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An Investigation of Information Processing Efficiency in Elite Athletes via Workload Capacity

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Previous studies have demonstrated superior cognitive function and information processing efficiency in elite athletes. However, most researchers drew such conclusions only by means of evaluating mean reaction times (RTs), which cannot be used to directly infer information processing efficiency in athletes. This impedes research development and practical cognitive science applications in the field of sports science. Here, we investigated differences in information processing capacity between elite soccer players and non-athletes by comparing mean reaction time and workload capacity evaluated using Systems Factorial Technology (SFT) (Townsend & Nozawa, 1995). A total of 27 first division soccer players and 26 controls from the general student population took part in the experiment. All participants were matched for weight, height, and age. A double-dot redundant-target task was adopted to examine the effect of visuo-spatial attention between the two groups. Further, event-related potential (ERP) was employed to explore the neural mechanisms underlying the responses. The behavioral findings demonstrated that soccer players exhibited faster reaction time than the controls, while no significant between-groups differences in workload capacity were found. In terms of ERPs, the results revealed a significantly shorter N1 latency for the soccer players compared to the controls, while such an effect was not observed for N1 amplitude. According to these findings, athletes practicing strategic sports may have superior processing speed while performing a visuo-spatial detection task. However, such cognitive superiority might not be associated with information processing capacity in this case. On the other hand, greater processing speed for soccer players may be inferred from the ERP results, which may explain why they had faster visuo-motor responses when performing the double-dot detection task. To summarize, this is study re-examined the cognitive superiority of athletes using a novel approach (i.e., SFT) along with ERP, and it is expected that this work may inspire researchers to further understand the role of cognition in sports from different perspectives.

Keywords: *event-related potentials, strategic athletes, systems factorial technology, workload capacity*

Extended Abstract

The purpose of the development of sports science is to apply professional knowledge from a variety of fields as a reference basis for the selection, cultivation, and application in athletes. However, most research focusing on physiological indexes has demonstrated low predictive power of success in sports. As a result, researchers been attempting to explore the important factors affecting sports performance based on other areas (i.e., psychological factors).

There is increasing evidence suggesting perceptual-cognitive expertise in athletes. Importantly, this cognitive superiority was found to be greater in athletes practicing

open-skill type sports relative to those practicing closed type sports. Notably, one meta-analysis reported that strategic sports (e.g., soccer, basketball, volleyball, and so on), which are examples of open skill sports, showed a very weak effect size regarding athletic superiority in domain-general cognitions. Indeed, some empirical research also reported no difference between strategic athletes and non-athletes in terms of cognitive functioning. Consequently, these findings may lead to the speculative possibility that cognitive function is not important for this type of sports.

Most research has investigated the cognitive superiority of athletes using mean measures such as mean reaction time (RT). However, the use of mean measures in prior research may have limited inferences related to the decision mechanism underlying perceptual-cognitive expertise. The current study was thus aimed toward further addressing this issue by investigating perpetual decision making in strategic sports players (i.e., soccer players) using a non-parametric and diagnostic tool, Systems Factorial Technology (SFT). Perceptual decision making is especially essential in any sport, including strategic sports. For instance, when playing a sport, athletes have to rely on perceptual evidence to make quick, optimal decisions essential to the results of the game. Perceptual decision-making depends on the simultaneous processing of multiple sources of information. For example, soccer players have to determine simultaneously whether pass or shoot based on the relative positions of teammates and opponents on the field. However, prior research on strategic sports only focused on the investigation of single-channel information processing, from which one cannot infer the efficiency of multi-channel information processing during perceptual decision-making. Therefore, in order to further explore information processing efficiency in strategic sports players, this study investigated workload capacity, a measure of the changes in processing efficiency as workload increases, and provided supplemental information regarding the cognitive superiority of athletes engaging in strategic sports.

Workload capacity has been suggested to be a valid index of information processing capacity. It represents the efficiency of the brain when processing multiple sources of information. To assess workload capacity, a redundant-target task was used in this study, in which the test display consisted of two targets (redundant-target trial), one target and one distractor (single-target trial) and two distractors (no-target trials). Specifically, we adopted a double-dot detection task, which is a classic widely used redundant-target task, to study information processing during perceptual decision-making. According to SFT, processing capacity can be divided into three processing systems: (1) supercapacity: increasing the workload speeds up the processing speed for an individual channel, (2) unlimited-capacity: a change in the workload does not affect the processing efficiency of an individual channel, and (3) limited-capacity: increasing the workload slows down the processing speed for an individual channel.

In addition, in order to understand the neural mechanism underlying the differences in perceptual decision-making between athletes and non-athletes, participants' electroencephalography (EEG) performance was also measured when performing the cognitive task. Among EEG analysis approaches, event-related potential (ERP) has been considered to have the capacity to objectively explore the neural activities that occur during the processing of a cognitive event. N1, one of the ERP components, is regarded as an important index of visual attention in the early stage of information processing. According to prior research, N1 amplitude is related to attention resource allocation, while N1 latency represents the speed of visual attention processing. Accordingly, we used N1 to explore whether visual attention in players has an important role in moderating differences in workload capacity between strategic sports players and non-athletes.

