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PSYCHOPHYSIOLOGICAL PATTERNS RELATED TO INDIVIDUAL ZONE OPTIMAL PERFORMANCE IN SELF-PACED TASK: A STEP FORWARD WITH MAP MODEL

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ABSTRACT

During the last decades, the analysis of the psychological, physiological, kinematic, and behavioural mechanisms underlying the performance of elite athletes has received increasing attention, in particular in precision sports (e.g., Goodman, Haufler, Shim, & Hatfield, 2009; Hatfield & Kerick, 2007). A multimodal and multidimensional assessment derived from the interaction of different fields, such as motor behaviour, sport psychology, and psychophysiology, has been advocated to measure performance-related affect. Assessment includes self-reports, behavioural and kinematic observations, and physiological recordings (Lang, 2000). The monitoring of the entire spectrum of psychophysiological and behavioural features related to performance is also important in order to develop and implement biofeedback and neurofeedback techniques aimed at helping athletes to identify individual zones of optimal functioning (IZOF), enhance their performance, self-regulate, and prevent choking under competitive pressure.

The psychophysiological, behavioural, or kinematic features of self-paced tasks (e.g., shooting, golf putting, dart-throwing, archery) have been usually studied between-subjects by comparing the performance patterns of skilled performers to those of novices (e.g., Haufler, Spalding, Santa Maria, & Hatfield, 2000; Konttinen & Lyytinen, 1992; Goodman et al., 2009; Salazar, Landers, Petruzzello, Hans, Crews, & Kubitz, 1990), or within-subjects by contrasting individual’s best and worst performance patterns (Guillot, Collet, Dittmar, Delhomme, Delemer, & Vernet-Maury, 2003; Konttinen, Lyytinen, & Viitasalo, 1998; Tremayne & Barry, 2001). More recently, several authors have used an idiosyncratic probabilistic approach in the framework of the IZOF theory to investigate the relationship between performance and affect in different sports (Bertollo, Robazza, Falasca, Stocchi, Babiloni et al. 2012; Edmonds, Mann, Tenenbaum, & Janelle, 2006; Medeiros Filho, Moraes, & Tenenbaum, 2008). This uni-dimensional categorization of performance (expert/optimal vs. non-expert/suboptimal) has been recently challenged by a 2x2 conceptualization in which performance is classified in terms of both performance level (optimal
and sub-optimal) and action control (automatized and controlled). This 2x2 performance arrangement has led Bortoli, Bertollo, Hanin and Robazza (2012) to develop a Multi-Action Plan (MAP) intervention model for performance optimization in the framework of IZOF theory (Hanin, 2000).

The aim of the present research project is to investigate the behavioural, psychophysiological, and cortical patterns related to Individual Zone Optimal Performance in self-paced task in the framework of MAP model.

**Method.**

Self-paced sport’s athletes have been investigated (e.g. pistol and rifle shooters, dart-throwers). Athletes have been asked to accurately describe their optimal sequence of actions for the execution of a single shot from start to follow-through, and then to identify a small number of the most important core components they believe fundamental for optimal achievements following the MAP procedure (Bortoli, Bertollo, Hanin & Robazza, 2012). Then they have been requested to perform a large number of specific actions (i.e. shooting or dart-throwing) during a practice session in order to examine the underpinning psychophysiological, cortical, emotional, and postural patterns associated with the four (2x2) performance categories derived from the MAP model. Prior to each action, the athletes have been asked to rate their hedonic tone (affective state) on a modified 11 point Borg scale. After each action, they have also been requested to rate their perceived levels of both control and execution accuracy of their core components. ECG, SCL and kinematic data have been collected throughout performance using Bioharness (zephyr technology), and UFI Skin conductance meter in conjunction with bio amplifier connected to power lab (ADIntruments). EEG data have been collected using a 32 channels ASALAB system by Advance Neurotechnology (ANT). A cap (Waveguard) specifically developed to minimize movement and muscular artefact, was used.
Results

Results showed specific psychophysiological, cortical, emotional, and postural patterns (i.e. indexes associated to IZOF) related to the 2x2 performance categorization, thereby providing strong support to the predictions stemming from the MAP model. In particular hedonic tone and behavioural results demonstrated that performance level can remain good also when the athlete focuses his attention on the core components of the action rather than on “supervising” them.

The emotional arousal reflected in the hedonic tone has also been mirrored Skin Conductance Level (SCL). Results revealed a lower SCL in type 1 performance than in type 2 and type 3 performances, with comparable SCL in type 1 and type 4 performances. Traditionally, SCL is considered one of the best indicators of arousal-activation in precision sport. It enables to discriminate between best and worst performances (Guillot et al., 2003; Tremayne & Barry, 2001), and it has been recently used as a valuable index to identify individual zones of optimal functioning (Bertollo et al., 2012; Edmonds et al., 2008). The finding that electrodermal activity is more elevated during type 2 and type 3 performances than during type 1 and type 4 performances suggests the existence of different mechanisms of energy mobilization and regulation. Focused attention, fatigue and stress are associated with an increased sympathetic activation, particularly electrodermal arousal, which is a reliable physiological response to stressors. Finding on respiratory rate and bodily position confirm this perspective.

Findings on neural patterns revealed differences in cortical activity with respect to performance types both in high alpha band and beta band. Overall, the findings for type 1, type 2 and type 4 performances at shot's release support the notion that this event is characterized by a lower cortical activation. This notion, supported by the ERD/ERS patterns obtained in both the high alpha and beta bands, is associated with an automatic performance, characterized by the quiescence, automaticity and fluidity of psycho-bio-social states, but is only partially in line with the well-established “neural efficiency hypothesis” and the model of stress-induced cortical dynamics, which link optimal performance to a particular “mental print” that features the same psycho-bio-social
states typical of type 1 and 4 performances (Hatfield & Kerick, 2007). Indeed, our results indicate that optimal performance is typical of types 1 and 2 only.

Therefore, it seems that optimal performance could be related not just to a lower cortical activation at shot's release, but also to the patterns of cortical activation during the seconds preceding the shot according to the neurobiological model proposed by Hatfield and Kerick (2007).

**Conclusion**

In conclusion, our findings echo the notion that functional performance states are plausible within a broad range of behavioural, psychophysiological and cortical antecedents. However, the analysis of the sympathetic/parasympathetic balance and the cortical activations related to the psychophysiological states underlying distinct performance-related experiences, as defined in the MAP model, has brought new insights on the neurobiological correlates of the control and performance levels separately.

Further investigation involving also the collection of biological marker, such as cortisol, in the multimodal and multidimensional assessment, will help to elucidate the entire neurobiological network involved in optimal performance.
RESUMO

Nas últimas décadas, a análise de fatores psicológicos, fisiológicos, cinestésicos e comportamentais tem sido amplamente investigada, sobretudo em desportos de precisão (e.g., Goodman, Haufler, Shim, & Hatfield, 2009; Hatfield & Kerick, 2007). Uma perspectiva multifatorial e multidimensional baseada em vários campos de conhecimento (e.g., comportamento motor, psicologia do desporto e psico-fisiologia) vem sendo utilizada na análise de experiências afetivas relacionadas à performance esportiva. Como tal, questionários, observações e dados fisiológicos são métodos importantes e comumente utilizados. De fato, o monitoramento de fatores psico-fisiológicos e comportamentais, particularmente os relacionados com a performance desportiva, é fundamental para o desenvolvimento de técnicas de bio-neuro feedback com o objetivo de (a) promover performance de excelência no desporto, (b) aumentar o tempo de permanência na Zona Individual de Ótimo Funcionamento (IZOF), e (c) aprimorar habilidades mentais como auto-controle e ativação.

Desportos caracterizados por pouca variabilidade ambiental vêm sendo estudados a fim de (a) estabelecer diferenças entre iniciantes e experts (e.g., Haufler, Spalding, Santa Maria, & Hatfield. 2000; Konttinen & Lyytinen, 1992; Goodman et al., 2009; Salazar, Landers, Petruzzello, Hans, Crews, & Kubitz, 1990), e (b) identificar critérios intra-individuais de performance ótima e sub-ótima (Guillot, Collet, Dittmar, Delhomme, Delemer, & Vernet-Maury, 2003; Konttinen, Lyytinen, & Viitasalo, 1998; Tremayne & Barry, 2001). De fato, diversos autores têm utilizado métodos idiossincráticos e probabilísticos no estudo das IZOFs (Bertollo, Robazza, Falasca, Stocchi, Babiloni et al. 2012; Edmonds, Mann, Tenenbaum, & Janelle, 2006; Medeiros Filho, Moraes, & Tenenbaum, 2008). Recentemente, um modelo 2x2 baseado em performance (ótima e sub-ótima) e controle da ativação (automático e controlado) foi proposto como uma alternativa a visões unilaterais do rendimento desportivo. De modo específico, o Modelo Múltiplo de Planos de
Ação (MAP) foi desenvolvido para orientar o treinamento mental de desportistas de várias modalidades esportivas.

O objetivo deste estudo foi investigar fatores comportamentais, psico-fisiológicos, e corticais relacionados as IZOFs em desportos de precisão, tendo por base as preposições do MAP model.

Método.

Desportos de precisão têm sido contemplados (e.g., tiro ao alvo, arremesso de dardo) em estudos sobre excelência esportiva. No presente estudo, tendo por base as proposições do modelo MAP, os participantes descreveram fatores considerados essenciais (“core factors”) para a performance de excelência (vide Bortoli, Bertollo, Hanin & Robazza, 2012). Subsequentemente, os atletas participaram de uma sessão de familiarização (i.e., tiro ao alvo) cujo objetivo era identificar fatores (psico-fisiológicos, corticais, emocionais, e posturais) relacionados com a categorização 2x2 proposta no modelo MAP. Antes de cada tiro ao alvo, os atletas reportaram seus estados afetivos numa escala Borg adaptada. Além disso, os atletas reportaram performance subjetiva e níveis de controle dos “core components”. ECG, SCL e análise cinestésica foram obtidos através dos sistemas Bioharness (zephyr technology) e Power lab (ADIntruments). Atividade cortical foi obtida através de equipamento de EEG contendo 32 canais (ASALAB, ANT). Um capacete Waveguard, capaz de minimizar artefatos relacionados a movimentação e atividade muscular, também foi utilizado.

Resultados

Os resultados demonstraram que padrões específicos de ativação cortical, emocional e postural estão relacionados com as diferentes categorias de performance propostas dentro do modelo MAP. Deste modo, é possível que atletas apresentem boas performances desde que focalizem nos seus “core components” de ação.
Valores de ativação reportados pelos atletas confirmaram SCL indexes. Performance tipo-1 e tipo-4 foram caracterizadas por valores maiores do que performance tipo-2 e tipo-3. Tradicionalmente, o SCL é considerado um dos melhores indicadores de ativação em desportos de precisão, pois tal análise permite discriminar entre performances ótimas e mediocres. Deste modo, os valores observados para performances tipo-1 e tipo-4 sugerem que tais performances requerem maior mobilização energética quando comparados com os tipos 2 e 3. De fato, focalização, fadiga, e estresse são fatores associados com atividade simpática, e sobretudo com ativação eletrodérmica. Valores de frequência respiratória e posição corporal corroboraram os resultados obtidos para atividade eletrodérmica.


Deste modo, é possível que – além de atividade neural no momento exato do tiro – performances de excelência (i.e., ótima performance) também estejam relacionadas com padrões corticais de ativação nos segundos que antecedem um dado tiro ao alvo (vide atfield & Kerick, 2007).

**Conclusão**

Concluindo, os resultados do presente estudo corroboraram a visão de que performance funcional e possível mesmo diante da expressiva variabilidade comportamental, psico-fisiológica e cortical. Contudo, a análise da atividade simpática/parasimpática e cortical, considerando as proposições do modelo MAP, gerou novas pistas acerca de fatores neuro-biológicos relacionados
com o controle de ativação e performance. Novos estudos devem expandir tal análise, através da consideração de marcadores biológicos como o cortisol, de modo a aprimorar o entendimento da performance humana por meio de uma perspectiva multimodal e multidimensional.
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Action situation as a person-environment-task constellation. (Modified from Schack &amp; Hackfort, 2007)</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Actions are based on bio-psycho-social systems. New technologies are addressing mostly the manipulation of the bio-physical or the socio-ecological system to influence the mental status (psychic system) of the athlete.</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Emotion mediates skill and performance</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Five basic dimensions (penta-basis) of performance-related psychobiosocial states; adapted from Hanin 2007</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>Emotion and action control in performance optimization (modified from Hanin &amp; Hanina, 2009)</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Pedagogical model of proficient performance development (modified from Bertollo, 2007)</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Temporal dynamics of affective phenomena. (Adapted from Oatley &amp; Jenkins (1996); Vallerand &amp; Blanchard, 2000)</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>An example of functional profile within IZOF. Courtesy from Y. Hanin</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>Five basic dimensions of the IZOF Model (Adapted with permission from Hanin, 1997, p. 35)</td>
<td>22</td>
</tr>
<tr>
<td>10</td>
<td>IAPZ Hypothetical Arousal Profiles</td>
<td>25</td>
</tr>
<tr>
<td>11</td>
<td>Mental state in terms of challenge level and skill level, according to Csikszentmihalyi's flow model</td>
<td>29</td>
</tr>
<tr>
<td>12</td>
<td>Caracteristics of the psychological preparation in elite athletes (Hardy, Jones, Gould, 1996; modified)</td>
<td>33</td>
</tr>
<tr>
<td>13</td>
<td>Direct and indirect effect of mental and action control on task execution</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>Multi modal and multidimensional monitoring of Athletes</td>
<td>44</td>
</tr>
<tr>
<td>16</td>
<td>Methodologies available for neuroimaging and biological information obtainable from the living human brain.</td>
<td>48</td>
</tr>
</tbody>
</table>
Figure 17: Temporal and spatial resolution of neurotechnology

Figure 18: Electromyography during shooting

Figure 19. EEG monitoring on the field during practice

Figure 20. Neurobiological model of the distress circuit during reactive motor behaviour (adapted from Hatfiedl & Kerick, 2007)

Figure 21. Key features of the four types of performance derived from the interaction between performance and control levels as conceptualized within the multi-action plan intervention model.

Figure 22. Performers’ skin conductance level trend during the 5 s before the shot and the 3 s before the dart-throw for the four types of performance. The instant at which the shot/flight is released is marked as 0. Type 1 is optimal/automatic, type 2 is optimal/controlled, type 3 is suboptimal/controlled and type 4 is suboptimal/automatic

Figure 23. Performance categorization according to MAP model

Figure 24. Average ERD/ERS maps in the high alpha band (10-12 Hz) at shot release (t=0) and during the three seconds preceding it, categorized for the four types of performance. Color scale: maximum ERD and ERS are coded in Red and Blue, respectively.

Figure 25. Average ERD/ERS maps in the beta band (13-30 Hz) at shot release (t=0) and during the three seconds preceding it, categorized for the four types of performance. Color scale: maximum ERD and ERS are coded in Red and Blue, respectively.

Table 1. Selected Individual Characteristics of Four Performance Situations

Table 2. Descriptive statistics of hedonic tone, behavioural, and psychophysiological data for optimal-automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4) performances in the shooter and in the dart-thrower.

Table 3. Post-hoc LSD analysis of hedonic tone, behavioural, and psychophysiological data across the four performance categories (type 1 optimal-automatic, type 2 optimal-controlled, type 3 suboptimal-controlled and type 4 suboptimal-automatic).
# TABLE OF CONTENTS

| Acknowledgement                              | I    |
| Abstract                                      | III  |
| Resumo                                       | VII  |
| List of Figures and Tables                   | XI   |

**Introduction**

1

**Chapter one**

Towards a definition of Performance: Insights from Motor Behaviour and Sport Psychology

5

**Chapter two**

The Affect-Performance Linkage in Sports: An Overview

15

**Chapter three**

Optimal Performance: An Umbrella Term for Peak Experience, Flow, Optimal Functioning Zone, and Peak Performance,

27

**Chapter four**

Mental and Action Strategies to Optimize Performance: Multi-Action Plan (MAP) Model

33

**Chapter five**

Being in Zone: Psychophysiological Monitoring of Performance in Sport

43
Chapter six
Behavioural and Psychophysiological Correlates of Athletic Performance:
A Test of the Multiple-Action Plan Model

Chapter seven
Cortical Patterns of Shooting Performance Within the Multi-Action Plan
Model

Conclusion

References
During the last decades there has been a growing interest in theoretical and applied studies regarding the psychophysiological processes underlying performance in sports (Strack, Linden, & Wilson, 2011). Psychophysiological monitoring in sports consists in the assessment of activation and functioning levels of the organism. Noteworthy, psychophysiological measures allow for a multimodal understanding of mind-body interactions (Cacioppo, Tassinary & Bernston, 2007). In the sport domain, such measures are used to uncover the mediating mechanisms that underlie expertise acquisition and optimal performance. In fact, multimodal and multidimensional assessments across domains (e.g., motor behaviour, sport psychology, psycho-neurophysiology) permit to measure performance-related cognitive and emotional experiences.

Together with classical sport and exercise psychology methods, such as self-reports, behavioural data, and kinematic observations, psychophysiological techniques, including electrodermal activity recording (EDA), breath rhythm via piezo-based respiratory belts, electromyography (EMG), electrocardiography (ECG), and electroencephalography (EEG), may help to elucidate the entire spectrum of psychophysiological, cortical and behavioural features of performance. A multimodal approach can be useful to (1) identify athletes’ individual zones of optimal functioning, (2) develop performance enhancement guidelines based on bio- and neuro-feedback techniques, and (3) improve self-regulation skills that would inhibit choking under competitive pressure.

The psychophysiological, cortical, behavioural, and kinematic features of self-paced tasks (e.g., shooting, golf putting, dart-throwing, archery) have been usually studied either with a between-subjects approach by comparing the performance patterns
INTRODUCTION

of skilled performers vs. those of novices (e.g., Konttinen & Lyytinen, 1992; Goodman, Haufler, Shim, & Hatfield, 2009; Salazar, Landers, Petruzzello, Han, Crews, & Kubitz, 1990), or with a within-subjects approach by contrasting individual’s best and worst performance patterns (Guillot, Collet, Dittmar, Delhomme, Delemer, & Vernet-Maury, 2003; Kontinnen, Lyytinen, & Viitasalo, 1998; Tremayne & Barry, 2001). More recently, several authors have used an idiosyncratic probabilistic approach in the framework of the IZOF theory to investigate the relationship between performance and affect in different sports (Bertollo, Robazza, Falasca, Stocchi, Babiloni, Del Percio, … & Comani, 2012; Edmonds, Mann, Tenenbaum, & Janelle, 2006; Medeiros Filho, Soares Moraes & Tenenbaum, 2008).

The uni-dimensional categorization of performance (expert/optimal vs. non-expert/suboptimal) has been recently challenged by a 2x2 conceptualization in which performance is classified in terms of both performance level (optimal and sub-optimal) and action control (automatized and controlled). This two-dimensional conceptualization has led Bortoli and colleagues (Bortoli, Bertollo, Hanin & Robazza, 2012) to develop a Multi-Action Plan (MAP) intervention model for performance optimization in the framework of the IZOF theory (Hanin, 2000). The MAP model reflects the notion that different psycho-bio-social states underlie distinct performance-related experiences.

A fundamental aspect of the 2 x 2 framework, upon which the MAP intervention model is constructed, is the notion that optimal performance can occur also in conditions of distress, fatigue, and other unfavourable circumstances provided that the athlete is able to mindful accept the situation and engage in action- and/or emotion-focused strategies.

The multi-action plan (MAP) intervention model has been developed to help athletes attain optimal and consistent performance. Empirical evidence suggests that attentional focus, affective states, and psychophysiological patterns differ among optimal-
automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4) performance experiences (Bortoli et al., 2012).

