THE EFFECT OF MENTAL FATIGUE ON PERFORMANCE IN ENDURANCE TASKS: A SYSTEMATIC REVIEW

EFECTO DE LA FATIGA MENTAL SOBRE EL RENDIMIENTO EN TAREAS DE RESISTENCIA: UNA REVISIÓN SISTEMÁTICA

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Abstract

Mental fatigue affects not only cognitive performance, but also physical performance. The main objective of this study was to review the existing literature on the influence of mental fatigue on the ability to withstand sustained physical efforts (endurance tasks). For this purpose, we performed a systematic literature review in the online databases Web Of Science, PubMed and Scopus with the following search terms and Boolean conjunctions: *mental fatigue* or *cognitive fatigue* and *exercise* or *endurance* and *time to exhaustion* or *time trial* or *running* or *cycling*. A total of 28 articles, comprising 29 interventions, were included with a high methodological quality (range: 6-8 points out of 10 possible) measured using the PEDro scale. A total of 86% of the included interventions show that mental fatigue reduces performance in the endurance tests compared to a control condition without mental fatigue. In addition, mental fatigue increases the subjective perception of effort, without altering heart rate or blood lactate concentration. Therefore, the results show the importance of avoiding any activity that involves high cognitive demands prior to training or competition events, due to the detrimental effects on endurance capacity.

Keywords: Cognitive fatigue, physical performance, endurance, time to exhaustion, time trial, running, cycling.

Resumen

La fatiga mental puede afectar, no solo al rendimiento cognitivo, sino también al rendimiento físico. Por ello, el objetivo principal del presente estudio fue revisar la literatura existente acerca de la influencia de la fatiga mental sobre la capacidad para soportar esfuerzos físicos mantenidos (tareas de resistencia). Para ello se llevó a cabo una búsqueda sistemática en la literatura existente en las bases de datos online Web Of Science, PubMed y Scopus con la siguiente estrategia de búsqueda: *mental fatigue* o *cognitive fatigue* y *exercise* o *endurance* y *time to exhaustion* o *time trial* o *running* o *cycling*. Se incluyeron un total de 28 artículos, que comprendían 29 intervenciones con una calidad metodológica alta (rango 6-8 puntos de 10 posibles) medida mediante la escala PEDro. Un 86% de las intervenciones analizadas muestran que la fatiga mental reduce el rendimiento en la prueba de resistencia utilizada en comparación con una condición control sin fatiga mental. Además, la fatiga mental incrementa la percepción subjetiva del esfuerzo, sin alterar la frecuencia cardiaca o la concentración de lactato sanguíneo. Por tanto, los resultados obtenidos destacan la importancia de evitar cualquier actividad que implique demandas cognitivas previas a las sesiones de entrenamiento o competiciones deportivas, debido a los efectos perjudiciales sobre el rendimiento en tareas de resistencia.

Palabras clave: Fatiga cognitiva, rendimiento físico, tareas de tiempo hasta la extenuación, contrarreloj, carrera, ciclismo.

Introduction

Mental fatigue is defined as a psychobiological state that can arise during or after cognitive activities. Increased fatigue rates influence the cognitive ability to act during prolonged periods of demanding physical exertion. It is characterized by a feeling of tiredness, decreased commitment, and therefore a greater aversion to continuing with the current activity (Van Cutsem et al., 2017). In other words, mental fatigue goes beyond cognition, as it also involves a significant emotional and motivational component (Van Cutsem et al., 2017). Although the total time spent on a demanding cognitive task influences the level of fatigue, tasks lasting as little as 30 minutes are capable of producing significant levels of mental fatigue (Boksem & Tops, 2008; MacMahon et al., 2019; Pageaux et al., 2014; Salam et al., 2018). Mental fatigue is different and should not be confused with chronic fatigue and cognitive decline associated with aging or disease. Unlike mental fatigue, in such conditions, subjective feelings of fatigue and cognitive impairment are chronic, and not necessarily related to mental exertion (Smith et al., 2015).

These findings have been corroborated in other studies that also suggest that impairment in physical performance induced by mental fatigue is more pronounced in those tasks that involve large muscle groups during prolonged periods of demanding exercise (> 75 s), such as time-to-exhaustion tasks (MacMahon et al., 2019; Marcora et al., 2009; Salam et al., 2018) or time trials (Filipas et al., 2020; Penna et al., 2018; Pires et al., 2018; Silva-Cavalcante et al., 2018) compared to exercises involving a shorter duration (Martin et al., 2019). However, not all studies corroborate the negative influence of mental fatigue on physical performance in endurance tasks (MacMahon et al., 2019; Martin et al., 2019; Penna et al., 2021). Consequently, more evidence is still required to establish firm conclusions about the possible link between mental fatigue and physical exercise performance (Holgado et al., 2020).

Therefore, the present systematic review aims to determine the effect of mental fatigue on endurance performance in dynamic multi-joint movements involving large muscle masses (e.g. running, cycling or rowing), such as time-to-exhaustion tests or time trials. In addition to analysing their effects on performance in these tasks, their effects on different parameters indicating effort at the cardiovascular (heart rate) and metabolic (blood lactate concentration) level as well as at the perceptual level (subjective perception of effort) will be examined. The initial hypothesis is that mental fatigue derived from a previously performed task will negatively influence performance in subsequent long-term activities, and that this deterioration in performance will be accompanied by higher rates of perceived effort, cardiovascular and metabolic effort.

Method

This review follows the recommendations of the Reference Items for Systematic Reviews and Meta-Analyses: the PRISMA *Preferred Reporting Items for Systematic reviews and Meta-Analyses* statement (Page et al., 2021).

Data Sources and Search Strategies

The search contains all those studies that have been published between 2009 and March 31, 2022 in the online databases Web of Science, PubMed and Scopus. After several combinations of the terms, a definitive search algorithm was selected with the following Boolean connectors: *mental fatigue* or *cognitive fatigue* and *exercise* or *endurance* and *time to exhaustion* or *time trial* or *running* or *cycling.*

Study Selection and Eligibility Criteria

The search strategy described was carried out by two independent authors (IMG and GM), who removed duplicates and analysed the remaining studies to determine if they met the inclusion criteria. This preliminary review consisted of the scrutiny of the titles and abstracts of each of the articles, excluding those that did not meet the criteria to be included. If reading the title or abstract was not sufficient to determine the inclusion of the article in the review, a detailed review of them was carried out, examining its complete version. To determine the inclusion or exclusion of the studies, the PICOS approach (Harris et al., 2014) was followed with the following criteria: (1) Population: Healthy adults who perform both recreational physical activity or any professional sport. (2) Intervention: Cognitive task that induces mental fatigue prior to performing an endurance test lasting ≥ to 30 minutes. (3) Comparator: A control condition in which the task that induces mental fatigue is replaced by another with a low cognitive load (e.g.: watch a documentary). (4) Variables: Performance in whole-body endurance tests with a duration of more than 75s, including time or distance trials, tasks to exhaustion or incremental tests to exhaustion. (5) Study Design: Randomized, controlled, crossover studies. In addition, we excluded systematic reviews and/or meta-analyses, studies using strategies for the reduction of mental and/or physical fatigue that were carried out during the experimental conditions (i.e.: caffeine consumption), studies where tests were carried out under specific temperature conditions of cold and/or heat, and studies in which the participants were not human or were clinically diagnosed for any pathological condition.

