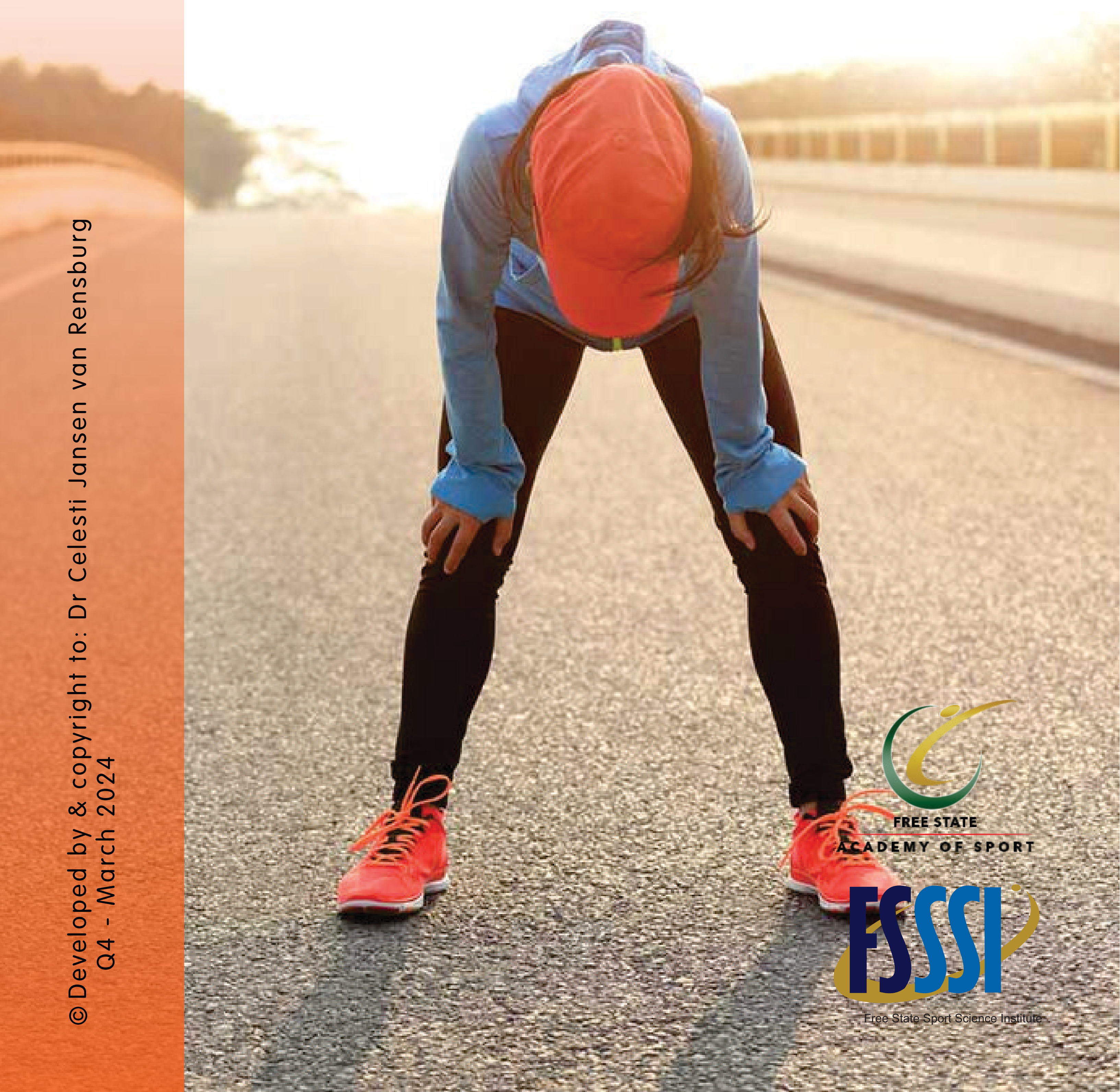
FATIGUE AND COGNITIVE PERFORMANCE



FREE STATE ACADEMY OF SPORT

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Introduction

Fatigue is a common occurrence in elite sports and has a significant impact on various aspects of athletes' performance, including cognitive function. Elite athletes, in their quest for excellence, face fatigue from intense training, competitive pressures, and demanding schedules, leading to both physical and mental exhaustion. While much attention is given to the physical effects of fatigue like muscle fatigue and energy depletion, its influence on cognitive performance is equally important. Cognitive skills are crucial in elite sports, influencing decision-making, reaction times, focus, and planning, all vital for peak athletic performance. Understanding how fatigue affects cognitive function in elite athletes is essential for improving training methods, enhancing performance, and managing mental fatigue-related performance declines. This detailed review delves into the complex relationship between fatigue and cognitive performance in elite sports, analyzing the physiological, psychological, and performance-related aspects contributing to fatigue-induced cognitive challenges. By summarizing current research and explaining the key mechanisms behind fatigue-related cognitive issues, this review aims to offer insights into effective fatigue management and cognitive training strategies customized for elite athletes. By grasping the connection between fatigue and cognitive function, coaches, sports scientists, and athletes can design targeted approaches to boost cognitive performance and maintain a competitive advantage in elite sports settings.

What is fatigue?

Fatigue refers to a decline in physical performance as the intensity of exercise increases. It is characterized by a decrease in a muscle's ability to produce force, resulting in a reduced capacity for physical activity. Prolonged performance of motor tasks causes motor fatigue, leading to a decrease in an athlete's force exertion. Muscle fatigue occurs due to the impairment of various physiological processes that affect the muscle's ability to generate force. Therefore, muscle fatigue does not have a single cause but involves a gradual process with notable physiological changes occurring before and during mechanical failure.

