INFORMATION PROCESSING AND DECISION MAKING IN SPORT

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Cognitive Psychophysiology as an Interface Between Cognitive and Sport Psychology

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This paper reviews the actual and potential benefits of a marriage between cognitive psychology and psychophysiology in the sport field. At present, in fact, cognitive psychophysiology has certainly been to the most profitable interface between these two theoretical domains to understand the functions of the mind and how these functions are implemented in the brain. First we will introduce the interrelationships between the two conceptual domains. Then we will briefly present the main theoretical assumptions of cognitive psychophysiology. Again, the implications of this marriage for sport cognitive psychology will be illustrated with the purpose of showing that psychophysiological measures, i.e., tamed and event-related Brain Potentials, may be fruitful tools in (a) understanding athletes' cognitive behavior, and (b) for investigating how extended practice in sport activities can lead to useful changes in both information processing mechanisms and cognitive strategies. Finally, an overview of our main experimental findings and some basic conclusions and directions for future research will be presented.

In sport psychology over the last 15 years, there has been a marked shift in emphasis towards the investigation of cognitive processes involved in athletes' performance. Just as cognitive psychology has become dominant within experimental psychology, its concepts and methods are now being applied with growing success to the study of athletes' performance. And just as every shift in emphasis within a scientific discipline brings fresh problems to the fore, and allows for old problems to be seen in new ways; this approach has also focused sport psychologists' attention in new ways, i.e., upon a') sensory, perceptual, mnemonic, and decisional processes used by athletes when dealing with their specific psycho-motor tasks, b) the cognitive and motor programming strategies of skilled performance viewed as complex sequences of behaviour and c) developmental aspects of the production of skilled motor behaviours.

However, it is not appropriate to consider cognitive psychology as a new school within psychology opposed to previous experimental approaches. Rather it is indicative of changes in emphasis: New concepts have been introduced and there is increased methodological sophistication. In the cognitive view, the human being is an information processing system which does not passively wait for stimuli but actively searches for, and picks up, information in the external environment. These processes are driven by continuously maintained and updated detailed models of what is imagined (or mentally represented) to be the state of the external and internal world. On the basis of these models the system makes decisions by using learned experiences and an analysis of its self- and environment-state at that current moment; it programs, executes, and controls its behavioural responses to adapt to the environment. Further, in this view research on cognition and affect proceed on a parallel, promising possibilities for more integrated theories on the human mind and behaviour (Solso, 1988).

Because of these new insights from cognitive psychology the cognitive aspects of sports are now analysed with unprecedented vigour by cognitive sport psychologists. There is the conviction that cognitive psychology may represent (1) a firm foundation for sport psychology through the identification of the processes involved in psycho-motor performance and human skills; and (2) a way to study the important part played by cognition in sport performance (Salbene, Rossi, & Cortili, 1986; Ripoll & Aznar, 1987). This has generated a large number of empirical studies. However, in spite of ingenious methodological solutions the major problem is that, just as for experimental and cognitive psychology, the covert intervening processes have to be inferred from the overt behavioural output (i.e., reaction time, choice, accuracy of response, etc) of the subjects (i.e., athletes) being studied. Then, the task of investigating the information processing system becomes more difficult, since its processes, and the dynamic temporal relationships between the latter, cannot be observed directly by experimenters. Certainly the cognitive experimental enterprise would be potentially more fruitful if direct measures of internal processes could be obtained together with the behavioural output of these processes.

In our view, an aid to overcoming this major problem, which is able to provide some direct evidence regarding these processes might come from psychophysiology.

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Concomitantly with the above theoretical developments, the last few decades have also witnessed an increase in investigations of cognitive processes from the psychophysiological point of view. However, unlike the behaviour approach which reasserted the secular «mind-body dualism», i.e. the possibility of studying the mind independent of its physical substrate, the brain, the psychophysiological approach focused upon integrated studies of the physical functioning of that great reservoir of the mind, consciousness, with the constraint that the mind and its functioning do not appear to exist apart from the brain. Then, long aware of the existence of bioelectric potentials in the body, psychophysicists developed sensitive electronic probes that provide a rather objective method for examining the relationships between the brain and covert mental processes, and overt behaviour. At present, the most fruitful of these methods has grown out of advances in computer technology and in electroencephalography, the measurement of electrical activity in the brain. Unlike the ordinary electroencephalogram, which shows the electrical activity that goes on continuously in the brain, this method marks the brain’s transient change of activity in response to physical stimuli, in association with psychological processes, or in preparation for motor activity. For this reason, they have become known as Event-related brain potentials (ERPs). Psychophysicists and brain scientists have proceeded with the conviction that the neuroelectric coding of information is well reflected in the ERPs. It was this conviction that led to the idea that the ERPs might contribute to our understanding of mental processes and cognition.