Data Extraction and Synthesis

One of the authors (IMG) extracted the following data from the included studies: study information (authors and date of publication), sample characteristics (size, sex, age of the subjects and type of sports practice), specific performance test, type of treatment and duration (experimental test and control condition), and results of both the main variable linked to performance in the task, as well as complementary results linked to physiological and/or perceptual variables.

Regarding the main variable, it was different depending on the type of test used in each study. In a constant load test until exhaustion, the main variable is how long the participant is able to sustain a given effort until exhaustion. In distance time trials, the main variable will also be the time, in this case the time invested in covering a certain distance. However, in time trials, the main variable will be the distance covered in a given time, the pedaling power (in the case of a cycle ergometer or rowing ergometer) or the average speed during the whole test. In intermittent running or cycling tests (e.g. YO-YO IR1), the main variables will be the distance traveled, the time or the intensity determined through the average or maximum speed.

The complementary or secondary variables are physiological variables that complement and support the conclusions of the result of the main variable. In the present systematic review, heart rate, maximal oxygen consumption, blood lactate accumulation, and subjective perception of exertion were included.

Assessment of Study Quality and Risk of Bias

Table 1
Methodological Quality

Article Criteria	1	2	3	4	5	6	7	8	9	10	11	Total score
Marcora et al. (2009)	S	S	N	S	N	N	S	S	S	S	S	**7**
Brownsberger et al. (2013)	S	S	N	S	N	N	N	S	S	S	S	**6**
Macmahon et al. (2014)	S	S	N	S	N	N	N	S	S	S	S	**6**
Pageaux et al. (2014)	S	S	N	S	N	N	N	S	S	S	S	**6**
Smith et al. (2015)	S	S	N	S	S	N	N	S	S	S	S	**6**
Smith et al. (2016)	S	S	N	S	N	N	N	S	S	S	S	**6**
Martin, Staiano et al. (2016)	S	S	N	S	N	N	N	S	S	S	S	**6**
Greco et al. (2017)	S	S	N	S	N	N	N	S	S	S	S	**6**
Veness et al. (2017)	S	S	N	S	S	N	N	S	S	S	S	**7**
Penna et al. (2018)	S	S	N	S	N	N	N	S	S	S	S	**6**
Penna et al. (2018)	S	S	N	S	N	N	N	S	S	S	S	**6**
Pires et al. (2018)	S	S	S	S	N	N	N	S	S	S	S	**7**
Salam et al. (2018)	S	S	S	S	N	N	N	S	S	S	S	**7**
Filipas et al. (2018)	S	S	N	S	N	N	N	S	S	S	S	**6**
Silva-Cavalcante et al. (2018)	S	S	N	S	N	N	N	S	S	S	S	**6**
Brown Denver et al. (2019)	S	S	S	S	N	N	N	S	S	S	S	**7**
Filipas et al. (2019)	S	S	S	N	N	N	N	S	S	S	S	**6**
Holgado et al. (2019)	S	S	S	S	N	N	N	S	S	S	S	**7**
Martin et al. (2019)	S	S	N	S	N	N	N	S	S	S	S	**6**
Macmahon et al. (2019)	S	S	S	S	N	N	N	S	S	S	S	**7**
Staiano et al. (2019)	S	S	S	N	N	S	S	S	S	S	S	**7**
Barzegarpoor et al. (2020)	S	S	N	S	N	N	N	S	S	S	S	**6**
Lopes et al. (2020)	S	S	S	S	N	N	S	S	S	S	S	**8**
Filipas et al. (2020)	S	S	N	S	N	N	S	S	S	S	S	**7**
Penna et al. (2021)	S	S	S	S	N	N	N	S	S	S	S	**7**
Filipas et al. (2021)	S	S	S	S	N	N	N	S	S	S	S	**7**
Weerakkody et al. (2021)	S	S	N	S	N	N	N	S	S	S	S	**6**
Lam et al. (2021)	S	S	N	S	N	N	N	S	S	S	S	**6**

Note. S = Meets Criteria, N = Does Not Meet Criteria, 1 = Specified Choice Criteria, 2 = Randomization, 3 = Hidden Assignment, 4 = Pre-Intervention Similar Groups with Respect to Key Variable, 5 = Subjects Blinded with Respect to Group Assignment, 6 = Therapists Blinded with Respect to a Subject's Membership in One Group or Another, 7 = Assessors who measured at least one key outcome were blinded, 8 = Key outcome measures obtained from more than 85% of the sample,