Fatigue during exercise refers to the gradual decrease in physical and/or mental performance due to prolonged exertion. Fatigue can take different forms, including muscular fatigue, which involves a reduction in muscle force, and central fatigue, which affects the nervous system's ability to efficiently control muscle contractions. Physiologically, exercise-induced fatigue can stem from various factors, such as:

- **Depletion of energy sources:** As exercise continues, stores of ATP and glycogen deplete, hampering the muscles' energy production for contractions
- **Buildup of metabolic byproducts:** Intense exercise leads to the accumulation of lactic acid and hydrogen ions in muscles, causing fatigue and hindering muscle function.
- **Disruption of ion balance:** Fluctuations in ion levels like potassium and calcium within muscle cells can impede muscle contractility and contribute to fatigue.
- **Central nervous system fatigue:** Intense or prolonged exercise can induce central fatigue, affecting neurotransmitter function and reducing neural impulses to muscles, resulting in decreased motor output and perceived effort.
- **Psychological influences:** Psychological aspects such as motivation, effort perception, and focus can also impact exercise-induced fatigue.

What is the difference between peripheral and central fatigue?

Peripheral and central fatigue are two distinct types of fatigue that can arise during exercise, each with unique underlying mechanisms and impacts on performance:

Peripheral fatigue:

Definition: Peripheral fatigue pertains to fatigue originating at the muscle and neuromuscular junction levels.

Mechanisms: Factors such as depletion of energy substrates (e.g., glycogen), accumulation of metabolic byproducts (e.g., lactic acid, hydrogen ions), disruption of ion balance (e.g., potassium), and muscle damage can lead to peripheral fatigue.

Effects: Peripheral fatigue mainly affects the muscles' ability to produce force and maintain contractions, resulting in sensations of muscle weakness, soreness, and reduced power output. It typically affects the specific muscles or muscle groups being used during exercise.

Examples: Muscle fatigue encountered during resistance training, sprints, or endurance activities like running or cycling exemplify peripheral fatigue.

Central fatigue:

Definition: Central fatigue refers to fatigue originating within the central nervous system (brain and spinal cord).

