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Inmunophysiology and exercise in "times of COVID"

Inmunofisiología y ejercicio en "tiempos de COVID"

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In "times of COVID", the importance of the Immune System has caught everyone's attention. Until now it was the great unknown of the physiological systems, surprisingly even among the medical community. We have understood and assimilated that, in the face of an attack by pathogens, and virus in particular (given that antibiotics are not effective) and most importantly during an initial contact or infection, no longer at an individual level but at a human level, our most effective weapon is the Immune System and the responses that it generates. The correct functioning of this system is also essential in order to generate an effective and correct response to vaccines. Physical exercise that is well-chosen and practised in a selected sports discipline, is the non-pharmacological strategy that has accumulated the greatest scientific evidence with regard to its beneficial effects (and also potential undesired side effects) on the Immune System, particularly in the prevention of infectious diseases. In fact, the *"International Society of Exercise Immunology"* (Padeborn, 1993) and its publication "Exercise Immunology" are of the greatest relevance in the context of Sports Sciences and Sports Medicine.

However, the Immune System also operates physiologically on health conditions, and the concept of Immunophysiology goes beyond the mere functioning of this system. This refers to the bidirectional interactions between the immune, nervous and endocrine systems, which are fundamentally mediated by the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system. These are known as immune-neuroendocrine interactions and neuroimmunomodulation. Without forgetting the fact that it also creates a situation of physiological stress, physical exercise regulates the said interactions both homeostatically and homeorhetically. Regulation is therefore different, depending on conditions of health or from an attack by pathogens and/or in the presence of other situations of physical or psychological stress. The dysregulation of these immune-neuroendocrine interactions clearly affects the course and prognosis of infectious, autoimmune and inflammatory diseases, including what is termed "low-grade inflammation"[1-3]. In this context, macrophages, glucocorticoids and catecholamines, together with inflammatory cytokines, are the most relevant immunophysiological players. In the nineties, it had already been demonstrated that the effects of exercise on macrophages were mediated by glucocorticoids and catecholamines[4-6]. It was thus established that the effects of exercise on the innate/inflammatory immune response were regulated by neuroendrocrine stress mediators[7]. More recently, we defined the bioregulatory effects of exercise as "those effects that mitigate or prevent an excessive inflammatory response and stimulate, or do not impair, the innate defences against pathogens, by generating immunophysiological adaptations through an optimal balance between the pro- and the anti-inflamatory responses and optimal transitions between macrophages in the tissues"[1]. Glucocorticoids and catecholamines (particularly noradrenaline) are able to measure the stimulation of the innate defenses against pathogens and, in turn, to regulate and prevent an exacerbation of the inflammatory response of the magrophages, avoiding what is known as "sterile inflammation" or hyperinflammation caused by excess response. Therefore, in an immunophysiological context, good "training of the immune system" through exercise, will make us less prone to infection and allow us to avoide "sterile inflammation" and, where appropriate, exacerbated hyperinflammatory responses. This is far more significant in obese individuals, with underlying low-grade chronic inflammation and a dysregulation of the interactions between the innate/inflammatory and stress responses[8].

What is known as the "cytokine storm" appears to underlie a dysregulated process of the macrophage function, triggering a

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hyperinflammatory condition in severe cases of COVID-19. This uncontrolled systemic (and also local) inflammatory response provokes increased circulating inflammatory cytokines[9] and, in all likelihood, an imbalance in the pro-inflammatory and anti-inflammatory cytokines, observing high levels of IL-6, particularly in obese individuals[10]. Today, we are now able to respond clearly and reliably to the following questions: Has serious COVID-19 been characterised, among other aspects, by hyperinflammation underlying a macrophage activation syndrome with high levels, for example, of IL-6? Yes. Have obese individuals been more prone to COVID-19 and did they have a worse prognosis for the disease? Yes. Do obese individuals have greater baseline levels of inflammatory cykotines such as IL-6 and a dysregulation of the interaction of this cykotine with stress mediators such as noradrenaline and glucocorticoids? Yes. Were the "anti-IL-6" and glucocorticoids among the most effective and most used drugs to prevent a serious or fatal outcome? Yes. And finally, based on scientific evidence, can obese individuals, through a good bioregulation of the innate/inflammatory response, be better protected against being infected by SARS-COV-2 and prevent a serious prognosis of infection by actively performing physical exercise? This is quite clear.... particularly in "COVID times" in which all we have is our Immune System.

