MENTAL FATIGUE IN SOCCER: A SYSTEMATIC REVIEW

FADIGA MENTAL NO FUTEBOL: UMA REVISÃO SISTEMÁTICA

FATIGA MENTAL EN EL FÚTBOL: UNA REVISIÓN SISTEMÁTICA

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ABSTRACT

Fatigue in soccer players is traditionally investigated based on neuromuscular and metabolic factors. However, given that soccer is one of the sports that has the highest cognitive demand, it is believed that players' performance might also be influenced by the high levels of attention, and frequent decision-making required in soccer. This systematic review aimed to verify the effects of mental fatigue on physical, technical, tactical and cognitive performance of soccer players. We searched in the electronic databases Pubmed, Web of Science and Scopus, for articles published up to 30 April 2018. We included articles that used a protocol of mental fatigue through cognitive tasks performed prior to a physical or cognitive task related to soccer. Only studies that presented an experimental design with the control condition (without mental fatigue) and the experimental condition (with mental fatigue) were selected. A total of six articles met the inclusion criteria, one study by backward reference search and other through the authors' indication. The results showed smaller distances covered in physical tests, while the effects of mental fatigue on physical performance in small-sided games were not clear. In technical tests, there were more penalties in passes and less accuracy and speed when kicking the ball when players were in conditions of mental fatigue. Regarding the tactical variables, it was found that mental fatigue had a detrimental effect on the synchronization between team players and on individual tactical performance in defensive actions. In cognitive tests, based on video recordings of game play, negative effects on the players' speed and accuracy of decision-making were observed. According to the results of the literature search, it can be inferred that mental fatigue is a factor that has a negative influence on soccer performance. ***Level of evidence II; Systematic review.***

Keywords: Mental fatigue; Psychology, sports; Athletic performance; Soccer.

RESUMO

No futebol, a fadiga é tradicionalmente investigada sob uma perspectiva neuromuscular e metabólica. Entretanto, já que o futebol é uma das modalidades esportivas com maior demanda cognitiva, acredita-se que a exigência de elevados níveis atencionais e as frequentes tomadas de decisões sejam fatores que influenciem o desempenho dos jogadores de futebol. Sendo assim, o objetivo do presente estudo foi verificar, através de uma revisão sistemática, os efeitos da fadiga mental sobre o desempenho físico, técnico, tático e cognitivo dos jogadores de futebol. Foram realizadas buscas nas bases de dados eletrônicas Pubmed, Web of Science e Scopus até 30 de abril de 2018. Incluíram-se artigos que utilizaram um protocolo de fadiga mental através das tarefas cognitivas realizadas previamente a uma tarefa física ou cognitiva relacionada ao futebol. Somente foram selecionados estudos que apresentaram um desenho experimental com a condição controle (sem fadiga mental) e experimental (com fadiga mental). No total, foram selecionados seis estudos que atenderam aos critérios estabelecidos, um estudo por busca reversa e outro por indicação dos autores. Os resultados indicaram menores distâncias percorridas em testes físicos, enquanto que os efeitos da fadiga mental sobre o desempenho físico em jogos reduzidos não foram evidentes. Em testes técnicos, houve maior número de penalizações em passes e menor precisão e velocidade da bola nos chutes na condição de fadiga mental. Em relação às variáveis táticas, foram encontrados efeitos prejudiciais da fadiga mental sobre a sincronização entre os jogadores das equipes e o desempenho tático individual em ações defensivas. Em testes cognitivos, também foram verificados efeitos negativos sobre o tempo e a precisão para a tomada de decisão dos jogadores em testes de vídeo. A partir dos resultados dos estudos analisados, torna-se possível inferir que a fadiga mental é um fator que influencia negativamente o desempenho dos jogadores de futebol. ***Nível de evidência II; Revisão sistemática.***

Descritores: *Fadiga mental; Psicologia do esporte; Desempenho atlético; Futebol.*