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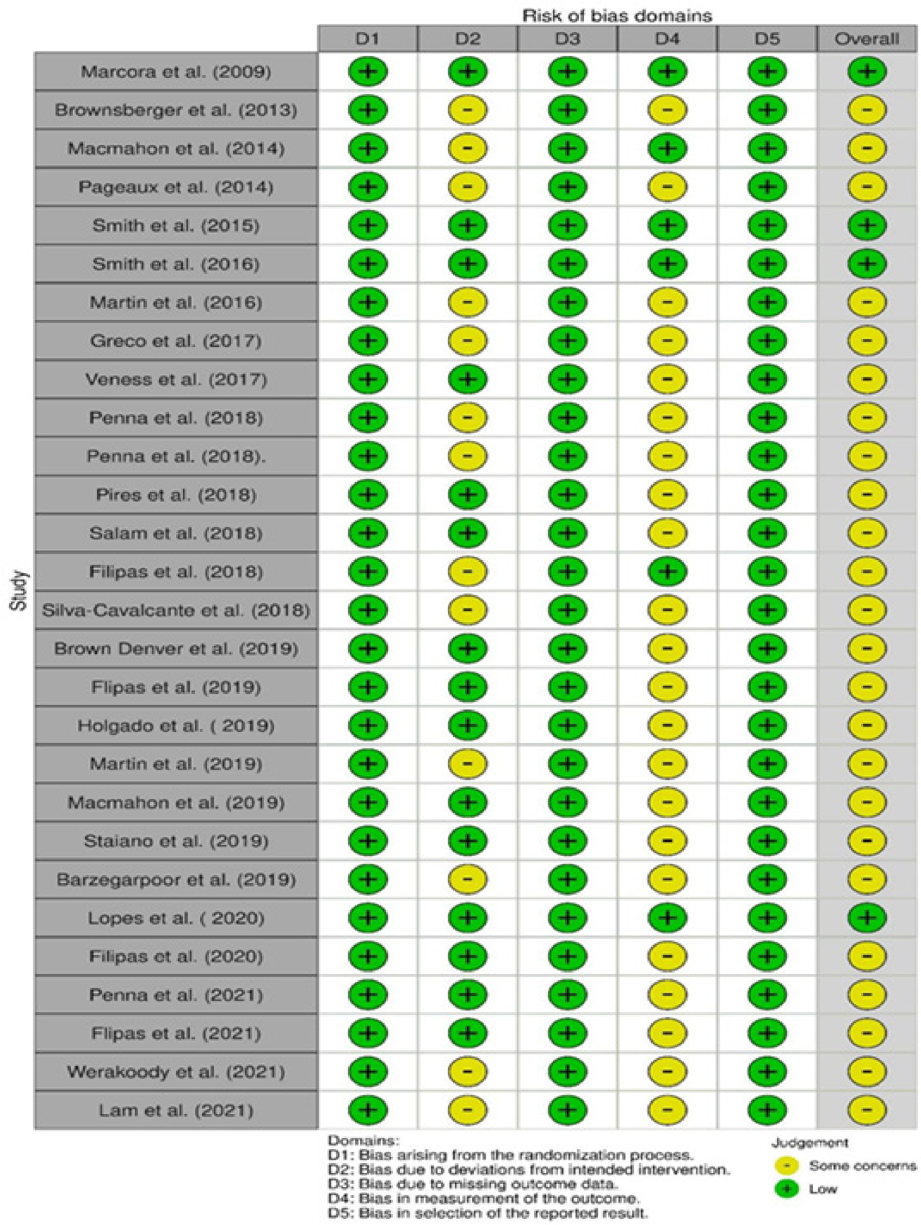
9 = Outcomes from all subjects who received treatment or were assigned to the control group, or when this could not be, data for at least one key outcome were analyzed by "intent to treat", 10 = Statistical comparisons between groups, 11 = Point and variability measures.

To know and determine the methodological quality of the included studies, the "PEDro" scale (https://pedro.org.au/spanish/resources/pedro-scale/) was used, which has proven to be reliable enough for use in systematic reviews. This scale consists of 11 criteria, of which the first has no value in the "PEDro" score. Each criteria was assessed with "S" (S = meet the criteria) and "N" (N = do not meet the criteria), giving an "S" score only when the criteria is clearly met. The maximum score that can be obtained will be 10 points if all the criteria are met. Included studies with a PEDro score ≥ 6/10 were judged to be of high quality, while those with lower scores were judged to be methodologically of low quality. The methodological quality of each study was rated by three review authors (IMG, GMS, DCP). The information on quality assessment is summarized in table 1.

To understand the reliability of the findings presented, a graph reflecting the assessment of risk of bias with the RoB.2 tool implemented through the online version of *Review Manager* is included. It reflects current knowledge about how causes of bias can influence outcomes and contains the most appropriate way to assess this risk. Judgments about each of the domains may be "low," have "some concerns," or "high" risk of bias. The information is shown in figure 1.

Figure 1
Rob.2.0.