And what about athletes? Are they better protected against infection? If infected, can they continue to train? In the same way as usual? It is also known that athletes with continuous high-intensity training sessions may be more prone to inflammation and respiratory viral infections, which are even more likely to occur during the periods referred to as the "open window", whenever the bioregulation of the innate/inflammatory responses is not adequate[1,11,12]. However, the moment when exercise is performed in relation to an infection is also extremely significant. For more than two decades, animal studies have shown that when intense training is performed in the presence of infection, then this is exacerbated and the prognosis is worse. However, training prior to an infection, even at intense levels, can improve the chances of survival[13]. And when should athletes be or not be vaccinated? It seems sensible to avoid the open window period following a training session. In other words, the two to four hours following an intense training session in which the specific or adaptive responses may be weakened, particularly for attenuated viral vaccines (which is not the case for those based on the mRNA technology, the most commonly used one today). However, physical exercise appears to alter the immunological response to the vaccine, modifying the antibody response, primarily or solely in obese individuals and in the sedentary elderly. And, talking about vaccines... Could exercise achieve good immunisation or be a "vaccine"? Although conceptually and in a strict sense, vaccination is focused on the production of specific antibodies and specific memory cells against the pathogen in the context of adaptive response, if we were to broaden the conceptualization of the effects of the immunisation to the prevention of the disease through the alteration of the immune response, then it would be possible to include the stimulatory effects of exercise on the innate response and the adaptations generated to protect the body from infection[1,14]. In fact, the emerging concept of "trained immunity" which describes "the long-term functional reprogramming of the innate immune cells (particularly monocytes and macrophages) induced by exogenous or endogenous stimuli, leading to an altered response towards a second challenge after the return to a nonactivated state"[15], is making it possible to develop vaccines that are based on this innate immunity "training". Therefore, could physical exercise induce trained immunity? Well, some time ago, our investigation group demonstrated that plasma from animals subjected to physical exercise stimulated the innate response of the macrophages of sedentary animals in baseline conditions[4,5], and these effects are mediated by stress hormones or endogenous danger signals[3,7,16]. This seems to be clear.

Unfortunately we have lived through a few months of accelerated reporting and investigation, of doubts and uncertainties. There have even been doubts as to whether the immune response would function as well as it has done up to now against this new coronavirus. Sometimes due to ignorance, and at other times due to the continuous exceptionality of an excess of information in the "alarmist" media, showing the most exceptional cases within a large infected population. And if the Immune System carries on functioning against the virus as expected, then physical exercise will continue to improve the immune responses for the prevention of viral infections... and vaccines work as well! "There's nothing new under the sun".

But let's look to the future. One piece of good news is that the COVID-19 pandemic appears to be coming to an end, which is also my opinion. But what is known as "persistent COVID" is and will still be here, with multiple and varied clinical symptoms that affect almost all the physiological systems. What is more, the title of this Editorial is in "times of COVID" (No. 19) given that this coronavirus will remain endemic and it will be followed by others. Let us hope that experience and the retrieval of information that, on many occasions, is already known, through a greater capacity to transfer basic research to clinical and medical practice, will allow us not to make the same mistakes again. At least the Immune System, and the responses that it generates, are no longer the great unknown.

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Índice

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Analysis of the potential of the Elevation Training Mask on biomarkers, respiratory parameters, and sports performance indicators: What ergogenic mechanisms are involved? Systematic review

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Summary

Introduction: The Elevation Training Mask (ETM) is a respiratory muscle loading device that works by reducing airflow through a valvular system. The ETM was originally intended to simulate altitude by allowing the application of hypoxia during exercise and has been growing in popularity among athletes.
Objective: To systematically review studies evaluating the effect of ETM associated with exercise on biomarkers, respiratory parameters, and sports performance indicators in physically active subjects.
Material and method: A structured search following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was performed in the Medline database (PubMed) until October 2021.
Results: Six studies are included reporting that the use of ETM in comparison with the control group, presented a greater tendency to increase in forced inspiratory vital capacity, forced vital capacity, without significant changes in pulmonary function; it did not affect the total load volume of strength training but attenuated the speed of execution; it significantly increased cerebral oxygenation and decreased oxygen saturation; heart rate was higher while inter-beat interval and sympatho-vagal balance were lower; there were no changes in hematological variables although there was a tendency to decrease muscle damage and attenuate the direct catabolic effect derived from exercise; no improvements in sports performance were observed.
Conclusion: The use of ETM as an altitude simulation device induces, if at all, a mild hypoxic stimulus that is clearly insufficient to trigger adaptive physiological responses on target organ systems. However, it could have some utility as a respiratory training system without combined exercise load by adequately adjusting the working resistances on the respiratory muscles..