The aim of the present dissertation is to investigate the behavioural, psychophysiological and cortical patterns related to Individual Zone of Optimal Performance within the MAP model. This understanding can help coaches and athletes to more efficiently reach peak performance and maintain optimal performance. Based on this new information, researchers will develop new biofeedback and neurofeedback interventions. Coaches and sport psychologist may combine it with psychological skill training to improve performance. Moreover it will permit to define properly cortical areas to investigate TMS and tDCS applications for performance optimization.

This dissertation is organized as follows:

- in Chapter 1 the features of performance are presented and discussed within the framework of motor behaviour and sport psychology;
- In Chapter 2 the relationship between affective states and performance in sports are introduced and some leading theories in this field are presented;
- In Chapter 3 the characteristics of the athletes when they reach peak performance are described, and the mechanisms through which they attain an optimal performance are explained;
- Chapter 4 is devoted to illustrate the MAP model that combine emotional/mental and action approaches to enhance performance;
- Chapter 5 is dedicated to describe the techniques, measures, instruments and methodologies useful to investigate the psychophysiological mechanisms underpinning performance in sport science;
INTRODUCTION

- In Chapter 6 the findings of the original research on the behavioural and psychophysiological correlates of athletic performance, obtained within the framework of the MAP model, are presented;
- In Chapter 7 the results of the original study of the cortical activation patterns in shooting performance are shown.
TOWARDS A DEFINITION OF PERFORMANCE:
INSIGHTS FROM MOTOR BEHAVIOUR AND SPORT PSYCHOLOGY

Performance is a complex phenomenon observed in people executing an action (skill), in a given context and under specific constraints, aimed at clearly defined goals. Action is strongly influenced by personal characteristics, such as physical conditions, capacities, motivation, anxiety, arousal level or, in more general terms, by a person’s physical, emotional, cognitive and mental states (Schmidt & Wrisberg, 2008). Movement patterns linked to an action are usually driven by underpinning coordinative structures and constraints, or by environmental features (Glazier & Davids, 2009; Davids, Button, & Bennett, 2008; Newell, 1986).

A basic action situation in applied sport settings consists of the following components: person, task, and environment (Newell, 1986; Schack & Hackfort, 2007; William, Davids, & Williams, 1999). This three dimensional approach allows for a more detailed understanding of every sport situation (see Figure 1).

![Figure 1. Action situation as a person-environment-task constellation. (Modified from Schack & Hackfort, 2007).]
Specifically, sport performance depends on the current physical and mental condition of the athlete (person), on the situational demand or the type of sport (task), and on the conditions under which the task is carried out. This may vary widely across training and competition (environment). From this perspective, actions are organized intentionally according to a person's subjective interpretation of a given person-task-environment constellation (action situation). Nonetheless, subjectivity does not imply full awareness of a person-task-environment interaction.

The assumption of intentionality in action theory has some important implications. First, it implies some kind of internal representation of the person-environment-task constellation. Second, it requires the formulation of a functional understanding of how intentions (ideas) find their path from the centre to the periphery\(^1\). Noteworthy, there are different cognitive tools (i.e., self-instructions) that forge an important link between intentions and external behaviour. Given that actions are embedded in systems (Schack & Hackfort, 2007), a holistic system-oriented perspective might be useful in promoting applied alternatives to conflicting ideas within the sport sciences domain.

Herein, we embrace the notion that an athlete should be primarily conceived as a bio-psycho-social unit (Figure 2). As a result, physiological processes (such as optimal arousal, regeneration or injury recovery) are also dependent on psychological and social framing conditions. The psychological system, on the other hand, is mutually influenced by both biological and social framing conditions. Importantly, the psychological system is capable of altering these framing conditions when degrees of freedom are added through goal-oriented action. Every action produces a specific type of performance associated with some standard or level of outcome.

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\(^1\) In the action regulation system, the brain/cognitive processes are regarded as the centre, and the muscles/body movements as the periphery
The role of a sport scientist is to help an athlete exploit additional degrees of freedom associated with optimal performance. For instance, learning how to cope with social stressors (spectators, mass media, etc.) are important in facilitating optimal performance experiences. However, it is also important to note that physiological variables (tiredness, stress, etc.) do not have a direct impact (in a deterministic way) on an athlete's performance. In fact, empirical evidence suggests that physiological variables are mediated by the psychological system (e.g. elite athletes may interpret increased heart rate either as beneficial or detrimental to performance according to individual level of functional arousal level). To this extent, psychophysiological tools can be used in the coaching process to monitor the psychic or bio-physical systems (emotions, motor skills or cognitive components) and, ultimately, improve athletic performance.

![Figure 2. Actions are based on bio-psycho-social systems. New technologies are addressing mostly the manipulation of the bio-physical or the socio-ecological system to influence the mental status (psychic system) of the athlete.](image)

Specifically, motor performance has been defined as the “observable production of a voluntary action, or a motor skill. The level of a person’s performance is susceptible to fluctuations in temporary factors such as motivation, arousal, fatigue, and physical conditions” (Schmidt & Wrisberg, 2008, p. 11). On the other hand, performance measures
indicate the details or specific characteristics of how a skill or action is produced (Lees, 2002) and this execution determine the following outcome.

Literature exists, based on both cognitive-behavioural and ecological-dynamical approaches, usually describes best and worst performance from an outcome point of view, forgetting the underpinning processes. More specifically, numerous scholars have focused on the psychophysiological, behavioural and kinematic features related to a common movement pattern, forgetting of common coordinative structures, and the idiosyncratic characteristics of elite athletes (Hatfield & Kerick, 2007; Temprado, Della-Grast, Farrell, Laurent, 1997; Zanone & Kelso, 1992)

In this regard, the Individual Zone of Optimal Functioning (IZOF) is a valid framework to investigate performance-related experiences, where emotions are the mediator between skills, effort, cognition, motivation and performance (Figure. 3).

![Figure 3. Emotion mediates skill and performance](image-url)
The idiosyncratic approach, developed by Hanin (2000), in which elite athletes are investigated using idiographic instruments, allows for consideration of psychobiosocial characteristics during optimal sub-optimal and non-optimal performance (Figure 4).

The five basic dimensions (pentabasis) of performance will be described in details in the next chapter.

![5 basic dimensions (penta-basis) of performance-related psychobiosocial states; adapted from Hanin 2007](image)

Recently, action-based approaches have been developed, advancing the traditional emotion centred intervention, into the framework of IZOF model; (Figure 5; Hanin & Hanina, 2009). Top-level athletes are highly skilled performers and their movement patterns (optimal and non-optimal) are usually automatic. Consequently, athletes are not fully aware of their movement patterns, and thus are unable to describe certain actions from both a conceptual and motor behavioural standpoint. In this context, the athlete’s
subjective description of the movement chain components and their interaction is defined as “individual optimal performance”.

Based on the definitions of performance presented above, two criteria are important in evaluating optimal performance as related to either a processual or outcome view. It should be noted that technique is a set of different motor execution mechanisms associated with the quality of an action. Optimal technique matches the context, task demands, and personal characteristics (constraints and available resources).

![Diagram of emotion and action control in performance optimization](modified from Hanin & Hanina, 2009)

From a different vantage point, dynamic systems theory has emerged in the movement sciences as a viable framework for modelling athletic performance. From this perspective, the human movement system is a highly intricate network of co-dependent sub-systems (e.g. respiratory, circulatory, nervous, skeletomuscular, perceptual) which are composed of a large number of interacting components (e.g. blood cells, oxygen molecules, muscle tissue, metabolic enzymes, connective tissue and bone). In dynamic
systems, movement patterns emerge through generic processes of self-organization found in physical and biological systems (see Chapter 7 of Williams, Davids, Williams, 1999 for an overview).

Dynamical systems theorists claim that the number of biomechanical degrees of freedom is dramatically reduced through the development of coordinative structures or temporary assemblages of muscle complexes (Turvey, 1990). The reduced dimensionality/complexity of the motor system encourages/antecedes the development of a functionally preferred pathway or "attractor" state which supports goal-directed actions. Within each attractor region (the “neighbourhood” of an attractor) a given system is highly ordered and stable, leading to consistent movement patterns for pre-specified tasks. Variation between multiple attractor regions, however, permits flexible and adaptive motor behaviour, allowing for free exploration of performance contexts by each individual (Davids, Glazier, Araujo, & Bartlett, 2003). The paradoxical relationship between stability and variability explains why skilled athletes are capable of both persistence/consistence and change in motor output during sport performance. Indeed, variability in movement behaviour allows performers to explore task and environmental constraints in order to enhance motor learning and acquire stable motor solutions. Handford, Davids, Bennett, Button (1997) provides a more detailed explanation of the stability-variability paradox in skill acquisition.

Moreover, using a humanistic perspective and according to Division-47 of the American Psychological Association, performance can be thought of as a noun or a verb. As a noun, it describes a discrete event where a performer (or performers) exhibits a specific set of developed knowledge, skills, and abilities (KSAs). Performance can also be a verb, when referring to the process of carrying out a plan of action for the execution
CHAPTER ONE: Performance definition

of KSAs during a performance event. Thus, performance assumes distinct connotations related to the use of knowledge, skills, or abilities (APA, 47 Division).

Altogether, performance is defined in terms of the competence exhibited by a performer striving for excellence. Different levels of proficiency can be observed and measured for a given performance trial. As Aoyagi and Portenga (2010) posited, “successful performance requires both the development and mastery of KSAs and the capability to consistently and reliably deliver (i.e., perform) KSAs at the time of performance” (p. 254).

Therefore, according to this definition, performance entails the (a) development of context-specific knowledge, skills, and abilities over time and, (b) recollection and use of KSAs during a discrete performance event. Furthermore, performance encompasses working towards a goal, which is usually measured against some standard of success.

There is also an expectation for how KSAs are retrieved and implemented during moments of action. Hence, the execution of KSAs is usually evaluated by the performer and various others actors (e.g. coaches). Additionally, expert performance involves a deliberate, effortful and public investment over extensive periods of time (Ericsson, 2007) Also noteworthy, performers rarely develop the appropriate KSAs or execute them at performance events in isolation. Typically performers have teachers or coaches, along with teammates, co-performers, and audience members.

The processes involved in the development of proficient performance have been investigated in Physical Education contexts (Bertollo, 2007) and the model is synthesized in Figure 6.

Attitudes, moods, and personal dispositions affect performance, as well as the psycho-bio-social states that tempered the action execution which is also modulated/moderated by environmental constraints. Proficient performance results from
practice aimed at refining action mechanisms and learning cues through cognitive-, dynamic-, or ecological-oriented training approaches. They permit the transfer of skills in a real applied environment, or the dynamic phase transition from the skilled state to the expert, mastery competent state. This switch is led by some order parameters, such as movement phase transition, under the constraints of the control parameters, such as movement frequency rate. Mental and action-oriented coping strategies are also valuable tools linked to expert performance development and meta-cognitive (i.e., five step strategies; Singer, 1988) understanding of person-environment-task interactions.

Cognition is the process used to improve competence in a specific performance based on knowledge, and facilitate the understanding of the entire process aimed at the development of expert proficient performance.

Figura 6. Pedagogical model of proficient performance development (modified from Bertollo, 2007)
This model advocate the multimodal and multidimensional assessment to measure and evaluate performance, monitoring during training, practice and competition the efficacy of the different mechanisms involved in task execution aimed to develop, enhance and optimize proficient peak performance.
THE AFFECT-PERFORMANCE LINKAGE IN SPORTS: AN OVERVIEW

The relationship between affective states and performance in sports has been addressed by numerous scholars (Ekkekakis & Petruzzello, 2000; Hanin, 2000; Robazza, Bortoli, Nougier, 2002; Laborde, Raab & Dosseville, in press). To this extent, there is a general agreement that specific affective states are more or less likely to be associated with optimal, moderate and poor performance levels (Hanin, 1997). Despite consensus on the affect-performance linkage, it is important to clarify the epistemological roots of the affective phenomena, as particularly related to emotional and mood fluctuations (Ekkekakis, 2009). In fact, affective states, moods, and emotions are related yet distinct theoretical phenomena. The distinction between affect, emotions, and mood states is briefly reviewed next. Subsequently, leading instruments used to examine affect, mood, and emotional responses in sports are presented. The Individual Zones of Optimal Functioning, a leading framework in sport psychology, is presented. The Individual Affective Probabilistic Zones estimation method is also reviewed.

Affect, Mood and Emotions: A Conceptual Synopsis

Affect comprises a wide range of psychological states, which includes both mood and emotional responses (Ekkekakis, 2009) (see Figure 7). The core affective phenomena is viewed as a comprehensive psycho-bio-social experience which can be defined as “a neurophysiological state consciously accessible as a simple primitive non-reflective feeling most evident in mood and emotion but always available to consciousness” (Russell, Feldman, & Barrett, 2009, p. 104). Of particular importance, core affect is a constant rather than sporadic or reactive experience. The two main dimensions of affect include pleasantness and arousal levels, which are considered essential descriptors of core
human affective experiences (e.g., pleasure, displeasure, relaxation, tension, energy, and tiredness) (Russell, 1978; 1979).

Emotional experiences are not broad and permanent as the notion of core affect portrays (Lazarus, 1991). Although a well-established definition of emotion is not available to date, Dess (2010) presents emotion as a “relatively brief episode of synchronized evaluative physiological, behavioral, and subjective responses” (p. 3). In essence, emotional experiences represent a reaction to something or someone, and usually involve subjective cognitive appraisal (Mulligan & Scherer, 2012). Accordingly, different cognitive appraisals (to a same given situation) may elicit highly idiosyncratic emotional responses (Lazarus, 2000). For instance, an athlete may perceive a capacity crowd as positive, thus experiencing pride; whereas another athlete may fear a crowded stadium. Also noteworthy, emotions motivate behavior, and influence communication patterns, social interaction, learning and memory (Eccles et al., 2011). Finally, emotional episodes involve physiological fluctuations such as increased heart-rate and skin-conductance responses (Morris, 2005).
On the other hand, mood represents a broad (rather than specific) internal state which is also extended in time (LeUnes & Burger, 2000). Simply put, mood states (e.g., depressive mood) are longer than emotional responses. From a conceptual standpoint, mood can be defined as “a group of persisting feelings associated with evaluative and cognitive states which influence all the future evaluations, feelings and actions” (Amado-Bocca, Donnet, Olié, 1993). Also noteworthy, there is empirical evidence suggesting that mood is a byproduct of negative and positive affect (Watson & Tellegen, 1985). In this regard, researchers have used different methods to identify and capture mood, as well as core affective and various emotional states associated with optimal and poor performance in sports.

**Measurement Tools**

Various psychometric instruments have been used to assess affective, emotional and moods states related to optimal and less-than-optimal performance in sports (Ekkekakis, 2009). Of particular importance, The Profile of Mood States (POMS) is one of the most well-known instruments in the domain of sport and exercise psychology (LeUnes & Burger, 2000). The Positive and Negative Affect Schedule (PANAS) is also a pervasive measure adopted by various scholars within and outside the sport sciences realm (Leue & Beauducel, 2011). Furthermore, The Affect Grid (Russell, Weiss, & Mendelsohn, 1989), and single-item measures of affect (e.g., self-efficacy specific measures) are commonly adopted by researchers interested in the relationship between affective experiences and performance in sports. Finally, bio and neurofeedback methods have also been used to assess affect, mood states, and emotional responses.

One of the most popular self-report measures in the domain of sport and exercise psychology, the POMS assesses six dimensions of affective experience (i.e., tension,
depression, anger, vigor, fatigue, confusion) (see Prapavessis, 2000). The popularity of this instrument is closely related to the “iceberg profile”, which emerged from findings suggesting that successful performance resembles an iceberg shape corresponding to (1) low scores in tension, depression, anger, fatigue and confusion, and (2) high scores in vigor (i.e., tip of the iceberg). A major criticism of the POMS pertains to the fact that only vigor is a measure of positive affect. Indeed, all the other scales represent negative affect experiences most likely because the POMS was originally conceived as a clinical tool (Renger, 1993). Despite this well-acknowledged limitation, the POMS remains a widely used instrument given its pervasive use in previous studies and continues to elicit research questions on the relationship between moods states and performance in sports.

The PANAS is subdivided in two statistically orthogonal dimensions which represent positive and negative activation, respectively. In particular, the PANAS is a 20-item questionnaire with 10 descriptors for positive activation (e.g., serenity), and 10 descriptors for negative activation (e.g., hostility) (see Watson, Clark, & Tellegen, 1988). In essence, the PANAS comprises a list of adjectives in which individuals report how they feel before, during or after competition (Crawford & Henry, 2004). Overall, although affective experiences are idiosyncratic in nature (Hanin, 1997), positive activation is hypothetically linked to better performance. Of note, a major limitation of studies utilizing the PANAS is epistemological in nature. Specifically, the PANAS represents a mixture of moods, emotions and core affect, thus hindering a robust theoretical interpretation of human affective experiences (Crook, Beaver, & Bell, 1998). Notwithstanding this limitation, the PANAS has been continuously used in studies in both exercise behavior and athletic performance as its single-item display seems to be relatively easily understood by exercisers and athletes (Hanin, 2007).
The Affect Grid (Russell et al., 1989) subscribes to the Circumplex Model of Affect which reflects the notion that pleasure and arousal are essential components of human affective experiences (Russell, 1980). Specifically, this model posits that affect can be organized into two orthogonal dimensions: pleasure-displeasure and degree of arousal (i.e., low-high arousal continuum). In this regard, Russell (1983) has also presented research suggesting that pleasure and arousal are global, pancultural descriptors of affect. A criticism of the affect grid pertains to its inability to discriminate among various qualities of affective experience (Killgore, 1998). Despite this limitation, the Affect Grid remains a popular tool as it is a quick and simple measure of affect, thereby (a) offering advantages over instruments with numerous and complex items, and (b) being appropriate to use repeatedly, such as in longitudinal studies (Filho, Moraes, & Tenenbaum, 2008). In fact, Acevedo and Ekkekakis (2006) claimed that the Circumplex Affect Model has received the most extensive amount of research in the affective psychological field.

Single-item measures are also popular tools used to assess affective experiences in sports. Single-item measures are usually developed by a group of researchers through peer-debriefing meetings and consultation with experts. An obvious advantage of single-item measures refer to the ease of data collection, especially in ecological settings during moments of action (i.e., in event). A major disadvantage pertains to its legitimacy, which is usually limited to face-validity. It is important to note, however, that single-measures grounded in sound theory may indeed inform research within the sport and exercise sciences domain. To this extent, Bandura’s (1997) recommendation on developing single measures items for assessing self-efficacy has been widely adopted and well-acknowledged in the literature of performance psychology in general, and sport and exercise psychology in particular.
Finally, bio and neurofeedback methods have also been used to assess affective experiences. Commonly utilized biofeedback methods include, but are not limited to, heart rate variability, skin-conductance response, and breathing patterns (Acevedo & Ekkekakis, 2006). Neurofeedback methods in sport psychology are primarily related to electroencephalography given that other measurement tools prohibit large scale movement patterns (Nakata, Yoshie, Miura, & Kudo, 2010). Noteworthy, bio and neurofeedback methods have been particularly implemented through the Individual Zones of Optimal Functioning Framework. This framework has served as the basis for various studies on affect, mood states, and emotional responses given its applicability in explaining optimal and less than optimal performance in sports. In chapter five we will see the psychophysiological monitoring tools in detail.

The Individual Zones of Optimal Functioning

The IZOF and other various models have been proposed to explain the link between athletic performance and affective experiences (Hanin, 2007). For instance, for many decades, the Yerkes and Dodson’s inverted-U hypothesis (1908) was used to explain athletic performance, as a function of arousal levels. Other well-known models depicting the influence of affect and emotions on performance in sports include the (a) *Drive Theory* (Hull, 1943), (b) *Catastrophe Model* (Hardy & Fazey, 1987), and (c) *Multidimensional Anxiety Theory* (Martens, Burton, Vealey, Bump, & Smith, 1990). Although conceptually appealing, these frameworks are nomothetic in nature, thus misrepresenting the idiosyncratic nature and complexity of affective experiences. The IZOF model, on the other hand, reflects the notion that affective experiences have idiosyncratic meanings, intensities, and functions associated with successful, average and poor athletic performance (Hanin, 1997; Hanin, 2000). Furthermore, this framework emphasizes that affect, mood states, and emotional responses (above and beyond pre-
competitive anxiety) should be examined in order to gain a deeper understanding of the psychological functioning of athletes competing in various sports. As a result, the IZOF model is considered a leading framework in evidence-based applied sport psychology (Robazza, 2006).