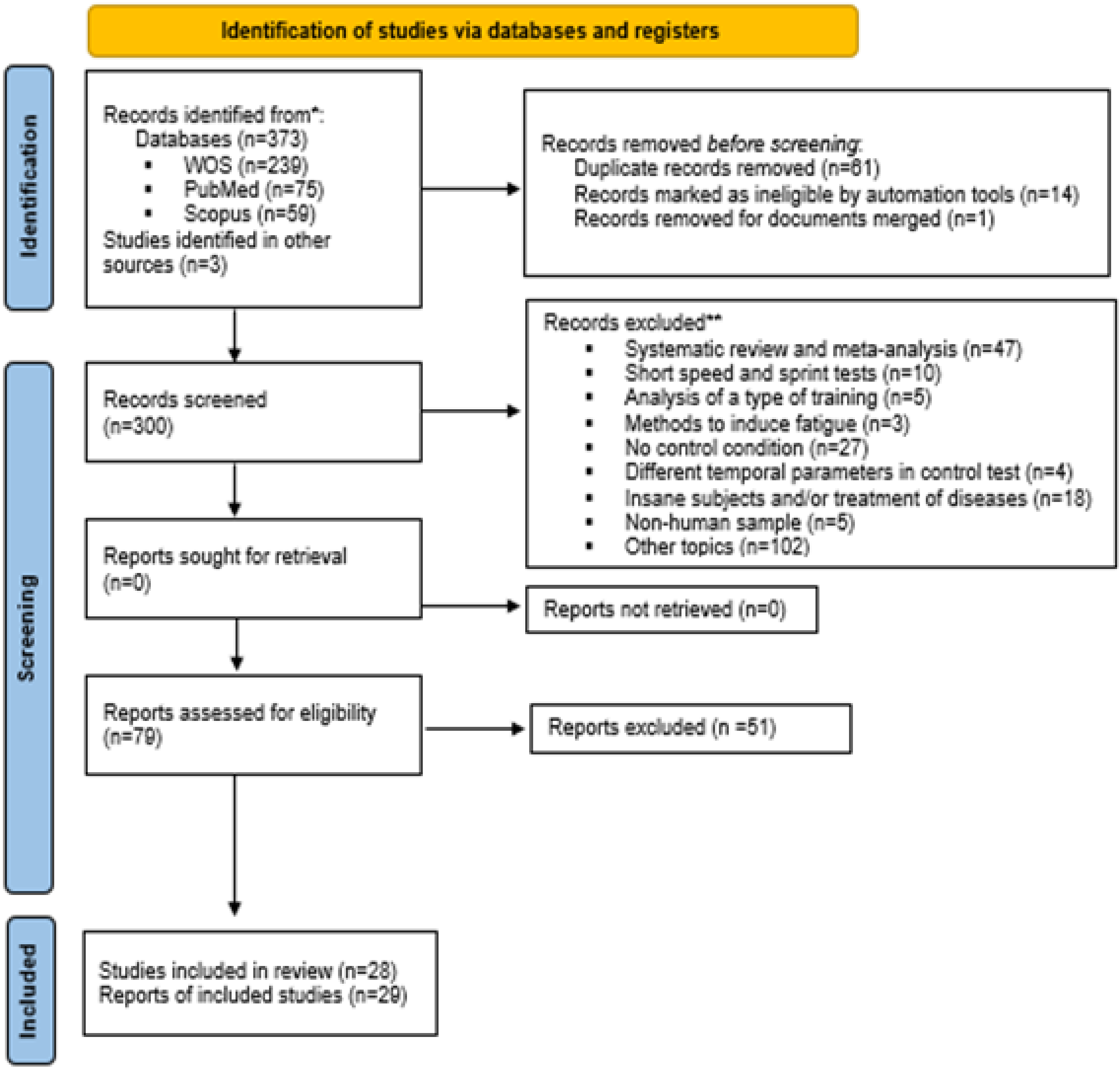


Results

Search Results

After the initial search, 373 studies were identified. After duplicates removal, 311 studies remained. After reviewing the title, abstract or full text, a total of 28 studies were included. Figure 2 shows the flow diagram of the systematic review.

Figure 2
Flowchart of the Systematic Review



Results of the Assessment of Quality and Risk of Publication Bias

Table 1 shows the quality scores of each of the included studies. The methodological quality of the studies in this review is high, according to the PEDro scale, since 100% of the included studies had a quality ≥ 6 points.

The results of the risk of bias reveal some concerns about the nature and strength of the effects of mental fatigue on the overall computation in most research. These come mainly from the item (D2) of risk with respect to the deviation from the planned intervention and the item (D4) of risk in the measure of the results. The possible presence of information biases in this literature raises the need for an improvement in the methodology, detailing and complying with the blinding of the evaluators to draw firm conclusions about the possible effect of mental fatigue on physical performance, among other parameters such as the perception of effort. The results are shown in Figure 1.

Characteristics of the Participants and the Type of Performance Evaluation Test

All relevant information from each study is summarized in table 2. The publication dates of the studies range from 2009 to 2021. The sample size varies between eight (Pires et al., 2018; Silva-Cavalcante et al., 2018) and 36 subjects

(Filipas et al., 2021). The mean age of participants ranges from 40 (Holgado et al., 2019) to 14 years (Filipas et al., 2021; Greco et al., 2017).

Table 2
Qualitative Synthesis of the Studies Included in the Literature Review

2.1. EFFECTS OF MENTAL FATIGUE (MF) ON TIME-TO-EXHAUSTION TESTS					
Study	**Sample**	**Performance Test**	**Type and duration of treatment**	**Methodological characteristics**	**Results**
Marcora et al. (2009)	10 men and 6 women. Age: 26± 3 years	Constant load test to exhaustion at 80% P_{peak}	EXP: AX-CPT. CTR: emotionally neutral documentaries. Duration: 90 min.	Randomized, controlled crossover study.	Main: TTE: EXP<CTR (640 ± 316 s vs 754 ± 339 s; p =0.003). Complementary: RPE: EXP>CTR FC: n.s. VO2: n.s. La: n.s.
Salam et al. (2018)	11 well-trained male riders. Age: 38 ± 6 years	Time to exhaustion test on cycle ergometer at 40, 60, 80 and 100% of V02max	EXP: Modified version of stroop word-colour task. CTR: reading a sports magazine. Duration: 30 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: TTE: EXP< CTR (p < 0.01). 40% V02max: EXP (648 ± 171) vs CTR (720 ± 180). 60% V02max: EXP (341 ± 84) vs CTR (422 ± 88). 80% V02max: EXP (231 ± 65) vs CTR (275 ± 58). 100% V02max: EXP (156 ± 38) vs CTR (190 ± 38). Complementary: RPE: EXP > CTR (p< 0.01). La: EXP< CTR (p< 0,05). FC: n.s.
Martin et al. (2019)	23 participants (15 women). Age: 26 ± 6 years	Pedaling test to exhaustion. 80% P_{peak}	EXP: stroop color task (modified version). CTR: Watch a documentary. Duration: 90 min.	Randomized, controlled crossover study.	Main Courses: TTE: CTR = EXP (628±247 s vs 601±245 s; p=0,074). Complementary: RPE: n.s.
MacMahon et al. (2019)	13 participants (3 women) Age: 19.92 ± 1.75 years.	Time to exhaustion test: *Beep Test* (20 m shuttle run test).	EXP: incongruent stroop task. CTR: congruent stroop task. Duration: 30 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: TTE: EXP < CTR (8:48±2:32 min vs. 9:20±2:28 min; p < 0,01). Complementary: RPE: EXP > CTR (p< 0.001) FC: n.s.
Barzegarpoor et al. (2020)	10 recreational male cyclists. Age: 21±3 years. Training > 150 km/week Peak power in incremental test: 320±31 watts.	Cycling test to exhaustion at 65% VO2max	EXP: stroop color-word test. CTR: Watching a movie. Duration: 45 min.	Randomized, controlled crossover study.	Main: TTE: EXP < CTR (67,6 min vs.95,7 min; p< 0.01). Complementary: RPE: EXP > CTR (p < 0.005) FC: n.s.
Lopes et al. (2020)	30 professional runners (15 women) of medium and long distance (from 800 m to marathon). Age: 25 ± 1 years	Test to exhaustion at 90% VO2max	EXP: incongruent stroop task. CTR: Watch a documentary. Duration: 45 min.	Crossover, randomized, controlled study.	Main: TTE: EXP < CTR (-27,7 s; p =0,043). Complementary: RPE: EXP>CTR (females: p< 0.001; males: p=0.022) FC: n.s

