Research in Physical Education, Sport and Health
2016, Vol. 5, No. 2, pp.101-105
ISSN(Print):1857-8152; ISSN(Online):1857-8160

PSYCHOPHYSIOLOGY AND THE SPORT SCIENCE

UDC: 612.821:796.011
(Original Scientific Paper)

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Psychophysiology is an interdisciplinary scientific approach which studies the connection between mind and body through measurement of the electrical activity of neural and muscular tissues and the conductivity of dermal tissue. The aim of this paper is to review some of the findings of psychophysiology research in sports. Two types of methods have been employed. The first one is the measurement of the changes in the brain electrical activity using the electroencephalography (EEG). Event-related potentials (ERP) are modalities of EEG which have largely been used in the research of performance in athletes. The other type of measurements is focused on the changes in cardiovascular system, respiratory system and skeletal muscles. The muscular electrical activity during sports performance has been investigated by electromyography (EMG). Both types of investigations can be combined. Psychophysiological level of measurement holds promise for understanding how cognitive-affective factors influence the quality of motor behavior.

***Key words**: psychophysiology, sport, EEG, ERP, EMG*

Introduction

Psychophysiology is an interdisciplinary science which studies the relationship between mental activities and physical function. Its establishment as an independent formal discipline is generally pinpointed to 1960s with the formation of the Society for Psychophysiological Research and the publication of their official journal Psychophysiology. In the first issue of the journal, John Stern (1964) defined the field as where behavioral variables are manipulated, and the effects of these independent variables are observed on physiological measures as dependent variables (Psychophysiology Vol1, 1964). Historical perspectives, however, distinguish psychophysiological approach in published articles on electro-dermal responses and their sensitivity to psychological processes (Fere, 1888), in studies of emotion and autonomic control (Cannon,1928) and in the work on conditioning of autonomic and visceral responses (Pavlov, 1927) in the last decades of the 19th and the first half of the 20th century (Hatfield et al.,1983). The rise of the discipline happened during the last three decades of the 20th century when it became an integral part of the neuroscience complex approach to human mind and body.

There are several general trends in contemporary psychophysiology. They include the emphasis on the reciprocal relations between psychological and physical domain, the interaction among systems (e.g. behavioral, endocrine, autonomic and immune) and the interest in explicating higher-level psychological processes. All these trends converge in sports psychology. Peak sport performance represents the ultimate goal that athletes and their specialist coaches, trainers and applied sport psychologists attempt to achieve and maintain. Williams and Krane, 1998 summarized athletes' reports on subjective experience of peak performance state which incorporate no fear of failure, no thinking of performance, total emergence in activity, narrow focus of attention, effortless performance, feeling of complete control, time and space disorientation and involuntary experience (Williams and Krane, 1998). Underlying psychological processes which enable peak performance include intrinsic motivation, selective attention, goal setting, working memory, decision making, positive self-concept and self-control (Pedersen, 2002, Cheron et al, 2016). Therefore, sports professionals have become interested in neuroscience methods that will help them to better understand the basic mechanisms underlying sporting behavior (the brain-behavior links) and as means to develop new methods to enhance performance.

The aim of this paper is to review some of the findings of psychophysiological research in sports and to point out possibilities for further application of psycho-physiological methods in sport science and in sports medicine.

Psychophysiological methods

The basic rationale for the methodology applied in psychophysiology is the electrical activity of neural and muscular tissues and conductivity of dermal tissue. The concept of psychophysiological measurements is based on the principles of electrophysiology. The most important areas of physiological data acquisition within human body are electrical potentials of the brain, muscle activity, sweat gland activity, eye movements and pupillary response, cardiac response, blood pressure, blood volume and respiration which can be recorded by electroencephalography (EEG), electromyography (EMG), electro dermal response (EDR), electrooculography (EOG), pupillometry, electrocardiography (ECG), plethysmography and pneumography, respectively. Electrical potentials are detected by transducers (electrodes and/or other types of sensors), and are derived as analog signal to a preamplifier and AD convertor which converts the analog to digital signal which is sent to amplifier which amplifies the signal. The signal is analyzed and then graphically displayed. There are many technical obstacles which need to be overcome in order to gain a clear and precise psychophysiological parameter which could be further analyzed (detailed elaboration of this topic is not the aim of this article). Psychophysiological methods are non-invasive and objective. Compared to other imaging methods, they have exceedingly high temporal resolution, which provides a direct real-time measure of the underlying neural activity and related behavior. It makes them ideal for tracking the rapid execution of sensory, cognitive and motor processes inherent to sporting behavior and therefore they provide an unbiased, objective index of psychological processes. However, their application in sports science is still limited. Some of the shortcomings of these methods are low spatial resolution (EEG) compared to other imaging methods, the absence of standardized methodologies for sport domain, the presence of different artifacts due to sport movements and the mismatch of lab tasks and real sporting activity.