A central belief in the IZOF theory is that optimal emotions, which are related to the best internal conditions and best performance, are highly idiosyncratic within and across different sports (Hanin, 1997; 2000). This assumption has been confirmed in empirical studies (Hanin & Syrjä 1997; Ruiz & Hanin, 2003), and proved the usefulness of an idiosyncratic approach to the understanding of affect-performance linkage in sports (Figure 8).

![The IZOF “iceberg” emotional profile](image)

Figure 8. An example of functional profile within IZOF. Courtesy from Y. Hanin

Noteworthy, the IZOF model has been recently adapted to represent a pentagram paradigm in which optimal performance is considered in terms of the following theoretical dimensions: (a) content, (b) intensity, (c) time, (d) context, and (e) form (see Figure 9).
The content dimension reflects the idea that athletes’ emotional experiences are organized according to their hedonic and functional tones as follow: (a) functional and pleasant emotions (P+); (b) functional and unpleasant emotions (N+); (c) dysfunctional and pleasant emotions, (P-); and (d) dysfunctional and unpleasant emotions (N-). Noteworthy, negative emotions are not always detrimental for performance, and positive affective states are not always beneficial. Perhaps more importantly, optimal performance is dependent upon a “match” (i.e., “the matching hypothesis”) between task demands and energy generation and utilization. In contrast, poor and dysfunctional emotions are the result of insufficient generation, or inefficient energy use (Hanin & Stambulova, 2002; Hagtvet & Hanin, 2007; Robazza & Bortoli, 2003).

The intensity dimension comprises the “in-out of the zone” notion which is a core concept in the IZOF framework. According to Hanin (1997), each individual has a specific intensity range of affect which is associated with optimal performance (Hanin, 2000). Accordingly, an athlete shall attain peak performance when s/he falls inside her/his optimal zone; otherwise, s/he shall perform poorly. Average performance is expected not
only when an athlete falls outside her/his optimal zone, but also when s/he falls outside her/his poor zone. Less successful athletes tend to remain closer to their poor zones, when contrasted with their more successful counterparts (Hanin & Syrjä, 1996).

The idea of optimal states is also related to the time dimension, which refers to the dynamics of affective experiences before, during or after performance (Hanin, 1997; 2000; Robazza, 2006). The notion of time also comprises the frequency of poor, average and optimal performance reported by an athlete during a specific period of time (e.g., a season, a week). In general, the assessments of athletes’ subjective experiences were mainly limited to prior and post competition emotions (Eubank & Collins, 2000). Recently, however, there have been studies capturing athletes’ “on the fly” affective experiences (during competitions) (see Filho et al., 2009; Johnson, Edmonds, Moraes, Filho, & Tenenbaum, 2007). Results suggest that athletes progress through different momentums, experiencing optimal and less-than-optimal performance, within a single competition day (Pellizzari, Bertollo, & Robazza, 2011).

The context dimension includes environmental aspects related to situational emotional, and performance patterns, within and between subjects’ analyses, intra and inters group approaches, and cross-cultural studies. Although contextual studies in light of the IZOF framework are still rare, there is evidence suggesting that individual psychobiosocial affective patterns are influenced by contextual factors. For instance, archers’ psychophysiological states were found to differ in practice and competition (Robazza, Bortoli, & Nougier, 2002), and in respect to target distances (e.g., 30, 50, 70 m) and competition venue (outdoor vs. indoor) (Johnson et al., 2007).

The form dimension reflects the notion that athletes manifest their subjective affective experiences through various “outlets”, such as cognitive, affective and bodily-somatic. In particular, at least seven “different channels” (i.e., cognitive, affective,
motivational, bodily-somatic, behavioral, performance, and communicative) have been found to be linked to performance in sports (Ruiz & Hanin, 2003). Hanin (2010) added an eighth modality named volitional. Noteworthy, affective and cognitive connotations have been reported as the most common descriptors of optimal performance experiences (Ruiz & Hanin, 2004). Other studies related to the form dimension were particularly aimed at bodily-somatic reactions and performance patterns (Robazza & Bortoli, 2003; Robazza, Pellizzari, & Hanin, 2004). Collectively, these studies support the overarching notion that individuals have highly idiosyncrasy autonomic responses, and that bodily-somatic symptoms can distinguish successful and less successful performers. Also pertinent to the study of psychobiosocial affective states, is the relatively recent proposal of the Individual Affective Performance Zones (IAPZ). Functional impact of psychobiosocial states was investigated within the framework of the IZOF model and the directional perception approach (Robazza, Pellizzari, Bertollo, Hanin, 2008). Findings provided support for the predictions stemming from both the IZOF model and the directional approach, as well as help in interpreting direction of anxiety and other idiosyncratic emotions within the IZOF framework. Athletes tended to perceive emotional levels approximating an individual’s optimal zone as facilitative–pleasant, and emotional levels approximating an individual’s dysfunctional zone as debilitative–unpleasant.

**IZOF probabilistic approach: Individual Affective Performance Zones (IAPZ)**

The probabilistic approach was initially introduced by Kamata, Tenenbaum, and Hanin (2002) in an attempt to increase the reliability of one’s zone of optimal performance through the use of logistic probability curves rather than descriptive statistics or graphics and later defined IAZP (see Figure 10). This probabilistic account of athletic performance, as a function of affect and physiological markers, has received
considerable attention in recently published literature within the sport psychology domain. For instance, Golden, Tenenbaum, and Kamata (2004) studied tennis players and observed that each athlete exhibited highly unique probability curves representing different likelihoods of optimal, moderate and poor performance. Furthermore, Cohen, Tenenbaum, and English’s (2006) study illustrated the applicability of this approach, in which collegiate golfers had their IAPZs determined and subsequently used as a framework for mental training sessions. More recently, a series of studies with elite archers reinforced the utility of the IAPZ approach in (a) capturing “on the fly” affective patterns associated with optimal performance in sports, and (b) informing intervention programs aimed at increasing one’s maintenance within her/his optimal performance zone.

Figure 10. IAPZ Hypothetical Arousal Profiles
Other studies with different sports echo the theoretical and applied value of the IAPZ approach, which extrapolates its inherently probabilistic nature. In fact, Kamata et al.’s (2002) IAPZ framework allows for ecological, real-time assessments during moments of action. This ecological approach is possible because the affective-performance curves are based on the aforementioned Affect Grid which, again, is of easy and quick administration. Despite these advantages, the IAPZ approach may still be advanced towards a more holistic probabilistic model, taking into consideration the simultaneous influence of multiple factors (i.e., predictors) and their potential interrelationships. On this note, a recently proposed model, adding brain imaging to the well-established IZOF theory and IAPZ probabilistic estimation, may offer further insights on the intricate affect-performance relationship in sports. This Multi-Action Plan (MAP) model will be presented in the chapter four.
CHAPTER THREE: Optimal performance

OPTIMAL PERFORMANCE: AN UMBRELLA TERM FOR PEAK EXPERIENCE, FLOW, AND OPTIMAL FUNCTIONING ZONE

Peak performance is also known as peak experience, “the zone” of optimal functioning, and flow-feeling. It refers to the very moment an athlete is in the zone, when everything flows, and when exceptional performance is experienced. Some say that peak performance is the ultimate goal of the prototype of ideal human existence (Privette, 1981; Jackson & Roberts, 1992). Unfortunately, peak performance is rare and may even be involuntary (Williams & Krane, 1993).

Kimiecik and Jackson (2002) proposed “optimal experience” as a useful umbrella term for classifying positive states in sport. This term subsumes parallel or overlapping concepts such as (a) peak experience—a momentum characterized by feelings of fulfilment and happiness of highest happiness and fulfilment (Ravizza, 1977); (b) flow—a completely absorbing and rewarding experience (Jackson & Csikszentmihalyi, 1999); and (c) peak performance—optimal or outstanding performance levels (Privette, 1981). In a review of the psychological characteristics of peak performance, Krane and Williams (2006) reported that athletes are able to learn and improve psychological skills and strategies through training by enhancing productive and controlling unproductive mental states.

Peak Experience

Although the concepts of peak experience and peak performance are viewed as synonymous, it is important to distinguish between them to prevent a misunderstanding of the construct of peak performance. Therefore, the distinction between peak experience and performance proposed by Privette and Bundrick (1991) will be employed in this chapter. These authors suggested that peak performance and peak experience are positive
extremes of performance and feeling, respectively. Peak experience describes the upper limits of joy and positive feeling, whereas peak performance involves optimal functioning. Thus, although peak experience and peak performance are not seen as mutually exclusive, they are described as distinct phenomena.

Ravizza (1977, 1984) observed that peak performance in sports is short in duration, and temporary; non-voluntary and not induced at will; and, unique and not necessarily associated with a successful outcome. He also found that mastering the basic skills of a given sport is a pre-condition of peak experiences which are characterized by (a) focus on the present moment, (b) effortless merging of action and awareness, (c) loss of personal ego, sense of control, and (d) clear feedback, and an intrinsic reward system. Athletes recalled these special moments during sport participation as salient, highly valued and extremely meaningful.

Flow

First definitions of flow describe a state in which people are highly involved with an activity that nothing else seems to matter (Csikszentmihalyi, 1990). Flow may be the basis for intrinsically motivated experiences (Csikszentmihalyi, 1985) or a precursor of the psychological processes underlying peak performance (Stein, Kimiecik, Daniels, & Jackson, 1995). Jackson and Csikszentmihalyi (1999) described flow as an optimal mental state that involves total absorption in the task or activity, which is characterized by a sense of self, full focus, complete involvement, a loss of personal ego, and total confidence. Jackson (1991) also noted that athletes’ descriptions of peak performance is consistent with those characteristics of flow. Flow may be required as a foundation upon which peak performance may occur, but it is not the same as peak performance; hence, you can experience flow but not peak performance.
Flow may be an underlying element in the development of peak performance states. Csikszentmihalyi (1975) posited the original definition of flow as an autotelic state of consciousness, particularly present when people are (1) engaged in an activity they enjoy, and (2) functioning at their fullest capacity. He further suggested that flow involves the centering of attention, total immersion in the activity, clear demands for action, unambiguous feedback, merging of action and awareness, feelings of being in control, and intrinsic rewards. Csikszentmihalyi posited that flow occurs when there is a perceived balance between one’s competencies and the demands/challenges imposed by/of a task. It is this balance between ability and demand that may “free” athletes from concerns about the outcome, and enable them to totally immerse themselves in the activity, which brings about the potential for human performance (Csikszentmihalyi, 1975). Csikszentmihalyi (1975) observed that two critical elements may contribute to the creation of flow in an individual. They are perception of ability and challenge. He suggested that flow is more likely to arise when individuals perceive their ability is sufficient to meet the challenge of achieving a goal or performing a task (Figure 11).

Figure 11. Mental state in terms of challenge level and skill level, according to Csikszentmihalyi's flow model
Further, he hypothesized that a state of flow is a necessary precursor for athletes who elevate themselves into a state of peak performance, or that athletes are in a state of flow during peak performance.

**Peak Performance**

Several definitions of peak performance are given in the literature. Maslow (1962) originally introduced this concept to explain an individual experiencing feelings of total unity, inner strength, and wholeness of being in his/her context hierarchical needs. Peak performance has also been defined as a state of superior functioning which characteristics are focused attention, lack of concern with outcome, effortless performance, perception of time “slowing down”, and a feeling of supreme confidence (Brewer, Van Raalte, Linder, & Van Raalte, 1991). Furthermore, Privette (1983) defined peak performance as behaviour which exceeds one’s average performance, or an episode of superior functioning. All the definitions of peak performance reviewed herein are consistent in presenting peak performance as a state of optimal or exceptional functioning. Thus, I propose that a synthesis of the various definitions of peak performance would yield the following definition: Peak performance is a state of exceptional functioning. An examination of the characteristics of peak performance, however, may allow for the development of a better understanding of the concept.

Several authors have examined the psychological characteristics present during peak performance states (see for review Harmison, 2006). These results were usually obtained by asking athletes to recollect their experiences, perceptions, and feelings during exceptional moments in sport. A number of characteristics seemed to be reported by various athletes. Some interesting trends emerge from the reading of literature: a) Feelings of being in complete control; b) effortless/automatic performances; c) a narrow
According to all these reports, athletes should develop and use mental skills, coping strategies, precompetitive and performance behaviors to reach self-control of internal processes, such as thoughts, emotions, and bodily reactions, in an attempt to create an ideal performance state. These premises are appealing for elite-level athletes who strive for excellence, and there is empirical evidence corroborating the beneficial effects of interventions for athletic performance enhancement (for reviews, see Greenspan & Feltz, 1989; Martin, Vause, & Schwartzman, 2005). However, Gardner and Moore (2004) noted that the same authors describing and encouraging the use of psychological skills training to regulate mental and emotional states. They are also critical about the inconclusive empirical support for such approaches (e.g., Gould, Damarjian, & Greenleaf, 2002; Williams & Leffingwell, 2002). Actually, peak performance and related states are often elusive, present themselves on rare occasions, and tend to be ephemeral despite the athletes’ levels of mental skills and their efforts to control and reinstate them.

The equivocal empirical support for the effectiveness of traditional methods towards self-control of internal states, decrease of negative emotions, and increase of positive cognitions and confidence levels, lead Gardner and Moore (2004, 2007) to advocate a Mindfulness-Acceptance-Commitment (MAC) to athletic performance enhancement. Aligned with clinical models of acceptance and commitment (Hayes & Smith, 2005) and mindfulness-based cognitive therapy (Crane, 2009), MAC approach interventions emphasise mindful acceptance. This attitude involves non-judgmental and present-moment awareness of both internal experiences and external stimuli rather than attempts to direct change, suppress, or control cognitive and affective experiences. Gardner and Moore also proposed that the traditional, control-based approaches to
athletic performance enhancement may inadvertently probe excessive cognitive (verbal-semantic, self-focused) processes rather than meta-cognitive (in-the-moment, nonjudgmental) activity, thus resulting in impaired ability to automatically engage in well learned athletic skills, to appropriately respond to environmental cues, and to maintain task-relevant focus. Hence, in addition to interventions aimed at assisting performers achieve optimal states, alternative methods have been proposed to help individuals accept negative (i.e., unpleasant) states and perform optimally in despite of their condition. There is a growing body of research investigating how athletes can be more mindful of their emotional experiences and subsequently act and perform optimally while still experiencing uncomfortable internal states (see Moore, 2009).

The above arguments also concur with the Individual Zones of Optimal Functioning (IZOF) model initially developed by Hanin (1978), and introduced in the previous chapter, to account for both facilitative and debilitative effects of anxiety on performance, and later extended to emotional states (Hanin, 2000, 2007). In essence, the IZOF model proposes that each performer experiences a specific content and intensity range of pleasant and unpleasant emotion-related psychobiosocial states that can be either functional or dysfunctional for performance. It is important to note that within the IZOF framework unpleasant emotional states, such as anxiety and rage, are viewed not only as debilitative for the task but also facilitative. In general, pleasant and unpleasant emotional states of different intensity were found to exert beneficial, detrimental, or both effects on performance, depending on their idiosyncratic meaning and intensity (for reviews, see Hanin, 2000, 2007; Robazza, 2006). In the next chapter I’m going to introduce the action focused approaches useful in optimizing performance and specifically the Multi-action Plan model developed by Bortoli and colleagues (2012).
MENTAL AND ACTION STRATEGIES TO OPTIMIZE PERFORMANCE:
MULTI-ACTION PLAN (MAP) MODEL

Psychological preparation in sport have a long tradition and psychological skill training have been implemented for a long time. In chapter one, we have described and analyzed the complex features of performance, reviewing the affect-performance linkage in chapter 2, and going inside to the psychological characteristics of elite performers in chapter 3. In this chapter we analyze the strategies that athletes use to reach and maintain optimal performance, presenting a new intervention model that combines emotion and action strategies to cope with distress.

Hardy, Jones and Gould (1996) defined a conceptual framework in which they combined the different demand of the system to reach peak performance. In their conceptualization nowadays we can add the recent insight derived from the literature about the combined use for performance optimization of action and emotion centered coping strategies (Figure 12).

![Figure 12. Characteristics of the psychological preparation in elite athletes (Hardy, Jones, Gould, 1996; modified)](image)

Emotion/mental-centered and action-centered profiling are suggested as two interrelated approaches to optimization of athletic performance in high-achievement sport
Individualized emotion-centered profiling provides the assessment tools within the framework of the IZOF model. The major focus in these assessments is on subjective and personally meaningful performance-related emotional experiences described by self-generated emotion descriptors. The approach is based on the analysis of the athletes’ past performance history and their awareness of the current situation.

The action-centered profiling was proposed for subjective description of movement sequence as perceived by the athlete within the framework of the Identification-Control-Correction (ICC) program (Hanin & Hanina, 2009). This approach provides a tool for dealing with inconsistency of athletic performance (instability of technique, a “lost move syndrome”, and “habitual” performance errors) and substandard performance under competitive stress.

Both mental/emotional and action centered approaches are based on the Individual Zones of Optimal Functioning (IZOF) model (Hanin, 2000, 2007) and include several assumptions:

1. Optimization as a process is multi-modal and not limited only to “cognitive and behavioral efforts”. Its targets involve motivation-centered, volition-centered, bodily-centered, action-centered, and communication-centered.
2. Optimization is not limited to managing negatively-toned emotions because some negatively-toned emotions are not always detrimental for athletic performance. On the other hand, some positively-toned emotions are not always beneficial for all performers.

3. The distinction between state-trait-meta experiences is helpful in the selection of effective coping strategies. State-like emotion intensity (optimal, dysfunctional, and actual) is first identified; trait-like emotion patterns indicate if they can be potential barriers to coping. Finally, meta-emotions as attitudes about experiencing specific emotions suggest if re-framing of existing attitudes (meta-experiences) is needed.

4. Emotion-centered approach uses a set of mental skills directed at the optimization of emotional states by maximizing impact of optimal emotions and minimizing harmful effects of dysfunctional emotions. As a result, the probability of random and habitual errors is reduced, however, disrupted performance may trigger dysfunctional emotions and then the action-centered approach could be more effective.

5. Action-centered profiling within the framework of the Identification-Control-Correction (ICC) program (Hanin & Hanina, 2009) provides a tool for dealing with inconsistency of athletic performance (instability of technique, a “lost move syndrome”, and “habitual” performance errors under competitive stress. Usually the optimization of action process triggers functionally optimal emotions with reactive coping targeted on current or past experiences and anticipatory coping focused on the future performance development.

6. Emotion-centered and action-centered approaches in high achievement sport represent a comprehensive program of optimization of athletic performance.
These two inter-related approaches are practitioner-oriented, enhance cooperation between athletes, coaches, and sport psychologists, and thus provide a framework and tools for consistent excellence.

To conclude, emotion-centered strategies serve to optimize performance process, whereas optimization of athletic performance affects the action process. Emotion-centered and action-centered coping in high achievement sport represent a comprehensive program of optimization of athletic performance. These two approaches are practitioner-oriented and enhance the cooperation between athletes, coaches, and sport psychologists in order to enhance and optimize performance.

Identification-Control-Correction Program

Embedded within the IZOF framework, Hanin and Hanina (2009) have recently developed an Identification-Control-Correction (ICC) programme aimed at optimizing performance levels and consistency of elite athletes. It was based on action-focused strategies, differently from the traditional IZOF intervention strategies emotion-focused to optimize. According to Hanin and Hanina “Research and anecdotal evidence suggest that a serious barrier to Olympic success refers to the inconsistency and unpredictability of their performance in major competitions, especially due to unexpected technical difficulties. This widespread phenomenon is usually manifested in: (a) instability of technique and a failure to consistently deliver expected results; (b) a sudden “breakdown” (or a “loss”) of skill; and (c) “habitual” performance errors under competitive stress.” (Hanin & Hanina, 2009; p. 47).