RESUMEN

En el fútbol, la fatiga es tradicionalmente investigada desde una perspectiva neuromuscular y metabólica. Entretanto, ya que el f'útbol es una de las modalidades deportivas con mayor demanda cognitiva, se cree que la exigencia de elevados niveles de atención y las frecuentes tomas de decisión sean factores que influencien el desempeño de los jugadores de fútbol. Siendo así, el objetivo del presente estudio fue verificar, a través de una revisión sistemática, los efectos de la fatiga mental sobre el desempeño físico, técnico, táctico y cognitivo de los jugadores de fútbol. Fueron realizadas búsquedas en las bases de datos electrónicas Pubmed, Web of Science y Scopus hasta 30 de abril de 2018. Se incluyeron artículos que utilizaron un protocolo de fatiga mental a través de las tareas cognitivas realizadas previamente a una tarea física o cognitiva relacionada al fútbol. Solamente fueron seleccionados estudios que presentaron un diseño experimental con la

condición control (sin fatiga mental) y experimental (con fatiga mental). En total, fueron seleccionados seis estudios que atendieron los criterios establecidos, un estudio por búsqueda reversa y otro por indicación de los autores. Los resultados indicaron menores distancias recorridas en tests físicos, mientras que los efectos de la fatiga mental sobre el desempeño físico en partidos reducidos no fueron evidentes. En tests técnicos, hubo mayor número de penalizaciones en pases y menor precisión y velocidad de la pelota en los tiros en la condición de fatiga mental. Con relación a las variables tácticas, fueron encontrados efectos perjudiciales de la fatiga mental sobre la sincronización entre los jugadores de los equipos y el desempeño táctico individual en acciones defensivas. En tests cognitivos, también fueron verificados efectos negativos sobre el tiempo y la precisión para la toma de decisión de los jugadores en tests de vídeo. A partir de los resultados de los estudios analizados, se hace posible inferir que la fatiga mental es un factor que influencia negativamente el desempeño de los jugadores de fútbol. ***Nivel de evidencia II; Revisión sistemática.***

Descriptores: *Fatiga mental; Psicología del deporte; Rendimiento atlético; Fútbol.*

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INTRODUCTION

Mental fatigue is conceptualized as a psychobiological state characterized by feeling of "tiredness" and "lack of energy" caused by prolonged period of cognitive activity.[1,2] The most recent research aimed at understanding the mental fatigue phenomenon has found negative effects on physical performance in endurance exercises and sports-specific tasks.[3-8] Although mental fatigue is a current research topic, the first research into mental fatigue effects on physical performance dates from the late 19th and early 20th centuries.[9,10] In 1891, a physiologist named Angelo Mosso has conducted an investigation that observed a poor strength performance in teachers after performing hours of intellectual work.[10,11]

In fatigue research, the classic model "cardiovascular-catastrophic" associates fatigue mainly to the failure of the cardiovascular system to supply oxygen demands in exercise, the accumulation of lactate and, consequently, the inability to generate voluntary muscle contraction.[12] The "cardiovascular/catastrophic" model predicts that as fatigue increases during exercise, the central nervous system recruits additional muscle fibers, ensuring mechanical work rate. Gradually, this process continue until the available motor units in the muscles were recruited, reaching a point where the work rate would fal, and fatigue would be manifested. However, research has been showed only factors associated with the capacity to generate muscle contraction would not determine the regulation of physical performance and exercise tolerance.[13,14] For instance, research have shown that approximately 35% to 50% of muscle fibers are recruited in sustained muscle work, and under maximal conditions, up to 60%. Additionally, there are evidence that physical performance is determined not only by muscle contraction capacity, but the willingness to carry out a maximum effort (motivation) and how the physical task is perceived (perceived exertion).[15-17]

In soccer, fatigue has traditionally been investigated under a neuromuscular and metabolic approach.[19] Scientists have associated fatigue with a lower frequency of movement such as acceleration and sprinting,[20,21] poor passing and shooting quality,[22] and a higher incidence of goals in the ended of match.[23,24] However, these facts are considered consequences restricted to muscle fatigue, and little attention has been given to the psychological and cognitive aspects related to the soccer players performance.[25]