Key words:
Ventilatory restriction masks. Hypoxia. Respiratory training. Biological markers. Sports performance. Pulmonary function.

Análisis del potencial de la *Elevation Training Mask* sobre biomarcadores, parámetros respiratorios, e indicadores de rendimiento deportivo: ¿Qué mecanismos ergogénicos están implicados? Revisión sistemática

Resumen

Introducción: La *Elevation Training Mask* (ETM) es un dispositivo de carga muscular respiratoria que funciona reduciendo el flujo de aire a través de un sistema de valvular. La ETM fue originalmente pensada para simular la altitud permitiendo la aplicación de hipoxia durante el ejercicio y ha ido creciendo en popularidad entre los deportistas intentando maximizar su rendimiento deportivo.
Objetivo: Revisar sistemáticamente los estudios que evalúan el efecto de ETM combinada con ejercicio sobre biomarcadores, parámetros respiratorios e indicadores de rendimiento deportivo en sujetos físicamente activos.
Material y método: Se realizó una búsqueda estructurada siguiendo las directrices de los Elementos de Información Preferidos para Revisiones Sistemáticas y Metaanálisis (PRISMA) en la base de datos Medline (PubMed) hasta septiembre de 2021.
Resultados: Se incluyen 6 estudios reportando que el uso de la ETM en comparación con el grupo control, presentó una mayor tendencia al aumento en la capacidad vital inspiratoria forzada, capacidad vital forzada, sin cambios significativos en la función pulmonar; no afectó al volumen total de carga entrenamiento de fuerza pero atenuó la velocidad de ejecución; no se observaron mejoras en el rendimiento deportivo; aumento significativamente la oxigenación cerebral y disminuyó la saturación de oxígeno; la frecuencia cardíaca fue mayor mientras que el intervalo entre latidos y el equilibrio simpaticovagal fueron menores; no se produjeron cambios en las variables hematológicas aunque se observó una tendencia a disminuir el daño muscular y atenuar el efecto catabólico directo derivado del ejercicio.
Conclusión: La utilización de la ETM como dispositivo de simulación de altitud induce, un leve estímulo hipóxico que es claramente insuficiente para desencadenar en respuestas fisiológicas adaptativas sobre los sistemas orgánicos diana. Sin embargo, podría tener alguna utilidad como sistema de entrenamiento respiratorio sin carga combinada de ejercicio ajustando adecuadamente las resistencias de trabajo sobre los músculos respiratorios.

Palabras clave:
Máscaras de restricción ventilatoria. Hipoxia. Entrenamiento respiratorio. Marcadores biológicos. Rendimiento deportivo. Función pulmonar.

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2021 SEMED Research Award

Introduction

Athletes around the world have used altitude training for years using multiple methodologies, depending on where they live and where they train, in the pursuit of maximising athletic performance[1]. The potential benefits of altitude training are based on adaptive physiological responses, which compensate for the relative lack of oxygen (O_2) in the air, on the muscular, blood, cardiovascular, respiratory, hormonal, metabolic and nervous systems[2]. Since altitude training is not easily available, strategies have been developed in recent years to make simulated altitude training generate effects similar to those of real altitude training[3]. For this reason, some companies have started mass-producing simulated hypoxia equipment, making it easier to obtain and providing the opportunity for recreational and/or elite athletes to train in conditions mimicking altitude[4]. One method to simulate altitude is to induce normobaric hypoxia conditions, or to minimise the amount of air an individual is allowed to consume[5]. For this reason, restrictive devices are employed to limit airflow and potentially provide athletes with the physiological responses of altitude training[6].

The Elevation Training Mask 2.0 (ETM; Training Mask LLC, Cadillac, MI, USA) is a respiratory muscle loading device which works by reducing airflow through a valve system; when inhaling, you have to breathe deeper. The ETM was originally designed to simulate altitude by causing a moderate decrease in oxygen saturation (SpO_2) during exercise[7–9] through insufficient hyperventilation and rebreathing of carbon dioxide (CO_2)[8]. This mechanism is similar to that of hypoxicator masks, which modify the concentration of respirable gases to imitate altitude. In this way, microhypoxic environments (generated by ETMs)[8] and high altitude hypoxic conditions (generated by hypoxicators)[3] can give rise to the beneficial adaptations of altitude exposure.

