Mini-Review/Systematic Review

Mental fatigue and ball sports: a narrative review focused on physical, technical, and tactical performance

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Abstract - Aim: This narrative review aimed to explore the effect of mental fatigue on physical, technical, and tactical performance in ball sports. **Methods:** Three Databases, PUBMED, SCOPUS, and SCIELO, were used to search for a scientific publication. The criterions adopted were: a) published in a peer-reviewed journal; b) adopted at least one manipulation check related to mental fatigue; c) mental fatigue induced by a cognitive task before the outcome task, and d) study participants were ball sports athletes. **Result:** The quality of this narrative review was rated at 11 (SANRA scale 0-12), and the papers analyzed were published between 2015 and 2022. Twenty-one experimental studies were included in this review. Most studies were in invasion sports (n = 13; 72%), and non-ecological tasks were used to induce mental fatigue (n = 15; 83%). Regarding performance in endurance tests, mentally fatigued athletes had performance impaired. However, when assessed during a small-sided or simulated game, data were inconclusive within the literature. Moreover, athletes presented attenuated perceptual skills (e.g., visual field). Consequently, this worsened motor skills, technical-tactical performances, and tactical behavior. **Conclusions:** Cognitively demanding tasks should be avoided before training and sports competitions because they can lead the athlete to mental fatigue and impair performance. This impairment is identified in physical performance (endurance tasks) and technical and tactical performance. Finally, it is recommended that athletes do not perform tasks that cause mental fatigue 2 h before the sports event.

Keywords: cognitive neuroscience, cognitive fatigue, sport psychology, cognitive effort, athletic performance.

Introduction

Ball sports (i.e., sports that use a ball or similar objects) are mainly determined by a holistic relationship between physical, technical, and tactical aspects[1]. Regarding the physical demands, intensity variation and brief rest periods (i.e., intermittent) are common in those modalities. Also, muscle power is essential to perform several actions (e.g., sprints, jumps, and kicks)[1]. In the technical (e.g., kick, header, forehand) and tactical (e.g., decisions and actions to gain an advantage over the opponent) aspects, perceptual-cognitive skills are required because most actions are open. In other words, they happen in an unpredictable environment, making it difficult to anticipate movements' execution[2]. Therefore, executive function (i.e., mental processes that regulate attention, memory, and other cognitive skills; see more details in Diamond[3]) is fundamental to performance. For example, attentional control is responsible for the perception of relevant information, the decision making to find a better way of playing, and memory that directs attention and sustains elements that contribute to decision making[4]. In sports science, factors that impair performance are often investigated. For this reason, mental fatigue has garnered the interest of researchers, coaches, and athletes alike.

Conceptually, mental fatigue is a psychobiological state associated with a feeling of tiredness and/or lack of energy after long periods of cognitive activities that contain high levels of attention, inhibitory control, or monotony/boredom[5,6]. Using social media on smartphones[7], playing video games[8], and performing computational cognitive tests[9,10] are examples of activities bringing about mental fatigue if performed for a prolonged period (i.e., $\geq$ 30 min). Additionally, contextual factors (e.g., traveling to compete) and cognitive demands during the match can also contribute to the increased perception of mental fatigue[11].

One mechanism that seems to explain mental fatigue is the inability to resynthesize adenosine triphosphate (ATP) due to cognitive effort[12]. ATP (i.e., a combination

of adenine, ribose, and a set of three phosphate derivatives, the oxidation of carbohydrate, protein, and lipids) is utilized during several human processes (e.g., muscle contraction, brain function)[13]. Blood glucose passes through the blood-brain barrier (i.e., formed by endothelial cells that select substances from blood into nervous tissue) and is regulated by the glucose transporter-1 (GLUT-1) membrane protein and hexokinase in a membrane-bound and intracellular fashion[14]. Glucose is converted to lactate in the brain, released into the extracellular space, and then transported to neurons and oxidized[15].

Cognitive demand for a prolonged period requires a significant contribution from glucose for cerebral energy, which can be observed from the increase in lactate in extracellular regions. Although of short duration, the phosphocreatine (PCr) energy system appears to play an essential role in maintaining cognitive performance when the cerebral glycolytic system is overloaded[16]. When performing demanding cognitive activities, the demand for ATP surpasses the resynthesis capacity and, consequently, there is an increase in the concentration of cerebral adenosine, mainly in the anterior cingulate cortex[6,17]. It can be observed in situations of cerebral hypoxia, in which there is an increase in adenosine concentration and a decrease in ATP due to compromised oxygen supply[18].

Adenosine increases are associated with reduced cortical activity[19]. For example, a systematic review with meta-analysis reported an increase in theta wave (4-7.5 Hz) in frontal regions and low-frequency alpha (7.5-13 Hz) in central cortical regions occurred in mentally fatigued subjects[20], suggesting deactivation of brain areas. The practical effect is an impairment of executive function (e.g., working memory, attention)[21] since these waves are associated with inhibitory processes, mainly in the frontal region, especially due to attenuation of dopamine activity, an excitatory neurotransmitter[17].