Soccer performance is directly linked to players' ability to direct attention to environmental information and integrate it into existing knowledge in order to select and execute appropriate responses.[26] During a soccer game, the cognitive requirement to maintain high attention levels, anticipate actions of opponents and make decisions in restricted space and time, combined with a constant situation of environmental pressure (e.g. game situations, opponents, fans, etc.) induces players to experience a mental effort.[27,28] Also, there are emotional, affective, and motivational consequences marked by rewards and losses in high-level of performance.[29] In this sense, research has shown that mental effort prior[30] to or simultaneous[31] to a physical task, as well as stress and anxiety[32] cause changes in soccer performance. Thus, considering cognitive and psychological demands of soccer, it is assumed that the cognitive engagement of players to give practical solutions to the game may cause mental fatigue.[33,34]

Regarding to this important research topic, the increasing number of papers about the influence of mental fatigue on performance in exercise and sport can be observed, including systematic reviews.[35,36] However, there is still no systematic review on the effects of mental fatigue in soccer. Therefore, this systematic review aims to verify mental fatigue effects on physical, technical, tactical and cognitive performance in soccer players.

METHODS

A systematic review was conducted according to PRISMA guidelines – Preferred Reporting items for Systematic Reviews and Meta-Analysis[37]. The inclusion criteria followed PICO acronym (Table 1).

Two independent authors separately screened titles and abstracts to identify articles based on inclusion criteria. The selection of articles began reading the titles and abstracts. If needed, the authors did complete reading full-text in order to verify if it met all inclusion criteria. Original papers published only in English language were selected.

Information Sources and Search Process

The databases used to search of papers were Pubmed, Web of Science and Scopus for relevant publication prior April, 2018. Key words used in the searches were (Soccer OR Football) AND ("Mental Fatigue" OR "Cognitive Fatigue" OR "Mental Effort" OR "Cognitive Effort" OR "Mental Exertion"). After this process, it was performed a backward research through references of selected articles in this review. Altogether, 89 articles were screened through databases. After the selection process, six articles were included in this review. All the selection process can be observed in Figure 1.[37]

Initially there was founded 89 articles in databases. All duplicates articles were removed, and the screening it was carry out by title reading and abstract, follow by reading of whole the article (Figure 1).

RESULTS

The results of studies are summarized in Table 2.

Cognitive tasks

Four different cognitive tasks were used as a protocol for inducing mental fatigue, the AX-CPT (90 minutes), the Stroop paper[38-41] and computer version (20 – 30 minutes)[42,43], and the motor coordination task

(20 minutes)[44]. In control condition, the subjects read magazines[38-40], watched TV documentaries[30,42], and performed a warm-up lasting the same time as the intervention condition[44].

Subjective ratings

Subjective scales were applied before and after cognitive tasks to verify the effectiveness to induce mental fatigue. Six studies used the Visual Analogue Scale (VAS) to measure the level of mental fatigue, mental effort and motivation[38-42,44]. One study applied the BRUMS questionnaire to evaluate the measures of fatigue and the Matthews, Campbell and Falconer scale[45] for motivation, while one study did not apply any subjective ratings.[43] The Borg Scale – 6 to 20[38] and CR-10[30,41,42,44] were applied to measure perceived exertion in the physical task following the mentally fatiguing cognitive task. It were observed higher mental fatigue levels after cognitive tasks in all studies which subjective ratings were available. In the control condition, just one study reported higher mental fatigue and perceived exertion levels in the post-moment.[44] None of the articles found differences in the motivation index between mental fatigue and control conditions.

Table 1. PICO (Population, intervention, comparison and outcomes).