Conceptually, the ICC programme is based on the notion that the motor task is represented in memory as a movement sequence (“chain”) in which core components (“key points”) influence each other, ultimately leading to optimal or non-optimal results.
Movement patterns associated with optimal performance in top-level athletes are self-referenced and therefore could be dissimilar to an “ideal” pattern derived (e.g., a biomechanical analysis of a sample of performers). In addition, optimal and non-optimal movement patterns of highly skilled performers are usually executed in an automatized, instinctive-like manner that often precludes full awareness on the part of the individual.

The ICC program enables performers to become aware and identify their key points in the chain associated with effective and ineffective outcomes, and those functional links linking the key points which mediate performance outcomes. Enhancing the athletes’ awareness of their idiosyncratic core components is expected to increase movement control and self-confidence in practice and competition. At the end of the intervention, the action pattern is re-automatized and performers can simply “supervise” the correct execution of their key points in the movement chain.

Grounded on the action and emotion control approaches Bortoli, Bertollo, Hanin & Robazza (2012) have developed an integrated model to help athletes to attain optimal performance labelled Multi-Action Plan intervention model (MAP).

**The Multi-Action Plan Model**

The multi-action plan (MAP) intervention model has been developed to help athletes attain optimal and consistent performance. The MAP conceptualization originates from different theoretical views discussed in the previous chapters. These include the optimal experience framework, the mindfulness-acceptance-commitment based approach, the individual zones of optimal functioning model, and the identification-control-correction program. The MAP model identifies four performance categories deriving from the interaction of optimal/suboptimal and automatized/controlled performance dimensions (Figure 14).
In an optimal/automatized (type 1) performance state, the athlete experiences high levels of physical and mental energy, and tends to execute actions in an effortless, smooth, and consistent manner. Competitive stress, fatigue, or unexpected performance difficulties can enhance the performer’s attention to movement execution and reinvestment in conscious processing, thereby leading to disruption of movement automaticity and, ultimately, decreased (type 3) performance. Poor (type 4) performance can also occur in conditions of low task involvement and, consequently, ineffective movement coordination. Finally, distress, fatigue, or unexpected events can trigger functionally optimal states and action-tendencies, provided that the athlete is able to “mindfully accept” his or her state, focus on the individual’s core components of the action and, therefore, enter in an optimal/controlled (type 2) performance state.

Similar to the IZOF and IAPZ frameworks, the multi-action plan (MAP) is an idiographic rather than nomothetic account of psycho-bio-social states underlying different performance experiences. Nonetheless, the MAP model is unique in considering
the interaction of affective experience with cognitive workload from a multi-modal standpoint (e.g., behavioural, kinematic, neurological analysis). In particular, the MAP model reflects the notion that athletes’ awareness of their idiosyncratic core components linked to optimal performance varies as a function of attentional control and affective experiences as measured by physiological (e.g., skin conductance responses) and behavioural markers (e.g., kinematic analysis). Noteworthy, initial empirical evidence supports the notion that attentional focus, affective states, and psycho-physiological patterns differ among optimal-automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4) performance experiences (Bortoli, Bertollo, Hanin, & Robazza, 2012).

In particular Optimal/instinctive-like performance (type 1) is typified by an optimal experience. The performer feels self-confident, in complete control of the situation, having high levels of physical and mental energy, and capable of directing energies towards the achievement of a task. As a consequence, the movement appears effortless, smooth, autonomous, and consistent (Ericsson, 2003; Hanin, 2000; Harmison, 2006; Jackson & Csikszentmihalyi, 1999). This ideal state, can be easily disrupted as a consequence of competitive stress, fatigue, unpredictable events, or unexpected performance problems. Performance can drop from optimal to suboptimal (type 3). In such unfavourable conditions, athletes tend to try to suppress unwanted thoughts and unpleasant emotional reactions, overly focusing on movement execution in an attempt to solve problems and correct mistakes. A task-irrelevant focus of attention (i.e., negative thoughts and emotional responses, external distractions) and a conscious processing of a skill is thought to replace meta-cognitive task-relevant attention and functional goal-directed behaviour (Wegner, 1994). Distraction and an excessive reinvestment in controlled processing can undermine fluidity and automaticity (Maxwell, Masters, &
Eves, 2000; Oudejans, Kuijpers, Kooijman, & Bakker, 2011), thereby leading to suboptimal performance in top level athletes and choking in less proficient performers. Suboptimal performance may also occur when psychophysical conditions are good and feelings pleasant, but the athlete is not much involved or interested in the task and does not invest enough energy or make adequate efforts to execute the goal directed action (type 4). Although instinctive, the resulting behaviour, is not sufficiently coordinated to effectively accomplish the task/meet the task requirements.

Beyond the three performance conditions portrayed in the quadrants 1, 3, and 4 of Figure 3, a fourth option is suggested. As widely acknowledge by coaches and athletes, it is important to have a “Plan B” especially under highly stressful situations, when it is not possible to perform in an optimal/instinctive-like manner. Under these conditions, an athlete may “mindfully accept” the own mental and bodily states rather than struggling to control them (Gardner & Moore, 2006, 2007). As soon as a mindful mind-set is operative, the athlete should switch to the condition of optimal/controlled performance (quadrant 2) by focusing on the individual’s key points (i.e., the core components of action) identified during practice. In table 1 are summarized some individual characteristics underlying the four type of performance.

Summarizing, a fundamental aspect of the 2 x 2 framework, upon which the MAP intervention model is constructed, is the notion that optimal performance can occur also in conditions of distress, fatigue, and other unfavourable circumstances provided that the athlete is able to mindful accept the situation and engage in action- and/or emotion-focused strategies.

The MAP model is congruent with the increasing need for multi-methods research studies aimed at diverse structural components (e.g., emotional processes, cognitive functioning, motor behaviour) underlying human performance (see Tenenbaum et al.,
Accordingly, additional studies based on a multi-modal idiographic account of human performance should be encouraged. Studies addressing the psychophysiological and cortical pattern underpinning of the affect-performance linkage in sports are particularly welcomed.

Table 1. Selected Individual Characteristics of Four Performance Situations

<table>
<thead>
<tr>
<th>Individual variables</th>
<th>Type 1 performance: Optimal, automatic</th>
<th>Type 2 performance: Optimal, controlled</th>
<th>Type 3 performance: Suboptimal, over-controlled</th>
<th>Type 4 performance: Suboptimal, under-controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>Optimal</td>
<td>Stress, difficulties, fatigue</td>
<td>Stress, difficulties, fatigue</td>
<td>Comfortable</td>
</tr>
<tr>
<td>Situational appraisal</td>
<td>Challenge</td>
<td>Threat</td>
<td>Harm</td>
<td>Benefit</td>
</tr>
<tr>
<td>Emotional states</td>
<td>Functional-pleasant (excited, happy)</td>
<td>Functional-unpleasant (nervous, angry)</td>
<td>Dysfunctional-unpleasant (dejected, upset)</td>
<td>Dysfunctional-pleasant (pleased, complacent)</td>
</tr>
<tr>
<td>Energy</td>
<td>High level, matching task demands</td>
<td>High level, compensatory</td>
<td>Misuse</td>
<td>Low level</td>
</tr>
<tr>
<td>Resources</td>
<td>Effective recruitment and utilisation</td>
<td>Effective recruitment</td>
<td>Low level, ineffective recruitment and utilisation</td>
<td>Lacking</td>
</tr>
<tr>
<td>Behaviour</td>
<td>Action tendencies</td>
<td>Action tendencies</td>
<td>Action withdrawal</td>
<td>Action withdrawal</td>
</tr>
<tr>
<td>Focus</td>
<td>Task relevant “supervision” of the core components of action</td>
<td>Task relevant focus on the core components of action</td>
<td>Task irrelevant/too much focus</td>
<td>Lack of focus</td>
</tr>
<tr>
<td>Performance control</td>
<td>Minimal conscious</td>
<td>Consciously focused</td>
<td>Conscious, unfocused, or task irrelevant</td>
<td>Minimal conscious</td>
</tr>
<tr>
<td>Action plan</td>
<td>Maintaining “Plan A” Ready to use “Plan B” if “Plan A” does not work</td>
<td>Maintaining “Plan B” Trying to move to “Plan A”</td>
<td>Moving to “Plan B” by minimising generalised control</td>
<td>Moving to “Plan B” by enhancing focused control</td>
</tr>
</tbody>
</table>

Further research is clearly needed to advance our understanding of the theoretical rationale underlying the core action components and how they should be most effectively
used for designing individual interventions through the application of both emotion-centred and action-centred strategies.

Finally, future studies should also consider and distinguish the role of emotions and moods in skilled performance in sports. Merging the IZOF idiographic theme with advanced probabilistic analysis and neuroscience techniques may be key to unlocking mediating factors associated with optimal and less-than-optimal performance in sports.
In the last 20 years, there was a growing interest in the study of the theoretical and applied issues surrounding psychophysiological processes underlying performance (Strack, Linden, & Wilson 2011). The psychophysiological monitoring, which enables the study of these processes, consists in assessing the activation and functioning levels of a given organism. A multidisciplinary approach to study mind-body interaction focuses on holistic questions as historically raised by philosophers across times (Cacioppo, Tassinary & Berntson, 2007; p. 16). Holistic approaches within the sport domain target processes underlying performance and athletic training (Hatfield and Landers, 1987). Common techniques include Electromyography (EMG), Electrocardiography (ECG), assessment of electrodermal activity (EDA), breathing rhythm, Electroencephalography (EEG) and functional Magnetic Resonance Imaging (fMRI).

A multimodal and multidimensional assessment (Figure 15) based on various fields, such as motor behaviour, sport psychology, and psychophysiology, has been proposed as holistic alternative to measure performance-related affect. Assessment includes self-reports, behavioural and kinematic observations, and physiological recordings (Lang, 2000). Monitoring the entire spectrum of psychophysiological and behavioural features related to performance is also important to develop and implement bio and neurofeedback techniques aimed at helping athletes to (a) identify their individual zones of optimal functioning (IZOF), (b) enhance performance, through self-regulation strategies, and (c) prevent choking under competitive pressure.
Techniques and Measures for Psychophysiological Monitoring

Electromyography (EMG) is a technique to register and analyse electrical signals generated by physiological changes within muscle fiber membranes. In particular, kinesiological electromiography uses surface electrodes to identify neuromuscular activation in postural tasks, functional movements, working conditions or exercise (Konrad, 2005). This technique allows for online assessment of muscle contraction, thus informing on anatomic and physiological mechanisms underlying assorted physical activities and sport modalities. From a psychophysiological point of view, muscular tension has also been linked with emotional experiences. For instance, a tighter trapezium (it is a large superficial muscle that extends longitudinally from the occipital bone to the lower thoracic vertebrae and laterally to the spine of the scapula) has been linked to somatic anxiety across sub-populations groups.

Electrocardiography (ECG) measures heart electrical signal and provides parameters such as Heart Rate (HR) or Heart Rate Variability (HRV) (i.e., an analysis
that produce a set of indexes describing the variability ratio among successive heart beats). Nowadays, state of the art instruments, use infrared light sensors to record changes in the capillary flow distribution, which accurately represent a wide spectrum of cardiovascular responses. Chest bands, such as the Bioharness (Zephyr), are also modern instruments capable of monitoring cardiovascular responses through wirelessly technology. Recently, heart rate variability analysis has been widely use to investigate the influence of breathing rate, emotional states, anxiety and stress on cardiovascular responses. These analyses can be processed in the time or in the frequency domain. The Fast Fourier Transformation (FFT), a commonly adopted frequency analysis of the recorded signal, uses an algorithm to identify frequency bands associated with sympathetic and parasympathetic activity (Berntson, Quigley and Lozano, 2007). This algorithm decompose the recorded variability in the following frequency components: (1) a very low component (Very Low Frequency: VLF) ranging from 0.03 to 0.05 Hz, usually associated with temperature regulation; (2) a low frequency component (Low Frequency: LF) ranging from 0.05 to 0.15 Hz, usually associated with blood pressure regulation; and (3) a high-frequency component (High Frequency: HF) ranging from 0.15 to 0.4 Hz, associated with the breathing and particularly with the natural variation of heart rate defined Respiratory Sinus Arrhythmia (RSA) (Grossman, 1992).

The body ability to change its balance to the sympathetic or parasympathetic system is very important to ensure a healthy cardiac functioning. HF band is positively associated with a good health heart and sports performance, and negatively related to mental stress (Wilson & Somers, 2011). Specific patterns of heart rate variability can provide important information regarding cardiovascular dynamics as related to both central and peripheral control. Heart rate variability, which is linked to variations in parasympathetic control due to breathing patterns, can be used as an index of vagal
control. In detail, the variability in HF band reflects changes in vagal sino-atrial control, thus representing a selective index of parasympathetic control.

Within the sport sciences domain, there is great interest in the relationship between heart rate, variability and arousal. Previous research suggest that the HF band increases in stress and high anxiety conditions, especially when linked to focused attention and motor inhibition (see for review Cacioppo, Tassinary & Bersnton, 2007). From a physiological point of view, heart rate variability within the VLF and LF bands, consists of the sympathetic and the parasympathetic nervous combined activity. In particular although the LF band can be useful in evaluating cognitive workload its psychological meaning is less clear then the meaning of HF band.

Skin conductance or Electrodermal activity (EDA), also known as Galvanic Skin Response (GSR) or Psychogalvanic Reflex (PGR), pertains to the degree of electrical conductance (the inverse of resistance) present on the skin surface. It varies with sweat volume and it an indicator of psychophysiological activation state in general, and of the sympathetic nervous system in particular. Electrodermal measurement is popular among scholars due to its non-intrusive nature and sensitivity to psychological states. This method has been used in several fields of study: from basic research on activation levels to the study of elaborative processes and emotion monitoring (cfr. Dawson, Schell & Filion, 2007).

Regarding EDA, tonic and phasic activity have been highlighted as two EDA components reflect different brain systems; nowadays they are associated respectively with Skin Conductance Level (SCL), i.e. the level of skin conductance, and Skin Conductance Response (SCR), i.e. the response of skin conductance. Tonic activity expresses the absolute value of the skin electric resistance, and it is an index of general nervous system activation. Phasic activity is an index of rapid electrodermical system
responses to purely emotional and sensory stimuli. Woodworth and Schloberg (1954) observed that tonic activity is generally lower during sleep and wake states. They also related phasic activity to selective attention to new and intense stimuli. Noteworthy, EDA is a set of responses to stimuli which are ultimately mediated by the autonomic nervous system. Unlike most autonomic nervous system response, EDA provides a relatively direct representation of the activity of the sympathetic system. In fact, the exocrine glands, which are involved in central and local temperature regulation, are controlled by the sympathetic nervous system. Therefore, increases in skin conductance response are associated with increased in sympathetic activation, while also representing a somatic indicator of emotional states, such as anxiety and fear.

Studying subjects’ reaction to a stimuli that causes anxiety, electrodermal system may be used as the immediate response physiological system. Discrete stimuli able to evoke conductance responses (phasic) are those with strong positive or negative affective valence, or associated with decision making. A situation, instead, with continuous stimuli that produces increases in conductance level (Tonic activity) is realized performing a task.

Munro, Dawson, Schell and Sakai (1987) noted that electrodermal activity (generally) increases during task execution and suggested two possible explanations. First, performing a task requires attention which leads to a greater activation of the autonomic nervous system (Jennings, 1986). Further, stress and emotion, affection, often linked to social situation, are very important, rather than attention and effort and this can lead to an activation of the autonomic nervous system.

Another recordable physiological parameter is the respiratory rhythm, usually assessed through a tool placed around the abdomen under rib cage (strain gauge). During a task, an athlete can often change his breathing. For example, a shallow breathing
involves mainly shoulders muscles and not the abdomen. An athlete may also hold his/her breath or voluntarily increase his/her respiratory rate. Altogether, respiratory rhythm has been associated with heart rate variability, and breathing techniques are particularly helpful in advancing a sense of self-control and on optimizing performance (Lagos, Vaschillo, Vaschillo, Lehrer, Bates & Pandina, 2008). These variations, facilitated also by factors such as anxiety and stress have been associated with poorer performance (Wilson and Somers, 2011).

Neurotechnology is a set of procedures, methods, tools and devices used to study the human brain (see textbox 1), particularly higher order activities such as consciousness and decision-making. It includes technologies designed to monitor, improve and treat brain function, thus allowing researchers and clinicians to visualize and stimulate brains’ structures and functions. Over the last century, different technologies and methodologies have been developed to acquire neurophysiological, neuroimaging, and biological information from the living human brain. Indeed, information about the structure and function of the human brain may be obtained from a variety of sources (Figure 16).

Figure 16. Methodologies available for neuroimaging and biological information obtainable from the living human brain.
TEXTBOX 1. NEUROTECHNOLOGIES

ELETTROPHYSIOLOGICAL MEASUREMENTS

Electroencephalography (EEG) is a non-invasive method for measuring brainwave activity. A number of electrodes are placed on the head and scalp and electrical signals are measured. In the sport science domain, EEG is used to study neurocognition mechanisms underlying skilled performance (Hatfield & Kerick 2007), and affective states related to exercise behaviour (Acevedo & Ekkekakis, 2006). The increasing number of electrodes utilized along with the development of specific algorithms for source analysis (e.g., Loreta) has enlarged the scope and reliability of EEG analysis. Event related Potentials (ERPs) offers a different outlook on human brain processes (Pontifex & Hillman, 2008).

Magnetoencephalography (MEG) is another method for measuring electrical currents in the active brain. This method, which captures tangential blood flow and associated magnetic fields in the scalp, offers a better spatial resolution when compared to EEG. Nonetheless, its costs and technical constrains have limited its use in the sport science field.

NEUROIMAGING TECHNIQUES

Computed tomography (CT) is a technology used for scanning the brain. It has been used since the 1970s to track the structure and activation of the human brain. Nowadays, CT is used to diagnose brain abnormalities and injuries. Through the use of an X-ray scanner, clinicians and researchers are able to detect radioactive markers linked to various injuries and diseases.

Positron emission tomography (PET) is imaging technology based on nuclear imaging. PET scans rely on positron emitting markers related to a relevant biological compound, such as glucose. Simply put, high active areas demand a higher nutritional flow, thus appearing as bright areas in the brain. PET scans are gaining popularity among researchers because of its ability to detect metabolic changes whereas MRI is activated on a more physiological basis (sugar activation versus oxygen activation).

Magnetic resonance imaging (MRI) produces high resolution images of the human body, and it is based on the same principles of nuclear magnetic resonance. MRI is used for scanning the brain for both anatomical and functional purpose. With the advent of functional MRI (fMRI) our knowledge about brain function are quickly grown. Functional MRI measures the oxygen levels in the brain upon activation, hence allowing researchers to understand which loci is responsible for activation linked to a given stimulus. Accordingly, functional MRI allows researchers to draw associative relationships between different loci and regions of the brain, ultimately providing a large amount of information regarding brain functioning.

TRANSCRANIAL STIMULATION

Transcranial magnetic stimulation (TMS) is a direct magnetic stimulation of the brain. Electric currents and magnetic fields are intrinsically related, stimulating the brain with magnetic pulses allows for the establishment of causal effects in the brain. This field of study and application is currently receiving a large amount of attention due to the potential benefits associated with a better understanding of the human brain.

Transcranial Direct Current Stimulation (tDCS) is a very old technique, which has been recently renovated. A constant direct current (i.e., a flow of electric charge that does not change direction) polarizes (i.e. changes membrane potentials) cells. It is applied to the brain by means of two electrodes: an active electrode, localized on the dysfunctional site, and a reference electrode, localized on a “silent” part of the brain. tDCS is different from transcranial magnetic stimulation (TMS) in that it does not directly activate neurons. tDCS implies injection of small amount of DC currents that depolarize (anodal currents) and hyperpolarize (cathodal currents) cortical pyramidal cells under the stimulation electrode.