Unfortunately, originally intoxicated by the heavy influence of behaviourist theories, psychophysiology has been (and is still often) perceived as a search for «neurophysiological correlates» of psychological processes. Moving away from this simplistic logic, however, cognitive psychophysiology has properly identified as its major research goal «not merely a search for correlates where the identification of correlates is an end in itself» (Donchin, 1982; Donchin & Coles, 1988), but the study of «processes» evoked, or invoked, in the brain as a part of information processing activity. In the light of this theoretical framework, the psycho-physiological measures, e.g., the ERPs, are manifestations recorded on the scalp surface, not correlates, of the processes going on in specific conditions under which an overt response of the individual (the possible «product» of these processes) is also measured. Thus, adopting structured tasks devised to elicit the process or the processes of interest, the ERP measures recorded during task performance may shed some light on the internal cognitive and affective structures of the continuous stream of information processing (IP) into the brain, by indicating the timing and order of the substages involved, and distinguishing between mechanisms of serial and parallel processing (Kutas & Hillyard, 1984; Zani, 1988).

In sport, although interest in the effects of physiological factors on performance dates back twenty years, as documented in Haldid and Burton’s review (1987), most of the psychophysiological research in this area has simply tried to determine the psychophysiological correlates, primarily related to autonomic nervous system activity, in athletic performance. Direct concern with cognitive processes was typically neglected and concepts developed within human cognitive psychology and psychophysiology were not even mentioned. Still, at present, only a few psychophysiological studies have shifted to measures of central nervous system activity and, in particular, to event-related brain potentials, calling upon concepts developed in these fields (Glerner & Matsen-Twisdale, 1979; Buckolz, 1980; Demaret & Timsit-Berthier, 1986; Dehousses & Timsit-Berthier, 1986; Zani & Rossi, 1987; Rossi & Zani, 1988a; 1988b).

In the following sections, after a discussion of the strict relationship between the ERPs and human information processing, we will review our findings on athletes, in order to demonstrate that cognitive psychophysiology may be a fruitful interface between cognitive and sport psychology. Properly used, this interface can make valuable contributions to the understanding of athletes’ performance and information processing in sport. On the other hand, the study of skilled performance in sport by means of this interface presents both cognitive psychology and psychophysiology with a unique opportunity for acquiring knowledge of cognitive structures in experts with wide ranges of ability and experience in real life skills.

**Event-Related Brain Potentials (ERPs)**

Despite warnings regarding the use of event-related brain potentials (ERPs) in experimental investigations, at present they remain the most fruitful and reliable technique for mSec-by-mSec analysis of information processing. Thanks to their high degree of temporal resolution ERP components represent a «window» on the timing and organization of conscious and unconscious sensory, cognitive, and affective mental processes of the brain leading to the assembly of what we experience as conscious perceptions, and overt or covert behavioural responses.

These components are obtained by averaging the sweeps of background electroencephalogram associated with a number of stimulus presentations...
or other external or internal events within a specific experimental condition. The component structure of the ERP waveforms recorded on the scalp is determined by the peaks and troughs in the average waveforms, even though the actual component structure may not fully correlate with visually recognizable deflections. This structure, in fact, has to be determined in relation to how the waveforms change with experimental manipulation such that a component is a source of controlled observable experimental variability. The peaks and troughs are labelled «P» or «N», depending on whether they are positive or negative. The Ps are labelled «P» or «N», depending on whether they are positive or negative. The P3 or N3 are followed by a number indicating the latency in msecs from the stimulus, or the order of occurrence in the waveform. Thus, the components are normally labelled N1, P2, N2, etc. It is in this way that electrophysiologists cope with the large variations in latency that these components show, for example, with modality or complexity of stimulus.

Early (<100 mSec) and long (100-200 mSec) latency components, as for instance P1, N1 and P2 (see fig. 1), have usually been labelled exogenous, as they seem to be determined entirely by the physical parameters of the stimuli. In other words, they are neural responses evoked by the stimuli. They occur whether the subject attends to the stimuli or not, is awake or asleep, aroused or relaxed. Hence, they are also defined as evoked components or potentials. Their scalp distribution varies as a function of

![Fig. 1: Idealized waveform of ERP. The solid line represents the exogenous components; the dashed and dotted tracings represent endogenous components elicited by stimuli that are selectively attended or task relevant and improbable. N4 = processing negativity; SW = slow wave; RP = readiness potential; CNV = contingent negative variation.](image)

stimulus sensory modality. For this reason, these components have been mainly used for studying the sensory coding of, or features extraction from information, and the influences of activation levels on these processes within an energetic approach. For this reason, they are usually recorded from the primary projection sensory areas of the brain in response to repeated simple stimuli (e.g., spatial gratings, bars, or checkerboards — for visual modality; pure tones and clicks for auditory modality; and electric shocks for sensory modality).

In the experimental conditions in which these components are usually recorded, the subjects are simply requested to passively direct their sensory receptors towards the source of stimulation (e.g., look at, listen to, etc.) without performing any evaluation of, or any operation on (i.e., count, choose, etc.) the stimuli. This does not necessarily imply, however, that the subjects do not actually attend to the stimuli and or give their attention to it. Attending to the stimuli, the subjects show changes of the long latency components. In this case misleading results can be obtained, because concern is focused on stimulus encoding by the sensory projection areas.