Mechanisms: Factors like changes in neurotransmitter function, diminished neural drive to muscles, alterations in motor unit recruitment patterns, and psychological aspects can lead to central fatigue.

Effects: Central fatigue impairs the brain's ability to signal and regulate muscle contractions, resulting in reduced motor output, compromised coordination, and increased perception of effort. It can impact performance across different activities and contribute to mental exhaustion.

Examples: Mental fatigue experienced during extended cognitive tasks or endurance activities such as long-distance running or cycling can exemplify central fatigue.

What are the broad effects of fatigue on elite performance?

Prolonged cognitive demands in sports can lead to cognitive fatigue, affecting decision-making abilities in dynamic environments like soccer and rugby. Cognitive functions such as attention and working memory are crucial for sports performance. Reactive agility is essential for quickly changing movement direction in response to stimuli during gameplay.

What is the relationship between cognitive and physical ability in athletes?

Cognitive ability significantly influences athletes' performance, particularly in team sports conducted in dynamic environments with independent and mentally challenging tasks. The connection between physical and psychological aspects of sport-specific skills and movement is clear. Athletes' adaptability in open skills relies on promptly adjusting to environmental changes. Thus, cognitive elements like visual scanning, anticipation, pattern recognition, and situational awareness are crucial for quick movements in team sports. Decision-making response time is linked to reactive agility in sports like netball and rugby. Recent studies indicate a correlation between cognitive assessment and motor test results, emphasizing the vital role of cognitive functions in sports-specific skills and movement.

How will fatigue influence certain elite sports?

Athletes possess sensory-cognitive skills that are closely tied to their respective sports. Elite team sport athletes demonstrate superior cognitive abilities, such as inhibition, short-term, and working memory, compared to sub-elite and amateur athletes. Processing speed, quick decision-making, and executive functioning play crucial roles in the open-skill setting of team sports. Fatigue, both central and peripheral, affects athletes' sport-specific skills, potentially diminishing technical and tactical performance.

Exercise-induced fatigue can negatively impact executive functions and proprioceptive responses, while short bursts of exercise can enhance neurotransmitter levels and stimulate the release of cortisol. Exercise can positively influence cognitive performance, with submaximal aerobic activities aiding information processing within 60 minutes. Prolonged exercise, however, can lead to fatigue and impair processing and memory functions due to factors like reduced muscle glycogen stores and fluid loss.