However, ETMs are much cheaper than hypoxicators, such as the GO_2 Altitude, Vital Air Hypoxia or Altipower (www.biolaster.com), which raises the question: are ETMs really effective? For the above reasons, we set out to systematically review studies which assess the effect of ETMs on respiratory parameters, physiological biomarkers and sports performance in physically active subjects.

Our research question was defined using the PICOS framework according to the standard methods proposed by the Guidelines on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[10] as follows: Population: healthy adults (without any chronic disease) who perform physical activity; Intervention: physical training using the ETM device; Comparison: placebo/control group or data prior to the use of the ETM; Outcomes: protocols of use, methodology used, respiratory parameters, haematological, biochemical, hormonal and/or sports performance biomarkers; Study type: single randomised controlled trial or randomised controlled crossover trial without placebo.

Materials and method

Search strategy

A structured search was developed using the Medline (PubMed), Sportdiscus, Scopus, Science Direct, and Springerlink databases for articles published in the last 5 years, considering the evolution in ergogenic hypoxia devices applied in sport, until 30 September 2021. The search was restricted to English and Spanish.

The search terms included refer to the ETM and physical activity: *elevation training mask, performance, muscle, hematological, biochemistry, muscle performance,* and *exercise* (Table 1). The Boolean operator AND was used to connect these search terms. Different bibliographies were also analysed to include studies of interest not found through the first search and draw in as many studies as possible. Second, to cover grey literature, the same terms as those used in the main search were used on the social network *Research Gate* (www.researchgate.net).

Table 1. Articles selected from the different databases.

No. of search	Database	Search term	No. of papers after applying filters	No. of papers after reading title	No. of papers read abstract	No. of papers selected
1	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND performance	17	7	5	5
2	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND muscle	7	6	5	5
3	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND hematological	0	0	0	0
4	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND biochemistry	0	0	0	0
5	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND muscle performance	6	6	6	6
6	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND exercise	11	5	5	5

Eligibility criteria

The selection of the studies was based on the following inclusion criteria to pick out the most suitable studies from those obtained in the search: a) healthy adult volunteers without any chronic conditions who do physical activity, excluding studies using animals; b) well-designed studies which include randomised and non-randomised clinical trials, and pre-test/post-test studies; c) studies which assess respiratory, haematological, biochemical, hormonal and/or sports performance parameters; d) interventions which assess the effect of ETMs with clear information on the model, duration, time and simulated altitude used; e) papers with a methodological quality of ≥ 10 points according to the McMaster University Occupational Therapy Evidence-Based Practice Research Group. Results which did not meet the above criteria were excluded from this systematic review.

Methodological quality assessment

The critical review form for quantitative studies developed by the McMaster University Occupational Therapy Evidence-Based Practice Research Group was used as a quality appraisal tool[11]. These guidelines establish the methodological quality of each study, covering the following 16 items: purpose; review of the literature; design; blinded assessor; description of the sample; size of the sample; ethics and consent; validity of the results; reliability of the results; description of the intervention; statistical significance; statistical analysis; clinical importance; conclusions; clinical implications; limitations. The quality of the papers was rated as 'poor' (≤8 points), 'fair' (9-10 points), 'good' (11-12 points), 'very good' (13-14 points) and 'excellent' (≥15).

Data extraction and synthesis

The information extracted from the selected studies included: name of the first author, year of publication, country in which the study was carried out, study type, sample size, sex and age of participants, model, simulated altitude used, time and duration of ETM application, physical activity intervention. The results and conclusions were also drawn independently by the review authors using a spreadsheet (Microsoft Inc, Seattle, WA, USA). Any disagreements were then resolved by discussion until consensus was reached.

Results

Bibliographic search

The systematic search for papers from the last 5 years to September 2021 gave 31 published results, of which 21 were obtained from the Medline (PubMed), Sportdiscus, Scopus, Science Direct and Springerlink databases, and 10 from additional sources. After excluding 17 duplicated papers, a total of 14 were examined. After reading the title and abstract, 9 papers were considered potentially relevant, and 5 were excluded because they did not involve an intervention. After reviewing the complete texts of 9 of the remaining publications, 2 were eliminated for using unhealthy subjects and 1 for not measuring any of the variables considered in the review. And so the six papers[4,6,7,9,12,13] included in this systematic review (Figure 1) were obtained.