2.2. EFFECTS OF MENTAL FATIGUE (MF) IN TIME TRIALS					
Study	**Sample**	**Performance Test**	**Type and duration of treatment**	**Methodological characteristics**	**Result**
Brownsberger et al. (2013)	12 participants (8 men and 4 women) regularly trained. Age: 21 ± 1 years	2 x 10-min time trials at self-selected power on a cycle ergometer at an intensity of RPE = 11 (light) and 15 (intense), respectively.	EXP: Continuous Cognitive Activity Test: Vigilance Task. CTR: Time-equal passive neutral observation task. Duration: 90 min.	Randomized, controlled crossover study.	Main: EXP < CTR (RPE 11: 83 ± 7 vs. 99 ± 7 W; p = 0.005; RPE 15: 132 ± 9 vs. 143 ± 8 W; p = 0.028).
MacMahon et al. (2014)	20 physically active participants (2 women). Age: 25.4 ± 3.24 years.	3,000 m race test on a 200 m indoor track.	EXP: AX-CPT. CTR: TV documentary on history before World War I. Duration: 90 min.	Randomized, controlled crossover study.	Main: Time in 3 Km: CTR< EXP (11:58, 56 ± 0:48.39 min. vs. 12:11.88 ± 0:48.39 min; p = 0.009). Complementary: FC: n.s. La: n.s. RPE: n.s.
Pageaux et al. (2014)	12 physically active subjects (4 women). Age: 21 ± 1 years	5km treadmill time trial test	EXP: incongruent stroop colour-word task CTR: congruent stroop colour-word task (modified version). Duration: 30 min.	Randomized, controlled crossover study.	Main: Time in 5 Km: EXP > CTR (24.4 ± 4.9 min vs. 23.1 ± 3.8 min; p=0.008, η2p = 0.489). Complementary: FC: n.s. La: n.s. RPE: EXP > CTR.
Martin, Staiano et al. (2016)	20 male subjects. 11 professional cyclists. Age: 23.4 ± 6.4. 9 recreational cyclists. Age: 25.6 ± 5.3.	20-minute time trial on a cycle ergometer.	EXP: incongruent stroop colour word task. CTR: cognitive task: focus on a black cross centered on a white background on the screen. Duration: 30 min.	Randomized, controlled crossover study.	Main: Average speed: Professionals: EXP = CTR (44.1 ± 2.2 vs. 44.3 ± 1.8 km/h; p = 0.261). Recreational: EXP < CTR (34.3 ±2.6 vs. 35.5 ±1.9 km/h, p = 0.003). Complementary: FC: n.s. La: n.s. RPE: n.s.
Penna et al. (2018)	16 trained and experienced swimmers (5 women). Age: 15.45 ± 0.51 years.	Swimming time trial: 1500 m.	EXP: Modified paper version of the stroop color-word task. CTR: Watch a video about the history of world aviation. Duration: 30 min.	Randomized, controlled crossover study.	Main: Average speed: EXP < CTR (1,155 ± 0,101 m/s vs. 1,169 ± 0,106 m/s; p < .05). Complementary: RPE: n.s. FC: n.s.
Pires et al. (2018)	8 male non-professional cyclists. Age: 29.3 ± 7.9 years.	20km cycling time trial.	EXP: RVP test. CTR: remain seated in a seat; Read an optional magazine. Duration: 30 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: Time: EXP > CTR (34.3 ± 1.3 min vs. 33.4 ± 1.1 min; (p=0.02). Complementary: RPE: EXP > CTR (p=0.002)
Filipas et al (2018)	18 prepubertal rowers (6 women) who train 2 days/ week. Age: 11 ± 1.06 years.	1500 m time trial on rowing-ergometer.	EXP: - Intervention 1: stroop task - Intervention 2: arithmetic test. CTR: low-demand cognitive activity (Mandala painting). Duration: 60 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: Time at 1500 m: n.s. EXP 1 y EXP 2 (445.29 ± 61.52 s y 446.35 y 446.35 ± 62.30 s) > CTR (442.59 ± 63.97 s Complementary: FC: n.s. RPE: n.s.

Silva-Cavalcante et al. (2018)	8 male road cyclists. Age: 33.8 ± 7.2 years.	Time trial on a 4km cycle ergometer.	EXP: AX-CPT. CTR: Watch two episodes of a series in your native language. Duration: 90 min.	Randomized, counterbalanced, controlled crossover study.	Main: Time: EXP=CTR (376±26 vs. 376±27; p = 0.717). Complementary: RPE: n.s. VO2: n.s. VE: n.s. FC: n.s.
Brown Denver et al. (2019)	25 university students (12 women). Age: 20.16± 1.48 years.	30-minute time trial at a self-selected power	EXP: AX-CPT. CTR: Watch a documentary and record the number of times the word “water” appears. Duration: 50 min.	Randomized, controlled crossover study.	Main: Total work (kJ) during the 30-minute pedaling sessions: CTR > EXP (189.6 ± 14.6 vs. 176.5 ± 13.1 kJ).
Filipas et al. (2019)	10 U-23 male road cyclists. Age: 20.0 ± 1.2 years. VO2max: 69.0 ± 4.4 mL·min$^{-1\cdot kg-1}$; > 300 km/week, > 3 years of experience	Time trial on cycle ergometer.	EXP: modified stroop color-word task CTR: Watch a video. Duration: 30 min.	Randomized, controlled, crossover, counterbalanced.	Main: Average power: EXP < CTR (287 ± 23 W vs. 295 ± 23 W; p =0,007). Complementary: FC: n.s. La: n.s. RPE: n.s.
Holgado et al. (2019)	28 trained male cyclists. Age: 27.03 ± 7.41 years. Weekly training > 6h/week.	20-minute time trial on a cycle ergometer.	EXP: Dual Task (n-back task and physical task) CTR: physical task only. Duration: 4 blocks totaling 20 min + 10 min.	Randomized, counterbalanced study.	Main: Average power: EXP=CTR (222 W (95 % CI 206,4–237,6) vs 217 W (95 % CI 201.9–232.1). Complementary: FC: n.s. RPE: n.s.
Staiano et al. (2019)	13 elite kayakers from the U-17 national team. Age: 16.4± 0.8 years.	2000 m kayak time trial.	EXP: Modified stroop colour word task. CTR: Watch a neutral documentary. Duration: 60 min.	Randomized, controlled crossover study.	Main: Time 2 Km: EXP > CTR (552± 30 s vs. 521±36 s). Complementary: La: EXP > CTR (ES = -1.09). HR: EXP < CTR (ES = -0.28 to -0.44). RPE: EXP > CTR (ES = moderate).
Filipas et al (2020)	20 untrained volunteers (14 women). Age: 27.6 ± 6.2 years.	Time trial on a 15-minute cycle ergometer.	EXP: Cognitive battery containing the following tasks: - 15-min flanker task; 0-min go/no-go task; 10-min of a 2-back task; and 10-min of a working memory task. - 40 min incongruent stroop colour – word task. - 5 min task-switching (flanker task). CTR: looking at a blank screen. Duration: EXP: 90 min (a: 45 min; b: 40 min-5 min). CTR: 15 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: Distance: EXP< CTR (average difference: -223 m; 95% CI −137 to −309; p < 0.001).