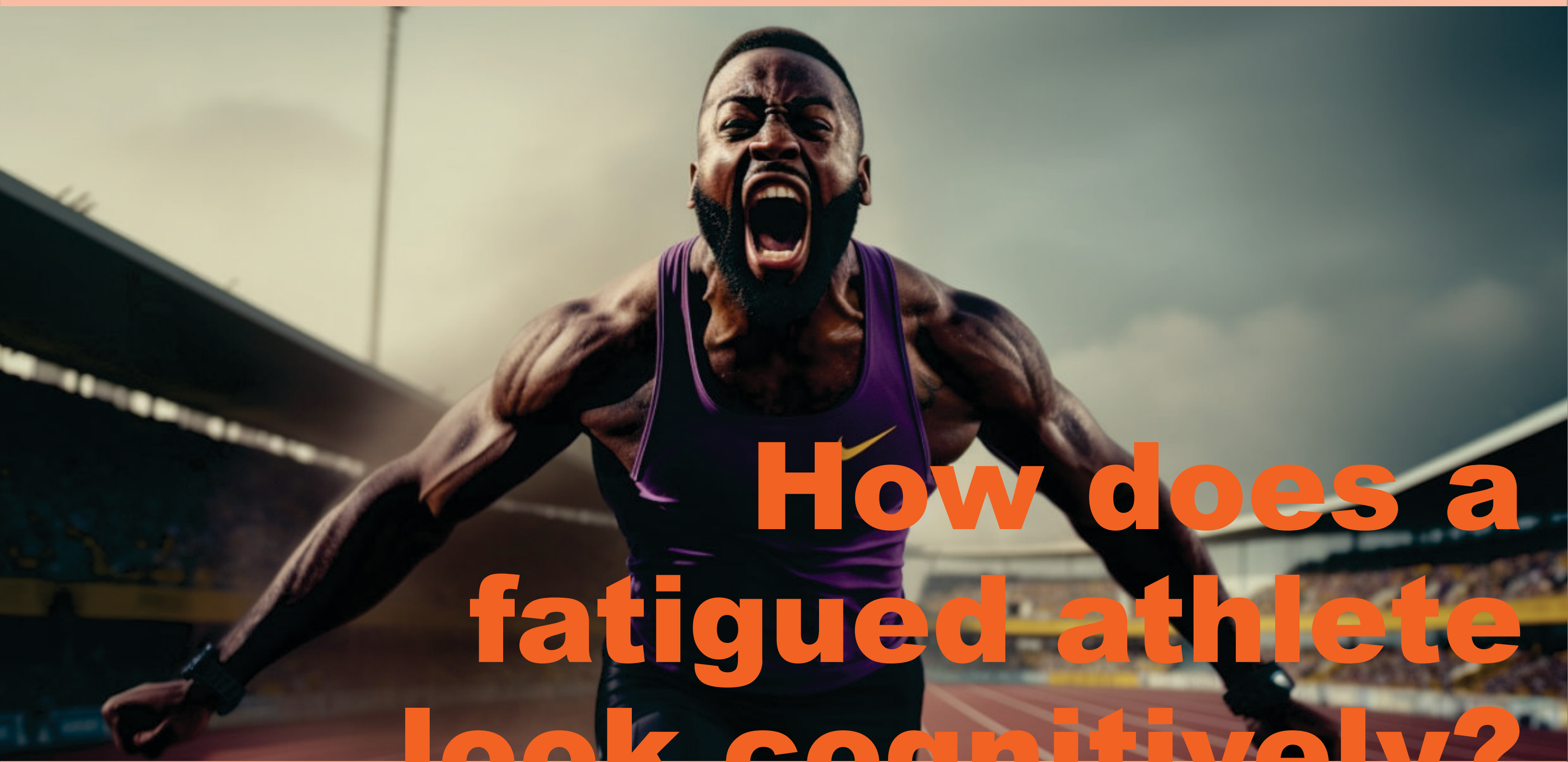
What is the link between cognitive performance & exercise specifications?

The impact of exercise on cognitive functions varies based on **exercise type, duration, intensity, specificity, and the athlete's fitness level.** Specific cognitive abilities like short-term visual memory and choice reaction benefit from acute exercise. Resistance and coordinative training yield positive psychological outcomes, but prolonged acute exercise may hinder them. The acute effects of physical exertion on athletes' cognition remain uncertain. Sport-specific loads, including external and internal factors, running speed, sprints, skills, and game situations, can affect players' cognitive functioning differently. Despite their significance in team sports, these abilities are often undervalued compared to physical attributes.

What is the link between decision making & fatigue?

Successful athletic performance hinges on the simultaneous mastery of a variety of physical and cognitive abilities. Distinguishing elite from amateur players is their sport-specific perceptual skills, with skilled athletes able to anticipate future events and explore strategic options beyond the immediate action. Effective decision-making involves perceiving and understanding environmental cues and choosing the right response, with processing speed and accuracy being pivotal factors. Apart from aiding in making sound decisions from various stimuli such as identifying space, predicting opponents' movements, and following instructions, sharp decision-making and sports intelligence are essential. However, executing these cognitive skills during competition is also influenced by other factors, including the onset of fatigue.