Methodological quality rating

Table 2 details the results of the criteria evaluated, where the main shortcomings found in terms of methodological quality were associated with items 6 and 11 of the questionnaire, referring to insufficient justification of the sample size and specification of the existence of cointervention or not in the studies. Scores ranging from 12 to 15 points were obtained, reflecting a minimum methodological quality of 75% and a maximum methodological quality of 93.75%. Of the 6 studies found, 4 were considered to be of "very good" quality[6,7,12,13], 1 of "excellent" quality[4] and 1 of "good" quality[9]. No study was excluded for failing to reach the minimum quality threshold.

Characteristics of the studies

The 6 studies[4,6,7,9,12,13] included in this review gave a total sample of 110 participants of both sexes (91 men and 19 women). Of these, 51 were subjects trained to amateur level, and 59 did exercise on a recreational basis. All the studies included in the systematic review used the ETM

Figure 1. Flow chart of strategy for searching and selecting studies included in the systematic review.

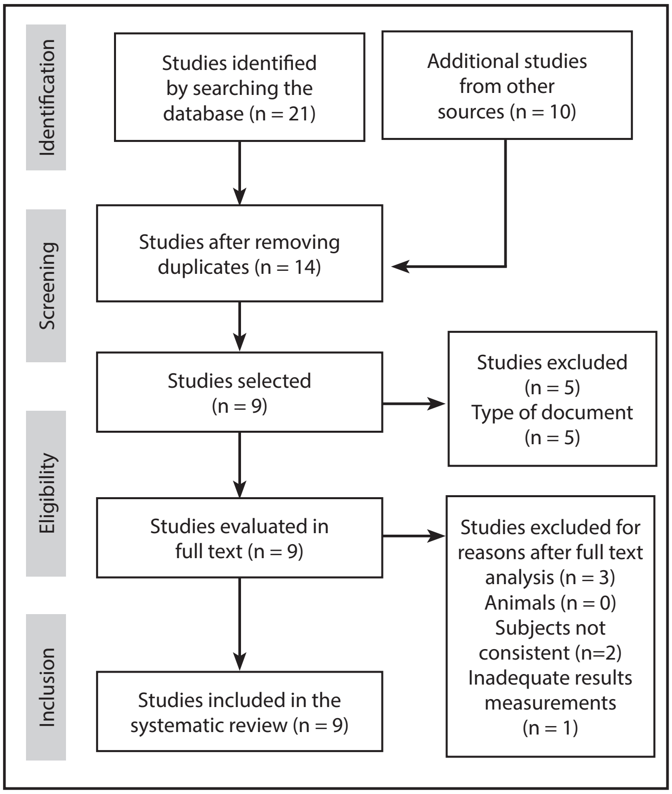

Table 2. Quality assessment of the studies included in the systematic review.

Author(s) /year/ reference	Ítems																T_s	%	MQ
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
Porcari *et al.*[13] 2016	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Jagim *et al.*[12] 2017	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Chul Jung *et al*. [7] 2018	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Romero-Arenas *et al.*[9] 2019	1	1	1	1	1	0	1	1	0	1	0	1	1	1	0	1	12	75	B
Biggs *et al.*[6] 2017	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Fernández-Lázaro *et al.*[4] 2021	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	15	93.75	E

Total items satisfied (T); Total items satisfied by study (TS); Criterion met (1); Criterion not met (0); Methodological quality (MQ): poor (P) ≤8 points; fair (F) 9-10 points; good (G) 11-12 points; very good (VG) 13-14 points; excellent (E) ≥15 points.

Table 3. Characteristics of the participants and the interventions of the studies included in this review.

Age range	20-23 23-26 26-29 >30	3 studies[6,9,13] 1 study[7] 1 study[13] 1 study[4]
Exercise level	Recreational Amateur	2 studies[9,12] 4 studies[4,6,7,13]
Mask model	ETM 2.0	6 studies[4,6,7,9,12,13]
Altitude simulated	914 m 1,829 m 2,743 m 3,658 m	2 studies[4,9] 3 studies[4,9,12] 5 studies[4,6,7,9,13] 1 study[13]
Type of exercise	Cycling Running Back squat Bench press CrossFit®	3 studies[7,9,12] 2 studies[6,13] 1 study[13] 1 study[13] 1 study[4]
Duration	1 week 3 weeks 4 weeks 6 weeks 12 weeks	1 study[7] 1 study[12] 1 study[13] 2 studies[6,9] 1 study[4]
Time of use of Elevation Training Mask	Before During After	6 studies[4,6,7,9,12,13] 6 studie[s4,6,7,9,12,13] 5 studies[4,6,9,12,13]