In attended conditions, so-called «mesogenous» components can be recorded at early latency after stimulation (50-250 mSec), determined by both physical and psychological factors. The neurotopographical distribution of these components is invariant to changes in sensory modality of the eliciting stimuli (i.e., maximum at Vertex). When the stimuli are attended, for instance, the amplitude of the negative wave occurring at about 100 mSec (N1 or N100) is greater than when the stimuli are ignored or passively heard. This seems to be due to an endogenous negative shift (the so-called processing negativity), which is very likely representing an early selective attentional evaluation of the stimuli, superimposed in time to the exogenous N1 component and outlasting it (see Figure 1).

Unlike the former, the so-called «endogenous» components of the ERPs (>250 mSec) appear to be reliable reflections of mental states allowing us to interact with the external world. The latency and amplitude of these late latency components seem to be determined by the psychological significance of the stimuli to the subject rather than by the physical nature of the latter. In other words, they are not obligatory neural responses to stimuli as indicated in Figure 1.

Instead, they are the reflection of endogenous neuro-cognitive processes subjectively «invoked» by individuals relative to the psychological demands of the experimental conditions. This view is strongly supported by the fact that a particular stimulus may or may not elicit such components in differ-
ent psychological conditions; or by the fact that they may be elicited by the absence of a stimulus in a sequence, if such omission is both unpredictable and task relevant. Again, the amplitude and latency of these components are invariant to changes in the physical parameters of the eliciting stimulus; further, with rare exceptions (i.e., N2), their neurotopographical distribution is also invariant to changes in the sensory modality of the eliciting stimulus.

Particularly strong in this class of components are, for instance, the event-preceding preparatory potentials. The latter are related, on the one hand, to specific motor activity, such as the slow negative-going Readiness Potential (RP) occurring prior to voluntary motor actions and, on the other hand, to the preparation for a perceptual judgment or a cognitive decision, such as the slow rising Contingent Negative Variation (CNV). Just as robust as the previous ones are the so-called «integrative» endogenous components, related to complex human information processing. Described briefly, very consistent members of this sub-class resulted as, among others, (1) the negative going N2 component elicited by rare or unexpected events (i.e., physically mismatching with current brain models of our self- and world-state), whether or not the subject pays attention to them, (2) the P300 positive going component obtained in response to task relevant and attended rare stimuli (i.e., conceptually mismatching with held brain models of our self- and world-state) and reflecting a process of contextual updating of the cognitive schemata within the working memory, and (3) the positive going slow Wave component reflecting a process of further processing called upon information stored permanently in the long term memory store.

In light of this, it should be clear that the distinction drawn between exogenous, mesogenous and endogenous components is mostly heuristic. Altogether, they remain remarkably robust phenomena sublimely responsive to diverse sensory and psychological factors, and providing a continuous record of events occurring in the brain in the course of information processing.

Exogenous Components and Sensory-Perceptual Processes in Sport

In order to understand the mechanisms of athletes' information processing, one of the first steps is to study sensory-perceptual processes. Indeed, it is important to understand how their sensory systems actively probe the environment for stimuli relevant to (pre)conceptions embodied in the momentary states of their internal models. In this regard, the recent development in chronopsychology has shown clear time-of-day effects on most sensory and cognitive functions, and individual differences based on the nature of individuals, for example, in terms of so called «morningness/eveningness» or circadian typology (Kerkhof, Willemse-v.d Geest, Korving & Rietveld, 1981; Zani, 1986).

Considering the importance of these processes and of their fluctuations in functionaility for athletes’ performance, we carried out some electrophysiological studies aimed at investigating their underlying mechanisms.

**Time of day, and perceptual processing in athletes**

In order to investigate the implications of oscillations in activation over the day for sensory-perceptual neural processing, we carried out some studies based on the recording of exogenous components of ERPs from sensory projection areas at different times of day, in athletes in various sports.

A first study (Rossi & Mecacci, 1985) compared top-level Olympic fencers, pentathletes, clay-pigeon shooters, and a control group of non-athletes in an experimental paradigm in which average ERPs were recorded in response to pattern-reversed checkerboards (i.e., alternately the white checks became black and vice versa) at two times of day (i.e., 8:00 a.m and 7:00 p.m.). The peak-to-peak amplitudes of the N75-P100 and P100-N150 components were measured and analysed. Results showed no differences between groups for the N75-P100. However, this component was at the right occipital area of lower amplitude for the evening session than for the morning session, even if as a whole it was greater than the one recorded at the left area. This indicates that even if early processing of information is not influenced by the specific skills of different groups, very likely because it is automatized, it changes as a function of time of day.

Interestingly, instead, the four groups attained P100-N150 of different amplitudes, thus indicating a direct influence of the specific skills of the groups on the mechanisms of information processing. In this regard, fencers showed a predominance of the right hemisphere, significantly stronger than the other groups. It is likely that this is consistent with the specific features of the sport task performed by these athletes, which undoubtedly requires more sustained attention than other disciplines. This conclusion seems to be supported by the finding that the most «closed» sport (within those investigated in our study), i.e., shooting, showed less intervention of the right hemisphere. However, strong support for the notion of a large influence of sustained attention in fencing comes also from the EEG and CNV results obtained by Demart and Timits-Berthier (1986).
Another study (Rossi & Mecacci, 1987), carried out on Italian Olympic team fencers, attempted to investigate the influences of time of day on processing of sensory signals in relation to arousal and mental load. In order to induce arousal and processing load, six runs, in three of which continuous white noise was also delivered, were administered to the athletes in a counterbalanced order in each of the planned morning and evening sessions. As for the above study, the peak-to-peak amplitudes of N75-P100 and P100-N150 were measured.