Fatigue can impact cognitive functions, altering player performance in both testing scenarios and simulated games. The extent of cognitive change is influenced by the duration and intensity of the fatigue-inducing task, while the role of specificity remains unclear. Team sports like soccer, cricket, and rugby heavily rely on cognitive abilities, with physical fatigue in competitive sports attributed to energy depletion, thermal strain, dehydration, and central mechanism alterations. For instance, soccer players cover less ground and show a decline in performance in the second half compared to the first half of a match. Decision-making accuracy also decreases in the final 10 minutes of play. Fatigue leads to altered perceptual states and impaired central nervous system function, affecting decision-making. Studies show that high-intensity or prolonged exercise impacts cognitive functions, potentially enhancing decision-making speed but compromising accuracy. These effects are associated with physiological changes at central and peripheral levels. Increased physical load during exercise can divert athletes' attention, reducing anticipation accuracy. In conclusion, research indicates that fatigue affects athletes' decision-making during training and matches, with the degree of impact determined by the physical load and intensity of exercise and game play.



How does a fatigued athlete look cognitively?

Fatigue can significantly influence the cognitive abilities of elite athletes, affecting key aspects of mental function crucial for top athletic performance. Here's how fatigue can impact cognitive performance:

Reduced attention and concentration:

- Fatigue can hinder an athlete's focus and ability to maintain attention on important cues during competition. This may lead to increased distraction, reduced vigilance, and difficulty filtering out irrelevant information.

Slower reaction times:

- Fatigue can cause delays in processing sensory input and responding physically, resulting in slower reaction times. This delay can be particularly damaging in sports requiring quick decision-making and swift responses to changing scenarios.

Impaired decision-making:

- Fatigue may compromise an athlete's judgment under pressure, affecting cognitive flexibility, problem-solving skills, and leading to reliance on habitual responses rather than considering all options.

Decreased working memory capacity:

- Fatigue can impact an athlete's ability to hold and manipulate information temporarily, making it challenging to retain tactical instructions, opponent strategies, or execute complex game plans effectively when tired.

Increased risk-taking behaviour:

- Fatigue can alter risk perception and willingness to take risks during competition, leading to impulsive decisions, recklessness, or high-risk choices that can jeopardize performance or increase errors.

Impaired situational awareness:

- Fatigue can reduce an athlete's ability to assess their environment accurately and predict future events in competition, resulting in diminished awareness, difficulty tracking opponents, and failure to anticipate strategic changes.

Heightened emotional reactivity:

- Fatigue can intensify emotional responses like anxiety, frustration, or irritability, impacting cognitive functions. Athletes may struggle to regulate emotions, affecting cognitive control and decision-making.

Impaired motor coordination:

- While mainly physical, fatigue can also affect motor coordination, which in turn impacts cognitive performance. Athletes may find it challenging to execute precise movements or maintain optimal technique, leading to execution errors and decreased performance.

In summary, fatigue can extensively and negatively affect elite athletes' cognitive performance, influencing attention, reaction times, decision-making, memory, and emotional regulation. Effective fatigue management through proper rest, recovery, nutrition, and stress control is crucial for optimizing cognitive function and sustaining peak performance during training and competitions.

What is the link between lactate and decision making?

The impact of lactate on decision-making among elite athletes is an area that continues to be researched and debated. Lactate, also known as lactic acid, is a byproduct of metabolism produced by muscles during intense exercise when oxygen supply falls short of demand (anaerobic metabolism). Traditionally, lactate has been linked to fatigue and muscle discomfort. However, new findings suggest that lactate might also influence cognitive function and decision-making during physical activity. Here's how lactate could affect decision-making in elite athletes:

Brain Fuel:

- Recent studies propose that lactate can act as an alternative energy source for the brain during exercise, contrary to the belief that it is merely a waste product. By crossing the blood-brain barrier, lactate can be metabolized by neurons for energy, potentially supporting cognitive function and decision-making under metabolic stress conditions.

Neurotransmitter Modulation:

- Lactate may influence neurotransmitter systems in the brain, such as glutamate and gamma-aminobutyric acid (GABA), which are key to cognitive processes like attention, learning, and decision-making. Changes in neurotransmitter levels due to lactate accumulation could impact an athlete's cognitive state and decision-making abilities during competition.