model Elevation Training Mask 2.0[4,6,7,9,12,13]. The simulated altitude ranged from 9144,9 to 3,658 metres[9] on top of the altitude of the location where the research was conducted, and two studies used progressive increases in simulated altitude during the research period[4,9]. The studies lasted from 1 to 12 weeks, using protocols of 1 week[7], 3 weeks[12], 4 weeks[9], 6 weeks[6,9] and 12 weeks[4]. The ETM was used before[4,6,7,9,12,13], during[4,6,7,9,12,13] and after[4,6,9,12,13] exercise (Table 3).

Results of the studies included

Table 4 analyses the information pertinent to the data obtained from the study sources (including authors, year of publications and country); study type: characteristics of the participants; mask model; altitude simulated and exercise intervention protocol used. Tables 5, 6 and 7 analyse the results of and conclusions drawn from the respiratory, physiological biomarker and sports performance parameters in the studies included in the systematic review.

Discussion

The main objective of this review was to critically analyse the scientific evidence of the effects of the ETM on respiratory parameters and haematological, biochemical, hormonal and/or sports performance biomarkers. To this end, 6 articles were included which analyse the use of the ETM 2.0 in healthy adults involved in different kinds of sporting activity, such as cycling[7,9,12], athletics[6,13], powerlifting[13] and Crossfit®[4]. Comparing the Mask Group (MG) with the Control Group (CG), the use of the ETM as a means of restricting breathing led to a greater tendency to increase forced inspiratory vital capacity (FIVC), forced vital capacity (FVC) and maximal oxygen uptake (VO_{2max})[6]; did not affect total strength training load volume but lowered execution speed[12]; significantly increased brain oxygenation[9] and decreased oxygen saturation (SpO_2)[7,9,12]; increased the heart rate (Fc)[7,12] and lowered the interval between beats and sympathovagal balance[12]; and did not change haematological variables[13], although a tendency was observed to decrease muscle damage and attenuate the direct catabolic effect of exercise[4]. However, it was difficult to determine the true effectiveness of the ETM on the different parameters and biomarkers proposed because the results could be influenced by the type of exercise, the altitude simulated (which ranged from 914 to 5,486 metres), the moment at which the ETM was used and the duration of the intervention with the ETM. Also, the characteristics of the participants, such as age, sex, ethnicity, body composition, level of training, differences in training, nutrition and health status, may also have influenced the results.

Table 4. Characteristics of the studies included in the systematic review.