Penna et al. (2021)	10 experienced master swimmers. Age: 30±6 years.	800-meter swimming test in an Olympic pool.	EXP: incongruent stroop color test. CTR: Watching an emotionally neutral video. Duration: 45 min.	Cross-over, randomized, counterbalanced, and controlled study.	Main: Time in 800 m: EXP = CTR (695±45 vs. 692±42 sec). Complementary: RPE: n.s.
Lam et al. (2021) (Study 2)	9 recreational runners (2 women). Age: 21.1 ± 1.2 years.	Studio 2: 5k treadmill race.	EXP: incongruent stroop test. CTR: emotionally neutral documentary. Duration: 30 min.	Study with simple and controlled randomization.	Study 2 Main: Time in 5K: EXP > CTR (24, 1 vs 23, 6 min; ES=0.2, small). Complementary: RPE: n.s. FC: n.s.

2.3. EFFECTS OF MENTAL FATIGUE (MF) ON INTERMITTENT EXHAUSTION TESTS

Study	Sample	Performance Test	Type and duration of treatment	Methodological characteristics	Result
Smith et al. (2015)	10 men playing team sports. Age: 22 ± 2.	Intermittent running protocol-45 min.	EXP: AX-CPT. CTR: emotionally neutral documentaries. Duration: 90 min.	Randomized, controlled crossover study.	Main: Velocidad media: EXP < CTR (1,50 ± 0,18 m/s vs. 1,54 ± 0,18 m/s; p =0.022). Complementary: FC: n.s. La: n.s. VO2: EXP < CTR (p =0.007).
Smith et al. (2016) (Study 1)	12 male soccer players, moderately trained. Age: 24 ± 0.4.	Yo-Yo IR1.	EXP: incongruent stroop color-word task. CTR: reading at a leisurely pace a selection of magazines on a variety of topics. Duration: 30 min.	Randomized, controlled crossover study.	Main: Distance EXP < CTR (1203 ± 402 vs. 1410 ± 354; p < 0.001). Complementary: RPE: EXP > CTR (p < 0.001). FC: n.s.
Greco et al. (2017) (Study 1)	16 young, young, healthy male footballers. Age: 15.0 ± 1.1 years.	Yo-Yo IR1.	EXP: a motivating and competitive activity that consisted of drawing figures on the phone screen to solve puzzles, proposed by an app ("Brain It On"). CTR: usual activities prior to the training of the subjects. Duration: - EXP: 30 min. - CTR: not detailed.	Randomized, counterbalanced, and controlled crossover design.	Main: Distance: EXP < CTR (1610 ± 135 m vs. 1780 ± 249 m; *p* =0.0460) Complementary: RPE: n.s.
Veness et al. (2017)	10 elite male cricket players. Age: 21 ± 8 years old.	Yo-Yo IR1.	EXP: stroop task. CTR: reading magazines with neutral content. Duration: - EXP: 30 min. - CTR: 30 min.	Randomized, controlled crossover study.	Main: I-Yo IR1 distance: EXP < CTR (1732 ± 402 m vs 1892 ± 357 m; p = 0.023). Complementary: RPEsession: EXP > CTR (p =0.001). n.s.

Penna et al. (2018)	12 regional level handball players. Age: 17.50 ± 3.63	Yo-Yo IR1.	EXP: Modified paper version of the stroop color-word task. CTR: Watch an emotionally neutral video about the history of global aviation. Duration: 30 min.	Randomized and controlled crossover study.	Main: Distance: EXP< CTR (655 ± 182.5 m vs. 720 ± 145; p < 0.05) Complementary: RPE: EXP > CTR (p < 0.001) The: n.s.
Filipas et al. (2021)	36 football players. Age: 12 U-14, 12 U-16 and 12 U-18.	Yo-Yo IR1.	EXP: Modified incongruent computer version of incongruent stroop colour word task (computerized). CTR: leisurely reading magazines. Duration: - EXP: 30 min. - CTR: 15 min.	Randomized, counterbalanced, controlled crossover trial.	Main: Yo-Yo IR1 distance: EXP < CTR (sub-14=-12%, sub-16=-15%, and sub-18=(-18%; p < 0.05; p < 0.01; p < 0.001, respectively). Complementary: FC: EXP > CTR (iso-time comparison; p< 0.05). RPE: EXP > CTR (iso-time comparison; p< 0.05).
Weerakkody et al. (2021)	25 male participants. Age: 23.8±4.6 years.	Yo-Yo IR1.	EXP: stroop task CTR: viewing of a documentary of an emotionally neutral nature in a quiet environment. Duration: - EXP: 35 min. - CTR: 30 min.	Randomized controlled crossover trial.	Main: Yo-Yo IR1 distance: EXP < CTR (1040.00 ± +492.75 vs 1182.40± +537.78). Complementary: FC: n.s. RPE: EXP > CTR (p=0.06) n.s.
Lam et al. (2021) (Study 1)	9 recreational male athletes (various sports). Age: 22 ± 2.6 years.	Yo-Yo IR1.	EXP: incongruent stroop task CTR: emotionally neutral documentary. Duration: 30 min	Study with simple and controlled randomization.	Main: Distance Yo-Yo IR1: EXP < CTR (-55.6 ± 37.1 m; ES=0.51, moderate) Complementary: RPE: EXP > CTR (ES=0.33, moderate).

Note. RPE: perceived exertion index; EXP: experimental test; CTR: test control; p: probability; W: watts; AX-CPT: AX-Continuous Performance; k: km; min: minutes; HR: heart rate; La: blood lactate accumulation; km/h: kilometers per hour; RVP-test: (Rapid Visual Information Processing); VO2: maximum oxygen consumption; mL.min: milliliters per minute; m: meters; GXT: Graded Cardiovascular Exercise Test ; kJ: kilojoules: ; CI: confidence interval; Yo-Yo IR1: Yo-Yo Intermittent Recovery Test 1; $RPE_{session}$: index of perceived exertion in the session.

In relation to the sex of the participants, there are no studies including only women, and only in some of them included women as a part of the sample (Brown & Bray, 2019; Brownsberger et al., 2013; Filipas et al., 2018; Lam et al., 2021; Lopes et al., 2020; MacMahon et al., 2014, 2019; Marcora et al., 2009; Martin et al., 2019; Penna et al., 2018). In these studies, only two of them have female participation exceeding male participation. (Filipas et al., 2020; Martin et al., 2019).