It should be noted that the perceived exertion during exercise for the same external load is greater when the athlete is mentally fatigued[22]. It seems that perception of effort is decisive for exercise tolerance (for more details, see the psychobiological model)[23]. Moreover, executive function (executive control and perceptual speed) was associated with sports performance skills[24], in which more skillful athletes exhibit superior cognitive function[25]. Thus, how mental fatigue affects executive functions and technical and tactical aspects might change depending on the individual[6]. Then, once players are expected to perform cognitive activities (e.g., social media, playing video games, school/university class) before training and matches (for more detail, see Thompson et al.[11]), it is crucial to investigate the effect of mental fatigue in ball sports.

Other reviews have attempted to shed light on the effect of mental fatigue on sports performance. Van Cutsem et al.[26] examined the effect of mental fatigue on endurance, maximal strength, power, and anaerobic work. Recently, Cao et al.[27] focused only on basketball, and Grgic et al.[28] observed its effects on intermittent tests (i.e., Yo-Yo Test) and specific tests for football. Thus, a study to synthesize the information on mental fatigue and ball sports is absent to date, so we though it pragmatic to produce such an analysis. This review will assist coaches and other professionals responsible for athletes' performance. This narrative review aimed to explore the effect of mental fatigue on physical, technical, and tactical performance in ball sports.

Methods

This article adopted "ball sports" as any sport played with a ball or similar object (e.g., badminton shuttlecock). A narrative review was performed using the databases PUBMED, SCOPUS, and SCIELO with the terms "mental fatigue" OR "cognitive fatigue" AND "sports" on the 11th of April 2022. In addition, a manual search by the title was performed in ResearchGate when the full version of the paper was not available in databases. Only papers that had access to the full version were taken for analysis. The criterions adopted were: a) published in a peer-reviewed journal; b) adopted at least one manipulation check related to mental fatigue (e.g., Stroop Test, visual analog scale - VAS); c) mental fatigue induced by a cognitive task (e.g., AX-CPT) before the outcome task; and d) being ball sports athletes [any person who is regularly training in sports, regardless of level (e.g., grassroots, amateurs, and professionals players) was considered].

Data analysis

The scientific publications were organized according to the type of sport, participants, and mental fatigue tasks. Moreover, this category is presented in an absolute and relative frequency distribution.

Result

The quality of this narrative review was rated at 11 (SANRA scale 0-12, see more details in supplementary files) using the Scale for the Assessment of Narrative Review Articles[29], and the searched papers were published between 2015 and 2022.

Research on mental fatigue in ball sports and characteristics

Table 1 presents the 21 experimental studies included in this review. Following the Hughes and Bartlett[30] classification, most research focused on invasion games (n = 16; 76.19%), mainly due to investigations with soccer players (n = 11; 66.67%). These studies were conducted primarily with male athletes, and only two studies (9.53%) had female participants. To induce mental fatigue (i.e., independent variable), most studies used the Stroop Test

Table 1 - Research on mental fatigue in ball sports with methodological characteristics.

Reference	Sport	Sport type	Participant	MF Task
Smith et al.[34]	*Various sports	***	10 M	AX-CPT
Smith et al.[22]	Soccer	Invasion	12 / 14 M	Stroop
Smith et al.[45]	Soccer	Invasion	12 M	Stroop
Badin et al.[35]	Soccer	Invasion	20 M	Stroop
Veness et al.[32]	Cricket	Striking/Fielding	10 M	Stroop
Coutinho et al.[36]	Soccer	Invasion	12 M	Motor coordination
Kunrath et al.[51]	Soccer	Invasion	6 M	Stroop
Penna et al.[31]	Handball	Invasion	12 M	Stroop
Moreira et al.[38]	Basketball	Invasion	32 M	Stroop
Coutinho et al.[60]	Soccer	Invasion	10 M	Stroop
Le Mansec et al.[9]	Table Tennis	Net	22 M	AX-CPT
Gantois et al.[10]	Soccer	Invasion	20 M	Stroop
Fortes et al.[7]	Soccer	Invasion	20 M	Smartphone (Social Media)
Van Cutsem et al.[43]	Badminton	Net	4 M - 5 F	Stroop
Kunrath et al.[37]	Soccer	Invasion	18 M	Stroop
Kosack et al.[40]	Badminton	Net	19 M	Stroop
Fortes et al.[8]	Soccer	Invasion	25 M	Smartphone (Social Media), Video game
Filipas et al.[33]	Soccer	Invasion	36 M	Stroop
Habay et al.[44]	Table Tennis	Net	7 M 4F	Stroop
Fortes et al.[47]	Basketball	Invasion	16 M	Video game
Gianmarco et al.[55]	Soccer	Invasion	10 M	Video-based tactical

*Soccer, Australian football, rugby league, rugby union, and field hockey; M: male; F: female; MF task: mental fatigue task.

(n = 14; 66.67%). Furthermore, non-ecological activity (Stroop and AX-CPT) represented more than 79% (n = 15) of investigations. Only 23.81% (n = 5) considered ecological tasks, that is, activities potentially reproducible in a real-life scenario.

Furthermore, a series of tests and task configurations were used. In this way, Table 2 organizes these by sports. In this sense, it is observed that, except for football, most other sports invest in using physical tests. Finally, simulated matches with the same characteristics as official games are rarely used.