Author(s), year and country	Type of study	Population	Mask and altitude simulated	Exercise intervention
Porcari *et al.*[13] 2016. USA	Randomised controlled trial without placebo	N = 24 >18 y.o. GC: n=12 (4 ♀, 20.8 y.o., 169 cm, 66.1 kg, BMI = 23.2%; 8 ♂, 21 y.o., 185 cm, 83.8 kg, BMI = 24.4%). MG: n=12 (4 ♀, de 21 y.o., 165 cm, 58.8 kg, BMI = 21.6%; 8 ♂ 22.9 y.o., 178 cm, 82.4 kg, BMI = 25.9%)	ETM 2.0 Wk 1 → 914 m Wk 2 → 1,829 m Wk 3-4 → 2,743 m Wk 5-6 → 3,658 m	Prog. of 6 weeks of cycle ergometer HIT (2 sessions/week). 30´ session (5´ WU, 20´ HIT and 5´ CD)
Jagim *et al.*[12] 2017. USA	Randomised controlled crossover trial without placebo	n= 20 ♂, 21.4 ±2.1 y.o. 180.7 ±8.8 cm 85.5±12.1 kg BFP=13.5±4.9%	ETM 2.0 Session 1-2-3-4 → 2,743 m	1st Session: 2 series of 10 rep at 50% 5 RM (back squat and bench press) + 25´´ sprint. 2nd Session: 2 series of WU 5-10 rep at 50% 5RM (back squat and bench press) with 3´ R + 25´´ sprint (100% effort). 3rd and 4th Sessions: 5´ WU with dynamic mov. + 6 series of 10 rep at 85% 5RM with 2´ R+ another series to failure. (1st back squat rest of 20´ and bench press) +25´´ sprint.
Chul Jung *et al.*[7] 2018. USA	Randomised controlled crossover trial without placebo	n= 15 (9♂ and 6♀) 27±1.14 y.o., 171.3±2.6 cm 72.7±4.04 kg BFP= 16.4±2.4%	ETM 2.0 Session 1-2-3 → 1,829 m	1st session: measure h, body weight, fat%, Resp. Func., VO_{2peak} 2nd and 3rd sessions: 2 pp. of cycling (with and without ETM), each pp. 40´ (10´ WU + 10´ at 50% VO_{2peak}+ 10´ at 70% VO_{2peak} +10´ Rec.). 7 days between sessions.
Romero-Arenas *et al.*[9] 2019. Spain	Randomised controlled crossover trial without placebo	n = 14 ♂ 24.2 ±3 y.o. 177.4 ±6.0 cm 74.8±6.9 kg	ETM 2.0 Test → 2,743 m	1 week before: complete session to familiarise with ETM. Test session: 2 cycling tests, 1st 5´ WU followed by test at 0W and P ↑ 25 W per ´ at 70-75rpm to exhaustion. The test ended when they could not carry on above 65rpm. The 1st test was with ETM and the 2nd without.
Biggs *et al.*[6] 2017. USA	Randomised controlled trial without placebo	n = 17 12 ♂ and 5 ♀, 21.2 ±1.7 y.o.	ETM 2.0 Entire pp → 2,743 m	6-week pp. of 4 days/week M-Th. The running pp. (HIIT) was modified from 90% VO_{2max} to HRR. The subjects had to maintain 80% HRR for 6 intervals of 90´´ followed by 3´ active R. In the active R, the subjects had to maintain 50-60% HRR. First there was a WU and afterwards a CD lasting 5´-10´.
Fernández-Lázaro *et al*[4]. 2021. Spain	Randomised controlled trial without placebo	n = 20 ♂ CG: n = 10 38.4 ±3.8 y.o. BMI: 24.6±2.7 kg/m^2 51.5 ± 6.5 $mL\text{-}kg^{-1}\text{-}min^{-1}$ MG: n = 10 36.7 ±5.3 y.o. BMI: 22.9±3.1 kg/m^2 53.1±7.3 $mL\text{-}kg^{-1}\text{-}min^{-1}$	ETM 2.0 Wk 1 → 914 m Wk 2 → 1,829 m Wk 3-12 → 2,743 m	12-Week Pgm. of 3 days/week of CrossFit. Warm-up, a strength and/or skill component + programmed strength or conditioning training 10-30’) + cooldown and/or mobility work.

n: number of participants; y.o.: years old; CG: control group; MG: mask group; ♂:male; ♀:female; cm: centimetres; kg: kilograms; BMI: body mass index; BFP: body fat percentage; ETM: elevation training mask; HIT: high intensity; WU: warm-up; Pp: protocol; h: height; Pgm: Programme: CD: Cooldown; R: Rest; wk: week; m:metre; ´:minute; ´´: seconds; rep: repetition; mov: movement; RM: repetition maximum; %:percentage; VO_{2peak}/ VO_{2max}: maximum oxygen consumption; W:watts; rpm: revolutions per minute; HIIT: high intensity interval training; HRR: heart rate reserve; Resp. Func.: Respiratory function; Rec.: recovery; P: Power; M: Monday; Th: Thursday.; USA: United States of America.

Table 5. Summary of respiratory parameter results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	FVC (L) FEV_1 (L) FEV_1/FVC MIP (cmH_2O) SpO_2 (%)	↔ MG ↔ CG ↔ MG ↔ CG ↔ MG ↔ CG ↑ MG ↑ CG ↓* MG ↓* CG	↔ ↔ ↔ † †
Jagim *et al.*[12] 2017 USA	SpO_2 back squat (%) SpO_2 press bench (%) SpO_2 sprint (%)	↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↓ CG	† † †
Chul Jung *et al.*[7] 2018 USA	SpO_2 (%) RPBE	↓* MG ↓* CG ↑ MG ↑ CG	# †
Biggs *et al.*[6] 2017 USA	FIVC (L/second) FVC (L)	↑ MG ↑ CG ↑ MG ↑ CG	† †
Romero-Arenas *et al.*[9] 2019 Spain	SpO_2 (%)	↓ MG ↓* CG	#

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; FVC: forced vital capacity; FEV1: forced expiratory volume in the first second; MIP: maximum inspiratory pressure; SpO_2:oxygen saturation; RPBE: rate of perceived breath effort; FIVC: forced inspiratory vital capacity; MG: Mask group; CG: Control group; L: litres; cmH_2O: centimetres of water.