For the N75-P100 component, it appeared that the white noise induced larger amplitudes at the sensory projection areas of both hemispheres, thus implying a greater level of activation of the latter; however, this resulted true only for the morning session. Instead, a complex change in amplitude was found for the P100-N150 as a function of time of day and condition (noise vs. noise), exclusively for the right hemisphere.

It seems to us that altogether these data indicate that early sensory processing is more generic in nature, just reflecting aspecific arousal levels oscillating on the day, whereas intermediate-latency sensory processes are affected by specific attentional mechanisms whose hardwiring is of a different nature for the two hemispheres, and whose functioning changes over the course of the day.

**Menstrual cycle and sensory-perceptual processing**

Although the menstrual cycle has always been a primary topic in sport literature concerning female athletes, its effects on performance have not yet been clarified. Moreover, endocrine and physiological aspects or classical psychological problems related to this cycle, for example, mood variations and fear of failure, have been and are still the main areas of investigation.

In order to provide some knowledge of the complex relationships between the various phases of the menstrual cycle and sensory information processing, two groups of young athletes, (on or not on the pill) were studied. The amplitudes and latencies of the N1-P2 and P2-N2 components of the ERPs recorded in two successive runs, for each of four phases of the menstrual cycle (menses, follicular, ovulatory, and pre-menstrual phases) during a passive binaural listening condition of auditory clicks, were analysed. Going from the menses to the pre-menstrual phase, both groups showed a relatively constant decrement of the amplitudes of these components. Furthermore, the latency of the latter showed an anticipation between the menses and the follicular phase, and a constant increase across the latter and the ovulatory and pre-menstrual phases. This can be clearly seen in Figure 2. However, compared with spontaneously menstruating athletes, athletes on the pill showed significantly longer latencies. Nevertheless, they showed stable results across the two runs.

Altogether, these findings can be taken as evidence of the fact that, (1) although the logistics of the neural sensory processors functionality related to the menstrual cycle is largely respected by oral contraceptives, they can produce a delay of processing mechanisms, and (2) changes occur over the course of the menstrual cycle in the time taken by sensory information to be handled by neural pathways and, as a consequence of this, in the quantity of information handled per time unit (Zani, 1989). It might tentatively be speculated that in sport these effects may influence performance, being more negative in disciplines in which speed of processing is a necessary condition for agonistic success (e.g., fencing or table-tennis). The contrary may be true for athletes coping with tasks based on response accuracy (e.g., shooters or gymnasts). It might be speculated, again, that the amplitude variations across the recording runs observed in spontaneously men-

![Fig. 2. N2 component latency measures for the four different phases of the menstrual cycle (A = menstrual period; B = follicular phase; C = ovulatory phase, and D = luteal/premenstrual phase) for spontaneously menstruating (circles) and on-pill athletes (squares). Empty and filled circles and squares represent the first and second run, respectively.](image-url)
structing athletes might be of mesogenous nature, due to variations in attentional levels allocated to the auditory stimuli. In our view, this hypothesis, presupposing a strict influence of endogenous processes on information encoding, could reliably account also for the results reviewed in the previous section showing interindividual differences related to specific characteristics of the athletes.

ERP Endogenous Components and Cognitive Processing

Our most recent line of research is the study of cognitive and attentional strategies of athletes practicing sports in which attention plays a relevant role. Unlike the above studies, our concern has been with the endogenous components of ERPs, and some general areas were covered. These will be reviewed in the following sections.

Attentional Strategies, Cognitive Processing and Task Demand

In this section, we will present the data collected in an attempt to give support to our hypothesis, according to which athletes adopt different strategies in tasks requiring different decision spaces and responses, even if the same information is available. In our view, then, in attempting to shed some light on athletes’ cognitive and attentional processes, it is important to evaluate the attentional costs and IP mechanisms also in conditions in which, for example, decisions have to be made but motor responses (1) do not have to be executed, and/or (2) have to be actively inhibited.

In order to probe the changes of cognitive processing in different conditions, we used an oddball paradigm in which series of two different acoustic tones (1000 vs 2000 Hz) with different occurrence probability (20 vs 80%) were delivered in random order. Three conditions were created by different instructional sets in which the athletes were requested:

a) to give a manual response as soon as possible with their preferred hand only to the RARE stimuli, in order to study possible attentional strategies related to selective motor response programming (active overt response task);

b) to ignore the frequent stimuli and to keep a mental count of RARE stimuli, in order to disentangle the selective attention strategies from motor response programming (active covert response task); and,

c) to relax and ignore all the stimuli, in order to study the athletes capability of filtering information and the attentional mechanisms linked to this specific ability (passive task).

The hypothesized adoption of specific selective strategies in relation to the different relevance of stimuli and task demands was monitored measuring electrophysiological responses, i.e. N1 and P300 components, to the frequent stimuli immediately preceding (PRE) and following (POST) the rare deviant stimuli, labelled «RARE», together with the electrophysiological and behavioural responses to the latter.