Discussion

Physical performance

Endurance tests

Ball sports involve intermittent exercise, so tests such as Yo-Yo Intermittent Recovery Test (Yo-Yo IR tests) are best suited to assess endurance capacity. Several authors have reported poorer Yo-Yo IR test performance following mental fatigue quantified by less distance covered[22,31-33]. The lower tolerance to exertion cannot be explained by physiological variables (i.e., heart rate, lactate), as these were not influenced by mental fatigue. For example, soccer athletes showed no difference between mental fatigue and control for heart rate[22], which was later consolidated in handball athletes with no difference in blood lactate and heart rate recovery[31]. In another study using an intermittent treadmill test, mentally fatigued athletes reduced velocity at low intensities[34]. Thus, mental fatigue causes athletes to terminate tests earlier than control conditions because of increased subjective perception of effort (RPE)[6].

Small-sided games and simulated match

In a small-sided soccer game (5 vs. 5) of 15 min, athletes covered the same distance between conditions (mental fatigue or control) when assessed by the global positioning system (GPS) but reported a greater perception of effort under mental fatigue[35]. Another study, also with soccer athletes, using another small-sided game configuration[36], reported similar results. But the results observed by Coutinho et al.[36] cannot be guaranteed that they were exclusively due to mental fatigue since the inducing task involved physical effort. Curiously, mentally fatigued soccer players covered greater distances during a small-sided game[37], which may be explained by different tactical behaviors between conditions (Stroop Task vs. watched a video documentary). Finally, in a study with basketball (a small-sided game) and two other simulated soccer matches, the internal load (IL = RPE * time) was

Table 2 - Tests and tasks performed by athletes organized by sport.

Sport	Reference	Tests and talks
Various sports*	Smith et al.[34]	Intermittent running on a treadmill
Badminton	Kosack et al.[40]	Badminton-specific test
	Van Cutsem et al.[43]	Visuomotor task (LED lights)
Basketball	Fortes et al.[47]	Videos for the decision-making task
	Moreira et al.[38]	Small-Sided Games (4 Vs 4; Four sets 2 min 30 s / 1 min half-time)
Cricket	Veness et al.[32]	Cricket run-two test, Batak Lite reaction time test, and Yo-Yo-IR1 test
Handball	Penna et al. [31]	Yo-Yo IR1 test
Soccer	Smith et al.[22]	Yo-Yo IR1 test / LSPT and LSST
	Filipas et al.[33]	Yo-Yo IR1 test / LSPT and LSST
	Smith et al.[45]	Videos for the decision-making task
	Badin et al.[35]	Small-Sided Games (5 Vs 5; 2 sets 7 min / 1 min half-time)
	Coutinho et al.[36]	Small-Sided Games (Gk+6 Vs 6+Gk; 3 sets 6 min / 3 min half-time)
	Coutinho et al.[60]	(Gk+5 Vs 5+Gk; 3 sets 6 min / 3 min half-time)
	Gianmarco et al.[55]	Small-Sided Games (5 Vs 5; 2 sets of 7 min / 1 min half-time)
	Kunrath et al.[37]	Small-Sided Games (Gk+3 Vs 3+Gk; 12 min)
	Kunrath et al.[51]	Small-Sided Games (Gk+3 Vs 3+Gk; 12 min)
	Fortes et al.[7]	Simulated Match (Official Rules)
	Fortes et al.[8]	Simulated Match (Official Rules)
	Gantois et al.[10]	Simulated Match (Official Rules)
Table Tennis	Le Mansec et al.[9]	Maximal voluntary contractions / table tennis test
	Habay et al.[44]	Visuomotor task (LED lights)

*Soccer, Australian football, rugby league, rugby union, and field hockey; Gk = goalkeeper; Yo-Yo IR1 test = Yo-Yo-Intermittent Recovery Level 1; LSPT = Loughborough Soccer Passing Tests LSST = Loughborough Soccer Shooting Tests.

similar between conditions[38]. However, GPS or any other technique was not used to measure the external load. In addition, the number of participants and task configuration could be a confounding factor for analyzing the physical aspects directly in small-sided games or simulating matches (i.e., official model). For example, the physical demands are different in small games according to the game space and the number of participants. Furthermore, the subjective perception of the session[39] should be used in future investigations. This method would facilitate the comparison between studies as it considers aspects of the internal (RPE) and external (time) load.

Strength, speed, and power tests

As a strength, speed, and power tests are of short duration, the subjective perception of effort has little importance in regulating performance in these tasks. Thus, in a study that verified torque production capacity in the elbow flexors and knee extensors, there was no reduction in the maximum voluntary contraction under mental fatigue, even though there was a tendency towards a greater subjective perception of effort[9]. Another study found lower limb power, quantified by vertical jumps with countermovement, and a specific test for badminton reported by the authors with a wide anaerobic characteristic were not impaired by mental fatigue[40]. Surprisingly, cricket athletes were slower on a modality-specific speed test[32]. However, this test had a technical component involved, which may explain the reduction in performance even though it is a short-term activity.