BRAIN COMPUTER INTERFACE

Neurofeedback is a technique of self-regulation by means of EEG-based biofeedback. In this technique, some current parameters of EEG recorded from a subject’s scalp (such as an EEG power in a given frequency band) are presented to the subject through visual, auditory or tactile modality with the task to voluntarily alter these parameters in a desired direction, leading to a more efficient mode of brain functioning. Different from the devices and methodologies previously described, neurofeedback implies active involvement of the subject in voluntarily changing of the EEG parameters recorded from a given electrodes. The individual performs a task while receiving online visual and auditory feedback on his/her theta, beta, Sensory Motor Rhythms or other brainwave activity. The information are used to help individuals learn to change brainwaves to desired levels.
The oldest method is related to electrical activity of the brain due to a neuron firing toward the synapses. Electroencephalography (EEG) and Magnetoencephalography (MEG) are two important methods used to record brain electrical activity.

The advent of functional imaging modalities such as Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), functional Magnetic Resonance Imaging (fMRI), opened new research avenues in the study of brain function. Indeed, the most important energy resource of the human brain is glucose. Glucose metabolism can be measured using Positron Emission Tomography (PET). Oxygen metabolism, necessary to synthesize ATP molecules from glucose, can also be measured using PET. Noteworthy, glucose and oxygen molecules are supplied through continuous blood flow. Brain regions with increased activity are accompanied by an increase in blood flow due to capillary dilation. To date, regional cerebral blood flow changes can be measured using various methods such as fMRI and Near-Infrared Spectroscopy (NIRS).

During the last two decades, the development of brain neurophysiological and neuroimaging techniques has advanced our knowledge about central mechanisms underlying human behaviour. Recently, the improvement of spatial and temporal resolution techniques (Figure 17) has allowed for further insights on the specific areas linked to cognitive and motor behaviour. (see Hatfield & Kerick, 2007).

Figure 17: Temporal and spatial resolution of neurotechnology
Recently, trans-cranial stimulation techniques have been developed to interfere with specific loci in the brain in an attempt to obtain a predictable effect. The most used are: Trans-cranial Magnetic Stimulation (TMS), and Trans-cranial Direct Current Stimulation (tDCS).

The latest challenge for neuroscientists is to simultaneously monitor the coherence and connectivity among brain regions, from both functional and effective perspectives, while evolving and implementing neurotherapeutic interventions such as online neurofeedback. For this reason many algorithms and techniques have been developed or applied to brain study (i.e. Diffusion tensor imaging –DTI, Granger causality, Graph theory, Dynamical causal modelling).

**Psychophysiological Monitoring Applied to Sports**

Over the past 20 years the analysis of psychophysiological processes underlying sport performance has grown exponentially among scholars, practitioners, and coaches. Sports that use closed skills, which take place in stable and predictable contexts where the athlete is totally free to manage execution times and modalities, have particularly benefited from this line of research. In particular, precision sports, where athletes are stationary (as in archery and shooting), are optimal for accurate measurements.

One of the most studied aspects is arousal/activation level, given its relevancy for athletes and integral part of mental preparation programs. With this concept we refer to modification of individual basic physiological and behavioural levels in preparation for expected events and in response to internal or external stimuli. This answer can be functional or dysfunctional in sport performance and depends on the intensity level and cognitive interpretation that the athlete gives to it.
Arousal/activation management is considered, an important mental skill in sports psychology. Specifically, arousal is traditionally defined as a general physiological and psychological state that waves from deep sleep to intense reactivity (Gould & Krane, 1992). The term arousal has been often used as a synonym for activation until Barry and colleagues tried to differentiate them with their experiments (Barry, Clarke, McCarthy, Sclikowitz, Rushby and Ploskova, 2004; Barry, Clarke, McCarthy, Sclikowitz and Rushby, 2005; Vaez Mousavi, Barry, Rushby and Clarke 2007; Vaez-Mousavi, Hashemi-Masoumi, and Jalali, 2008; Vaez Mousavi, Naji and Hassanzadeh, 2011). According to these authors, arousal corresponds to a "readiness" of the body in preparation for a task, while activation corresponds to the mobilization of arousal when a person is involved in a task. Activation level is measured as the difference between the level of SCL that a subject presents before the task and the level of SCL that s/he reaches during the task. Arousal is the difference between resting SCL and SCL immediately before the task.

Psychophysiology typically uses a multimodal and multidimensional approach, integrating psychological measures with behavioural and physiological data. Measures such as skin conductance or those arising from electroencephalography, electromyography and electrocardiography are linked to characteristics such as attention and emotional states. The modulation of physiological parameters represent an element of control and increased performance.

For example, heart rate acceleration and deceleration have been studied in relation to cognitive processes involved in the execution. Physiological processes underlying these cognitive components are important factors to investigate for performance improvement and optimization (Abernethy, 2001; Abernethy, Maxwell, Masters, Van der Kamp and Jackson, 2007), in particular with regard to information processing about a task, motor action control, skill learning and improvement, in which internal or external
attentional focus can be crucial for the success (Wulf, 2007). Lacey and Lacey (1980) developed a theory called "stimulus intake/rejection" in which the stimulus intake, corresponding to a state of focused attention, would be associated with a heart rate decrease. Conversely, a state of focused attention on internal stimuli would be accompanied by a heart rate increase. Obrist (1981) provided a different explanation of the relationship between physical training and heart rate decrease, such that heart rate variation is not directly connected to the attention, but might be an indirect effect of motor activity reduction. According to this hypothesis, during a focused attention state, heart rate deceleration indicates the general absence of motor activity.

Physiological changes often accompany modulations of attention. Thus, a decrease in heart rate seems to be indicative of changes in the state of attention, as highlighted in a study by Tremayne and Barry (2001), where heart rate and skin conductance in elite pistol shooters and novice shooters were compared. The study included three different situations each lasting 150 seconds. In the first situation, the athlete had to shoot at a target located 25 metres away. In the second, the shooter remained in firing position. Finally, in the third situation the shooter was instructed to aim again at the target. For each shot, heart rate values and conductance were registered every half-second from 20 seconds before to 10 seconds after the shot. A gradual reduction in skin conductance and heart rate before the shot was noted in expert shooters, with values then returning immediately after shooting. This phenomenon was not observed in novice shooters. Heart rate deceleration has been observed even in tasks where reaction ability is important (Reaction Time task). According to the model proposed by Jennings (1986), a heart rate deceleration indicates the ability to perform mental operations on expected stimuli ("assumption of ability"). Further, heart rate acceleration would be considered an index of processing, and has been found during engagement in mental activity (Lacey,
Kagan, Lacey & Moss, 1963). In a study by De Pascalis, Barry and Sparita (1995), 60 subjects participated in a recognition task of geometric pictures which required pressing different keys, with the right or left hand, depending on the images. Every action was followed by feedback on reaction time and accuracy in execution. During the test, heart rate data was gathered according to two different conditions (i.e., stress and non-stress). In both situations two moments of heart rate deceleration were observed, one preceding visual stimulation and the other preceding feedback. Deceleration preceding feedback was more pronounced than that detected prior to the stimulus. This because feedback was simply a visual information that did not require a subject’s specific motor response inhibition (using the left or right hand) as the subjects had to do during the task, and therefore of heart rate deceleration has been considered only the expression of computational processes.

Radlo, Steinberg, Singer, Barba and Melnikov (2002) examined direction of attention, asking novice athletes to throw darts at a target using two different attentive strategies: 1) bring attention outside, toward the target, or 2) inside, on their movements (i.e. external and internal focus of attention). An external attentional focus is associated with a pronounced heart rate deceleration immediately before the shot, while internal focus is associated with an acceleration prior to the shot. The best performance results occurred with the use of an external focus, associated with heart rate deceleration.

Other authors have considered the variability of heart rate increases and decreases, assessing individual components of the frequency spectrum in relation to cognitive processes. Mulder (1992) proposed the heart rate variability reduction in the LF band as an index of mental effort spent performing a task. Cooke, Kavussanu, McIntyre and Ring (2010), however, noted that heart rate variability in LF band increases rather than decreases under greater pressure during putting in golf. The authors attributed this result
to a probable increase in breathing volume under pressure. In that case, an increase in heart rate variability in HF band is explained by its sensitivity to changes in breathing. However, researchers observed no changes in HF band despite the increased pressure and a perception of greater effort during the task. It seems that the impact on cardiovascular measures of physical and postural demands, although minimal, is higher than that of mental activity (Veldhuizen van Zanten, Thrall, Wasche, Carrol & Ring, 2005). These results therefore reveal some problems in using heart rate variability as an index of mental effort performing tasks in which there is an excessive physical load.

Furthermore, Neumann and Thomas (2009) examined heart activity and breathing in novice and expert golfers, who had to make a 2.4 m long putt. Expert and elite golfers, compared to novices, showed, in addition to a lower heart rate in general, a pronounced heart rate deceleration immediately before the shot, explained as a consequence of a more effective external attentional focus. In addition, experts and elite athletes showed a greater heart rate variability in VLF band. In terms of respiratory activity, expert and elite golfers had a greater tendency to use expiration immediately before the putt. Results suggest a general lower attention level in the expert and elite golfers compared to novices. Novice golfers probably invest a greater attentional effort during the putt, as a result of performing a new task. A higher level of motor skills is, therefore, associated with an increase in heart rate variability in LF band. This is consistent with the idea that attainment of a certain level of skill in sports is associated with increased executive automation and reduction of attention requests (Abernethy et al., 2007; Wulf, 2007).

Mullen, Hardy and Tattersall (2005) provided a different explanation to the meaning of heart rate variability. They conducted a study with novice golfers, proposing a putt in a single task condition or with a contemporary distracting task. They found that heart rate variability in HF band was higher during the putt run in the distracting task.
condition. The authors explained this HF increasing with the adoption of relaxation strategy based on breathing, and we know that breathing influences heart rate variability in HF band.

Regarding the relationship between arousal/activation and performance through electrodermal activity monitoring, Tremayne and Barry (2001) describe skin conductance as a reliable index of arousal/activation level in precision sports. Electrodermal activity data, registered to monitor the individual state of arousal/activation moment by moment, have shown a decrease in expert athletes before the shot, possibly reflecting a state of calmness in the last seconds before the shot, followed immediately by a return to initial values. These data help to elucidate the complex perceptual/cognitive processes involved in the performance of elite pistol shooters and indicate the usefulness of a psychophysiological perspective in sports psychology. As previously mentioned, Vaez Mousavi and colleagues (Vaez-Mousavi et al., 2008; 2011) tried to differentiate the level of arousal from activation in shooters. Arousal is the difference between the basal skin conductance and the one immediately preceding the task, while activation is the difference between skin conductance preceding task and skin conductance detected during the task. Only activation would, according to these authors, be useful in predicting performance. Peper and Schmid (1983), on the other hand, used the electrodermal activity to evaluate relaxation or stress during training in conjunction with imagery, and noted that gymnasts with higher electrodermal activity have poorer performance in competition.

The use of integrated monitoring systems allows for the combination of physiological data: heart rate is more related to attention, and SCL more related to alertness/awareness. This monitoring permits to better understand athlete’s functioning. To this extent, the IZOF probabilistic model developed by Kamata et al. (2002), which subscribes to the individual zone of optimal functioning, help to verify individual
physiological patterns associated with optimal and sub-optimal performance in high-level athletes (Bertollo et al., 2012).

Monitoring psychophysiological and behavioural characteristics linked to performance is, therefore, important in developing and improving techniques designed to support athletes in identifying their individual zone of optimal functioning, managing emotions, and improving performance (Bertollo, Bortoli, Gramaccioni, Hanin, Comani & Robazza in press).

Electromyography has been used to evaluate, for example, the different muscle activity related to motor tasks with internal and external attentional focus (Figure 18).

![Figure 18. Electromyography during shooting](image)

In a study conducted by Zachry, Wulf, Mercer and Bezodis (2005) participants performed three basketball free throws with internal focus (i.e., focus on movement of the wrist), and external focus (i.e., focus on the basket). During the task, electromyography activity was recorded in the muscles of the shooting arm. Results revealed that free-throw
accuracy increased when participants adopted an external attentional focus. In addition, electromyography activity of certain muscle groups was slower with an external attentional focus compared to internal. This suggests that an external focus could increase the economy of movement and reduce the elements of disturbance in motor systems which disturb movement control and make the result less accurate.

**How to Choose the Appropriate Neurotechnique in Sport Psychology?**

During the last ten years different neurotechniques have been implemented in sport science to monitor brain activity during physical activity, the effects of exercise on brain and cognition, and the neural processes that support high achievement in sports (Hillmann, Erickson, & Kramer, 2008; Yarrow, Brown, & Krakauer, 2009; Boecker, Hillman, Scheef, & Strüder, 2012). The issues related to the use of each specific methodology have been investigated and applications have been recommended.

For instance, PET and fMRI are useful in a laboratory or clinical setting (Tashiro, Itoh, Fujimoto, Masud, Watanuki, & Yanai, 2008; Zaichkowsky, 2010) to explore brain activity needing high spatial resolution and to investigate deeper structures of the brain. In particular, they are helpful in investigating imagery skills in athletes (Holmes & Calmels, 2008), assisting rehabilitation and intervention after a concussion or injury (Pulsipher, Campbell, Thoma, & King, 2011), exploring subcortical structures such as basal ganglia during coordination task (De Luca, Jantzen, Comani, Bertollo, & Kelso. 2010), amygdala activity during performance (Milton et al, 2007), or the efficacy of exercise training on hippocampus size increasing and memory improving (Erickson et al. 2011).

EEG and NIRS have been used in the field conditions for their portability and lower sensitivity to artefact (Thompson, Steffert, Ros, Leach, & Gruzelier, 2008; Perrey, 2008). After the development of active electrodes and, more recently, dry electrodes,
EEG may become even more popular among scholars and practitioners. EEG has a long tradition in sport and exercise sciences (see Hatfield & Kerick, 2007; Acevedo & Ekkekakis, 2006; Pontifex & Hillman, 2008), while NIRS is a younger technology with a promising future in sport settings as well as the exercise psychology field (Ekkekakis, 2009).

Moreover, tDCS in conjunction with neurofeedback provides electrophysiologically-based tools for activation or suppression of cortical neuronal networks or specific loci as it has been previously shown in psychiatric setting (Kropotov, 2009). Indeed, the latest neurotechnology developments have convinced many companies to develop more affordable, high resolution wireless tools, which are useful for neurofeedback purposes. Despite this technological evolution practitioners have to pay a lot of attention to the reliability, sample frequency and data filtering of those devices to avoid misinterpretation of the data acquisition.

**Understanding the Athletes Brain**

Studies of athletes' brains show that motor-related activities and higher cognitive processing are flexibly modulated by long-term perceptual and motor training. These findings, in conjunction with studies on brain concussions in athletes, indicate the plasticity of neural activity in the human brain (see for review Nakata, Yoshie, Miura, & Kudo, 2010). Besides it is also important to detect and discover the specific cortical activity associated to the characteristics and specificity and each sport (see for review Yarrow, Brown, & Krakauer, 2009; Boecker, Hillman, Scheef, & Strüder, 2012).

In sport psychology, the sensory systems, attention networks, executive system, affective system and memory systems have been investigated using multimodal and multidimensional perspectives, to (a) provide a neurobiological model to explore peak
performance, (b) highlight stress interference on performance and (c) describe the strategies to manage stress-perturbations (Hatfield & Kerick, 2007). On the other hand, in exercise psychology, the main goal of research was to provide a neurobiological perspective for physical activity (Acevedo & Ekkekakis, 2006).

Pioneering studies by Hatfield and colleagues have provided a cognitive and affective neuroscience perspective about the psychology of superior sport performance (Hatfield & Kerick, 2007). However, more investigations are necessary about memory, executive and affective systems using ecological paradigms and setting on the field (Figure 19).

![Figure 19. EEG monitoring on the field during practice](image)

Recently, mental skills useful in sport settings have also been investigated using neurophysiological and neuroimaging methods. Cortical arousal has been investigated and tempo-parietal asymmetry was found to be related to peak performance (Hatfield &
Kerrick, 2007). Del Percio et al. (2009) showed that visuo-attentional and sensorimotor alpha rhythms are related to visuo-motor performance in athletes. In general, athletes have shown better neural efficiency compared to non-athletes across different sport (see Nakata et al, 2010).

Traditionally, imagery is important mental skill in sport and exercise psychology. Specifically, Guillot et al. (2008) combined functional magnetic resonance imaging with physiological, behavioural, and psychological measures to relate cortical activity to imagery skills. Results revealed that people with better imagery ability activated parietal and ventrolateral premotor regions to a greater extent, and these regions are thought to play a critical role in the generation of mental images. Further studies have demonstrated that the modulation of motor cortex excitability during motor imagery depends on imagery quality (Lebon, Byblow, Collet, Guillot, Stinear, 2012). Indeed, Davis and colleagues (2008) hypothesized that athletes at risk for repeated failures show the greatest decrements in premotor activity, while more resilient athletes may exhibit activation of premotor cortex as a result of self-action observation.

Regarding the emotional and affective system, the frontal and prefrontal asymmetry in alpha band frequency has been shown during physical activity (Acevedo & Ekkekakis, 2006).

Regarding the memory system, neural correlates of motor learning and performance have been investigated by Pitto and colleagues (2011). They found that practice led to an increased theta synchronization in the frontal areas and successful trials were preceded by higher theta synchronization, and alpha and beta desynchronization. Zhu, Poolton, Wilson, Maxwell, & Masters (2011) have shown neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement.
Moreover, neurotechnologies (e.g., PET, fMRI, EEG) are useful tools to detect endophenotype (such as EEG power in specific frequency band or ERP components, or brain network; Kropotov, 2009) and to define the specific neurointervention and neurotherapy to investigate the phenotype of a subject. Initial studies about the efficacy of tDCS have demonstrated success in improving motor performance and motor learning in healthy individuals, and restitution of motor deficits in stroke patients (Reis & Fritsch, 2011). To our knowledge, there is only one study in sport science that has shown the efficacy of tDCS, applied over the human motor cortical areas, in improvement of isometric force endurance.

In the current sport and exercise psychology domain, a combination of Neurofeedback and tDCS is a promising field of intervention to assist athletes in improving performance during practice, as previously experienced in a psychiatric setting (Kropotov, 2009).

**Cortical Activity in Sports: The Most Recent Research Lines**

The study of cortical activity in sports has gained attention in recent years, given the significant progress in specific technologies. The two most commonly used techniques are functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). Using fMRI, studies have been conducted examining differences in brain activity between the observation of an action already learned and a new action, in order to assess whether the brain processes during the observation of an action are modulated by experience and by personal motor repertoire (Calvo-Merino, Glaser, Grezes, Passingham and Haggard, 2005). Furthermore, expert dancers in two different kinds of dance (Ballet or capoeira) and control subjects underwent fMRI imaging during which they viewed movies of both kinds of dance. Dancers watched their
personal style first and then the other style. Dancers showed greater activation of the premotor cortex, parietal areas and superior temporal sulcus, predominantly in the left hemisphere, watching watched their personal style of dance. For control subjects, however, activation differences were not found in specific brain areas. Therefore, while all three groups underwent the same visual stimuli, brain areas responses differed depending on the observer's specific motor experience. Thus revealing the influence of motor cortical activity experience during the observation of an action. Other research has highlighted, however, the extensive ability of functional magnetic resonance imaging to identify subtle differences in neural activation patterns associated with a particular psychophysical state that features better performance, when athletes are in their "zone of optimal functioning" (Ferrell, Beach, Szevereneyi, Krch and Fernhall, 2006).

