention (Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007). Thus, it is possible to hypothesize that these findings support the value of training specialized task-related attention mechanisms so to achieve superior motor performance.

Even facilitating a sense of control and confidence proved to positively influence the performance after a neurofeedback treatment targeting the sensorimotor rhythm (Gruzelier, Inoue, Smart, Steed, & Steffert, 2010). The sensorimotor rhythm is associated to the maintenance of a relaxed but ready mindset, to focusing and concentration, and to a reduction of the information-processing within the sensorimotor network (Vernon et al., 2003). This interpretation is similar to the mental characteristics of peak performance in trained athletes (Krane & Williams, 2006), and it is in agreement with the concept of automaticity proposed by Fitts and Posner (1967). So, sensorimotor rhythm power not only may be a sensitive marker of activity within sensorimotor cortex (Mann, Sterman, & Kaiser, 1996) but it also shows a potential for empowerment interventions with precision sports athletes. Indeed, neurofeedback-induced enhancement of sensorimotor rhythm seemed to results in better visuomotor performance and, then, in superior putting skill.

Even biofeedback appears to improve golf performance, specifically as a consequence of the reduction of performance anxiety in competitions. In particular, a detailed understanding of the psychological and physiological state of the participant and a continuous monitoring of heart rate variability during the sport performance may improve the player's ability to cope with stress by increasing the ability to achieve optimal performance. As such, that technique might help to induce substantial improvements of practicers' state of mind and confidence, to reduce the stress experienced during golf competitions, and to improve athletic outcomes.

Using Biofeedback and Neurofeedback with Gymnasts

Goal setting in biofeedback and neurofeedback training begins with identifying potential suboptimal physiological responses and with defining whether these suboptimal states occur during specific situations or contexts, such as competition.

Following neurofeedback training, gymnasts showed improved self-regulatory skills during competitive periods with respect to their initial ability. Furthermore, neurofeedback training proved to promote the rapidity of complex coordinated motion learning, to improve vestibular stability, and to fine-tune self-estimation of functional condition (Svyatogor, 2000). Since they aim at encouraging athletes to maximize their potential in the race, bio/neurofeedback techniques can also be used to strengthen gymnasts' mental components that often affect the outcome of a sport performance. Namely, a coach who wants to improve mental training of athletes can use such techniques to work on their coping strategies and to enhance a sense of inner confidence.

Recent studies have tested the effectiveness of a bio/neurofeedback training program to foster optimal pre-performance mind-body status so to improve balance beam performance in competition for gymnasts. Shaw and colleagues (2012) specifically investigated the effectiveness of a combined bio/neurofeedback training program designed to foster an optimal pre-performance mindset and the related neural state so to improve balance beam skills of gymnasts. Since previous studies acknowledged, among their limitations, that physiological patterns were partly different between training and competition contexts, the authors devised the training so that it could be applied both in the laboratory and at the gym, in an attempt to facilitate the transfer of skills. The training included exercises to improve heart rate variability (HRV) and sensorimotor rhythm. The assessment included baseline measures, psychophysiological evaluation by an independent judge, balance beam performance during competition, and subjective experience reported by the

gymnasts. Gradual improvement of balance performance across the training sessions suggested that participants experienced some benefit associated with training. Yet, after the end of the training, those benefits did not remain. It is further worth noting that the withdrawal of training had a negative effect on mood and performance of athletes.

Technical and Practical Notes

Even if there still is no universally valid gold standard protocol for the improvement of athletes' performance, we will briefly describe a couple of protocols exemplifying neurofeedback applications in the field of sport science.

- Alpha training: this protocol mainly focuses on relaxation in order to achieve a calm state of mind. The montage includes one or two recording channels used to collect EEG data and thus compute the real-time feedback on the presence, power, and maintenance of alpha activity (8–12 Hz). Usually, the athlete is asked to keep his/her eyes closed during training, so to help relaxation and to allow the rewarding feedback to start. Feedbacks are usually provided in the form of pleasant acoustic stimuli, e.g. flutes, cellos, violas, natural sounds, etc. Training is designed to facilitate entering an alpha-wave state and concurrently to signal the potential increase of prevalence of lower frequency components (theta and delta oscillations) that are associated to deep inner connection, drowsiness, and lowering of consciousness. Achieving and maintaining that relaxed but aware state is useful for reducing dysfunctional stress and its associated effects, and it also helps to minimize the effect of anxiety, anger, disappointment, and other negative emotions that may arise in the course of a competition. Alpha training may alternatively be focused on the coherence of the activity of right and left hemispheres. Such specific practice aims is thought to promote emotion-regulation, creativity, and sense of well-being, and, as a consequence, to increase the ability to keep the mind clear and play effectively.
- Sensorimotor rhythm (SMR) training: this protocol is mainly aimed at enhancing the ability to focus. The montage typically includes one or two EEG sensors placed in correspondence to sensorimotor areas, so to record SMR fluctuations in the 12-to-15 Hz range. Sessions can be done with the eyes open so to mimic real-life situations. Acoustic and/or visual feedbacks are used to foster the amplification of SMR oscillations while inhibiting theta and high-frequency EEG activities. The SMR collected over central scalp regions has been associated to mental focus and motor readiness.