Perceived Exertion:

- High lactate levels in the blood can contribute to feelings of effort and fatigue, indirectly affecting an athlete's decision-making. As lactate builds up during intense exercise, tasks may seem more challenging, prompting adjustments in strategy, risk-taking behaviour, or pacing decisions.

Attentional Focus:

- Lactate accumulation might affect an athlete's ability to sustain focus and attention during physical activity. Increased lactate levels have been associated with heightened arousal and vigilance, potentially enhancing certain aspects of decision-making (e.g., responding to opponents' actions) while potentially hindering others (e.g., complex cognitive processing).

Interplay with Other Physiological Factors:

- Lactate accumulation interacts with various physiological factors like adrenaline release, acid-base balance, and oxygen supply, collectively influencing an athlete's cognitive state and decision-making abilities during exercise. The intricate interplay between lactate and these factors makes it challenging to pinpoint lactate's specific effects on decision-making.

Although ongoing research continues to explore the direct impact of lactate on decision-making in elite athletes, it is evident that lactate serves a more significant role than a metabolic waste product. Understanding lactate's multifaceted role in physiological and cognitive processes is crucial for a comprehensive assessment of its influence on athletic performance and decision-making strategies in sports.

How will lactate affect cognitive skills during high intensity sports in elite athletes?

During high-intensity aerobic or anaerobic sports, lactate can impact the cognitive abilities of elite athletes in several ways. Here's how lactate accumulation might affect cognitive skills during these activities:

Increased arousal and alertness:

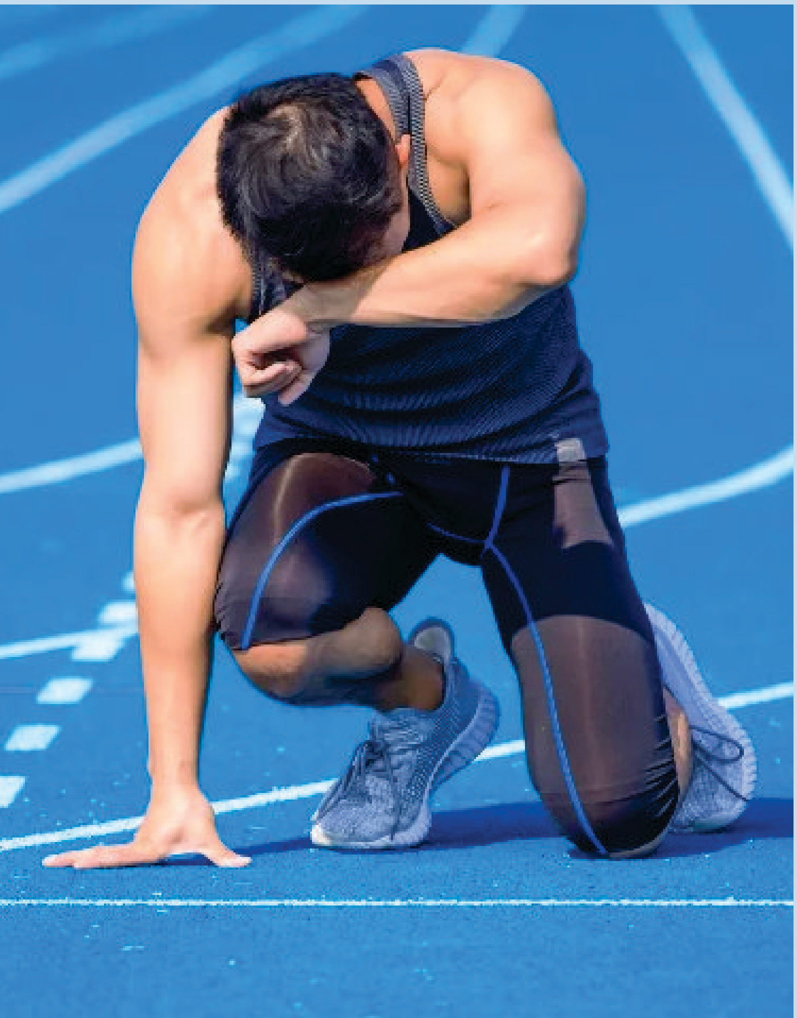
- Lactate buildup in high-intensity sports can boost arousal and alertness. This heightened state can improve an athlete's vigilance, attentional focus, situational awareness, and response time.