Technical and tactical performance

Technique in ball sports is usually investigated from a biomechanical perspective. However, for open skill sports, it is not overly relevant, as it cannot determine the result per se compared to predominantly closed skills sports, like sports with a greater technical emphasis (e.g., artistic gymnastics, rhythmic gymnastics). Moreover, in sports with a perceptual-cognitive aspect, tactics are of utmost importance for performance, as it relates to decisions and actions to gain an advantage over the opponent and manage the game space[41,42]. Thus, many studies have been developed to assess the effect of mental fatigue on perceptual-cognitive skills (response time, visual behavior, and decision making) and motor skills. These investigations were included in this section to infer the effect of mental fatigue on sports with technical-tactical aspects and tactical behaviors.

Perceptual-cognitive skills

In badminton, athletes were tested using a visual-motor task with target and distracting stimuli, athletes' response times were slower when mentally fatigues[43]. Table tennis athletes also had attenuated performance (i.e., reaction time) on a slightly modally adapted visual-motor task[44]. In addition, the authors made an important contribution, indicating that mental fatigue modified the brain waves through the electroencephalogram. In this sense, decreases in the alpha band (upper: 4-8 Hz) and theta (10-13 Hz) were reported. Thus, in another study involving simple stimuli (specific test for badminton with four alternatives, without distractor), authors did not identify a negative effect of mental fatigue on performance[40]. These studies suggest that response time may be maintained in simple tasks, but in complex tasks, athletes require more time to develop an adequate motor response.

Two studies with soccer athletes demonstrated that mental fatigue causes visual changes. First, changes in the visual behavior of athletes were verified through eye-tracking[45]. In this study, there was a tendency for mentally fatigued athletes to focus more on the ball and defender than on free spaces and unmarked attackers. Secondly, there was a reduction in the visual field (i.e., a lower range of peripheral vision)[37]. This effect of mental fatigue on the visual field is important because it reduces the input of helpful information for decision making, therefore, attenuating tactical performance. For example, it was recently identified that soccer athletes with greater tactical efficiency also had greater peripheral perception[46]. Recently, this assumption was confirmed with basketball athletes fatigued by video games, showing changes in visual behavior (i.e., decreased number of fixations), compromising decision making (i.e., lower accuracy and more extended response time)[47].

Furthermore, other studies also reinforce decision-making impairment in both controlled and open tasks. In soccer-specific decision-making tasks, soccer athletes exhibited poorer accuracy in determining the best option and response time in soccer-specific decision-making tasks[45]. The main limitation of this study is using a screen test, although real scenes were used. It differs from the requirements of a real match as motor actions were not necessary. However, this limitation extends to the previously presented study with basketball athletes[47]. In another study in which soccer athletes performed a simulated match with official rules, it was found that decision-making concerning passing was impaired under mental fatigue[10]. The authors demonstrated that 30 min of demanding cognitive activity was required to impair subsequent performance. Subsequently, these results were corroborated[7,8] with two investigations as they incorporated mentally fatiguing activities likely to be completed by athletes (e.g., video games and social media). Thus, it demonstrates higher ecological validity than 'artificial' mentally fatiguing tasks (as athletes are unlikely to undertake the Stroop test in their leisure time or before a match). In addition, the data from these studies allow considering the visual, pre-motor, and supplementary motor brain areas as possibly affected by mental fatigue because they are directly related to perception and transformation of visual stimulus into a motor action[48].

Motor skills

To assess passing and shooting skills in soccer players, Smith and colleagues used the Loughborough Soccer Passing Test, and the Loughborough Shooting Tests, respectively[22]. Data from this study revealed mental fatigue increased the number of penalties associated with the passing test and reduced speed and accuracy in shooting. More recently, using the same tests, mental fatigue was compared in three age groups (U-14, U-16, and U-18)[33] with authors reporting a negative effect of mental fatigue in only U-18 athletes in the Loughborough Soccer Passing Test. It is possible younger athletes are less susceptible to mental fatigue due to less development of the prefrontal cortex[49,50], however, more studies are needed in this regard. In a real match scenario, it is necessary to consider the opposition, but even in these 'artificial' tests discussed above, without the additional level of difficulty of facing opponents, accuracy was impaired which would be advantageous for opponents in retaking possession or not being threatened with shots at goal. Moreover, in net sports in which accuracy is highly important since error directly results in a point for the opponent, less accuracy and ball speed in table tennis were observed in mentally fatigued athletes[9]. Despite few studies, sports-specific motor skills seem to be affected by mental fatigue, but this area requires larger confirmatory studies.

Technical-tactical performance and tactical behavior

Mental fatigue seems to interfere with both technical-tactical performance and tactical behaviors. Mentally fatigued soccer players participated less during a small-sided game, missed more passes, lost control of the ball more easily, and had less success in dispossessing the ball of opposing player[35]. Similarly, mentally fatigued basketball players have been observed to make more turnovers under mental fatigue[38]. Two studies conducted by Kunrath and colleagues with young U-15[51] and university soccer players[37] assessed tactical behavior based on the principles of game and spatiality. Regardless of age, mentally fatigued athletes mainly neglected defensive principles. Furthermore, university players reduced collective tactical behavior and instead chose more individual actions in the attack.