Results showed that altogether the passive task led to N1 and P300 components with less energy than the two active tasks. This suggested that stimulus processing was carried out in an automatic, bottom-up manner, without any voluntary control. Furthermore, the fact that no differences were found between the PRE, RARE and POST stimuli-related N1 amplitudes, suggested that the athletes did not allocate their attentional resources to the incoming stimuli at early levels of processing, and, above all, that they did not adopt any intentional strategy for stimulus pick up. It seems reasonable to think that this was due to the fact that, in terms of active pick up within the attentional channel, all stimuli were considered equally irrelevant in agreement with the experimental instructions. These data indicate that, on the continuum between the bottom-up and top-down processes, at this low-order selective processing this passive task was characterized by an IP mode clearly shifted toward the bottom-up extreme.

However, the P300 data recorded in this task showed that unlike the frequent PRE and POST stimuli, the deviant RARE stimuli elicited a large P300 component. This finding is consistent with an assumption of automatic control of the state of the external environment. It is likely, in fact, that whenever these stimuli were delivered, they triggered a so-called Automatic Attention Response (AAR), in agreement with Fisk and Scerbo’s (1986) proposals, since they mismatched with the mental model of stimulus condition held in the working memory at that current moment. As a consequence of this response, these RARE stimuli reached the higher-order psycho-semantic level of processing; the mental models were updated, and a large P300 was elicited.

Different results were obtained for the two active tasks. The athletes seemed to adopt voluntary strategies, more expensive but useful, to optimize task solution. As already noted, in these conditions both the N1 and P300 components showed larger amplitudes than in the passive task, in particular for the RARE stimuli. Furthermore, it was found that the two components showed a dynamic variation in amplitude as a function
of the relevance subjectively attributed to the different stimuli. For the covert task, however, this variation was different from the one found for the overt task. Interestingly, when there was no time pressure, as in the counting task, a controlled, bottom-up, mode for processing information was adopted by the athletes. In this case, the subjects voluntarily directed their attention only to the relevant RARE stimuli, as indexed by the large N1 amplitude recorded only in response to these stimuli, and this triggered the subsequent controlled updating processes associated with the mental count of the latter, as suggested by the large P300 elicited by these stimuli.

Instead, the data recorded for the motor task suggest that, under time pressure, athletes attempt to draw inferences about incoming stimuli, presumably in order to maximize the speed of their responses and to optimize their execution. In fact, the physically identical PRE and POST stimuli elicited N1 and P300 of different amplitudes, i.e., PRE significantly larger than POST, thus implying a shift toward a top-down mode of IP and a change in the internal procedures (Zani & Rossi, 1987, 1988).

Altogether, these findings indicate that the same stimuli choice may be processed in different ways by athletes, regardless of the sport (sprint, tennis, shooting, clay pigeon shooting, modern pentathlon and fencing). They also indicate that the type of processing strategy characteristically used by athletes depends on the specific task demands.

Cognitive Styles and Information Processing in Athletes

Recently, by adopting behavioral methods some students showed that in laboratory tasks athletes tend to reproduce the same strategies as those adopted in field conditions (Nougier, Ripoll, & Stein, 1987). With these results as a starting point, we wondered if sport discipline specialization could be reflected also in various stable internal differences in IP.

More particularly, we wondered if the regular practicing of certain kinds of sport tasks, in which the intervention of attention is particularly relevant, could lead athletes to develop some stable strategies, linked to their specific sport skills. These strategies — defined as styles — to stress their stability should be generalized to other tasks requiring controlled attention. Then, this would produce individual differences between athletes, whose relationships with their neural «hardwares» cannot be assumed to be simple.

To evaluate this hypothesis, top-level athletes (Italian National Team) practicing two specialties (trap and skeet) of clay-pigeon shooting were chosen as subjects. A massive attentional effort is required by both of these specialties. However, whereas for skeet the clay-pigeon trajectories are limited in number (i.e., n = 16) and are a priori well known (consistent task), for the trap specialty unpredictability reaches the highest levels, the trajectories being almost unlimited (inconsistent task).

With regard to these characteristics, we specifically hypothesized that, in order to optimally cope with their specific sport task and to minimize attentional costs, the trap shooters would take advantage of an allocation of their attentional resources mainly to the early phases of IP (fast detection of incoming stimuli and decision making based on sensory-perceptual coding). On the contrary, the skeet shooters would have more advantage in allocating their resources to the cognitive phases of IP, like memory updating, in order to improve their knowledge of the situational features just faced and to face them again in a similar successive series of trials during the sport races.

Our predictions were stunningly confirmed by results obtained in a paradigm in which the athletes had to deal with one passive and two active conditions (go/no-go tasks in which a motor response with the right or the left hand had to be given). The trap shooters showed a greater amplitude for the relatively early latency N2 component, whereas the contrary was true for the late latency P300 and slow wave components as shown in Figure 3. It is worth emphasizing, however, that these differences showed up only in the active tasks requiring voluntary control of incoming information. These findings indicate that the same stimuli were processed in different ways by each group, and are consistent with our suggestion of different processing styles (Zani & Rossi, 1988).