Psychophysiological research in sports

Two types of methods have been employed in psychophysiology research in sports. The first one is the measurement of the changes in the brain electrical activity during cognitive tasks and sports performance or during the preparation for sports performance using the electroencephalography (EEG).The event-related potentials (ERP) and neurofeedback are modalities of EEG which have largely been used in the research of performance in athletes. The other type of measurements is focused on the changes in the peripheral physiological systems active during sports performance such as cardiovascular system, respiratory system and skeletal muscles. The muscular electrical activity during sports performance has been investigated by the use of electromyography (EMG). Both types of investigations can be combined.

Electroencephalography (EEG)

Electroencephalography has been recognized as one of the oldest brain imaging methods. It is recorded using electrodes placed at specific locations across the scalp (frontal, temporal, parietal, and occipital); it is non-invasive, relatively inexpensive and easy to apply (Park et al, 2015). The typical wave like appearance of the EEG signal reflects the rhythmic activity of the underlying synaptic processes which are possibly driven by the thalamus pacemaker. Distinct cortical areas produce different rhythms which comprise the composite EEG signal. During analysis, in order to decompose the "raw EEG signal" Fourier spectral analysis is typically used. Several frequency bands have historically been categorized as delta (< 4 Hz), theta (4-8Hz), alpha (8-12 Hz), beta (13-30Hz), although alternative classifications have also been employed such as gamma frequency band (>30Hz) (Thompson et al, 2008). Slower waves such as delta are typically associated with sleep, while faster beta waves are associated with arousal and mental activity. Alpha rhythm has been linked to relaxed focus.

The first EEG study related to peak sports performance was published by Hatfield et al, in 1984 (Hatfield et al.,1984). It examined left-hemispheric and right-hemispheric brain activity in world-class competitive marksmen as they aimed at a target and prepared to execute shots. Since then, most of EEG studies in athletes have been undertaken in precision sports such as archery, rifle/pistol shooting, golf, basketball free throw, dart throw and billiard sports. These sports are particularly useful for studying attentive states with EEG technology because the athletes are motionless, yet highly engaged psychologically (Hartfield -

Psychophysiology of sport). The experimental conditions involved expert performers versus novices and intra-individual performance variations. Two types of EEG parameters have been analyzed: the frequency domain and "power spectrum" parameters of the brain rhythms (delta, theta, alpha, beta and gamma) and the time domain parameters i.e. event-related potentials (ERP). ERPs reveal changes in brain activity specifically associated with an event of interest (e.g., seeing a stimulus or making a response) and are typically characterized as modulations in the amplitude (magnitude) and latency of the neural activity measured over a particular period of time, at specific locations over the scalp when contrasting across experimental conditions (Luck, 2005).

Frequency domain EEG studies

Most of the studies within the frequency domain have focused on the properties of alpha rhythm in athletes during peak performance. Recently in their systemic review on brain oscillations Cheron et al, (2016) suggested that much attention should also be paid to changes in other rhythms, especially theta and gamma which are connected to motor control and cognitive processes (perception, attention, working memory and associative memory) during sport performance (Cheron et al., 2016). Baumeister et al., (2008) reported that expert golfers performed better than novices during putting toward a target from 3 meters and better performance was associated with an increase in upper alpha power at parietal electrodes along with an increase in theta power at frontal electrodes (Baumeister et al., 2008). Increased alpha power over left hemisphere during preparatory period immediately prior performance in experts compared to novices; in successful versus unsuccessful performance and during learning of performance in athletes has been found in different experimental designs across many studies (Haufler et al., 2000, Deeny et al., 2003, Hung et al., 2008, Lin et al., 2009). These findings are interpreted in accordance with the psychomotor efficiency hypothesis (Hartfield and Hillmans, 2001) which postulates that a reduction in the activity in nonessential cortical regions is a characteristic of skilled motor performance. Alpha rhythm is increasingly regarded as reflecting a global inhibition of the cortex in order to exert a cognitive control of the final performance (Klimesch et al., 2007 Haegens et al., 2010). Higher alpha over left hemisphere suggests inhibition of the left brain verbal -analytical activity (e.g. self-talk) and a shift to the right brain visual-spatial activity which is necessary in sport performance. During superior performance an enhanced communication between visuo-spatial parietal sites and regions associated with motor control and attention processing occurs represented by enhanced functional coherence of alpha rhythms prior to execution. These findings suggest that expertise acquired over practice can elicit changes in functional organization of the athlete's brain. The details of the connection between alpha rhythm and expert performance still remain unclear regarding the specific task demands of the sport activity and the functional significance of this relationship. It has been argued that lower levels of alpha indicate increased cognitive engagement, while medium levels index a reduction in this engagement moving toward greater automaticity of execution, and higher levels indicate "cortical idling" which results in poorer performance (Deeny et al, 2003). Currently many authors suggest that it is important to look for simultaneous changes in other frequency bands and possible interactions between frequencies in order to gain more consistent interpretation of brain oscillation data in general (Park, et al., 2015).