Coutinho et al.[36] reported mental fatigue affected athletes' environmental perception sufficiently to harm their positioning on the field. For example, lateral syn-

chronization was 13% lower than in a control condition without mental fatigue. In terms of cerebral activity, it is noteworthy that the anterior cingulate cortex appears directly related to a reduction in performance of tasks with technical-tactical and tactical behavioral demand as this area is functionally associated with attention, focus, and inhibitory control. However, it is still necessary to investigate whether mental fatigue acts in regions such as the cerebellum and all the "observation network" since they are fundamental areas for anticipation and refining movement[52], a fundamental skill in ball sports.

In general, mental fatigue seems to impair all technical and tactical performance components. However, especially in "Motor skills" and "Technical-tactical performance and tactical behavior", extrapolating the results between sports is challenging. This fact happens due to the variability of the task configuration. For example, even in a single sport like soccer, the configuration of the small-side games is quite distinct (more details in Table 2). It indicates that it is essential to investigate the specific demands of each sport because of the complex nature of sports. In addition, more investigations need to be done using the official rules of each sport.

Can motivation moderate mental fatigue?

In the model proposed by Ishii et al.[53], mental fatigue is regulated by the facilitation and inhibition system (i.e., "double regulation system"), with motivation being a moderating factor for the overlap of one system over another[53]. Moreover, Martin et al.[17] suggest that due to increased adenosine and reduction in dopaminergic activity, motivational aspects would be attenuated. The rationale is more motivated athletes could maintain performance even with an increase in the subjective perception of effort. However, investigations concerning motivation in ball sports are relatively limited. Studies carried out with badminton[40], soccer[22], and handball[31] athletes did not identify any difference in motivation with the mentally fatigued athletes. However, these studies did not use a validated instrument for this purpose. To our knowledge, only one study evaluated motivation using a validated questionnaire (i.e., Assessment of motivational states in performance environments)[34]. Regardless, these results were similar to those utilizing an unvalidated assessment method, in that, there was no difference in motivation. The self-determination theory[54] proposes three dimensions of motivation (i.e., intrinsic, extrinsic, and demotivation). The studies presented, regardless of the instrument seem to consider only the intrinsic motivational state. Thus, future investigations could investigate how extrinsic motivation moderates mental fatigue and subsequent performance.

Practical recommendations

It is recommended that coaches involved with ball sports guide athletes to avoid performing activities with high mental demands for more than 30 min, at least 2 h before training and competitions[10]. For example, electronic games and social networks on smartphones should be avoided[8,11]. It is essential because it prevents athletes from training or playing in a state of mental fatigue and consequently reduces their performance, especially the cognitive and technical-tactical ones. Moreover, it is widespread to use video before games to convey tactical information, and it should be used with caution. Only one study has shown that this type of activity for 30 min does not impair soccer athletes' performance[55].

In addition, monitoring of mental fatigue is indicated through the visual analog scale (10 cm - magnitude: 0-1, no fatigue; 2-4, mild fatigue, 5-7, moderate fatigue, 8-10, several fatigues)[56,57], and short-term Stroop Test using accuracy and especially the response time as indicators[7]. These tools are accessible and easy to apply compared to an electrophysiological resource sensitive to mental fatigue such as an electroencephalogram[58].

Limitations and future research

The results presented may be affected by the publication bias of the articles used, mainly due to the visual analog scale as a manipulation check (i.e., subjective measurements). Another important limitation of studies on mental fatigue is the task used (i.e., independent variables). Many studies use tasks like Stroop and AX-CPT tasks that are almost impossible to do in the real world before a match. However, there seems to be a concern in more recent studies to verify the effect of more ecological tasks. For example, Thompson et al.[11], surveyed soccer young English athletes (i.e., U-14 to U-20), verifying that 2 h before the official games, the athletes used social networks (58%), used smartphones (12%), or played video games (9%), exactly the tasks used by Fortes et al.[7,8]. From this point forward, manipulation checks like VAS (e.g., subjective way) and Stroop task (i.e., behavioral way) can be used together, but an advance in this area would be the use of neurophysiological measures (i.e., electroencephalogram), and measure adenosine levels.

Recent studies have shown a positive effect of using caffeine to mitigate mental fatigue in endurance sports[59]. In the future, investigations with caffeine can clarify the mechanism related to adenosine, as it is a classic inhibitor, and an ergogenic aid for situations in which mental fatigue cannot be avoided (e.g., successive matches, travel). Moreover, strategies such as the use of transcranial direct current stimulation and mindfulness can also be tested to mitigate mental fatigue. Additionally, long-term studies with repeated effects need to be conducted to investigate