More recently, the Italian National Team of Modern Pentathlon was subjected to the same paradigm. Compared with the clay-pigeon shooters, these athletes attained significantly lower amplitudes for the N2 component only for the two active tasks, very likely implying a more automatized and less analytic style at this level of IP for these athletes (Rossi & Zani, submitted).

These processing styles also affect the timing of IP. The present conclusion can account for the data obtained studying the relationships between reaction times and the N2 and P300 latency by means of an auditory discrimination task with two levels of difficulty (i.e., 1000 vs 2000 and 1000 vs 1050 Hz). In this task, the speed of processing and motor response of the trap specialists was only relatively affected by the difficulty of discrimination. The latencies of the N2 and P300 components and RT remained constant across the two experimental conditions for these athletes.
On the contrary, the skeet specialists showed an increment in the latency of both the endogenous components and RTs in the difficult discrimination condition. Due to this trend, their RTs, the same as those obtained by the trap shooters in the easy condition resulted significantly slower than those of the trap specialists in the difficult condition, although the N2 and P300 latencies of the latter were significantly longer. As a whole, these results seem to be consistent with the notion that cognitive and motor functions are relatively parallel cascading processes: their trend depends on task demands and particular dimensions of cognitive style. It is reliably clear, in fact, that the data suggest a data-driven centered mode and a knowledge-driven centered mode of information processing for trap and skeet, respectively (Rossi & Zani, 1991).

In conclusion, the findings which we have reviewed in this section seem to strongly support the hypothesis that: (1) individual differences in information processing can be found between specialists in various sport disciplines; and (2) these differences do not depend on different basic neurofunctional levels of activity, but (a) on the voluntary adoption of attentional and cognitive strategies in tasks requiring controlled attention, and (b) on the automatic generalization to these task of different stable attentional strategies, or «styles», developed by athletes as a function of their skilled behaviours.

Hemispheric Asymmetries and Information Processing

Evidence has been accumulated which challenges the idea that hemispheric asymmetries are structurally determined and suggests that they are functionally more complex than was believed in early studies in which they were considered relative to the dominance of one hemisphere over the other and, above all, handedness. For example, a clear relationship has been found between the laterization of IP and attentional and cognitive strategies (Azémar, Ripoll, Stein, & Nougier, 1983; Zani & Rossi, 1987), on the one hand, and diurnal typology, time of day, and activation levels (Zani, 1986), on the other.

Having these results as a starting point, as well as the data presented above relative to sensory processing, we further studied hemispheric asymmetries investigating the possible interactions existing between the hemispheres, attention, and motor functions, in a sample of athletes belonging to various sport disciplines (i.e., modern pentathlon, tennis, clay pigeon and fencing). The same stimuli were administered in one passive listening task and two active tasks (go/no-go tasks — hold response to frequent stimuli — 1000 Hz pip tones: 80% —, and push button to rare ones — 2000 Hz pip tones: 20% — with the right or left hand). The amplitude of the N2 and P300 components in the ERP wave forms elicited by RARE, and frequent PRE and POST stimuli, at right (C4) and left (C3) central motor areas of the cerebral hemispheres were measured. The results did not yield any significant asymmetry for the P300 amplitude. Instead, for the two active tasks, the amplitude of the N2 component, closely preceding athletes’ motor responses, indexed a right hemisphere lateralization of processing for the RARE stimuli only. This lateralization was not affected by hand used. The fact that for the passive task no hemispheric asymmetries could be found seems to exclude that the right hemisphere superiority was simply a reflection of a perceptual mode of this hemisphere, known in the literature to be the most fit for dealing with non-verbal information, such as that used in our study. Again, the fact that the lateralization observed was not affected by the hand used, makes it reasonable to think that this right hemisphere superiority might be due to the intentional adoption of a controlled modality of attention sustained over time for the purpose of motor decision making (Rossi & Zani, submitted).

In conclusion, these data clearly support the hypothesis that hemispheric asymmetries are influenced by cognitive and attentional strategies adopted to cope with different task conditions. At present, it cannot be said whether different patterns of asymmetry can be demonstrated for the athletes of the various specialities: this is a matter for further investigation.
Developmental aspects of attentional processes

Considering the interest which has developed from the results obtained with the adult athletes, and the lack of data on developmental aspects of IP, we reasoned that, for sport psychologists, it could be very useful to single out critical developmental phases of attention to aid in the design of instructional programs. In an attempt to shed some light on the information processing dynamics at different ages, two groups of young athletes (10 and 14 years old) were studied. Assuming that developmental changes associated with perceptual, cognitive, and motor functions are related both to the structural maturation of brain areas and the emergence of organizational patterns dependent on individual interaction with the environment, the ERPs were recorded from frontal, central motor, and parietal areas, known for having different maturational trends. A series of different acoustic stimuli (1000 vs 2000 Hz tones) with different occurrence probabilities (80 vs 20%) were administered to the young athletes. The task was to give a motor response with the preferred hand to the RARE tones. Selective attention was monitored measuring the N1 and P300 components elicited by RARE and frequent PRE and POST stimuli. Although results proving the immaturity of the frontal lobes with respect to the other monitored areas have been found for the younger group, this immaturity seems to affect only the lower-order orienting mechanism of attention, indexed by the N1. At these levels of selective orienting of attentional resources towards the chosen information channel, the younger group showed a lower ability for selective attending. This lower ability was associated with significantly lower N1 amplitudes than in the older group at the frontal location. However, at higher-order levels of selective stimulus categorization, indexed by a centro-parietal distributed P300, they showed a pattern of processing comparable to that of the 14-year-old group.