Enhanced decision-making under pressure:

- Lactate levels can influence an athlete's ability to make quick decisions during intense sports. Despite being linked to fatigue, research suggests lactate may enhance cognitive function, especially in scenarios requiring rapid decision-making.

Effects on attention and concentration:

- Lactate accumulation may impact an athlete's attention and concentration during high-intensity sports. While arousal can enhance focus initially, prolonged exposure to high lactate levels might lead to mental fatigue and decreased attentional control.



Changes in risk-taking behaviour:

- High lactate levels might alter an athlete's risk-taking tendencies during intense sports. Lactate could influence neurotransmitter systems related to reward processing and risk assessment, affecting decision-making on risk-taking strategies.

Interference with complex cognitive tasks:

- Lactate buildup could disrupt the performance of complex cognitive tasks requiring sustained mental effort. Increased perceived effort and mental fatigue from high lactate levels could impair cognitive skills like working memory and problem-solving.

Individual differences and training adaptations:

- The impact of lactate on cognitive skills can vary among athletes due to factors like training status, genetics, and psychological traits. Athletes with high-intensity training backgrounds may develop adaptations influencing their cognitive response to lactate over time.

The effects of lactate on cognitive skills in high-intensity sports are intricate and diverse. While lactate accumulation can have positive and negative impacts on cognitive function, specific effects may hinge on individual differences, sport-specific demands, and training experience. Further research is essential to deepen our understanding of how lactate metabolism affects cognitive performance in elite athletes during high-intensity sports

How should elite athletes train to minimize the effect of fatigue on cognitive performance?

It is important understand the physiological/psychological response and work rate demands placed on athletes from amateur to professional level. This would provide the opportunity for the development of individualized strength and conditioning programs for athletes. For sports that is High Intensity Intermittent Exercise (HIIE) of nature the development and use of highly intermittent training activities is critical. Intermittent running activities should focus on 3 key abilities: aerobic power; anaerobic capacity; and anaerobic power. Current-reported GPS measures indicate that there is a range of demand and response patterns. This illustrates both the variation between athletes and the type of sport being played. Strength and conditioning coaches should consider designing programs using the following variables as guidelines for the desired intensity: High-intensity speed (>51% Spmax); High-speed acceleration and deceleration (2.5–6ms2); Sprints (>80% Spmax); Metabolic power (W/kg); and High-intensity HR (>80%HRmax). Individual athlete maximums can be established from general measures. Maximal speed and high-speed acceleration and deceleration can be calculated from the standing 40-m and maximal HR from the Yo-Yo IRL1 or BRONCO. All 4 measures require a maximal effort and can be recorded accurately with GPS units (Watches or Pods). Through various research, HIIE has been shown to improve levels of athlete's physical capacity, and therefore, match performance. Maximum aerobic speed sessions are time efficient and can be used to develop aerobic power, whereas repeated sprint and sprint activity can develop anaerobic capacity and anaerobic power, respectively. A typical training week should aim to include 2–3 HIIE sessions (Pre-Season), which engage multidirectional movement to mimic game patterns. Importantly, a portion of the training efforts during the week should overload the athlete and include some decision-making activities. The travelling agenda of athletes should be kept in mind when planning detail on training load and periodization, as it is a major challenge that athletes deal with regularly and makes load planning programming problematic. A better understanding of the relationship between physical activity and decision making (DM), as well as the use of intermittent running activity will hopefully enable athletes to keep up with play while accumulating less fatigue, allowing for accurate decision making.