The fMRI equipment, however, is not able to be used during real sport situations. Therefore, electroencephalography is the most commonly used technique to monitor brain activity during sport moment, in real sporting events. In particular, precision sports present ideal conditions for EEG recordings. In fact, athletes remain still and, before the execution of the technical gesture, which requires maximum precision, a strong component of attention is required. This has provided researchers with sufficient ability to describe optimal pattern of cortical activity during aiming in various sports, including archery (Landers et al., 1991; Salazar, Landers, Panikood, Han, and Kubitz Krews, 1990), golf (Babiloni et al., 2008; Crews and Landers, 1993), and shooting (Hatfield and Kerick, 2007; Del Percio et al., 2009, 2011; Doppelmayr, Finkenzeller and Sauseng, 2008; Konttinen and Lyytinen, 1993). The electroencephalography is used in shooting sports to identify predictors of optimal performance, and observe electroencephalographic differences in shooting between experts and non-experts’ performance, and both optimal and non-optimal execution in the same athlete. The use of electroencephalography has
made it possible to study certain characteristics of brainwaves and their frequencies, relating them to specific situations.

Hatfield, Landers and Ray (1984), for example, noted that there was a temporal asymmetry in the cortical area in the alpha frequency band in rifle shooters, highlighted during a period of 7.5 seconds before the shot while the subjects were in a standing position. The recording targeted the left and right temporal sites T3 and T4, and left and right occipital O1 and O2 using Cz as the reference electrode. Alpha power showed a marked increase in the interval of 7.5 seconds in the temporal T3 site in the left hemisphere, while only a slight increase at the right site T4 was observed. Assuming that alpha activity is inversely related to cortical activation, a high T4/T3 ratio reflects a larger cortical activation in the left hemisphere, while a lower ratio reflects a larger cortical activation in the right hemisphere. The same authors have interpreted the observed increase in the alpha activity in the left hemisphere as an activation decrease of this hemisphere. Further, it was noted that the site T3 corresponds to areas linked to language. It has been speculated that the increase of alpha activity could indicate a verbal and symbolic activity reduction, a self-dialogue reduction, and an attentional focus on visuo-motor aspects of shooting increase. This interpretation seems consistent with the description of optimal states of performance presented by Williams and Krane (1993) and with the concept that self-dialogue could "disrupt" performance (Bunker, Williams and Zinser, 1993).

Kontinen and Lytyinen (1992, 1993) examined the "slow cortical potential" in expert and non-experts shooters to compare brain activity during the task in terms of specific motor and visual components. Focusing on the motor aspects of the task, without having a specific target, largely reduces the negativity of slow cortical potential that seems to be due to the visual component of the task and the maintenance of focus outside
the motor component. Salazar et al. (1990) performed a similar study on archers in four different conditions: 1) normal shooting situation; 2) archers who supported a heavy bow without pulling; 3) same previous condition but with reduced bow weight; and 4) archers in a relaxed position while staring at a target. A hemispheric asymmetry was observed in all situations (with encephalographic power greater in the left hemisphere particularly in the frequency range between 10 and 14 Hz), and was more pronounced in the real shooting condition. Findings may suggest that this condition is accompanied by a greater reduction of cortical activation in the left hemisphere compared to the normal condition, possibly due to the effort to keep the bow or to the motor skills and postural demands of the archers. Subsequently, Landers, Han, Salazar, Panikood, Kubitz, and Gannon (1994) compared electroencephalographic measurements in T3 and T4 (temporal areas) of novice archers before and after a 14-week training course. It was noted that the asymmetry to electroencephalography changed as a result of training. Specifically, after training, the asymmetry substantially increased during the shot, especially in the left hemisphere. In sport performance, a direct approach to assess the differences in skill level and mental states, as previously mentioned, is to compare novice and experts in a specific task. In general, non-expert athletes are active primarily during the perceptual processes of stimulus identification in order to identify relevant internal and external information, while experts are already able to filter information and focus on strategy and decision processes (Wrisberg, 2001). In a study by Baumeister, Reinecke, Liesen, and Weiss (2008), using the search paradigm "experts/inexperienced" in golf, results showed a significantly better performance in expert golfers. This situation was associated with a frontal-midline theta power higher and power values of parietal high alpha higher compared to cortical activity associated to putt in novice athletes. In addition, results suggest that as skill level increases golfers may develop task resolution strategies,
including focus and economy in information processing, resulting in a more successful performance. Del Percio et al. (2009) found that elite pistol shooters were characterized, during preparation for shooting, by an increase in the power of alpha2 (about 10-12 Hz) and beta (approximately 14-35 Hz), probably linked to processes of attention and neural efficiency. In a subsequent study, results revealed that elite athletes are characterized by a stabilization of the functional coupling of preparatory waves between the visual-spatial and other posterior cortical areas (Del Percio et al., 2011). Doppelmayr et al. (2008), instead, noted a steady power increase over the last 3 seconds before rifle shooting evident only in expert athletes. This result indicates that experts show a higher theta activity, in an area near the anterior cingulated in the fronto-medial cortex, when compared to their novice counterparts. Experts and novices, in fact, use different strategies during the aiming period. Specifically, while novice athletes maintain a relatively constant load of attention, experts are able to increase the attention exactly at the time when the trigger is pressed. These results are consistent with the concept that for a higher performance there is a greater psychophysiological growth (Harung, Travis, Pensgaard, Bored, Cook-Greuter & Daley, 2011).

Electroencephalographic methodologies applied to the sports world date back to 1950, when clinical researchers examined the health consequences associated with boxing (Busse & Silverman, 1952; Ravina, 1952). Historically, researchers in this field have focused on two themes: electro-cortical differences before and after combat, and long-term differences between healthy adults and professional boxers undergoing repeated trauma to the head. Similarly, studies also focused on the long-term effects of repeated head trauma in football players caused by contact between head and ball. These studies demonstrated the usefulness of electroencephalography for evaluation of brain injury in sports such as football or boxing.
Currently, electroencephalography, although lacking the spatial resolution of more complex and expensive methods (e.g., fMRI), offers an excellent temporal resolution. Furthermore, its wireless hardware, not possible with other techniques of imaging technology, allows for multiple acquisitions in situations more closely reflecting real athletic performance.

**Neurobiological Model to Explain Peak Performance in Sport**

An interesting and promising model to study cortical dynamics during performance in sport has been proposed by Hatfield and Kerik (2007). Their neurobiological model (Figure 20) draw the processes and outcomes underlying stress reactivity and integrates affective and cognitive activity with psychomotor performance.

![Figure 20. Neurobiological model of the distress circuit during reactive motor behaviour (adapted from Hatfield & Kerick, 2007)]
A central tenet of the model is that lack of executive control over subcortical processes would result in heightened emotional influence (limbic structures) that, in turn, disrupt higher cortical association processes that resulting in alterations in the activation of the motor loop – the fronto-basal ganglia structures that initiate and execute movement. Such disregulation interferes with attention and the motor loop connections (i.e., basal ganglia) to the motor cortex that largely control corticospinal outflow and the resultant quality of motor unit activation. Excessive networking in the cortex may result in undesirable alterations in information processing as well as inconsistency of motor performance. In this manner the motor cortex becomes “busy” with excessive input from limbic processes via increased neocortical activity in the left hemisphere then inconsistent motor behavior would likely result. Refinement or economy of cortical activation would more likely result in enhanced attention and smooth, fluid, graceful, and efficient movement. Any reduction of associative networking with motor control processes would also help to reduce the complexity of motor planning and should result in greater consistency of performance.

According to this model individuals under high stress will exhibit reductions in prefrontal asymmetry (box 1) compared to a low-stress condition implying a lack of executive control over the fronto-meso-limbic circuit. Consequently, participants will experience heightened activation of the limbic region (amygdala) (box 7). The resultant emotional reactivity, in turn, will result in EEG alpha desynchrony particularly in the left temporal (T3) and parietal (P3) regions (box 8) along with increased cortico-cortical communication between these regions and the motor planning centers (box 4). Such disregulation of the cerebral cortex will be expressed as inconsistent input to the motor loop (boxes 2 - 5) resulting in inconsistent corticospinal output and shooting performance (motor unit activity – trigger pull – boxes 9 and 10). It is well established that attention
capacity shrinks with arousal and, consistent with this notion, the excessive cortico-cortical networking during heightened stress, as proposed here, would compromise information processing. In addition, cardiovascular activity (vagal tone) will be inversely related to the activity in the CNS such that vagal tone will be reduced in the high-stress condition. Cortisol levels will rise. The magnitude of change specified in the model will be related to degradation in shooting performance (i.e., slower and inaccurate).

Conclusion

Behavioural, psychophysiological, neural and cortical monitoring of performance represents an important source of information regarding the athlete. Specifically, heart rate, heart rate variability, skin conductance level and response, electrical brain intensity and brain waves are important information, as they have allowed for better understanding of the complexity of sport performance. The aforementioned physical-medical techniques for monitoring athlete behaviours are useful methodologies to understand the processes underlying sport performance in general and cortical processes in particular.

Indeed the past 20 years have witnessed unprecedented progress in our ability to study human brain function noninvasively. The high temporal resolution of electromagnetic measurements (EEG/MEG) continues to offer a unique window into the dynamics of brain function. In particular, EEG measures are exquisitely sensitive to spontaneous and induced changes of the functional brain state allowing investigation of brain mechanisms associated with covert internal states, which may not necessarily be accessible to introspection or behavioral observation. The field of EEG research has perhaps witnessed its largest advances in the critical area of source imaging. A variety of innovative and sophisticated solutions for estimating intracerebral sources are continuing to emerge.
The ultimate purpose of psychophysiological monitoring, therefore, is to use these techniques to provide useful feedback to assist athletes, as well as people in general, to (a) learn more about their bodily functions and (b) develop self-regulation of those functions.

In fact, currently existing biofeedback and neurofeedback systems allow, through computer programs, online, real-time interaction between an actor and a software/program. We can also detect more types of integrated signals, promoting greater understanding of the factors related to performance and self-regulation systems.
BEHAVIOURAL AND PSYCHOPHYSIOLOGICAL CORRELATES OF ATHLETIC PERFORMANCE: A TEST OF THE MULTIPLE-ACTION PLAN MODEL

During the last decades, the analysis of the psychological, physiological, kinematic, and behavioural mechanisms underlying the performance of elite athletes has received increasing attention, in particular in precision sports (e.g., Goodman, Haufler, Shim, & Hatfield, 2009; Hatfield & Kerick, 2007). A multimodal and multidimensional assessment derived from the interaction of different fields of investigation, such as motor behaviour, sport psychology, and psychophysiology, has been advocated to measure performance-related emotional experiences. Assessment includes self-reports, behavioural and kinematic observations, and physiological recordings (Lang, 2000). Monitoring the entire spectrum of psychophysiological and behavioural features related to performance is important in order to develop and implement biofeedback and neurofeedback techniques aiming to support athletes in the identification of their individual zones of optimal functioning, in the enhancement of their performance, and in the self-regulation of emotions and prevention of choking under competitive pressure.

The psychophysiological, behavioural, and kinematic features of self-paced tasks (e.g., shooting, golf putting, dart-throwing, and archery) have often been studied at a between-subjects level by comparing the performance patterns of skilled performers to those of novices (e.g., Haufler, Spalding, Santa Maria, & Hatfield, 2000; Goodman et al., 2009; Konttinen & Lyytinen, 1992; Salazar, Landers, Petruzzello, Hans, Crews, & Kubitz, 1990), or at a within-subjects level wherein individual’s best and worst performance patterns have been contrasted (Guillot, Collet, Dittmar, Delhomme, Delemer, & Vernet-Maury, 2003; Konttinen, Lyytinen, & Viitasalo, 1998; Tremayne & Barry, 2001). More recently, some authors have used an idiosyncratic probabilistic
CHAPTER SIX: Psychophysiological correlates of MAP

approach within the framework of the individual zones of optimal functioning (IZOF) theory (Hanin, 2000, 2007; Kamata, Tenenbaum, & Hanin, 2002) to investigate the relationship between performance and affect in different sports (Bertollo et al., 2012; Edmonds, Mann, Tenenbaum, & Janelle, 2006; Medeiros Filho, Moraes, & Tenenbaum, 2008). This uni-dimensional categorization of performance (expert vs. non-expert and optimal vs. non-optimal) has been recently extended in a multiple-action plan (MAP) model (Bortoli, Bertollo, Hanin, & Robazza, 2012) where two dimensions are considered: performance and control. Performance is then classified in terms of performance level (optimal vs. sub-optimal) and conscious action control level (automatic vs. controlled). This conceptualisation leads to the identification of four performance categories: Optimal-automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4). The key features of the four performance categories are summarized in Figure 21.

![Figure 21. Key features of the four types of performance derived from the interaction between performance and control levels as conceptualized within the multi-action plan intervention model.](image-url)
Optimal-automatic (type 1) performance is typified by functionally optimal-pleasant emotional states (P+), self-confidence, perception of control of the situation, high levels of physical and mental energy, and effortless, smooth, autonomous, and consistent movement (Ericsson, 2003; Harmison, 2006). This ideal state can be easily disrupted as a consequence of competitive stress, fatigue, or unexpected performance problems. As a consequence, performers can enter a suboptimal-controlled condition (type 3) characterised by dysfunctional-unpleasant emotional states (N-), excessive and task-irrelevant focus of attention on movement execution in an attempt to deal with problems and mistakes that, as a consequence, reduce movement smoothness and automaticity, with forced “reinvestment” (Maxwell, Masters, & Eves, 2000; Oudejans, Kuijpers, Kooijman, & Bakker, 2011). Suboptimal performance can also occur when individual psychophysiological conditions are fine and feelings are pleasant (P-), but the performer is not much engaged or motivated and does not invest enough energy to execute the task (type 4). The resulting automatic behaviour is not coordinated enough for the task at hand. The fourth condition is typified by optimal-controlled (type 2) performance, in which the individual’s perception of threat tends to prompt functionally optimal, although unpleasant, emotional states (N+) and action-tendencies that are properly directed toward the execution of the task. To attain type 2 performance, the athlete can be instructed to pay attention to only one or two key (core) components of the action previously identified as functional to task achievement. In this way the athlete should be able to prevent excessive reinvestment or attention disruption, and to focus on the relevant aspects of the task that lead to a smooth and automatic movement. Within this framework, Bortoli and colleagues (2012) have developed the MAP intervention model for performance optimization, which was applied to the Italian shooters in preparation for the Olympics to help them to adopt a range of emotion-centred as well as
action-centred strategies to attain a good performance. Emotion-centred strategies usually involve cognitive and somatic procedures, whereas action-centred strategies focus on behavioural techniques to help individuals identify their core components of the entire action, which have then to be accurately performed during task execution (for more details, see Bortoli et al.; Hanin & Hanina, 2009). Findings showed beneficial effects on performance derived from the use of the MAP intervention, and provided initial empirical support to the $2 \times 2$ performance conceptualisation (i.e., performance $\times$ control level).

Despite the preliminary support, further investigations are necessary to corroborate the MAP model and to examine its advantages in comparison to the uni-dimensional classification of performance. For this reason, the present study was conceived to substantiate the existence of the four performance categories as hypothesised in the MAP model, and to investigate whether some specific affective, psychophysiological, and postural trends may typify each category. Several studies have been already conducted to separately investigate the effect of affective, psychophysiological, and postural patterns on performance in different disciplines. For instance, it has been shown that when athletes perform a precision task in a fluent, effective, and automatic manner (i.e., with minimal conscious control), their focus of attention is external and they are just “supervising” (overseeing) the execution (as it can occur during type 1 performance). Furthermore, arousal-activation, measured via skin conductance level (SCL), and vigilance, assessed through heart rate (HR), are lower with respect to poor performance (possibly represented by type 3 performance) (Guillot et al., 2003; Tremayne & Barry, 2001). Finally, the posture is stable and slightly reclined backward from the target in comparison to poor performance characterised by a prevalence of internal focus (see Lohse, Sherwood, & Healy, 2010; Radlo, Steinberg, Singer, Barba, & Melnikov, 2002; Wulf, Mercer, McNevin, & Guadagnoli, 2004; Wulf &
In particular, Wulf and colleagues (2004) suggested that supra-postural task goals have a strong influence on postural control, reflecting the tendency of the motor system to optimize control processes on the basis of the desired movement effect. With regard to breathing dynamics, the typical respiratory pattern of shooters consists of breath holding with slow expiration preceding the trigger pull (Konttinen & Lyytinen, 1992), but not all athletes exhibit this pattern. For example, Guillot et al. (2003) found high variability in respiratory frequency among shooter athletes.

Based on previous findings of empirical research and on our theoretical framework, we predicted: (1) a similar level of SCL in type 1 and type 4 performances. This level was expected to be lower than in type 2 and type 3 performances. SCL in type 3 performance was also expected to be higher than all other performance categories; (2) a lower level of HR in type 1 performance than type 2, type 3, and type 4 performances, due to the different levels of vigilance and to the different focus of attention; (3) a higher respiratory rate in type 2 performance compared to type 1 and type 4 performances, although lower than in type 3 performance; (4) a bodily position less reclined backward with respect to the target in type 3 performance as compared to the other performances as a consequence of an excessive level of attention or a task irrelevant focus. In summary, the expected differences among type 1 (T1), type 2 (T2), type 3 (T3), and type 4 (T4) performances can be schematically represented as follows:

- Skin conductance level: T3 > T2 > T1 = T4
- Heart rate: T2 = T3 = T4 > T1
- Respiratory rate: T3 > T2 > T1 = T4
- Posture: T3 > T1 = T2 = T4
Method

Participants. A 20-year-old athlete of the Italian shooting team who won the silver medal during the Junior World Championship in 2010, and a 46-year-old athlete of the Italian dart-throwing team participated in the study. They were not previously engaged in structured action-based interventions or systematic mental preparation programmes. After the general purpose of the intervention was explained to them and to the coaches, the athletes agreed to participate in the study and provided written informed consent. The study was conducted in accordance with the local ethical guidelines, and conformed to the declaration of Helsinki.

Procedure. Before data acquisition, the critical actions of the full shooting/dart-throwing sequence were identified by each athlete according to the MAP model (Bortoli et al., 2012; Hanin & Hanina, 2009). The participants were asked to accurately and extensively describe their usual optimal movement sequence (i.e., the chain of actions) in a single shot/dart-throw from start to follow-through/flight release. The shooter reported to pay attention to: feet position, balance, body alignment, handgrip, breathing, trigger pull, gun and sight alignment, and follow-through. The dart-thrower reported to pay attention to: body weight on the right foot, hip position, right knee, back leg, grip, fingers relaxed, arm bent, elbow alignment, wrist bent, attention focused on target, execution.

The participants were then asked to choose the two elements of their chain of actions (i.e., core components) deemed fundamental in order to optimally perform. To help the athletes identify their core components, they were asked: “What are the actions that determine your shooting/throwing scores to drop from optimal to suboptimal levels when they are executed less accurately?” The shooter identified the trigger pull and the alignment of the gun sight on the target as core components. They were labelled as
CHAPTER SIX: Psychophysiological correlates of MAP

*trigger* and *aiming*. The dart-thrower chose the elbow alignment and the attention on target, which were labelled as *elbow* and *aiming*.

After this phase, the shooter performed a total of 121 air-pistol shots. He was free to relax between two consecutive shots and to shoot when he felt ready (average inter-shot interval of about 1 min). The distance between the shooter and the target was 10 m and the diameter of the target was 6 cm, according to the international shooting competition rules (www.issf-sports.org/theissf/rules/english_rulebook.ashx). The score obtained at each shot was automatically recorded with electronic scoring targets. During the execution of the shots, the athlete was asked to switch off his LCD monitor displaying online shot information, in order to evaluate the accuracy of his perceived result just after each shot.

The dart-thrower performed a total of 122 flights using the same methodology of the shooter. The distance between the thrower and the target was 237 cm. The regulation board was 451 mm in diameter and was divided into 20 radial sections; the centre of the target was placed at 173 cm from the floor, according to the international dart gameplay regulation (www.pdc.tv/page/Rules/0,,10180,00.html).

