ERD/ERS Patterns of Shooting Performance within the Multi-Action Plan Model

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Abstract—**The multi-action plan (MAP) model reflects the notion that different psychophysiological states underlie distinct performance-related experiences. Previous empirical evidence suggested 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.**

The purpose of this study was to test the cortical patterns correlated to the performance categories conceptualized within the MAP model.

Three elite pistol shooters (age range 16-30 years), members of the Italian Shooting Team and with extensive international experience, participated in the study. Participants performed 120 air-pistol shots at 10 meters from an official target. After each shot, they reported perceived control and accuracy levels on a 0-11 scale. Objective performance scores were also gathered. Electroencephalographic (EEG) activity was recorded with a 32 channel system (ANT). High alpha band ERD/ERS analysis during the three seconds preceding each shot and at shot's release was performed. Findings revealed differences in cortical activity related to performance categories. In particular, type 1 and type 4 performance were characterized by a clear relative decrease in signal power (ERS) at shot's release involving the central areas and the contralateral parietal and occipital areas, but differed for the cortical activity patterns before the shot. No ERS pattern was observed at shot's release in type 2 performance, while a interesting relative increase of signal power (ERD) occurred in the frontal and occipital areas just before the shot, similarly to what occurred in type 1 performance.

Our preliminary results suggest that lower cortical activation at shot's release is associated with an automatic performance, partially supporting the "neural efficiency hypothesis". Additionally, the analysis of the cortical activations related to the performance-related experiences defined in the MAP model supports the hypothesis that distinct neural activation patterns are associated with the control and performance levels.

Keywords—**ERD/ERS, MAP model, EEG, performance, shooting.**

I. INTRODUCTION

The analysis of psycho-bio-social mechanisms underlying optimal performance experiences has received great attention in the domain of sport science [1]. 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 [2]. To this extent, Bortoli and colleagues [3] have recently developed a multi-action plan (MAP) intervention model to help elite level shooters in improving, stabilizing and optimizing their performance during practice and competition. According to the authors, behavioral patterns underlying distinct performance levels (i.e., optimal-suboptimal) 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 1).

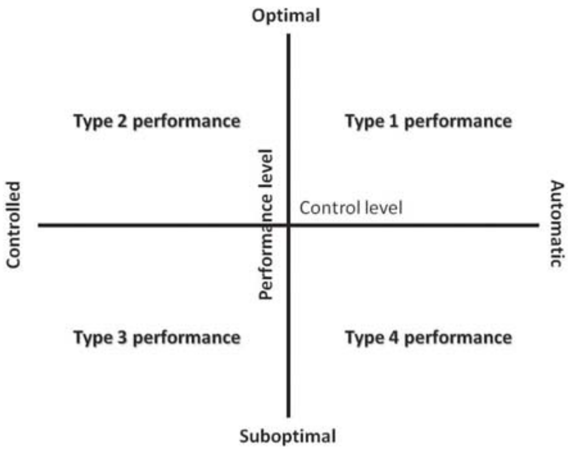

Fig. 1 Performance categorization according to MAP model

In a subsequent study, Bertollo and colleagues [4] assessed specific affective, behavioral, psychophysiological (e.g., skin conductance responses, heart rate), and postural trends on shooting and dart-throwing performance. Findings provided further empirical support to the 2 × 2 (optimal/suboptimal × automatic/controlled) conceptualization.

Neurophysiological mechanisms in general, and cortical activity in particular, are at the core of an integrated view of human performance [5]. Electroencephalographic (EEG) and event-related potential (ERP) measurements have been essential in shaping our understanding of skilled performance in sports [6]. For instance, "economy of effort"

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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) [5, 7, 8, 9]. Altogether, skilled performance in sports has been associated with decreased cortical activation (i.e., "the economy of effort principle" or "the neural efficiency hypothesis") [10].

In order to better analyze cortical functioning and the "neural efficiency hypothesis", Event Related Desynchronization/Synchronization (ERD/ERS) analysis has been used. ERD and ERS are relative measures of local cortical activity at a certain time and location. It has been found that an event-related reduction of signal power in the alpha and beta bands localized in the sensorimotor areas denotes cortical information processing related to voluntary movement. On the other hand, a visual input results not only in a power reduction of occipital alpha rhythms but also in an enhancement of central alpha rhythms, while the opposite is found during self-paced, voluntary hand movement [11]. Research using ERD/ERS analysis can therefore unravel new information about the neurodynamics of cortical networks. This analysis, recently applied to analyze shooting performance [9], 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 [12]. The individual zones of optimal functioning [1] framework and, more recently, the idiographic affective probabilistic zones methodology are further well-known concepts shaped through idiosyncratic analysis and single-case designs [13,14].