Component	Detail
Population	Soccer players
Intervention	Mental fatigue protocol
Comparison	Control (without mental fatigue) and experimental group (with mental fatigue)
Outcomes	Physical, technical, tactical and cognitive performance

Physical and physiological performance

Three articles measured physiological variables such as heart rate – HR[30,38,42] lactate concentration [la], glucose and oxygen uptake - VO_2[30]. Among them, only one found a decrease in VO_2 values during the physical task in mental fatigue condition.[30] Six studies measured physical variables[30,38,41-44] using a laboratory protocol[30] and five studies[38,41-44] used a field protocol. In the lab's protocol, Smith et al.[30] verified a decrease in the total distance covered on the treadmill test and shorter distances covered at lower zones of speed. In the field protocols, Smith et al.[38] found a decreased of 16.3% on Yo-Yo Intermittent Recovery Test performance. In other two studies, no clear effects of mental fatigue were identified in small-sided games.[42,44] Coutinho et al.[41] observed shorter total distances covered and Kunrath et al.[43] found higher values of distance covered at speeds between 10 and 12.9 km/h and ≥ 18 km/h.

Technical performance

Regarding technical variables, two studies evaluated the technical performance through the Loughborough Soccer Passing and Shooting Test – LSPT and LSST,[38,40] and small-sided games.[42] In mental fatigue condition, there were more penalties, 38 higher total errors and fewer perfect passes in the LSPT,[40] while lower