With regard to the motor results, the younger athletes showed a significant delay in emitting their responses after the occurrence of the P300 and a significantly higher number of omissions and false alarms. On the whole, these findings support the idea that the motor performance of the younger athletes is not directly related to categorization processes. They give the impression of having less ability to make use of the IP outputs, and more problems with programming and inhibiting their motor responses. This conclusion is strongly supported also by the finding that the amplitude of the late-latency positive Slow Wave, indexing a further processing of signals, was significantly much larger for this group, suggesting that younger children need greater control of the results of their analyses (Zani, Rossi, Dalla Pozza, & Pesce, 1990).

Pre-stimulus expectancies and motor preparation processes

As we noted above, in the view of cognitive psychology the human processor draws inferences relative to incoming information. These anticipation processes, based on pre-stimulus subjectively assigned probability of occurrence of specific signals, are modified as a function of the arrival of stimuli, their specific goal being to improve performance in successive trials. Up until now, the results of studies aimed at investigating the influences of inferential strategies on athletes' signal processing, have been discussed exclusively. However, bearing in mind that these inferences also surely affect athletes' pre-stimulus preparation processes to sensory-perceptual and motor activities successively triggered by the incoming stimuli, as proposed by Abernethy (1987), we reasoned that the most concrete evidence of the existence of pre-stimulus cognitive processes would come from studies of pre-stimulus brain activity.

In an attempt to probe these inferential strategies in athletes, we monitored the electrical brain activity of clay-pigeon shooters before the arrival of stimuli delivered at short fixed interstimulus intervals in two recording runs in which they had to perform a go/no-go push-button RT task. In the 800 msec of ERP waveforms preceding the delivery of RARE, PRE and POST frequent stimuli, results showed a negative-going slow rise of brain potentials. This pre-stimulus negative shift, that could index a readiness potential reflecting the dynamics of the preparatory processes subserving the motor response, changed in amplitude as a function of the stimulus sequence.

The data also indicated that the skeet specialists showed changes in amplitudes of the pre-stimulus readiness potential as a function of stimulus sequence (PRE vs RARE vs POST). This suggested that they made use of specific pre-stimulus inferential strategies, very likely to minimize the costs of attentional resource allocation. On the contrary, the trap specialists did not show any change in negative brain potential preceding the stimuli. This suggests that they put a constant effort into the allocation of their voluntary attentional resources, as a reflection of a more controlled mode of IP.

These findings indicate that pre-stimulus anticipation processes, which are largely influenced by cognitive-driven subjective expectancies, go on in the athletes' brain, in agreement with the proposals advanced by Alain, Sarrazin, and Lacombe (1984). Further, they also indicate the existence of individual differences, thus implying that these anticipatory processes are reliably associated with particular dimensions of style of IP, in strict relationship with the individual skills (Zani, Rossi, & Pesce, in preparation).
Conclusions and Perspectives

In conclusion, it seems to us that the findings reviewed in the above sections give strong support to our claim that cognitive psychophysiology can actually be used as a valuable interface between cognitive and sport psychology. In fact, the cognitive concepts upon which this approach is based offer the possibility of framing research on athletes' performance and IP mechanisms in the light of general models of human IP. Also, cognitive psychophysiology overcomes the limitations of more behavioural approaches by providing sport scientists with an open window on the internal processes subserving these mechanisms. Properly used, this window may certainly contribute to deepening our understanding of these mechanisms, aiding us in disentangling their sensory, cognitive, and motor aspects. Although application of this approach to sport psychology is recent, it has already allowed us to obtain knowledge about some interesting phenomena in athletes. Most relevant, are the findings that the same information is derived in different ways by athletes in different conditions, or that the same behavioural output may be subserved by different internal procedures of IP. These different procedures, aimed at optimizing costs and timing of the internal processes, are a function of the strategic demands of contextual conditions and are associated with the specific skills developed by athletes practicing diverse sport tasks. Perhaps it is too early to think of these findings in a practical perspective, but, as a first proposal, it seems to us they have many implications for teaching young athletes to run their attentional resources in a more economic way.

Much remains to be done in investigating IP and performance in athletes. In fact, until now only the mechanisms relative to sport specialties strictly based on attentional processing have been investigated. It is worth emphasizing, however, that in many sports performance is mainly founded on other internal processes rather than attention, such as, time estimation and cyclical motor decisions (e.g., swimming, diving, marathon, etc.). Tailoring proper tasks to probe these specific processes, the endogenous motor and cognitive components of ERPs might increase the understanding of the timing of decision making in sports primarily based on these abilities.

Again, the affective aspects of athletic performance, in particular the effects of arousal, anxiety and personality on IP, have been neglected. This is unfortunate because athletes perform under emotionally charged conditions. Thus, investigations in this area will have to be carried out. Indeed, a reliable model of athletic performance will have to incorporate elements that can explain why a little excitement is not enough and a lot is too much for optimal IP and performance. In this regard, perhaps the greatest difficulty will come from trying to match peak arousal and the time of competition. Some interesting findings in this area have already been provided by our studies on sensory processing and time of day, but further cognitively-oriented studies will have to be carried out.