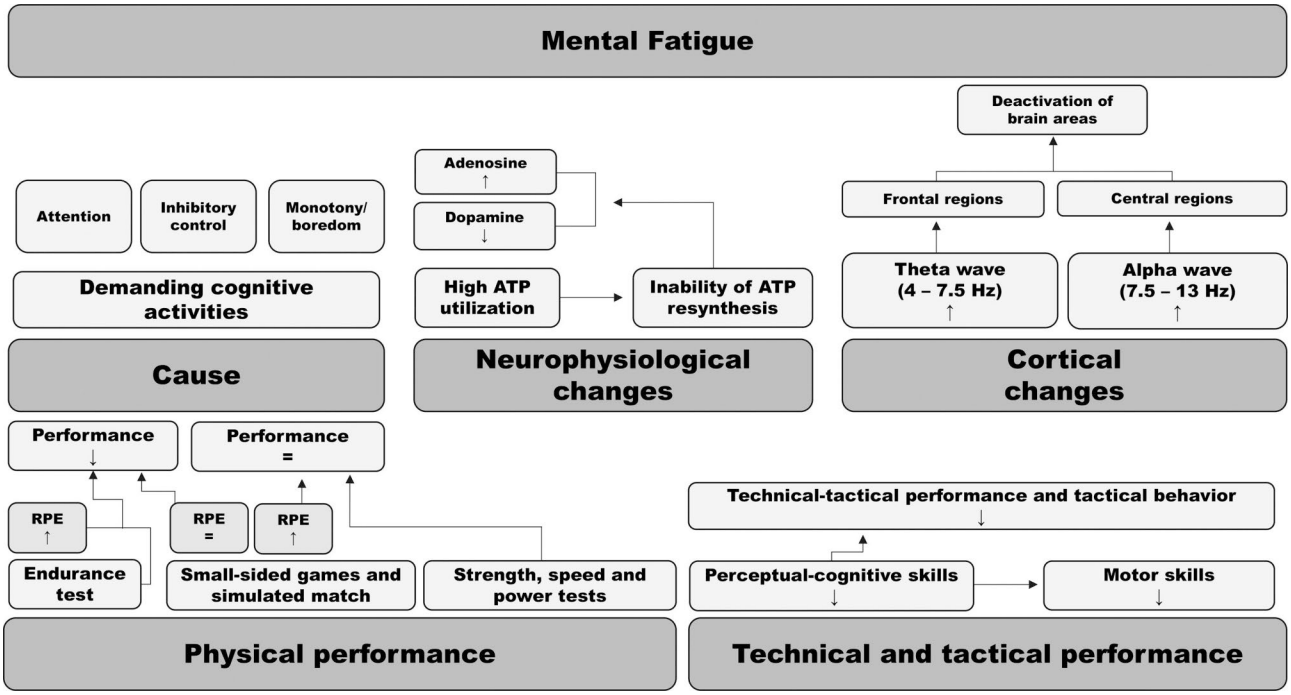

Figure 1 - Conceptual model of mechanisms involved in mental fatigue and effect on performance in ball sports. ↑ increase; ↓ decrease; = remain the same.

the effects of mental fatigue on athletes' preparation and consider the season and expand sports, categories, and genders.

Conclusions

In conclusion, mental fatigue appears to have harmful consequences on performance in ball sports (Figure 1). Regarding physical aspects, mental fatigue reduces endurance performance of periodic tests due to a greater perception of effort. During games (small-sided games or simulated), there is some inconsistency in findings, but mentally fatigued athletes choose to maintain RPE, thus worsening physical performance or reducing the physical effort to maintain RPE. Finally, perceptual-cognitive aspects are affected and contribute to worse performance in isolated tasks, small-side games, or matches. Consequently, it is recommended to avoid cognitively demanding activities 2 h before training and matches.

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References

1. Bangsbo J. Performance in sports - with specific emphasis on the effect of intensified training. Scand J Med Sci Sport. 2015;25(4):88-99. Doi: doi
2. Gallahue DL. Classifying movement skills: a case for multidimensional models. J Phys Educ 2002;13(2):105-11.
3. Diamond A. Executive functions. Annu Rev Psychol. 2013;64(1):135-68. doi
4. Afonso J, Garganta J, Mesquita I. Decision-making in sports: the role of attention, anticipation and memory. Rev Bras Cineantropometria e Desempenho Hum. 2012;14:592-601. doi
5. Marcora SM, Staiano W, Manning V. Mental fatigue impairs physical performance in humans. J Appl Physiol. 2009;106 (3):857-64. doi
6. Smith MR, Thompson C, Marcora, SM, Skorski S, Meyer T, Coutts AJ. Mental fatigue and soccer: current knowledge and future directions. Sport Med. 2018;48(7):1525-32. doi
7. Fortes LS, Lima-Junior D, Nascimento-Júnior JRA, Costa EC, Matta MO, Ferreira MEC. Effect of exposure time to smartphone apps on passing decision-making in male soccer athletes. Psychol Sport Exerc. 2019;44(1):35-41. doi
8. Fortes LS, Lima-Junior D, Fiorese L, Nascimento-Júnior JRA, Mortatti AL, Ferreira MEC. The effect of smartphones and playing video games on decision-making in soccer players: a crossover and randomised study. J Sports Sci. 2020;38(5):552-8. doi
9. Le Mansec Y, Pageaux B, Nordez A, Dorel S, Jubeau M. Mental fatigue alters the speed and the accuracy of the ball in table tennis. J Sports Sci. 2018;36(23):2751-9. doi
10. Gantois P, Ferreira MEC, Lima-Junior D, Nakamura FY, Batista GR, Fonseca FS, et al. Effects of mental fatigue on passing decision-making performance in professional soccer athletes. Eur J Sport Sci. 2019;20(4):534-43. doi
11. Thompson CJ, Noon M, Towlson C, Perry J, Coutts AJ, Harper LD, et al. Understanding the presence of mental fati-