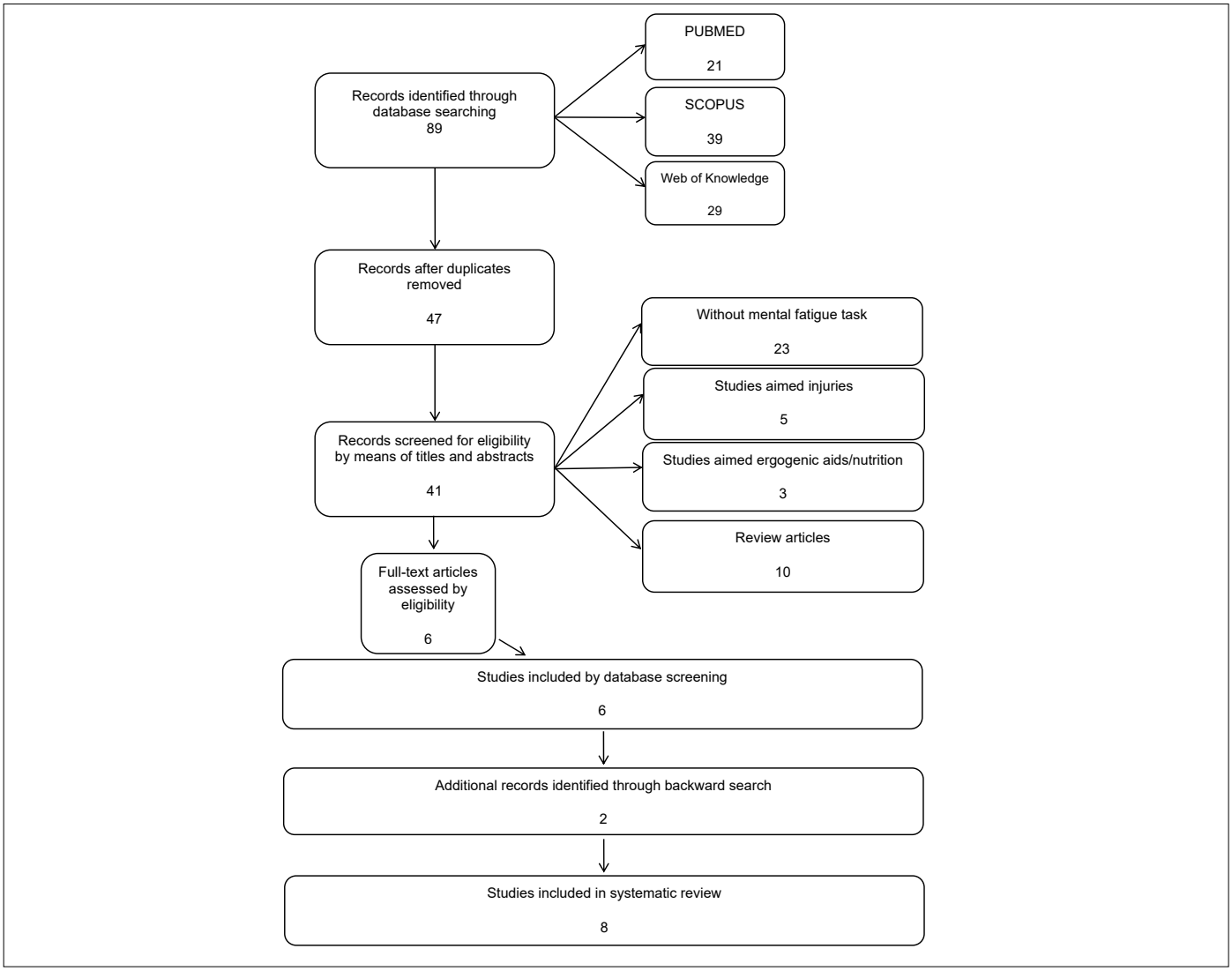

Figure 1. Selection process for research articles included this systematic review

Table 2. Summary of mental fatigue intervention protocols, exercise protocols and main results.

Study	Subject	Mental fatigue task	Control task	Task performance	Results
Smith et al.[30], 2015	Intermittent sports team participants (soccer, rugby league, field hockey) n=10 22 ± 2 years	AX-CPT 90′	Documentary 90′	Self-paced, intermittent running protocol 45′	↔ Blocks RPE ↑ Session RPE ↓ Low-intensity activity ↔ High intensity running ↓ Total distance covered ↔ HR ↔ [BLa] ↔ Blood glucose concentration ↓ Oxygen consumption
Smith et al.[38] (2016Level 1 (Yo-Yo IR1) - study 1	Recreational soccer players n=12 24 ± 0.4 years	Stroop paper version 30′	Reading magazines 30′	Yo-Yo IR1	↑ RPE ↔ HR ↓ Total distance covered
Smith et al.[38] (2016Level 1 (Yo-Yo IR1) - study 2	Soccer players n=14 19.6 ± 3.5 years	Stroop paper version 30′	Reading magazines 30′	LSST and LSPT	LSPT ↔ Original time ↔ Performance time ↑ Penalty time LSST ↓ Shot accuracy ↓ Shot speed ↔ Shot sequence time
Smith et al.[39] (2016)	Soccer players n=12 19.3 ± 1.5 years	Stroop paper version 30′	Reading magazines 30′	Soccer-specific decision-making task	↑ RPE ↓ Overall response accuracy ↑ Response time ↔ Visual search (fixations/s and fixation duration)
Smith et al.[40] (2017)	Soccer players n=14 19.6 ± 3.5 years	Stroop paper version 30′	Reading magazines 30′	LSPT	↑ RPE ↑ Errors ↓ Perfect passes ↔ Time test ↔ Performance speed
Coutinho et al.[41] (2018)	Amateurs youth soccer players n=10 13.7 ± 0.5 years	Computerized version of Stroop 30′	-	Small-sided game (5 vs 5)	↑ RPE ↓ Total distance covered ↓ Longitudinal synchrony
Badin et al.[42] (2016)	Soccer players n=20 17.8 ± 1.0 years	Computerized version of Stroop 30′	Documentary 30′	Small-sided game (5 vs 5 - without goalkeeper)	↑ RPE during the test ↓ HR ↔ Physical performance ↓ Involvements ↓ Possessions ↓ % Pass accuracy ↓ % Tackle success ↑ Control error
Kunrath et al.[43] (2018)	Amateurs youth soccer players n=6 14.7 ± 0.59 years	Computerized version of Stroop 20′	-	FUT-SAT	↑ Distance covered (10 - 12,9 km/h) ↑ Distance covered (≥ 18 km/h) ↓ Balance ↓ Defensive unity
Coutinho et al.[44] (2017)	Highly trained amateur youth soccer players n=12 15.9 ± 0.8 years	Motor coordination task 20′	Light general aerobic exercises 20′	Small-sided game (6 vs 6)	↑ RPE ↓ Lateral synchronization ↓ Dispersion speed ↓ Contraction speed

accuracy and speed shot in the LSST.[38] Also, there were decreases in the technical involvement actions quality and ball possessions, as well as a greater number of technical errors that resulted in loss ball possession.[42]