EXAMPLE:

Time:	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Hab and/or Activation							
AM:	Gym (Str.)	Gym (Str.)	Rest	AN-P/NMS (Gym)	Rest	Rest	Recovery
PM:	AN-C1 (MIT)	Sport Spes.	AN-C2 (SIT + DM)	Sport Spes. AN-P (Field) Sp-Ag + DM	Match Prep	Match	Rest
AN-C1 (MIT): 120s Work @ HR (85–95%) HRmax, @ RPE 7–9 with 60s Active Rest @ HR (60–70%) HRmax @ RPE (3–4), repeat six times. Target 1500m – 1800m High-Intensity Speed Running							
AN-C2 (SIT+DM): 50m run @ 80-90% Top Speed every 20s x 6; Rest 3min; Repeat. DM activity could include video clip on tablet to make a decision or puzzle solving etc. straight after running effort. Target 500m High-Intensity Running (10 Sprints; 8-10 High Speed Accelerations/Decelerations)							
AN-P/NMS Gym: 4-5 Compound Lifts (Clean/Snatch/Jerk/BB Bench Press/Squat/Jump etc.); 5 Reps x 5 Sets @ 60% 1RM							
Str. Gym: 4-5 Key compound Lifts (BB Bench Press/Squat/Deadlift/Bent over Row/Shoulder Press/DB Step Ups etc.); 6-8 Reps x 3-5 Sets @ 80% 1RM							
ANP(Field) - Sp.-AG + DM: (1) Sp.: 5m – 50m runs with 30s recovery efforts @ 90⁺% SpMax. Note: High-speed accelerations and decelerations achieved with each effort. Rest 5min with no active movement; (2) agility: reactive direction changes off lighting system or cone drills for 4–8s x 4–6 every 50s. Note: Target sport Specific patterns with 4–5 high-speed accelerations and decelerations for both speed and agility.							

Note: *Str. – Strength; AN-C – Anaerobic Capacity; AN-P – Anaerobic Power; NMS – Neuromuscular Stimulus; MIT – Medium Intensity Training; SIT – Short Interval Training; DM – Decision Making; Sp. – Speed; AG - Agility*

What is the take away message?

In summary, the overwhelming evidence indicates that fatigue significantly affects cognitive performance in elite athletes, leading to declines in attention, decision-making, reaction times, and overall mental sharpness. The intricate nature of fatigue, involving physiological, metabolic, and psychological aspects, highlights the complexity of its impact on cognitive function. Physiologically, fatigue-related changes like energy depletion, neurotransmitter variations, and central nervous system fatigue can hinder cognitive processing and motor coordination. Metabolically, the buildup of byproducts such as lactate, along with disruptions in ion balance and neurotransmitter function, can further compromise cognitive abilities. Psychologically, fatigue can result in heightened perceived effort, emotional reactions, and mental tiredness, all influencing crucial cognitive skills necessary for elite sports performance.

To counteract the negative effects of fatigue on cognitive function, elite athletes must incorporate specific training adjustments to alleviate fatigue-related declines and enhance performance. Effective fatigue management techniques, such as structured training schedules, proper recovery strategies, nutritional support, and mental skills training, can help athletes develop resistance to fatigue and improve cognitive capabilities. Additionally, integrating targeted cognitive training practices like attention exercises, decision-making drills, and visualization techniques into athletes' routines can enhance cognitive skills relevant to sports performance.

Moreover, understanding individual variances in fatigue susceptibility and response to training stimuli is crucial for tailoring interventions to meet each athlete's specific requirements. Athletes and coaches should work closely together to monitor fatigue levels, adjust training intensities accordingly, and apply recovery methods to prevent overtraining and optimize adaptation. By embracing a comprehensive approach to fatigue management and cognitive training, elite athletes can foster the mental fortitude and cognitive adaptability needed to excel in high-pressure competitive settings while reducing the impact of fatigue on performance. Ultimately, integrating tailored training adjustments to address fatigue-related cognitive declines represents a proactive strategy to boost athletic performance and achieve success at the elite sports level.

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