Regarding the previous physical activity experience of the participants in the analyzed studies, I general (n = 23) participants are physically active except in one, where the participants are untrained young adults (Filipas et al., 2020). In five studies, this information is not reported (Brown & Bray, 2019; MacMahon et al., 2019; Marcora et al., 2009; Martin et al., 2019; Weerakkody et al., 2021). In addition, studies with well-trained athletes included runners (Lopes et al., 2020), cricket players (Veness et al., 2017), cyclists (Martin, Staiano, Menaspa, et al., 2016; Pires et al., 2018) or kayakers (Staiano et al., 2019). In the remaining cases, the participants were recreational athletes, or their level of performance was not reported. One study compared the results of both population profiles, trained and non-trained participants (Martin, Staiano, Menaspà, et al., 2016).

To determine the influence of mental fatigue on performance, all studies employed tests performed at maximal intensities or at various intensities corresponding to maximum oxygen consumption or a specific pedaling power output. Specifically, the studies included time-trial tests over a specific distance in swimming (Filho, Penna, Wanner, et al., 2018; Penna et al., 2021), rowing, running (Lam et al., 2021; MacMahon et al., 2014; Pageaux et al., 2014), or cycling (Brownsberger et al., 2013; Filipas et al., 2019; Martin, Staiano, Menaspà, et al., 2016; Pires et al., 2018; Silva-Cavalcante et al., 2018); or tests analyzing time to exhaustion using constant-load tests (Barzegarpoor et al., 2020; Lopes et al., 2020; Marcora et al., 2009; Martin et al., 2019) or incremental-load tests (MacMahon et al., 2019; Salam et al., 2018). Intermittent performance tests have also been considered (e.g., Yo-Yo IR1) (Filipas et al., 2021; Greco et al., 2017; Lam et al., 2021; Penna et al., 2018; Smith et al., 2016; Veness et al., 2017; Weerakkody et al., 2021) since they also met the inclusion criteria.

Results on the key Variable Depending on the Type of Test

Time to Exhaustion

Regarding heart rate during the time-to-exhaustion task, none of the studies (Barzegarpoor et al., 2020; Lopes et al., 2020; MacMahon et al., 2019; Salam et al., 2018) found differences between the experimental condition and the control condition. Regarding blood lactate, the results are inconclusive, since one study does not report differences between conditions (Marcora et al., 2009), while the results of (Salam et al., 2018) suggest a greater accumulation of lactate in the control test than in the tests performed after performing a demanding cognitive activity.

Time Trials

Several studies (n = 8) used time trials in which participants had to complete a certain distance in the shortest possible time. Most of them, regardless of whether the test was on a cycle ergometer (Pires et al., 2018), kayak (Staiano et al., 2019) or a treadmill (Lam et al., 2021; MacMahon et al., 2014; Pageaux et al., 2014), observed an increase in the time needed to complete the target distance in the cognitive fatigued condition. However, four of the seven studies that included this type of test did not observe a negative effect of mental fatigue on performance in cycling (Silva-Cavalcante et al., 2018), swimming (Penna et al., 2021), and rowing (Filipas et al., 2018) performance.

Other studies included different time-trial tests, where the maximum distance covered in a predetermined time (Filipas et al., 2020), power output (Holgado et al., 2019), or work generated (Brown & Bray, 2019), as well as average speed (Filho, Penna, Wanner, et al., 2018), were measured. These studies consistently showed a reduction in performance under conditions of mental fatigue prior to the test, with the exception of Holgado et al. (2019). The results of one study suggest that the effects of mental fatigue on a time-trial task on a cycle ergometer, where participants aimed to cover the maximum distance possible in 20 minutes, may be influenced by the participants' level of experience. No differences were observed between the control and experimental conditions in professional cyclists, but significant differences were found in recreational cyclists (Martin, Staiano, Menaspà, et al., 2016).

However, with regard to perceptual variables, the subjective perception of effort was higher in conditions of mental fatigue in only four out of 15 studies (Brownsberger et al., 2013; Pageaux et al., 2014; Pires et al., 2018; & Staiano et al., 2019). (Filipas et al., 2018, 2019; Holgado et al., 2019; Lam et al., 2021; MacMahon et al., 2014; Martin, Staiano, Menaspa, et al., 2016; Pageaux et al., 2014; Penna et al., 2018; & Silva-Cavalcante et al., 2018). it is reported that the differences between conditions are not significant. Only one study (Staiano et al., 2019) reports lower heart rate values in the experimental condition during a 2,000-meter time trial conducted by kayakers, when compared to the control condition. For blood lactate (La), we have four studies establishing that lactate accumulation does not differ between conditions (Filipas et al., 2019b; MacMahon et al., 2014; Martin, Staiano, Menaspa, et al., 2016; Pageaux et al., 2014). Staiano et al. (2019) reports higher levels of La in the experimental condition than in the control condition.

Intermittent Test Results

A total of eight articles were included in this review that analyse the effects of mental fatigue on performance in intermittent endurance tests. The main variable that informs about the performance in these tests is the distance covered (Campos, Filho, Penna, et al., 2018; Filipas et al., 2021; Greco et al., 2017; Lam et al., 2021; Penna, Filho, Campos, et al., 2018; Philippas et al., 2021; Smith et al., 2016; Veness et al., 2017; & Weerakkody et al., 2021), except in one study where average speed was used (Smith et al., 2015). The result of the main variable confirms that, in this type of test, both the average speed and the distance traveled are lower when the participants have been subjected to a previous demanding cognitive task.

On the other hand, all the articles have examined the subjective perception of effort in this type of test, providing results that confirm the effect of mental fatigue in the experimental condition, with this variable increasing compared to the control condition. Regarding cardiovascular control, only one study reports a higher heart rate in the condition with mental fatigue compared to the control condition (Filipas et al., 2021). La accumulation during this type of test also does not seem to be influenced by mental fatigue (Campos, Filho, Penna et al., 2018; Smith et al., 2015).

Discussion

The main objective of the present systematic review was to determine the effect of mental fatigue on performance in endurance tasks performed in dynamic multi-joint exercises involving large muscle masses (e.g., cycling, running, swimming, etc.). After the analysis of the 29 interventions included in this systematic review, the main results show that, regardless of the type of test included to evaluate performance, 86% of the interventions analyzed (25 of 29 interventions) showed that mental fatigue reduces performance in the endurance test compared to a control condition without mental fatigue. In addition, exertion indicators such as subjective perception of effort have been increased by mental fatigue, while heart rate or blood lactate concentration do not show any alteration.