Tactical and cognitive performance

Regarding cognitive performance, one study found that mentally fatigued players needed more time to make decisions and less accurate decision-making.[39] About tactical performance, Coutinho et al.[44] found lower lateral synchronization, longitudinal synchronization and team contraction speed, while in the other study, the authors found lower values only for longitudinal synchronization.[41] For individual tactical performance, Kunrath et al.[43] found impairments of tactical actions quality related to the fundamental tactical principles of balance and defensive unity.

DISCUSSION

The aim of this systematic review was to verify the influence of mental fatigue on soccer players' performance. As a whole, the studies included in this review suggested that mental fatigue causes changes and detrimental effects on physical, technical, tactical and cognitive soccer players' performance.

Methodological aspects of studies

In this review, the experimental design and data collection procedures similarities are facilitators to understanding the investigated phenomenon. For instance, Stroop task and AX-CPT were used in order to induce mental fatigue. These cognitive tests require attention and automatic response inhibition, and are tasks that potentially induce mental fatigue when employed over extended periods.[2,46] Regarding to the cognitive test duration, the cut-off point established was ≥ 20 minutes. The cut-off point was set at 20 min based on the vigilance decrement that typically starded after 20 of continuous work[47] on the tasks used to induce mental fatigue.

Stroop and AX-CPT are not soccer-specific tasks. However, the tests required important cognitive skills to achieve high levels of performance as selective and sustained attention, and inhibitory control. In soccer, the selective and sustained attention enables active processing of information from the enormous amount of information available in soccer game (or environment).[48] Given the information available at the soccer game, the ability of players to inhibit automatic responses, actions or initiated behaviors judged inadequate or competing distracting stimuli that may compromise performance is considered.[49] Mental fatigue can be manifest subjectively, behaviorally, and physiologically. We have observed there was little information of

behavior (i.g. error rate, reaction time) and physiological responses (i.g. brain activity, pupil behavior) in cognitive tasks as a Stroop and AX-CPT. This is an important topic of research, and it can be considered in future studies. On the other hand, researchers have also suggested specific-tasks to induce mental fatigue, as proposed by Coutinho et al.[44] through activity of agility ladder drills while juggling a tennis ball to increase attentional demands. Although it is a motor task, the underrepresentation in soccer[28] and the limited possibility of control should be considered.

The Visual Analogue Scale (VAS) was applied to measure mental fatigue, mental effort, and motivation. The Borg Scale (RPE and CR-10) was applied to measure physycal level perception. Only Smith, Marcora and Coutts' study[30] used cognitive performance indicator to identify mental fatigue. The authors' found the number of incorrect responses during the final 15 min of the AX-CPT was higher compared to the first 15 min. Regarding the interval between the control and experimental intervention, the researchers respected a period of two to seven days for data collection. In relation to the methods adopted in this studies, Smith, Marcora and Coutts[30] justify that investigating the effects of mental fatigue during a soccer game would not be practical because its effects could influence game's outcome. Moreover, the environment would not provide controlled conditions necessary to accurately assess the physiological and psychological mechanisms underlying the mental fatigue effects.[30] However, the advances in research and the evidence of the effects of mental fatigue on physical performance[2,30,50] and sports performance[3,6,38] allowed them to be adopted experimental protocols more practical applicability.

Physical tests and small-sided games were used to verify mental fatigue effects on physical performance. In the physical tests, the players underwent an intermittent self-regulated treadmill protocol[30] and the Yo-Yo Test.[38] Both aforementioned studies[30,38] showed negative effects of mental fatigue on physical performance. Research results' showed a decreasing in total distance covered and lower average speed in ranges of lower speeds, such as walking and running at low intensity. It is noteworthy that, although no higher values of physiological indicators of glucose, [la], VO_2 and HR[30,38] were found, higher levels of perceived exertion were observed during the test and at the time of disengagement in the physical task.