The purpose of the present study was to assess the 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-like minimal conscious control, high level of energy matching 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 high level of conscious control, task irrelevant focus, 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.

II. METHOD

Participants: Three 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 asked to identify the core components of their "chain of action" that they deemed fundamental for optimal performance, and then asked to choose one element (i.e., an idiosyncratic core component) deemed fundamental in order to optimally perform. 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 the idiosyncratic core component of action, and (b) the accuracy level related to the execution of the core component (from 0 to 11 on a Borg scale). After this evaluation, the actual shooting score (i.e. the objective performance) of each shot was made available to the shooter. Beside self-evaluation, the electroencephalogram was recorded using a 32 channels EEG ASAlab system and the waveguard cap by ANT (Advanced Neuro Technology, Enshede, Netherlands).

EEG Recordings: EEG data were continuously recorded (sampling frequency: 1024 Hz) from the 32 scalp electrodes (active electrodes for movement compensation) positioned over the whole scalp according to the 10-20 system. 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 [15]. Accordingly, only the epochs free from artifacts were considered in the 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 power, the individual alpha ERD/ERS maps were calculated following the procedure proposed by Zanow and colleagues [15], where ERD and ERS are defined, respectively, as the percent increase and decrease of signal power as compared to the baseline. This definition is opposite to that proposed by Pfurtscheller and da Silva [11]. The Hilbert transform was performed before ERD/ERS analysis. Then, for a given frequency band, ERD/ERS maps were calculated for a given interval of interest as the percent variation of the signal power with respect to the power of the baseline signal in each EEG channel.

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. Given that the IAF of our athletes were very similar (9.9, 10 and 9.9 Hz), we considered the frequency band 10-12 Hz 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_{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.

III. RESULTS

Findings revealed differences in cortical activity with respect to performance types (Figure 2). In particular, 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 central areas 3 s before the shot and in the frontal and occipital areas at -2 and -1 s. 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 central areas just 1 s before the shot.

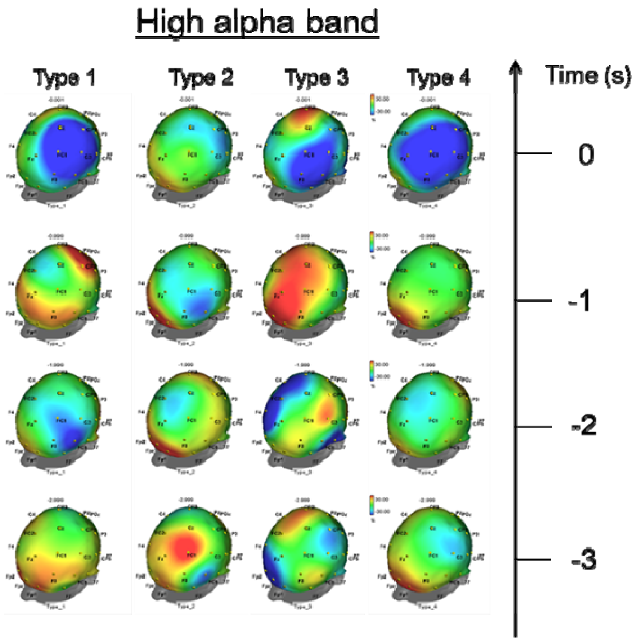

Fig. 2 Average ERD/ERS maps in the high alpha band (10-12 Hz) at shot release (t=0) and during the three seconds preceding it, categorized for the four types of performance. Color scale: maximum ERD and ERS are coded in Red and Blue, respectively

IV. DISCUSSION AND CONCLUSIONS

Overall, our preliminary findings for type 1 and type 4 performances support the notion that lower cortical activation at shot's release is associated with an automatic performance, corresponding to a state of quiescence of the organism, task relevant focus of attention, and movement automaticity and fluidity. This notion is partially in line with the "neural efficiency hypothesis", which links optimal performance to optimal psychophysiological conditions, as found only in type 1 performance. Indeed, our results indicate that optimal outcomes, derived from a type 1 and not from a type 4 performance state, are rather determined by the patterns of cortical activation during the seconds preceding the shot, for which differences between the two performance states were found. In particular, one second before the shot type 1 performance state featured an increased signal power that involved not only the prefrontal areas, as in type 4 performance, but also the frontal and occipital areas, which are related to focused attention.

The hypothesis that the activation of the frontal and occipital areas during the seconds preceding the shot might be involved in optimal performance, is supported by the results obtained for type 2 performance (optimal-controlled), which indicate that the athletes can attain good performance levels also without total movement automaticity and fluidity, when they focus their attention on their core components of action. In this case, the athletes use consciously focused control that was mirrored, in our results, 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 pattern was found in type 3 performance (suboptimal-controlled).

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

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