Our analysis reveals that cognitive exhaustion produces negative effects on sports performance. This was evidenced by a decrease in the time to exhaustion, in the increase in time required to complete a fixed-distance time trial (e.g.: 20 km), a lower average speed, a decrease in self-selected power, and also in the distance covered during an intermittent test to exhaustion (YO-YO IR1). We might think that the fact that mental fatigue protocols have not been the same in all studies could have influenced the results, but even in the same study (Filipas et al., 2018) two interventions have been carried out with different cognitive tasks; the first a (stroop colour task) and the second, an arithmetic test, and the performance results support our initial hypothesis in both cases. In fact, if we take into account the results of the qualitative synthesis used to evaluate physical performance extracted from the present systematic review, we can observe that in 86% of the interventions (25 out of 29 studies) there is a deterioration in performance when the subjects were mentally fatigued.

Only in five studies (Holgado et al., 2019; Martin et al., 2019; Martin, Staiano, Menaspa, et al., 2016; Penna et al., 2021; Silva-Cavalcante et al., 2018) no negative effect on performance induced by mental fatigue has been observed. In this sense, two studies that used a maximum protocol of 3 minutes (Martin, Staiano, Menaspa, et al., 2016), and a protocol of 4 km pedaling on a cycle ergometer respectively (Silva-Cavalcante et al., 2018) are included, observing that mental fatigue did not deteriorate performance. This contradiction could be due to the fact that the task used is highly dependent on anaerobic metabolism and low cognitive load as it is so short in terms of duration, so cognitive strategies to maintain long-term effort are not decisive (Van Cutsem et al., 2017). In a study that assessed the effects of mental fatigue through average speed in a 20-minute time trial in two different population profiles: professional and recreational athletes (Martin, Staiano, Menaspa, et al., 2016), the results showed that professional cyclists were more resistant to the negative effects of mental fatigue over prolonged effort. The same was true not only with average speed, but also with a lower proportion of perceived effort than in non-professional athletes. These findings suggest that successful endurance performance, whether due to genetics or training, can generate greater inhibitory control and resistance to mental fatigue (Martin, Staiano, Menaspa, et al., 2016). In this sense, the results obtained by Martin et al. (2019) do not show a negative influence of mental fatigue on performance. However, these authors consider that the results could be due to the fact that the sample is composed of a larger number of women (15 of 23 participants are women) who are more resistant to fatigue (Ansdell et al., 2020). Despite this, the results obtained so far do not seem to indicate that there are differences in the effects of mental fatigue on performance between men and women (Lopes et al., 2020). However, the conclusions drawn regarding the relationship between sex and mental fatigue in different long-lasting activities should be taken with caution, due to the little research (one study only) in this area, and it would be advisable to generate new lines of research that carry out a more in-depth analysis of this factor.

After the analysis of the results and according to Martin et al. (2018) it can be observed that, regardless of the type of performance test studied, the variables that are traditionally considered to limit performance in endurance sports (heart rate, blood lactate accumulation, etc.) are not affected by mental fatigue. However, this assumption is somewhat misleading, since, if we take into account that the performance achieved in the physical tests carried out under conditions of mental fatigue was, in general, lower, with similar heart rate and lactate values, this would lead us to think that the physiological stress achieved in conditions of cognitive exhaustion is higher (i.e. the same heart rate for a lower average power or a shorter distance travelled). On the other hand, in general, there is an increase in the subjective perception of effort under conditions of fatigue by the participants, leading them to finish the stress test earlier until exhaustion (both continuous and intermittent). However, in time trials, in general, there are no differences in the response of this variable between conditions. According to what was established by Filipas et al. (2020) this could be justified because in a time-to-exhaustion test the power output remains constant for the duration of the test, while in a time trial, the power output fluctuates. This strategy could influence the results obtained in the subjective perception of effort. On the other hand, differences in the subjective rating of effort could also have their origins in the type of scale used. The variability in the results raises the need for well-controlled paradigms that take into account the relative contribution that other parameters, such as motivation and/or boredom in the test, may have (Möckel et al., 2015).

The information derived from this review should be interpreted with caution due to the limitations arising from the included studies. Some of them have used systems to examine fatigue, such as surface electroencephalography (Brownsberger et al., 2013) or subscales that evaluated the different cognitive tools used, through questionnaires or visual analog scales (Filipas et al., 2018; MacMahon et al., 2014; Smith et al., 2016) but not all study protocols have included these measures

(Weerakkody et al., 2021). This review highlights the need for future research, with standardized protocols regarding the cognitive tasks used in which the magnitude of mental fatigue caused in the individual before physical exercise can be quantified. Likewise, it is worth highlighting the importance of studying the impact of mental fatigue by differentiating groups based on the level of practice, since the chronic exposure to cognitive stressors that a professional athlete may experience can undoubtedly be a conditioning factor for them to be more resistant to the deleterious effects of mental fatigue prior to exercise.

Conclusions

After the qualitative synthesis made in this systematic review, it could be stated that mental fatigue induced by previous demanding cognitive work produces a deterioration of subsequent performance in endurance tests. In addition, to some extent, this impairment of the maximum capacity to withstand prolonged efforts under conditions of mental fatigue is linked to an increase in the subjective perception of effort. On the other hand, the vast majority of the studies analysed do not show differences in physiological variables such as heart rate or lactate values, despite a worsening of physical performance, which indicates an increase in the physiological stress of subjects who have been exposed to a demanding cognitive load prior to performing these physical tests. Therefore, the impact of mental fatigue should be evaluated and controlled in those endurance activities of longer duration, due to the deleterious effects described above. However, we must be cautious when assuming these conclusions, since a recent meta-analysis (Holgado et al., 2020), has cast doubt on the possible effect of mental fatigue on sports performance, since, when possible, publication bias is taken into account, the effect of mental fatigue on performance is reduced.

Statement of the Ethics Committee

Not applicable due to the nature of the publication, as it is a systematic review of the literature.

Conflict of Interest

The funding entities or institutions had no influence on the study design, data analysis, or interpretation of the results. The authors declare that they have no conflict of interest.

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Contribution of the Authors

I.M.-G., DC-P., VL-A., and G.M. devised the study. I.M.-G., D.C.-P. & G.M developed the methodology. I.M.-G. performed a database search, executed the selection process, data extraction and risk of bias assessment. When in doubt, D.C.-P. and G.M. participated in the process. I.M.-G. and G.M. wrote the initial draft of the manuscript. DC-P and VL-A. critically revised and corrected the initial draft of the manuscript. All authors have read and agree with the published version of the manuscript.

Data Availability Statement

Not applicable due to the nature of the publication.

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