Interpretations for aforementioned studies are basically centered on the psychobiological model.[2] The psychobiological model is an effort-based decision-making model[51] where it is assumed that conscious regulation (decision-making) of the exercise pace is determined by motivation and, above all, by the perception of effort. In this sense, it is postulated that prolonged cognitive activity could lead to an increase in extracellular adenosine concentration in the brain, including the anterior cingulate cortex.[52] In turn, the adenosine accumulation in the anterior cingulate cortex would be related to the increased conscious sensation of exertion perception, which consequently would influence the regulation of physical performance and exercise tolerance.[53] These assumptions are distinct from those traditionally prioritized by exercise physiology, in which fatigue is understood as a process entirely of neuromuscular and metabolic origin, associated with a physiological marker.[12,14,54]

Although impairment in physical testing performance is observed in the above studies, the small-sided games characteristic changed the results of them.[41-44] Two studies showed results indicating an increase in the number of physical actions, repeated sprints[42] and distance covered at speeds ranging from 10 to 12.9 km/h and above ≥ 18 km/h.[43] Two other studies showed opposite results to the above.[41,44] These findings seem to occur because small-sided games features allows players greater freedom to adjust their efforts and modify the pace of play,[42] as players are not required to exercise their maximum tolerance. Although there is a trend for higher perceived exertion indices in subjective responses,[42,44] the assumptions of the psychobiological model do not seem to fully meet the specificity of the soccer game. Apart from high physical demands of soccer, cognitive factors are also pivotal to achieve high performance levels. For instance, decision-making situations are based on problems about field occupation and play space management[55] rather than effort, as considered by psychobiological model.[51]

Technical performance

Regarding technical performance, two studies assessed mental fatigue effects on passing and shooting through the LSPT and LSST.[38,40] In the LSPT, players were required to make 16 passes as fast as possible, against standard benches around themselves, and with each mistake made, players were penalized with increased time (s) in the task. There were a higher number of penalties for errors, fewer perfect passes and higher errors in targets[38,40] when mentally fatigued. In the LSST, players should perform moves such as accelerations, changes of direction, ball control and shooting the ball at goal. Mental fatigue also impaired shot speed and accuracy.[38,40] In small-sided games**,** Badin et al.[42] verified a decrease in the quality of the technical actions of involvements (sum of the technical actions), possessions (passes received, intercepted and tackles) and in tackles. According to Smith et al.[38] technical performance was impaired because mentally fatigued players suffer a reduction in the amount of attention allocated to the task. In time-constrained environment, it is possible for players to prioritize the execution of technical actions over their quality.[40] In this sense, attention theories of central resources suggest that, when simultaneous activities compete for attention, it is ensured that attention is directed to the completion of the main task.[56]

Cognitive and tactical performance

Regarding cognitive performance, Smith et al.[39] observed negative effects of mental fatigue on timing and accuracy of players' decision making through video tests. Possibly, the impairment of cognitive skills, such as decreasing attentional levels[57] and the efficiency of information processing[58] has influenced players' decision-making.[39] Also, Smith et al. showed minimal impacts of mental fatigue on players' visual search. Despite having negative effects on time and accuracy to make decisions, mental fatigue had little influence on the visual search for information. Although players sought information in similar places on the environment (player with the ball, ball, opponents, free space), the players had reduced ability to identify and usage information. In order to cope with the complexity of the soccer game and achieve high performance levels, it is well-known that players must have well-developed cognitive skills to identify and select the relevant stimuli available in the environment, anticipate opponents' actions and make appropriate decisions game constraints.[59,60] At this point, once the importance of cognitive skills for soccer performance is established, the effects of mental fatigue are expected to be enhanced in the tactical dimension.