Last but not least, experimental paradigms aimed at investigating the mental costs of athlete's specific sequences of skilled behaviours directly «on field» might be tailored, based on the «probe technique», in which levels of processing of secondary signals provide knowledge of the resource costs for those specific sequences.

Greater emphasis on research of this kind might yield results of theoretical interest, as well as practical significance.

RÉSUMÉ

Cet article présente les bénéfices actuels et potentiels qui ressortent du mariage entre la psychologie cognitive et la psychophysiology dans le domaine du sport.

Actuellement, en effet, la psychophysiology cognitive semble être l'interface la plus profitable entre ces deux domaines théoriques afin de mieux comprendre les fonctions mentales en relation avec leur support structuraux.

Dans une première partie, les interrelations entre les domaines conceptuels de la psychologie cognitive et de la psychophysiology cognitive, et les hypothèses théoriques les plus importantes de cette dernière sont présentées. Ensuite, les implications de ce mariage pour le psychologie du sport sont illustrées, dans le but de montrer comment les mesures psychophysiology typiques, par exemple les potentiels évoqués et les potentiels Liés aux événements, peuvent représenter des outils fructueux a) pour comprendre les comportements cognitifs des athlètes et b) pour étudier comment l'entraînement spécifique et prolongé dans des activités sportives peut produire des changements profitables cognitifs.

Après avoir présenté nos résultats de recherche les plus importants, quelques conclusions générales et quelques indications pour des études futures sont proposées.

RESUMEN

Se exponen a continuación las ventajas actuales y futuras, para la psicología del deporte, de la unión entre psicología cognitiva y la psicofisiología. Actualmente, la psicofisiología representa el aspecto más avanzado de estos dos campos teóricos y ofrece la oportunidad de comprender de manera más directa las funciones de la mente y cómo estas son realizadas en el hardware neuronal representado por el cerebro.

La primera parte del presente trabajo pone de manifiesto las posibles relaciones entre estos dos campos conceptuales y se presentan los principales asuntos teóricos de la psicofisiología cognitiva.
Succivamente, si analizzano le implicazioni che questa unione produce in termini di psicologia del deporte in una duplice Perspetiva di dimostrare come i registri psicofisiologici, come i potenziali evocati e in correlazione con l'evento, possono essere strumenti preparati per (a) anticipare, in maniera più profondizzata, il comportamento cognitivo dell'atleta e (b) studiare come l'allenaamento progressivo in specifiche discipline sportive possa apportare cambiamenti positivi all'interno dei meccanismi di elaborazione delle informazioni e nelle strategie cognitive dell'atleta.

In parte finale di questo informe, si presentano e si analizzano i risultati sperimentali più importanti ottenuti, si discutono le conclusioni di carattere generale e si indicano linee di indagine a adoptare in lavori futuri.

ZUSAMMENFASSUNG

Es werden die heutigen und zukünftigen Vorzüge der a.Ehe zwischen Erkennenspsychologie und Psychophysiology für die Sportpsychologie erläutert: Darstellung der Erkenntnisse psychophysiological reefen der Forschung, die bereits berichtet worden sind, und die Bilder, die von der Deutschen Forschungsgemeinschaft, nach meiner Meinung, auf die Zukunftleitung des Athleten zu verweisen sind. Es wird weiterhin von der Deutschen Forschungsgemeinschaft auf die Zukunftleitung des Athleten zu verweisen sein. Es wird weiterhin von der Deutschen Forschungsgemeinschaft auf die Zukunftleitung des Athleten zu verweisen sein.

RIASSUNTO

Questo lavoro vuole illustrare quali siano, per la psicologia dello sport, i variazioni attuali e futuri del matrimonio tra psicologia cognitiva e psicofisiologia. Attualmente la psicofisiologia cognitiva rappresenta, infatti, l'unicità più avanzata tra questi due campi teorici e fornire l'opportunità di comprendere in maniera più diretta le funzioni del cervello e come queste siano implementate nell'hardware neuronale espresso dal cervello. Nella parte finale del lavoro vengono illustrate le interrelazioni possibili tra questi due campi concettuali e vengono presentati i principali aspetti teorici di psicofisiologia cognitiva.

Successivamente vengono analizzate le implicazioni che tale matrimonio produce in termini di psicologia dello sport nella duplice prospettiva di mostrare come i registri psicofisiologici, quali i potenziali evocati e correlati ad eventi, possono essere strumenti preparati per (a) anticipare, in maniera più profondizzata, il comportamento cognitivo dell'atleta e (b) studiare come l'allenaamento progressivo in specifiche discipline sportive possa apportare cambiamenti positivi all'interno dei meccanismi di elaborazione delle informazioni e nelle strategie cognitive dell'atleta.

In parte finale del lavoro, vengono presentati e discusse i risultati sperimentali più importanti ottenuti, vengono presentate le conclusioni di carattere generale e prospettate delle linee di indagine per i futuri lavori.

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