Neurofeedback protocols aimed at training athletes to voluntarily produce a specific brain activity pattern (specific waveforms in correspondence to specific locations) and to be aware of whether they are entering specific mind-brain states or not can be supported by recording additional physiological parameters (such as skin conductance level or muscle tension) to control for potential side effects due to discomfort during practice.

Setup, Recording and Data Processing

Measurements that are typically used in biofeedback training are:

- electrocardiography: electrical activity generated by the heart muscle is usually recorded by placing sensors in correspondence to the wrists and the ankle;
- electrodermography: a pair of electrodes are usually placed on the palm or on the fingers of the non-dominant hand so to collect data on the tonic and phasic components of skin conductance;

- pneumography: breathing patterns and respiratory activity at rest and under stressful conditions is collected via mechanical sensors;
- peripheral thermography: changes of peripheral skin temperature are collected via highly sensitive sensors placed in correspondence to the hands, feet, or the temples;
- electromyography: tension and sensitivity to fatigue of skeletal muscles is usually assessed and trained by using surface sensors.

Some examples of biosignal analysis approaches used to compute indices and biomarkers for assessment and training are spectrum analysis, trend analysis, analysis of peak activity and variability of responses over time, and rectification and analysis of the root mean square values.

A typical biofeedback setup uses data collected by sensors placed on the skin to detect both electrical and non-electrical peripheral biosignal, to distinguish between relevant physiological activity and noise, and to convert such relevant activity into easily-perceivable acoustic and/or visual feedbacks provided to the practicer (Prentice, 2003). Usually, sensor montages that are used to collect electrical biosignals include active sensors and a reference sensor, which is typically placed in-between the active ones, so to create a "differential amplifier" (Prentice & Voight, 2001).

Differently, neurofeedback practice grounds on recording brain activity via EEG sensors that are placed on the scalp and ear lobes. The placement of sensors can be determined on the basis of previous quantitative EEG assessments or it can be set a priori following standard electrode placement systems on the basis of available evidence on anatomical-functional correspondence. Brain biosignals are then processed by a computer program, which typically analyzes the collected data in the frequency-domain. Neurofeedback training does not include any kind of electrical stimulation of the brain. It simply relies on the collection of electrical neural activity, which is used to provide the practices with real-time feedbacks on such activity. The opportunity to see correlates of brain activity on a computer screen or to hear their modulations allows the practicer to build the ability to consciously monitor such activity and to modulate it, according to operant conditioning principles. Reinforcements and punishments are given to the practicer while he/she trains to develop the ability to voluntarily control his/her brain responses. Typical reinforcing tasks are brain-controlled videogames and video clips (Hammond, 2007). With the progression of practice – after a sufficient number of training sessions – brainwaves and related mindsets can be modeled so to try and achieve the desired self-regulation goals. At first, induced changes are short-lived, but they gradually become more consistent thanks to continuous feedback, coaching, and practice. Depending on the conditions that are being addressed and on individual needs, target frequencies and training protocols are usually personalized.

Ethical and Safety Guidelines

Bio/neurofeedback systems are used both in clinical settings to support functional recovery and treatment of clinical pictures and in training settings to empower individual performance, self-awareness, and self-regulation skills. The devices that are commonly used are typically designated as low-risk equipment, but must conform to special controls such as labeling requirements, post-marketing surveillance, and performance standards.

When used to treat a diagnosed condition, bio/neurofeedback training must be prescribed by a duly authorized dealer, such as a physician or a psychologist. Before the training, the trainer/therapists should collect initial data to properly test the effectiveness of the intervention. Further, he/she has to obtain the patient's written informed consent, which has to clearly state some key issue concerning the treatment/training:

- any risks related to bio/neurofeedback practice and associated techniques (allergic reactions to sensors or materials used to preparation the skin);
- relative risk-to-benefit ratios of bio/neurofeedback techniques;
- reference to potential alternative interventions (e.g. progressive muscle relaxation training without biofeedback to intervene on tension headaches);
- the client's rights and privacy norms.

The trainer/therapist must work with the client to establish mutually-agreed goals for the training. The client must be informed not only on the proposed therapeutic approach but also on the possibility that the intervention may not achieve the desired goals. The client needs to be informed on and to demonstrate proper understanding of the importance of informing the trainer/therapist of any changes in his/her medications, symptoms, and behaviors.

With regard to the client's privacy and dignity issues, country-specific guidelines usually include the consent for physical contact between client and professional. In many cases, however, the trainer/therapist can instruct the client in appropriate sensor placement without the need to touch him/her. While it may be easier for the trainer/therapist to directly place sensors, especially during applied intervention with athletes, touch should never involve areas of the body that would be considered as sensitive. Some therapists mistake their comfort with a client for the client's comfort with them. Clients, in fact, can be very uncomfortable in many situations but not be willing to verbalize their feeling.

Finally, especially in sport domain, training can also be provided at distance via web-based communication channels. Even in such cases, however, clients cannot be left to themselves during practice, since they cannot learn to control their bodily activity by merely observing a bio/neurofeedback display. Rather, clients must be properly coached throughout the bio/neurofeedback session by using the principles of operant conditioning and other training techniques. Athletes must not be left alone to attempt changes for significant periods of time unless this is a specific goal for the client (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research & Department of Health, Education, and Welfare, 1988).

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