As for tactical performance, with purpose investigating mental fatigue effects on teams collective behavior, Coutinho et al observed a decreased in time spent lateral synchronization and team contraction speed in small-sided games. In Coutinho's study[44], the research team further investigated a variation using additional reference lines (vertical and horizontal) in the field to verify if additional information could change collective behavior teams. With addition reference lines, mentally fatigued players spent less time synchronized horizontally. In another study, Coutinho et al.[41] aimed muscular and mental fatigue effects on soccer players performance. The authors' found that mentally fatigued

players spent less time longitudinal synchronization between players in the team. Indeed, both Coutinho's studies[41,44] presented detrimental effects of mental fatigue on the collective behavior of teams. In this sense, it can be infer that detrimental effects of mental fatigue on players' capacity to perceive and sustain their decisions based on environment available information have influenced teams' synchronization. However, both Coutinho's study results not necessarily should be interpretated as indicators of tactical performance, but as a collective tactical behavior. Therefore, the indicators measured in Coutinho's studies,[41,44] such as time spent longitudinal and lateral synchronization and team contraction velocity does not consider the result of tactical actions. For instance, the degree of synchronization presented between players on a team should not necessarily result in offensive situations that pose a danger to the opposing goal, or in defensive situations with the highest defensive protection.

In relation to the tactical performance, Kunrath et al.[43] found results showing mental fatigue impairments in actions related to the balance and defensive unity tactical principles. In soccer, this results showed that prolonged mental exertion impaired defensive actions which aimed offer safety to players involved actions inside the centre of play, levaving spaces uncovered and free passing lanes. Also, mental fatigue caused effects in actions that aimed to provide the necessary organization so defensive players press the opposing team, allowing bigger spaces for the opposing players' offensive organization. In addition, the higher distance covered after prolonged mental exertion found in this study were interpreted as a players' strategy, being a possible physical compensation to the detriment of decreased tactical performance.

Further investigations are suggested in order to understand the relationship between mental fatigue and tactical dimension. As mentioned earlier, despite studies by Coutinho et al.[41,44] consider tactical synchronization variables, they do not represent performance indicators. Moreover, the interactions between tactical behavior and physical performance in field testing demonstrated in the pilot study by Kunrath et al.[43] are subject to further investigation. Therefore, it is possible that the effects of mental fatigue on cognitive variables, tactical and physical in single study can provide new information on this subject.

Future investigations may also benefit from investing in mechanisms that underpin mental fatigue on the soccer players performance. Although recent conceptual model proposed by Smith et al.[28] clarifies a potential mechanistic pathway for the impact of mental fatigue on soccer performance, studies that prioritize controlling behavioral and physiological responses in cognitive tests are needed. In this sense, behavioral and physiological monitoring responses of cognitive tests will allow observing indicators of motivation, cognitive effort and players capacity to support high cognitive load. Controlling behavioral responses through errors and reaction time throughout cognitive testing, EEG or pupilometry usage to analyze physiological responses may be useful methods for investigation in this area. These instruments can provide information that identifies cognitive efficient players by supporting high levels of cognitive load during prolonged periods of activity. Considering the characteristics of the soccer game, it is believed that investigating the mechanisms underlying mental fatigue related to the tactical dimension is a fertile field of investigation.

CONCLUSION

In soccer, mental fatigue has been an area of growing interest among researchers. The studies selected for this review have similar experimental designs, analyzing the performance of players in control (without mental fatigue) and experimental (with mental fatigue) conditions, facilitating the comparison between the results. With the results obtained so far, it seems reasonable to infer that mental fatigue is a factor that negatively influences the physical, technical, tactical and cognitive performance of soccer players.

Since 2015, there has been a methodological advances in soccer mental fatigue research. Initially, researchers investigated the effects of mental fatigue on performance through treadmill running protocols, followed by physical/technical testing, small-sided games with adapted rules and, more recently, small-sided games with official rules. Currently, main limitations of this topic are still methodological. In this sense, it seems coherent to neglect the use of cognitive tasks with strict control of subjective, behavioral and physiological responses. In addition, proposals for cognitive/motor tasks that aim to induce mental fatigue and have greater applicability in training are also encouraged.

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