Before each shot, the hedonic tone level of the shooter’s affective state was assessed on a modified 11-point Borg scale (see Borg, 2001), which has been successfully used in psychophysiological studies as well as to investigate emotions (Hanin & Syrjä, 1996). The athlete was asked to evaluate his hedonic tone on the Borg scale ranging from -11 (extremely unpleasant) to 11 (extremely pleasant). The verbal anchors of the scale, developed to avoid floor and ceiling effects, were 0 = nothing at all, .5 = very, very little, 1 = very little, 2 = little, 3 = moderately, 5 = much, 7 = very much, 10 = very, very much, 11 = maximal possible. No verbal anchors were used for 4, 6, 8 and 9. Negative scores were assigned to unpleasant states. This procedure was used in previous studies to assess
emotional states occurring before and during performance (Bertollo et al., 2012; Pellizzari, Bertollo, & Robazza, 2011). After each shot, the shooter was asked to report his perceived result (ranging from 0 to 10.9), the hedonic tone level (from -11 to 11 on the modified Borg scale), the control level of the core components of action (trigger and aiming) and the accuracy level of the execution of the core components (from 0 to 11 on the Borg scale). After evaluation, the shooter was allowed to switch on the monitor of electronic target to detect the real score of his shot. The dart-thrower was requested to report the levels of control and accuracy of the core components of the action (aiming and elbow). The perceived result and the hedonic tone were not assessed because the actual result information on the dartboard remained always available to the dart-thrower and, therefore, his evaluations could have been biased by this information.

Besides self-evaluation, the following physiological and postural measurements were simultaneously performed:

1. SCL was measured using two Ag/AgCl electrodes attached to the fingertips of the second and third finger of the non-dominant hand. The electrodes were connected to the acquisition system (Powerlab 16/30, ADInstruments, Australia) via an UFI Skin Conductance Meter 2701. The electrodes were positioned 10 min before the experimental session and the athlete was asked to remain at rest for at least 10 s after each shot in order to avoid movement artefacts. SCL was recorded with a sampling frequency of 1 kHz.

2. The electrocardiogram (ECG) was recorded using a BioHarness (Zephyr technology) connected via wireless transmission to the acquisition system (Powerlab 16/30, ADInstruments, Australia).

3. The same instrumentation was supplied of a piezoelectric belt that permitted to record the respiratory rate.
4. The Zephyr Technologies BioHarness also permitted to record postural adjustments, which were measured via 3 axial accelerometers. The deflections from the z axis were measured in degrees.

All Zephyr Technologies BioHarness data were acquired with 250 Hz sampling frequency. A device based on acoustic technology (cardio-microphone and Powerlab 16/30, ADInstruments, Australia) was used to define the instant at which each shot was released, while the instant of dart release was recorded via a camera. Both the acoustic device and the camera were internally synchronised to the acquisition system. As a further control of synchronization, we also acquired the signal of a push button switch connected to the Powerlab 16/30. The push button was used by the experimenter whenever the participant pulled the gun trigger or released the flight. These signals were acquired with a sampling frequency of 1 kHz.

**Data Pre-processing.** The physiological data were partitioned into single trial segments of 5 s duration for the shooter and of 3 s duration for the dart-thrower before the shot/flight release. The different duration of the segments was due to the fact that the dart-thrower released three flight in a row, so there was a shorter time between two subsequent throws as compared to the time elapsed between two subsequent shots. The onset of each physiological data segment was aligned with the time instant when the shot/flight was released. All recordings were visually inspected by two independent observers using Labchart 7.1 (ADInstruments, UK) in order to detect instrumental, muscular, and movement artefacts. The recordings/segments affected by any of the listed artefacts were not considered for analysis. A number of shots and flights were also rejected owing to Bluetooth disconnection of the bioharness from the powerlab. A total of 100 physiological segments out of 121 were analysed for the shooter (25 shots for each
performance category), and a total of 76 segments out of 122 for the dart-thrower (19 flights for each performance category).

All data were down-sampled to 250 Hz. The peaks of ventricular depolarisation (R peaks) were automatically detected on the ECG traces using the ECG Analysis Module (Labchart 7.1). Instantaneous HR was determined as the inverse of the RR interval duration (in ms), calculated as the interval between two subsequent R peaks, detected with an error of ± 2 ms. The average HR was then calculated for each trial segment. The instantaneous values of SCL, respiratory rate, and postural deflection were also averaged for each trial segment. Those values were used for subsequent statistical analysis.

Statistical Analysis. To test the predictions stemming from the MAP framework, we categorized shots/flights in the four performance categories derived from the interaction of optimal/suboptimal and automatic/controlled performance dimensions. To this purpose, we split the shot/flight scores and the control levels with respect to their median, which was 10.1 for the shots and 6 for the flights. Suboptimal performance was then coded 0 and optimal performance 1 for both athletes in order to make their marks comparable. We also split the shot/flight scores on the basis of the median value of the corresponding control levels, which were 8 for trigger control (shooter) and 2 for aiming control (dart-thrower). We therefore categorized shots/flights performed with a low control level (i.e., below median value: automatic shots/flights) as 0, and those performed with a high control level (i.e., above median: controlled shots/flights) as 1. For the shooter, we decided to use trigger instead of aiming as the core component on the basis of which the shots were split because the correlation between trigger accuracy and shooting results was higher than between aiming accuracy and shooting results (trigger, \( r = .557 \); aiming, \( r = .293 \)). For the dart-thrower, we used aiming control instead of elbow control for similar reasons (aiming, \( r = .677 \), elbow, \( r = .634 \)).
A $2 \times 2$ (optimal/suboptimal $\times$ automatic/controlled) within subjects multivariate analysis of variance (MANOVA) was performed to test the differences among the four types of performance. The dependent variables were hedonic tone, accuracy of core components, SCL, HR, respiratory rate, and postural deflection scores. Analysis was conducted on a total of 100 shots and 76 flights equally distributed in the four performance categories (i.e., 25 shots and 19 flights per category).

**Results**

The correlation between perceived and actual shot’s results can be considered an index of reliability of the athlete’s own evaluation. In the case of the shooter, the Pearson correlation coefficient was $.895$ ($p > .001$). This correlation suggested that the shooter was able to reliably evaluate his performance. For the reason previously described in the Method section, we could not collect the perceived outcome in the case of the dart-thrower.

The descriptive statistics for each performance category derived from the interaction of optimal/suboptimal and automatic/controlled performance dimensions are summarized in Table 2.
Table 2. Descriptive statistics of hedonic tone, behavioural, and psychophysiological data for optimal-automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4) performances in the shooter and in the dart-thrower.

<table>
<thead>
<tr>
<th>Performer</th>
<th>Variable</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shooter</td>
<td>Shot results</td>
<td>10.38 (0.19)</td>
<td>10.58 (0.13)</td>
<td>9.72 (0.38)</td>
<td>9.52 (0.31)</td>
</tr>
<tr>
<td></td>
<td>Hedonic tone</td>
<td>8.08 (1.12)</td>
<td>7.20 (1.53)</td>
<td>6.48 (1.87)</td>
<td>7.88 (1.01)</td>
</tr>
<tr>
<td></td>
<td>Aiming accuracy</td>
<td>7.96 (1.21)</td>
<td>10.04 (0.84)</td>
<td>7.20 (1.87)</td>
<td>6.60 (1.08)</td>
</tr>
<tr>
<td></td>
<td>Trigger accuracy</td>
<td>7.52 (0.77)</td>
<td>9.04 (1.02)</td>
<td>7.64 (1.00)</td>
<td>6.64 (0.91)</td>
</tr>
<tr>
<td></td>
<td>Aiming control</td>
<td>7.56 (0.58)</td>
<td>9.68 (0.56)</td>
<td>9.40 (0.50)</td>
<td>7.16 (0.75)</td>
</tr>
<tr>
<td></td>
<td>Trigger control</td>
<td>7.56 (0.87)</td>
<td>9.12 (0.83)</td>
<td>7.76 (0.97)</td>
<td>6.92 (0.70)</td>
</tr>
<tr>
<td></td>
<td>Skin conductance (µs)</td>
<td>8.26 (5.94)</td>
<td>13.78 (6.87)</td>
<td>16.28 (4.47)</td>
<td>9.42 (5.04)</td>
</tr>
<tr>
<td></td>
<td>Heart rate (bpm)</td>
<td>84.90 (4.13)</td>
<td>85.97 (4.76)</td>
<td>85.11 (4.57)</td>
<td>86.45 (5.04)</td>
</tr>
<tr>
<td></td>
<td>Respiratory rate (bpm)</td>
<td>14.04 (2.48)</td>
<td>13.68 (2.67)</td>
<td>11.96 (2.17)</td>
<td>13.39 (2.55)</td>
</tr>
<tr>
<td></td>
<td>Posture (degrees)</td>
<td>-18.25 (9.81)</td>
<td>-13.41 (9.90)</td>
<td>-7.74 (9.41)</td>
<td>-16.95 (10.61)</td>
</tr>
<tr>
<td>Dart thrower</td>
<td>Flight results</td>
<td>22.11 (9.18)</td>
<td>41.05 (20.52)</td>
<td>6.16 (5.67)</td>
<td>2.89 (1.94)</td>
</tr>
<tr>
<td></td>
<td>Aiming accuracy</td>
<td>3.26 (0.65)</td>
<td>4.03 (1.70)</td>
<td>1.16 (0.94)</td>
<td>1.05 (1.01)</td>
</tr>
<tr>
<td></td>
<td>Elbow accuracy</td>
<td>4.05 (1.18)</td>
<td>3.92 (1.92)</td>
<td>1.21 (0.92)</td>
<td>1.16 (0.99)</td>
</tr>
<tr>
<td></td>
<td>Aiming control</td>
<td>0.16 (0.37)</td>
<td>3.47 (1.26)</td>
<td>3.21 (0.54)</td>
<td>0.68 (0.82)</td>
</tr>
<tr>
<td></td>
<td>Elbow control</td>
<td>4.18 (1.17)</td>
<td>0.53 (1.02)</td>
<td>0.50 (1.01)</td>
<td>1.66 (1.34)</td>
</tr>
<tr>
<td></td>
<td>Skin conductance (µs)</td>
<td>6.47 (3.55)</td>
<td>9.16 (2.93)</td>
<td>9.53 (3.92)</td>
<td>8.32 (3.40)</td>
</tr>
<tr>
<td></td>
<td>Heart rate (bpm)</td>
<td>76.21 (2.97)</td>
<td>76.89 (1.85)</td>
<td>75.84 (3.02)</td>
<td>76.16 (2.71)</td>
</tr>
<tr>
<td></td>
<td>Respiratory rate (bpm)</td>
<td>9.74 (2.62)</td>
<td>11.26 (2.77)</td>
<td>11.26 (2.77)</td>
<td>10.68 (2.52)</td>
</tr>
<tr>
<td></td>
<td>Posture (degrees)</td>
<td>-19.74 (2.64)</td>
<td>-19.16 (1.71)</td>
<td>-18.53 (2.76)</td>
<td>-20.26 (2.08)</td>
</tr>
</tbody>
</table>

Note. 1 Number of shots for each type of performance = 25; 2 number of flights for each type of performance = 19. The hedonic tone of the dart-thrower was not assessed.
MANOVA results on the shooter yielded significant main effects on performance, Wilks’ \( \lambda = .04, F_{7, 18} = 55.51, p < .001, \eta^2_p = .96, \) power = 1.00, and control, Wilks’ \( \lambda = .03, F_{7, 18} = 98.07, p < .001, \eta^2_p = .97, \) power = 1.00, as well as on their interaction, Wilks’ \( \lambda = .45, F_{7, 18} = 3.19, p < .03, \eta^2_p = .55, \) power = .83. Results on the dart thrower showed significant main effects on performance, Wilks’ \( \lambda = .14, F_{7, 12} = 10.26, p < .001, \eta^2_p = .86, \) power = 1.00, and control, Wilks’ \( \lambda = .29, F_{7, 12} = 4.15, p < .02, \eta^2_p = .71, \) power = .87. Significant effects were examined in detail through univariate follow up \( (p < .05) \) and post-hoc LSD analysis. Pairwise comparisons are reported in Table 3 only for those variables that were significant at follow up.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Shooter</th>
<th>Dart-thrower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
<td>Type 2</td>
</tr>
<tr>
<td>Hedonic tone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.031</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.000</td>
<td>.077</td>
</tr>
<tr>
<td>Type 4</td>
<td>.621</td>
<td>.095</td>
</tr>
<tr>
<td>Aiming accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.042</td>
<td>.000</td>
</tr>
<tr>
<td>Type 4</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Trigger/Elbow accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.649</td>
<td>.000</td>
</tr>
<tr>
<td>Type 4</td>
<td>.001</td>
<td>.000</td>
</tr>
<tr>
<td>Skin conductance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.000</td>
<td>.121</td>
</tr>
<tr>
<td>Type 4</td>
<td>.470</td>
<td>.007</td>
</tr>
<tr>
<td>Respiratory rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.608</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.004</td>
<td>.016</td>
</tr>
<tr>
<td>Type 4</td>
<td>.359</td>
<td>.685</td>
</tr>
<tr>
<td>Posture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>.089</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>.000</td>
<td>.047</td>
</tr>
<tr>
<td>Type 4</td>
<td>.646</td>
<td>.211</td>
</tr>
</tbody>
</table>

*Note.* The hedonic tone of the dart-thrower was not assessed. Respiratory rate results for the dart thrower are not reported because not significant.
The direction of significant differences among type 1 (T1), type 2 (T2), type 3 (T3), and type 4 (T4) performances can be summarized as follows:

- **Hedonic tone:** Shooter—T1 = T4 > T3; T2 = T3; T2 = T4
- **Aiming accuracy:** Shooter and dart thrower—T2 > T1 > T3 = T4
- **Trigger accuracy:** Shooter—T2 > T1 = T3 > T4
- **Elbow accuracy:** Dart thrower—T1 = T2 > T3 = T4
- **Skin conductance:** Shooter—T2 = T3 > T1 = T4; Dart thrower—T2 = T3 > T1
- **Respiratory rate:** Shooter—T1 = T2 = T4 > T3
- **Posture:** Shooter—T3 > T1 = T2 = T4; Dart thrower—T3 > T4

It is worth noting that, as expected, higher scores of perceived accuracy were reported for optimal performance compared to suboptimal performance. Furthermore, the hedonic tone pattern was reflected in the SCL pattern, in that differences were found between automatic and controlled performances (i.e., high hedonic tone levels and low SCL were associated with automatic performance). The time course of SCL intensity prior to execution is depicted in Figure 22. The SCL intensity decrease during the few seconds before the shots/flights was in agreement with the findings reported in the literature (Bertollo et al., 2012; Tremayne & Barry, 2001).

![Figure 22. Performers’ skin conductance level trend during the 5 s before the shot and the 3 s before the dart-throw for the four types of performance. The instant at which the shot/flight is released is marked as 0. Type 1 is optimal/automatic, type 2 is optimal/controlled, type 3 is suboptimal/controlled and type 4 is suboptimal/automatic](image-url)
Finally, the pattern of the respiratory rate was reflected in a similar pattern of bodily position in relation to the target, with differences between type 3 performance and the other categories.

**Discussion**

The main purpose of this study was to investigate affective, psychophysiological, and postural patterns associated with the four performance categories posited in the MAP model in two precision sport athletes. Consistently with the findings of a previous work (Bortoli et al., 2012), hedonic tone and behavioural results demonstrated that performance level can remain good also when the athlete focuses his attention on the core components of the action rather than on “supervising” them. With regard to the intensity level of the hedonic tone, the shooter reported a higher level of pleasant state during type 1 performance compared to type 2 and type 3 performances, as expected according to the flow theory (Kimiecik & Jackson, 2002). However, the level of pleasant state in type 1 performance was also similar to that of type 4 performance. This finding contrasts with the predictions of the flow theory, because type 4 performance is suboptimal. From an applied perspective, this result supports the indications of the Bortoli et al’s MAP intervention model and the Hanin and Hanina’s (2009) identification-control-correction programme, in which action-centred strategies are viewed as effective in maintaining optimal task execution and in dealing with dysfunctional situational changes. Athletes can use action-centred strategies in combination with emotion-centred strategies to switch from type 1 to type 2 performance states, thereby maintaining a good condition for task execution. We suggest that, under unfavourable circumstances, athletes can accomplish this state shift by using the information on their emotional condition, and psychophysiological state, and by paying more attention on their action core components.
The emotional arousal reflected in the hedonic tone has also been mirrored in some psychophysiological data. In agreement with our hypothesis, in the shooter we found a lower SCL in type 1 performance than in type 2 and type 3 performances, with comparable SCL in type 1 and type 4 performances. A similar pattern emerged in the dart-thrower. SCL is a transient change in the electrical properties of the skin and indicates the state of arousal or activation through the activity of sympathetic cholinergic neurons at the level of eccrine dermal sweat glands (Barry & Sokolov, 1993). Traditionally, SCL is considered one of the best indicators of arousal-activation in shooting sport. It enables to discriminate between best and worst performances (Guillot et al., 2003; Tremayne & Barry, 2001), and it has been recently used as a valuable index to identify individual zones of optimal functioning (Bertollo et al., 2012; Edmonds et al., 2008). The finding that electrodermal activity is more elevated during type 2 and type 3 performances than during type 1 and type 4 performances suggests the existence of different mechanisms of energy mobilization and regulation. An information processing interpretation of this finding could be related to an effortful allocation of attentional resources to the task associated with heightened autonomic activation. A different, but not necessarily alternative, explanation could invoke the concepts of stress and affect rather than attention and effortful allocation of resources (see Dawson, Schell, & Filion, 2007).

According to both views, focused attention, fatigue and stress are associated with an increased sympathetic activation, particularly electrodermal arousal, which is a reliable physiological response to stressors. This interpretation has potential implications for an applied setting; coaches could monitor the psychophysiological state of the athletes and teach them the best strategies to optimize performance, also by using biofeedback techniques to monitor specific individual activation levels and improve self-regulation. With regard to HR of both athletes, we did not find differences between the four types of
CHAPTER SIX: Psychophysiological correlates of MAP

performance. HR has been proposed as a psychophysiological index of vigilance (Tremayne & Barry, 2001). The large number of shots thrown by both athletes could have caused a significant level of fatigue resulting in enhanced HR. Other authors have found cardiac acceleration in precision sports athletes in response to the physical demands of experimental requirements (Hatfield, Landers, & Ray, 1987, in shooting, and Salazar et al., 1990, in archery).

Respiratory rate enabled us to discriminate type 3 performance from the other performance categories, in partial agreement with our hypothesis. The decrease in respiratory rate suggests the breathing process to be influenced by the level of fatigue derived from a sustained attentional control that the performer exerts on the action in an attempt to deal with stressful conditions and ineffective performance. This argument is consistent with Guillot et al. (2003) who found a decrease in respiratory rate from the first shots to the last ones. In both athletes, the pattern of the respiratory rate was reflected in a similar pattern of bodily position in relation to the target, with differences between type 3 (suboptimal-controlled) performance and the other categories. More negative values in bodily position observed during type 1 (optimal-automatic) performance indicated that the athletes leant back and relaxed while shooting/throwing and concentrating on the task-related external cues. A smaller tilt was found during type 3 performance, in which the athletes are supposed to exert excessive control. They leant forward, probably in an attempt to regain proper attentional focus toward the target. This finding is in line with the suggestion that supra-postural task goals have a strong influence on postural control (Wulf et al., 2004).

Taken together, the findings on respiratory rate and bodily position suggest that precision sport athletes may attempt to deal with the adverse conditions of fatigue and stress by reducing their breathing frequency and adopting a forward body inclination.
Although these behaviours may ensure, to some extent, body stability and a position closer to the target, they do not seem to be very effective. Rather than adopting these ineffective compensatory behaviours, we propose that a better strategy would be to focus the attention on the core components of the action.