Time domain EEG studies - Event related brain potentials (ERPs)

Beyond the information provided by examination of the EEG frequency domain, ERPs offer an additional tool in understanding performance, as they are indicative of specific temporal processes. They are defined as a manifestation of brain activities that occur in preparation for or in response to discrete events (Hatfield et al., 2001). ERPs represent cortical activation that is time-locked to a specific stimulus and they are derived from the average of multiple responses in order to increase the signal to noise ratio. Generally, ERPs are measures in terms of the direction of peak amplitude (i.e. positive or negative) and latency of the cortical waveform (for example a positive peak that occurs approximately 300ms after stimulus presentation would be referred as P300).

ERPs are typically elicited and recorded with a modified EEG technique, using a warned choice reaction time task (an S1-S2 protocol) during which participants respond as quickly as possible to imperative stimuli which occurs after a warning stimulus (with differential significance- neutral v,s. discriminative) while reaction times are measured. The functional significance of different ERPs which occur during this cued reaction time paradigms is that they reflect the processes of preparation, attention flexibility, inhibition, decision making, motor response preparation, execution as well as detection and evaluation of the stimulus and selection of the response.

The literature reveal that a comparatively small number of sports performance studies have examined neural activity in the time domain compared to frequency domain. Reports on movement related event potentials such as the readiness potentials recorded in elite table tennis players compared to amateurs and non-athletes (Hung et al., 2004), elite rifle shooters, fencing and karate athletes compared to non-athletes show variable results with both increases and decreases in their amplitude. It is argued that these inconsistent results could reflect the influence of the exact nature of the sport in question. While findings relating to movement potentials are mixed, studies examining ERP effects related to stimulus detection and response selection have produced more consistent results. ERPs recording during a cued reaction time task (S1-S2) i.e. Go/NoGo paradigms, such as P300, N200 and CNV show consistent findings of larger effects (amplitude and latency) over frontal and parieto-occipital locations in experts compared to novices in different studies with different sports.

Electromyography

Electromyography obtains the electrical activity from the muscle in rest or in contraction (maximal and static voluntary contraction). In its classical application it electromyography helps to the diagnosis and follow-up of a process of neuromuscular type. Surface electromyography (SEMG) allows the study of muscular activity in dynamics, applicable to biomechanical movement analysis, gait analysis, studies of muscular fatigue, sport performance and follow up of the recovery process of athletes in sports medicine.

Future direction

Despite early recognition of the potential utility of brain imaging for sports, the application of EEG techniques to assess factors contributing to performance is still in its infancy (Park, et al., 2016). The limitations highlighted in literature include strict technical requirements of the recording procedure in order to prevent the appearance of artifacts of external origin and to obtain high quality of EEG data. In future, work should adhere more closely to existing guidelines detailing accepted standards for recording and analysis of EEG data in wider literature (Thomson et al., 2008). Other limitations incorporate a general lack of ecological validity (mismatch of results obtained in laboratory and real sporting activity), critical differences in methodology, a lack of consistency in analysis strategy and failure to address individual differences. One of the issues of particular concern is the disconnection between the evidence provided by EEG studies and the functional interpretation of the findings. In frequency domain studies all interpretation has been focused on alpha rhythms, despite evidence from the wider literature which link changes in other frequency bands (gamma and theta) with cognitive functions highly relevant to sports performance.

Over the last decade there has been significant advance in technology in order to move EEG from the lab into the real-world sporting activity by development of mobile EEG equipment (miniaturized, portable and wireless EEG system). From the perspective of sport practitioners it is critical that mobile EEG equipment and procedures do not impede sporting activity, or lead to significant interruptions during training. From a neuroscience perspective, mobile EEG systems must be able to deal with motion artifacts effectively whilst closely matching the performance of lab-based set up. At this stage, work validating mobile EEG technologies for use is in pure research applications is ongoing, but initial signs are promising. Most success has been achieved in the technology of EPR recordings (P300 effects). Several studies confirm the validity of mobile EEG technology for capturing P300 effects during moderate whole body movement (Park et al., 2015).

Intense work has been done addressing the issue of functional interpretation of the findings and in identification of biomarkers of sport performance. Cheron et al., (2016) suggest an integrated approach towards biomarkers of performance within the technological platform assuming the perfect synchronization between biomechanical recordings, multiple EMG, high density wireless EEG, eye movements and signals coming from ANS which will provide large variety of parameters in order to allow finer mathematical analysis to optimize sport performance (Cheron et al., 2015).

Conclusions

The application of EEG techniques to assess factors contributing to performance is not entirely utilized by sports science. SEMG is a useful method for determination of the functional capacity of muscles.

Integrated psychophysiological level of measurement holds promise for understanding how cognitive-affective factors influence the quality of sports performance.

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