To this end, information processing during perceptual decision making was investigated in strategic sports players by means of a combination of SFT and ERP. Importantly, this study was also aimed toward re-examining the evidence regarding the cognitive superiority of athletes in studies using mean measures. This is because the traditional indexes cannot directly infer information processing efficiency. That is, faster response time is not equivalent to better information

processing efficiency. Here, we used SFT and a double-dot detection task to measure workload capacity for the purpose of inferring participants' information processing efficiency. In addition, we used N1 to explore visual attention processing when the participants were performing the cognitive task. If long-term participation in soccer training affects perceptual decision-making, we could expect there to be a group difference in workload capacity performance between athletes and non-athletes. On the other hand, we also expected a between-group difference in N1 if they processed the visual stimuli required in the task differently. Multiple cognitive indexes were used to re-examine the cognitive superiority of the athletes in the hope that the results will further the understanding of the role of cognitive function in sports.

Methods

Participants

Twenty-seven first division soccer players and 26 students from the normal population without any specific sports training participated in the current study. All of the participants were male, right handed, and ranged in age from 18 to 25 years. Participants were excluded if they were overweight (body mass index (BMI) ≥ 24) or underweight (BMI < 18.5) and if their scores in the Chinese version of the Beck Depression Inventory-II (BDI-II) were over 16.

Double-dot detection task

Initially, a white cross was fixed in the middle of the computer screen. After 1,800 milliseconds (the interval is randomly appearing in this interval), a 1°×1° bright spot appeared at a distance of 6° above or below the cross (luminance = 0.031 cd/m^2). There were three conditions in the required task: (1) redundant target condition: a spot appears at both the top and bottom of the cross at the same time; (2) single target condition: only one spot appears; (3) no-target condition: no spot appears. This double-dot detection task is a go / no-go version; that is, when a redundant or a single target appears, the participant was asked to press the corresponding keyboard as quickly and accurately as possible, while no response was needed if no target was presented. There were 5 formal blocks in this task, and each condition had 100 trials, for a total of 400 trials. In addition, the probability of each condition was equal and presented randomly.

System Factorial Technology

SFT is based on the non-matrix analysis method and the dual-factor experimental design to compare differences in response time distribution across different conditions in order to derive the capacity coefficient (C (t)). The formula is as follows:

$$C(t) = \frac{\log[S_{1,2}(t)]}{\log[S_1(t) \times S_2(t)]}$$

where t is any time point greater than 0 ($t > 0$), and $S_{1,2}$ (t) and S_1 (t) and S_2 (t) represent the redundant target and single target survivor functions, respectively. When C (t) <1, it represents limited capacity; when C (t) = 1, it represents unlimited capacity; when C (t) > 1, it represents super capacity. In addition, for the statistical analysis, C (t) can be converted into a single value (the Cz value) via a z score transformation. When the Cz value is negative and significantly less than 0, it represents limited capacity; when it is not significantly different from 0, it represents unlimited capacity; when it is positive and significantly larger than 0, it represents super capacity.

Results and Discussion

In this research, we used a novel diagnostic tool (i.e., SFT) and ERP to examine the efficiency of information processing in strategic sports players. The results revealed that although the overall mean RTs of the athletes was faster, their workload capacity did not differ from the control group. In terms of the ERP results, although N1 amplitude was not significantly different between the two groups, we found that the players exhibited significantly faster N1 relative to the controls, reflecting superior neural processing speed for detecting visual stimuli in the players.

It was expected that strategic sports players would show faster mean RTs along with greater workload capacity. Surprisingly, the results showed that although

the athletes had higher processing speed, their processing capacity did not significantly differ from that of the control group, suggesting that athletes may have greater visuo-motor processing speed rather than faster accumulation of perceptual evidence related to making decisions. It is also likely that the players may have a wider field of view for detecting visual stimuli, despite the fact that this cognitive advantage may not benefit their efficiency in terms of multiple information processing.

Despite the fact that a redundant-target effect on N1 amplitude was observed, the group difference in N1 amplitude did not reach the significance level, indicating that the allocation of attention resources for early visual processing did not differ between the two groups. On the other hand, the N1 latency results suggested that the manipulation of the redundant-target condition might not have affected the neural processing speed. However, we found that the strategic sports players exhibited faster N1 latency than the controls although this might not have been related to their workload capacity performance. Therefore, future research is needed to explore the possible mechanisms that affect the efficiency of athletes' information processing.

To summarize, we used a combination of different approaches to re-examine the issues of cognitive superiority in athletes and proposed new ideas and perspectives in this regard. Despite the promising findings, this study has some technical and inference limitations. For example, this study explored the neural mechanism that may explain the individual differences in workload capacity using ERP. However, it should be noted that the analytical principle of ERP is based on the average obtained from a greater number of trials, which makes it difficult to evaluate workload capacity at the neural level. According to the characteristics of SFT, a single trial analysis is required to calculate ERP workload capacity. Given this limitation, we suggest future researcher may wish to develop an application of SFT for analyzing brain signals, which would be helpful for future research exploring the important neurological workload capacity index.

This study was an attempt to re-examine information processing in athletes as well as their cognitive function using an innovative index. Although it did not meet our expectations, it provides another level of consideration for future researchers. In other words, it still should be considered whether mean reaction time should be used as the assessment index for the cognitive function of athletes. Also, although the double-dot detection task used in this study did not find superior performance in strategic athletes in terms of perceptual decision making, future research could still try to further explore this topic by manipulating attention control in the perceptual decision making task. The results of this study will inspire future researchers to explore perceptual decision-making mechanisms in athletes. In addition to re-examining past research results using traditional analysis methods, it is also possible to further clarify attention control in competitive sports from the perspective of decision making mechanisms and information processing theory.