gue in English academy soccer players. J Sports Sci. 2020;38(13):1524-30. doi
12. Dunwiddie TV, Masino SA. The role and regulation of adenosine in central nervous system. Annu Rev Pharmacol Toxicol. 2001;41(1):145-74. doi
13. Bonora M, Patergnani S, Rimessi A, Marchi E, Suski JM, Bononi A, et al. ATP synthesis and storage. Purinergic Signal. 2012;8(3):343-57. doi
14. McAllister MS, Krizanac-Bengez L, Macchia F, Naftalin RJ, Pedley KC, Mayberg MR, et al. Mechanisms of glucose transport at the blood-brain barrier: an in vitro study. Brain Res. 2001;904(1):20-30. doi
15. Dienel GA, Hertz L. Glucose and lactate metabolism during brain activation. J Neurosci Res. 2001;66(5):824-38. doi
16. Chen L, Schär M, Chan KWY, Huang J, Wei Z, Lu H, et al. In vivo imaging of phosphocreatine with artificial neural networks. Nat Commun. 2020;11(1):1-10. doi
17. Martin K, Meeusen R, Thompson KG, Keegan R, Rattray B. Mental fatigue impairs endurance performance: a physiological explanation. Sport Med. 2018;48(9):2041-51. doi
18. Nieber K, Eschke D, Brand A. Brain hypoxia: effects of ATP and adenosine. In: Illes P, Zimmermann H. Nucleotides and their receptors in the nervous system. Elsevier Science, Amsterdam; 1999. doi
19. Porkka-Heiskanen T. Adenosine in sleep and wakefulness. Ann Med. 1999;31(2):125-9. doi
20. Tran Y, Craig A, Craig R, Chai R, Nguyen H. The influence of mental fatigue on brain activity: evidence from a systematic review with meta-analyses. Psychophysiology. 2020;57(5):1-17. doi
21. Herrmann CS, Strüber D, Helfrich RF, Engel AK. EEG oscillations: from correlation to causality. Int J Psychophysiol. 2016;103(1):12-21.
22. Smith MR, Coutts AJ, Merlini M, Deprez D, Lenoir M, Marcora SM. Mental fatigue impairs soccer-specific physical and technical performance. Med Sci Sports Exerc. 2015;48(2):267-76. doi
23. Smirmaul BPC, Dantas JL, Nakamura FY, Pereira G. The psychobiological model: a new explanation to intensity regulation and (in)tolerance in endurance exercise. Rev Bras Educ Física e Esporte. 2013;27(2):333-40. doi
24. Trecroci A, Duca M, Cavaggioni L, Rossi A, Scurati R, Longo S, et al. Relationship between cognitive functions and sport-specific physical performance in youth volleyball players. Brain Sci. 2021;11(2):227. doi
25. Verburgh L, Scherder EJA, Van Lange PAM, Oosterlaan, J. Executive functioning in highly talented soccer players. PLoS One. 2014;9(3):e91254. doi
26. Van Cutsem J, Marcora SM, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. Sport Med. 2017;47 (8):1569-88. doi
27. Cao S, Geok SK, Roslan S, Sun H, Lam SK, Qian S. Mental fatigue and basketball performance: a systematic review. Front Psychol. 2022;12(1):819081. doi
28. Grgic J, Mikulic I, Mikulic P. Negative effects of mental fatigue on performance in the yo-yo test, loughborough soccer passing and shooting tests: a meta-analysis. J Funct Morphol Kinesiol. 2022;7(1):10. doi
29. Baethge C, Goldbeck-Wood S, Mertens S. SANRA - a scale for the quality assessment of narrative review articles. Res Integr Peer Rev. 2019;4(1):5. doi
30. Hughes MD, Bartlett RM. The use of performance indicators in performance analysis. J Sports Sci. 2002;20(10):739-54.
31. Penna EM, Filho E, Campos BT, Pires DA, Nakamura FY, Mendes TT, et al. Mental fatigue does not affect heart rate recovery but impairs performance in handball players. Rev Bras Med do Esporte. 2018;24(5):347-51. doi
32. Veness D, Patterson SD, Jeffries O, Waldron, M. The effects of mental fatigue on cricket-relevant performance among elite players. J Sports Sci. 2017;35(24):2461-67. doi
33. Filipas L, Borghi S, La Torre A, Smith, MR. Effects of mental fatigue on soccer-specific performance in young players. Sci Med Footb. 2021;5(2):150-7. doi
34. Smith MR, Marcora SM, Coutts AJ. Mental fatigue impairs intermittent running performance. Med Sci Sports Exerc. 2015;47(8):1682-90. doi
35. Badin OO, Smith MR, Conte D, Coutts AJ. Mental fatigue: impairment of technical performance in small-sided soccer games. Int J Sports Physiol Perform. 2016;11(8):1100-05. doi
36. Coutinho D, Gonçalves B, Travassos B, Wong DP, Coutts AJ, Sampaio JE. Mental fatigue and spatial references impair soccer players' physical and tactical performances. Front Psychol. 2017;8(1):1645. doi
37. Kunrath CA, Nakamura FY, Roca A, Tessitore A, Costa ITC. How does mental fatigue affect soccer performance during small-sided games? A cognitive, tactical and physical approach. J Sports Sci. 2020;38(15):1818-28. doi
38. Moreira A, Aoki MS, Franchini E, Machado DGS, Paludo AC, Okano A. Mental fatigue impairs technical performance and alters neuroendocrine and autonomic responses in elite young basketball players. Physiol Behav. 2018;196 (1):112-8. doi
39. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A new approach to monitoring exercise training. J Strength Cond Res. 2001;15(1):109-15.
40. Kosack MH, Staiano W, Folino R, Hansen MB, Lønbro S. The acute effect of mental fatigue on badminton performance in elite players. Int J Sports Physiol Perform. 2020;15(5):632-8. doi
41. Kaya A. Decision making by coaches and athletes in sport. Procedia - Soc Behav Sci. 2014;152(1):333-8. doi
42. Teoldo I, Manuel J, Greco PJ, Mesquita, I. Tactical principles of soccer game: concepts and application. Motriz: J Phys Edu. 2009;15(3):657-68.
43. Van Cutsem J, De Pauw K, Vandervaeren C, Marcora S, Meeusen R, Roelands B. Mental fatigue impairs visuomotor response time in badminton players and controls. Psychol Sport Exerc. 2019;45(1):101579. doi
44. Habay J, Proost M, De Wachter J, Díaz-García J, De Pauw K, Meeusen R, et al. Mental fatigue-associated decrease in table tennis performance: is there an electrophysiological signature? Int J Environ Res Public Health. 2021;18 (24):12906. doi