Conclusion

This is the first study intended to explore the underlying psychophysiological and postural features of performance within a $2 \times 2$ framework stemming from the MAP intervention model (Bortoli et al., 2012). A limitation of this study is that it was conducted in two athletes only. Further investigation on a larger population is necessary to examine the arousal-activation features and trends across the four types of performance described in the MAP model. Although the number of participants in a study is important to draw general conclusions, it is worth mentioning that the access to top-level athletes for research and intervention purposes is usually limited.

Future validation studies on the MAP model should also consider the relationship between posture and attention using the internal/external focus of attention approach as well as the supra-postural/postural task goals (Wulf, 2008; Wulf et al., 2004). Additionally, it would be interesting to investigate the cortical activity within the MAP model framework using electrical measures. These have been used in earlier research to compare expert vs. non-expert or optimal vs. non-optimal performances, and permit to measure the cortical arousal by means of alpha activity (Hatfield & Kerick, 2007), neural efficiency (Del Percio et al., 2009), beta band activity (Hillman, Apparies, Janelle, & Hatfield, 2000), frontal asymmetry (Janelle et al., 2000), and frontal midline theta activity (Doppelmayr, Finkenzeller, & Sauseng, 2008). This multimodal and multidimensional approach might be promising from both theoretical and applied perspectives.
CORTICAL PATTERNS OF SHOOTING PERFORMANCE WITHIN THE MULTI-ACTION PLAN MODEL

The analysis of psycho-bio-social mechanisms underlying optimal performance experiences has received great attention in the domain of sport science (Hanin, 2007). Current avenues of research involve the use of multi-methods that target diverse structural components (e.g., emotional processes, cognitive functioning, motor behavior) underlying human performance (Tenenbaum, Hatfield, Eklund, Land, Calmeiro, Razon, & Schack, 2009). To this extent, Bortoli and colleagues (Bortoli, Bertollo, Hanin, Robazza, 2012) have recently extended the uni-dimensional nomothetic categorization of performance into an idiographic multiple-action plan (MAP) model grounded in cross-tabulation of behavioral, psychological, physiological, and neurological data. According to the authors, behavioral patterns underlying distinct performance levels (i.e., Optimal-Sub-Optimal) and attentional demands (i.e., Automatic-Controlled) may be classified into four categories: optimal-automatic (type 1), optimal-controlled (type 2), suboptimal-controlled (type 3), and suboptimal-automatic (type 4) (Figure 23).

Figure 23. Performance categorization according to MAP model
Most recently, Bertollo and colleagues (Bertollo, Bortoli, Gramaccioni, Hanin, Comani, & Robazza, in press; see previous chapter) proposed that awareness of idiosyncratic core components linked to optimal performance in sports varies as a function of attentional and emotional control, as measured by physiological (e.g., skin conductance responses, heart rate) and behavioral markers (e.g., kinematic analysis).

Indeed, neurophysiological mechanisms in general, and cortical activity in particular, are at the core of an integrated view of human performance (Hatfield & Kerick, 2007). Electroencephalographic (EEG) and event-related potential (ERP) measurements have been essential in shaping our understanding of skilled performance in sports (Thompson, Steffert, Ros, Leach, & Gruzelier, 2008). For instance, “economy of effort” mechanisms have been widely studied with a neurophysiological approach, especially in precision sports and self-paced tasks (e.g., target shooting, golf putting, dart-throwing, and archery) (Hatfield, & Kerick, 2007; Goodman, Haufler, Shim, & Hatfield, 2009; Del Percio, Babiloni, Bertollo, et al., 2009; Del Percio, Iacoboni, Lizio, et al., 2011). Altogether, skilled performance in sports has been associated with decreased cortical activation (i.e., “the economy of effort principle” or “the neural efficiency hypothesis”) (Hatfield, & Hillman, 2001).

In order to better analyze the cortical functioning to verify the “neural efficiency hypothesis”, and to provide a neurobiological model to explain peak performance in sport, both spectral and temporal measures have been used to study cortical dynamics during reactive motor behavior (Hatfield & Kerick, 2007; Di Russo, Pitzalis, Aprile, Spinelli, 2005; for more details see chapter 5).

In the framework of spectral analysis Event Related Desynchronization/ Synchronization (ERD/ERS) analysis has been used to investigate cortical dynamics during expert performance. ERD (i.e., an event-related reduction in power at given
frequencies) denotes cortical information processing, while ERS (i.e., an event-related increase in power at given frequencies) denotes inhibition, selective cortical information processing, or cortical idling (Pfurtscheller, & Lopes da Silva, 1999).

Research using ERD/ERS analysis is important to unravel new information about the neurodynamics of cortical networks. ERD and ERS are relative measures of local activity at a certain time and frequency. This analysis, recently applied to analyze shooting performance (Del Percio, Babiloni, Bertollo, et al., 2009), has revealed that differences in the alpha band occur between expert and novices, and between best and worst performance.

In particular, EEG studies on attentional control and emotional content have focused on either comparing athletes and non-athletes, or two skill levels within sports (i.e., “the expert-novice paradigm”). While nomothetic investigations have greatly advanced our understanding of the “brain states” and physiological correlates of optimal experiences in sports, idiographic studies of experts are particularly important to advance our understanding of the mechanisms underlying expertise in a given domain (i.e., “the expert performance approach”). Noteworthy are studies on experts who are recognized through objective performance markers rather than subjective assessment methods, such as peers voting (Ericsson, 2006). The Individual Zones of Optimal Functioning framework and, more recently, the Idiographic Affective Probabilistic Zones methodology are further well-known concepts shaped through idiosyncratic analysis and single-case designs (Johnson, Edmonds, Moraes, Medeiros Filho, & Tenenbaum, 2007; Bertollo, Robazza, Falasca et al., 2012).

The purpose of the present study was to assess the alpha and beta ERD/ERS patterns underpinning the performance categories conceptualized within the MAP model. We aimed to test the following hypotheses: (1) optimal-automatic performance
experiences (type 1) are characterized by an instinctive minimal conscious control, high level of energy matching the task demands, and cortical arousal synchronized with the event (shot); (2) optimal-controlled experiences (type 2) are characterized by consciously focused control, with a compensatory high level of energy, and a cortical arousal higher than in type 1; (3) suboptimal-automatic experiences (type 3) are characterized by conscious unfocused level of control, task irrelevant, energy misuse, with cortical activity desynchronized with the event; and (4) suboptimal-controlled experiences (type 4) are characterized by minimal conscious control, low level of energy, with a cortical activity synchronized with the event.

Method

Participants: Five elite pistol shooters (age range 16-30 years), members of the Italian Shooting Team and with extensive international experience, agreed to participate in the study and signed a written informed consent. The study was conducted in accordance with the local ethical guidelines, and conformed to the declaration of Helsinki.

Procedure: Participants were interviewed about the core components related to their “chain of action” that they deemed fundamental for optimal performance. The Core components were assessed using the procedure proposed by Bortoli and colleagues (Bortoli et al., 2012), and, for each athlete, the most influential was identified. Afterward, they performed a total of 120 air-pistol shots, being “free to relax” between consecutive shots, and to shoot when they felt “ready to go” (average inter-shot interval of about 1 minute). The distance between the shooter and the target was 10 m, and the diameter of the target was 6 cm, in accordance with the international shooting competition rules (www.issf-sports.org/theissf/rules/english_rulebook.ashx). An electronic scoring target
was used to (automatically) record the shooting scores. Noteworthy, online shot information was initially concealed from the athletes because we were interested in assessing their perceived accuracy. Hence, after each shot, the athletes were asked to report their perceived shooting score (ranging from 0 to 10.9). They also reported (a) the control level of each idiosyncratic core component of action, and (b) the accuracy level related to the execution of each core component (from 0 to 11 on the Borg scale). After this evaluation, the actual shooting score (i.e. the objective performance) of each shot was made available to the shooter. Besides self-evaluation, the electroencephalogram was recorded using a 32 channels EEG ASAlab system and the waveguard cap by ANT (Advanced Neuro Technology Enschede, Nederlands).

**EEG Recordings:** EEG data were continuously recorded (sampling frequency 1024 Hz) from the 32 scalp electrodes (waveguard cap) positioned over the whole scalp according to the 10-20 system (Jasper, 1958). EEG signals were recorded with common reference; the ground electrode was positioned between Fpz and Fz; electrode impedance was kept below 5 KΩ.

A device based on acoustic technology (cardio-microphone and Powerlab 16/30, ADInstruments, Australia) was used to identify the instant of shot release. Acoustic signals were acquired with a sampling frequency of 1 kHz.

**Preliminary data analysis:** EEG data were band-pass filtered between 0.01 to 40 Hz, segmented into single epochs of 10 s duration, with each epoch starting at -6 s and ending at +4 s with respect to t=0 (i.e. the instant when the shot was released). Data epochs showing instrumental, ocular and muscular artifacts were identified, both via automatic detection (maintaining only the signal with amplitude between -150 µV and 150 µV) and by visual inspection, and excluded from further analysis (Zanow & Knosche, 2004). Accordingly, only the epochs free from artifacts were considered in the
CHAPTER SEVEN: Cortical patterns of MAP

analysis. The shooting results and the control levels exerted by each shooter on his/her core components of action were used to categorize the EEG epochs according to the four types of performance foreseen in the MAP model.

**ERD/ERS analysis:** To quantify the event-related changes in the high alpha or beta power, the corresponding individual ERD/ERS maps were calculated following the procedure proposed by Zanow and colleagues (2004). The Hilbert transform was performed before ERD/ERS analysis. Then, for a given frequency band, ERD/ERS maps for a given interval of interest are calculated as the percent variation of the signal power with respect to the power of the baseline signal in each EEG channel. In this procedure, ERD patterns account for a relative increase of signal power as compared to the baseline, whereas ERS patterns for a relative decrease. This procedure leads to opposite results with respect to those obtained with the procedure proposed by Pfurtscheller and da Silva (1999), where ERD patterns correspond to a relative decrease of signal power, and ERS patterns to a relative increase.

We calculated the ERD/ERS maps for the high alpha band, defined as the frequency band from the individual alpha frequency (IAF) to the IAF+2Hz, and for the beta band, defined as the frequency band between 13 to 30 Hz. Given that the IAF of our athletes were very similar (9.9, 10, 9.9, 10.1 and 9.9 Hz), we considered the frequency band 10-12 Hz as the high alpha band for all of them.

Three intervals of interest, each of 1 s duration, were considered during the 3 s preceding each shot (i.e. from -3 to 0 s, for $t_{\text{shot}}=0$), whereas the baseline signal was epoched from -5 to -4 s before the shot. Periods before -5 s were not suitable because of body movements, small adjustments of head/trunk, and respiration.

For each participant and for each group of EEG epochs categorized according to the types of performance foreseen in the MAP model, the baseline signals were averaged
to reduce background noise before ERD/ERS calculation. Similarly, averaged ERD/ERS maps for each interval of interest were obtained, for each participant and for each group of EEG epochs, from the single ERD/ERS maps. Finally, for each type of performance the individual ERD/ERS map were averaged across subjects to account for the cortical patterns underlying the four MAP model types.

Results

The correlation between perceived and actual shot’s results can be considered an index of reliability of the athlete’s own evaluation. In the case of our shooters, the Pearson correlation coefficient was ranged between .82 and .91 ($p > .001$). This correlation suggested that the shooters were able to reliably evaluate their performance.

Findings revealed differences in cortical activity with respect to performance types in both the high alpha band (Figure 24) and the beta band (Figure 25).

In particular in the high alpha band, type 1 and type 4 performances (optimal-automatic and suboptimal-automatic) seem to be characterized by a similar relative decrease in signal power (ERS) at shot's release, involving the central areas and the contralateral parietal and occipital areas. Conversely, they differ for the ERD pattern before the shot, involving prefrontal, frontal and occipital areas in type 1 performance, and prefrontal areas in type 4 performance.

In type 2 performance (optimal-controlled), no ERS pattern is observed at shot's release, while a clear relative increase of signal power (ERD) occurs in the prefrontal and occipital areas at -2 and -1 s, and in the central areas 3 s before the shot.

Type 3 performance (suboptimal-controlled) seems to be characterized by a relative decrease in signal power (ERS) in the contralateral frontal and parietal areas at
shot's release, with a high relative increase of signal power (ERD) in the prefrontal, frontal and central areas just 1 s before the shot.

Figure 23. Average ERD/ERS maps in the high alpha band (10-12 Hz) at shot release (t=0) and during the three seconds preceding it, categorized for the four types of performance. Color scale: maximum ERD and ERS are coded in Red and Blue, respectively.

With regard to the ERD/ERS patterns in the beta band, they generally differ from those found in the high alpha band. However, type 1 and type 4 performances (optimal-automatic and suboptimal-automatic) are still characterized by a similar pattern, with a relative decrease in signal power (ERS) at shot's release, which does not involve the central areas as in the high alpha band, but involves only the contralateral parietal and occipital areas. Type 1 performance is also characterized by a relative signal power
increase (ERD) in the frontal, central and ipsilateral parietal areas. The same pattern is also visible in type 4 performance, although with a much smaller intensity. As in the alpha band, type 1 and type 4 performances mainly differ for the ERD/ERS patterns observed during the last seconds before the shot. In type 1 performance, a clear relative increase in signal power (ERD) is localized in the bilateral temporal areas at -3 s, in the contralateral frontal and prefrontal areas, and in the occipital areas at -2 s, and in the contralateral parietal and occipital areas at -1 s. One second before the shot, also a relative decrease in signal power (ERS) occurs in the central and ipsilateral parietal areas. Conversely, no clear ERD/ERS patterns can be observed for type 4 performance during the seconds preceding the shot's release.

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Figure 24. Average ERD/ERS maps in the beta band (13-30 Hz) at shot release (t=0) and during the three seconds preceding it, categorized for the four types of performance. Color scale: maximum ERD and ERS are coded in Red and Blue, respectively.
Also in type 2 performance (optimal-controlled), a relative decrease in signal power (ERS) at shot's release involves the contralateral parietal and occipital areas, while no clear ERD/ERS patterns can be observed during the seconds preceding the shot.

Finally, type 3 performance (suboptimal-controlled) is characterized by a relative decrease of signal power (ERS) at shot's release in the bilateral frontal and parietal areas, and in the occipital areas. A relative increase of signal power (ERD) is observed in the central parietal and contralateral frontal areas 1 s before the shot, while an extensive relative decrease of signal power (ERS) is found in the central and ipsilateral frontal areas at -2 and -3 seconds.

**Discussion and Conclusions**

Overall, our preliminary findings for type 1, type 2 and type 4 performances at shot's release support the notion that this event is characterized by a lower cortical activation. This notion, supported by the ERD/ERS patterns obtained in both the high alpha and beta bands, is associated with an automatic performance, characterized by the quiescence, automaticity and fluidity of psycho-bio-social states, but is only partially in line with the well-established “neural efficiency hypothesis” and the model of stress-induced cortical dynamics, which link optimal performance to a particular “mental print” that features the same psycho-bio-social states typical of type 1 and 4 performances (Hatfield & Kerick, 2007). Indeed, our results indicate that optimal performance is typical of types 1 and 2 only. Therefore, it seems that optimal performance could be related not just to a lower cortical activation at shot's release, but also to the patterns of cortical activation during the seconds preceding the shot. In particular one second before the shot, type 1 performance features an increased signal power in the high alpha band that involves not only the prefrontal areas, as in type 4 performance, but also the frontal and
occipital areas, which are related to focused attention and here seem to account for the goodness of performance. Differences between these two types of performances during the seconds preceding the shot are observed also in the beta band.

This interpretation is supported by the results obtained for type 2 performance (optimal-controlled), which indicates that the athletes may experience functional levels of performance, translated in a relative decrease of the activation of the contralateral parietal and occipital areas in the beta band, even when exerting a voluntary control of their idiosyncratic core components of action. In this case, the athletes use consciously focused control that is mirrored, in our results for the high alpha band, in an over-activation of the central cortical areas at -3 s, and in the activation of the frontal and occipital areas during the 2 s preceding the shot, as in type 1 performance. No such patterns are found in type 3 performance.

In conclusion, our findings echo the notion that functional performance states are plausible within a broad range of behavioral and physiological antecedents. However, the analysis of the cortical activations related to the psycho-bio-social states underlying distinct performance-related experiences, as defined in the MAP model, can bring new insights on the neural correlates of the control and performance levels not only at shot's release, but also during the last second before the shot.

This findings need an improvement of the sample, and further types of investigation in temporal and frequency domains are welcome. For instance, Motor cortical related potential analysis can examine Bereitschaftspotential and motor potential in term of processing (preparation and/or execution) of the action.

Functional network and hemispheric specialization can be investigated using coherence analysis. Brain effective connectivity can be quantified through others techniques able to detect the direction of the information flow within brain functional
network, such as granger causality and dynamic causal modeling. The type of brain functional organization in term of brain efficiency can be further investigated through other approaches such as those referring to the graph theory.
The aim of the present dissertation was to investigate the behavioural, psychophysiological and cortical processes that underlie optimal performance in precision sport elite athletes. To reach peak performance, the athletes need to identify the individual zone of optimal functioning. To this purpose, the identification of the underlying psychophysiological features can be very helpful.

The original investigations conducted during the doctoral period have highlighted that athletes do not only experience a good or worse performance and their experiences are not only related to flow state or choking phenomena. They can cope with distress and choking, focusing on the core components of the action according to the Multi-Action Plan model. Indeed, we found that both mental-focused strategies and action-focused strategies can help the athletes to maintain an optimal performance and to prevent choking under pressure (which might lead to a suboptimal performance) despite of the maintainement of flow state.

The psychophysiological and cortical indexes underlying the different performances are associated with different states (e.g. flow: type 1 performance; optimal-controlled: type 2 performance) and sustain the theoretical view of the Multi-Action Plan intervention model, in which the athletes can switch from the supervision of the core components of action to the focus on it avoiding dysfunctional performance. Specifically, Skin conductance level is a good psychophysiological indicator of the functional/dysfunctional and pleasant/unpleasant emotion experienced by the athletes in the four types of performance. In addition, cortical activity highlights both arousal level and visuospatial coordination processes during performance, supporting only partially the neural efficiency hypothesis as the only explanation for the expert performance in elite athletes.

In conclusion, our findings echo the notion that functional performance states are plausible within a broad range of behavioural, psychophysiological and cortical antecedents. However, the analysis of the sympathetic/parasympathetic balance and the cortical activations related to the
CONCLUSION

psychophysiological states underlying distinct performance-related experiences, as defined in the MAP model, has brought new insights on the neurobiological correlates of the control and performance levels separately.

However, these results need to be confirmed also in different sports and not just in self-paced task or in closed skill sport; so will be interesting to apply the MAP model in open skill sport.

Additional investigation involving also the collection of biological marker, such as cortisol, in the multimodal and multidimensional assessment, will help to elucidate the entire neurobiological network involved in optimal performance.

Anyway, further line of investigation are mainly oriented toward applied setting. On the basis of the results obtained so far, it would be interesting to use the Multi-Action Plan model to stay in the Zone (i.e. type 1: flow performance) or, when distress led the athlete to suboptimal performance where over control, energy misuse and focus disruption are experienced, to move in type 2 performance, focusing on the core component of action. Indeed as an elite shooter said during world championship: “when in competition stress arises, you start to lose control and become panicked. Everything you did in practice and know very well seems to fade away. Your Plan A doesn’t work anymore… you have to suddenly switch to Plan B. If you have one!”. Plan B (e.g. type 2 performance) will permit to the athletes do not chock under pressure.

Multimodal and Multidimensional assessments and interventions in Sport Psychology are expected to support the athletes during training, practice and competition giving them a broader range of techniques and strategies to reach peak performance and maintain optimal performance. Indeed, the development of integrated (with) biofeedback and neurofeedback interventions employing also Psychological Skill Training is a forthcoming challenge, and both researchers and coaches should verify the efficacy of these techniques both in the lab and in real setting.

Lastly, this types of investigation would help to define the proper cortical areas to apply TMS and tDCS for performance improvement. This is still possible in the framework of the Wold Anti Doping Agency (WADA) rules, but it is on the boundary edge of the ethical principles.
REFERENCES


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