45. Smith MR, Zeuwts L, Lenoir M, Hens N, De Jong LMS, Coutts AJ. Mental fatigue impairs soccer-specific decision-making skill. J Sports Sci 2016;34(14):1297-304. doi
46. Andrade MOC, Costa VT, García-Calvo T, Figueiredo A, Figueiredo A, Teoldo I. Peripheral perception as discriminant factor of tactical behaviour efficiency of young soccer players. Int J Sport Exerc Psychol. 2021;19(6):1034-45. doi
47. Fortes LS, Lima-Junior D, Barbosa BT, Faro HKC, Ferreira MEC, Almeida SS. Effect of mental fatigue on decision-making skill and visual search behaviour in basketball players: an experimental and randomised study. Int J Sport Exerc Psychol. 2022;21(1)1-20. doi
48. Hülsdünker T, Strüder HK, Mierau A. The athletes' visuomotor system-cortical processes contributing to faster visuomotor reactions. Eur J Sport Sci. 2018;18(7):955-64. doi
49. Arain M, Haque M, Johal L, Mathur P, Nel W, Rais A, et al. Maturation of the adolescent brain. Neuropsychiatr Dis Treat. 2013;9(1):449-61. doi
50. Filipas L, Gallo G, Pollastri L, La Torre A. Mental fatigue impairs time trial performance in sub-elite under 23 cyclists. PLoS One. 2019;14(6): e0218405. doi
51. Kunrath CA, Cardoso F, Nakamura FY, Teoldo I. Mental fatigue as a conditioner of the tactical and physical response in soccer players: a pilot study. Hum Mov. 2018;19(3):16-22. doi
52. Balser N, Lorey B, Pilgramm S, Naumann T, Kindermann S, Stark R, et al. The influence of expertise on brain activation of the action observation network during anticipation of tennis and volleyball serves. Front Hum Neurosci. 2014;8 (1):568. doi
53. Ishii A, Tanaka M, Watanabe Y. Neural mechanisms of mental fatigue. Rev Neurosci. 2014;25(4):469-79. doi
54. Adams N, Little TD, Ryan RM. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. Am Psychol. 2000;55(1):68-78. doi
55. Gianmarco C, Antonio T, Mauro M, Harald, T. A video-based tactical task does not elicit mental fatigue and does not impair soccer performance in a subsequent small-sided game. Sports. 2022;10(3):31. doi
56. Smith MR, Chai R, Nguyen HT, Marcora SM, Coutts AJ. Comparing the effects of three cognitive tasks on indicators of mental fatigue. J Psychol Interdiscip Appl. 2019;153 (8):759-83. doi
57. O'Keeffe K, Hodder S, Lloyd A. A comparison of methods used for inducing mental fatigue in performance research: individualised, dual-task and short duration cognitive tests are most effective. Ergonomics. 2020;63(1):1-12. doi
58. Tanaka M, Ishii A, Watanabesaaki Y. Effects of mental fatigue on brain activity and cognitive performance: a magnetoencephalography study. Anat Physiol. 2015;5:S4. doi
59. Franco-Alvarenga PE, Brietzke C, Canestri R, Goethel MF, Hettinga F, Santos TM, et al. Caffeine improved cycling trial performance in mentally fatigued cyclists, regardless of alterations in prefrontal cortex activation. Physiol Behav. 2019;204(1):41-8. doi
60. Coutinho D, Gonçalves B, Wong DP, Travassos B, Coutts AJ, Sampaio J. Exploring the effects of mental and muscular fatigue in soccer players' performance. Hum Mov Sci. 2018;58(1):287-96. doi

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