Table 6. Summary of biomarker results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	Hb (g/dL) Hct (%) Max HR (beats/minute)	↓ MG ↓ CG ↑ MG ↑ CG ↔ MG ↔ CG	↔ ↔ ↔
Chul Jung *et al.*[7] 2018 USA	Systolic BP (mmHg) Diastolic BP (mmHg) HRV → IBI (seconds) time domain HRV → InLF seconds) frequency domain HRV → InHF InHF (seconds) frequency domain InLF / InHF HR (beats/minute)	↑ MG ↑ CG ↑ MG ↑ CG ↔ MG ↔ CG ↔ MG ↔ CG ↔ MG ↔ CG ↑ MG ↑ CG ↑* MG ↑* CG	† † ↔ ↔ † # #
Romero-Arenas *et al.*[9] 2019 Spain	HR (beats/minute) Muscle O_2Hb (μM-cm) Muscle HHb (μM-cm) Muscle tHb (μM-cm) Cerebral O_2Hb (μM-cm) Cerebral HHb (μM-cm) Cerebral tHb (μM-cm)	↑* MG ↑ CG ↓* MG ↓* CG ↑* MG ↑* CG ↑* MG ↑* CG ↑ MG ↑ CG ↑* MG ↑* CG ↑* MG ↑* CG	# # # # † # #
Fernández-Lázaro *et al*. 2021[4] Spain	LDH CK Mb TT C	↑* MG ↔ CG ↑ MG ↑ CG ↓ MG ↓ CG ↑ MG ↑ CG ↓ MG ↑ CG	↔ ↔ ↔ ↔ ↔

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; Hb: haemoglobin; Hct: haematocrit; HR: heart rate; SP: systolic pressure; HRV: heart rate variability; IBI: inter-beat interval; InFL: natural logarithm of low frequency; InHF: natural logarithm of high frequency; O_2Hb:oxyhaemoglobin; HHb: concentration of deoxyhaemoglobin; tHb: total tissue haemoglobin; LDH: lactate dehydrogenase; CK: creatine kinase.

The ETM aims to simulate training at altitude, adding from 914 to 5,486 metres to the real altitude at which the physical activity is carried out, by restricting oxygen (O_2) by means of a valve system[14]. The studies used different simulated altitudes and some even used more than one (Table 3). Substantial improvements in haematological variables have been reported after exposure to hypobaric hypoxia, normobaric hypoxia or during training in athletes[2,3,15–18]. However, the ETM caused a slight decrease in SpO_2 during exercise[7,12,13] with no changes in haemoglobin

Table 7. Summary of sports performance parameter results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	VO_2max ($ml\cdot kg^{-1}min^{-1}$)	↑* MG ↑* CG	†
	PPO (watts)	↑* MG ↑* CG	†
	RCT ($ml\cdot kg^{-1}min^{-1}$)	↑* MG ↑ CG	#
	PO at RCT (watts)	↑* MG ↑ CG	#
	VT (ml/kg/min)	↑* MG ↑ CG	†
	PO at VT (watts)	↑* MG ↑ CG	†
	Max HR (beats/minute)	↔ MG ↔ CG	↔
	La^+ ($mmol\cdot l^{-1}$)	↔ MG ↔ CG	↔
Jagim *et al.*[12] 2017 USA	No. rep. back squat	↓ MG ↓ CG	†
	No. rep. bench press	↓ MG ↓ CG	†
	Max speed/squat rep	↓ MG ↓ CG	†
	Max speed/bench press rep	↓ MG ↓ CG	†
	La^+ ($mM*L^{-1}$)	↓ MG ↓ CG	†
	Alertness & focus	↓ MG ↔ CG	#
Romero-Arenas *et al.*[9] 2019 Spain	PPO	↓* MG ↓* CG	#
	La+ ($mM*L^{-1}$)	↓ MG ↓ CG	†
	RPE (BORG CR-10)	↑* MG ↑*CG	†
Biggs *et al.*[6] 2017 USA	VO_{2max} ($ml\cdot kg^{-1}min^{-1}$)	↔ MG ↔ CG	↔
	VO_{2max} ($ml\cdot kg^{-1}min^{-1}$) over time	↑* MG ↑* CG	#
Fernández-Lázaro *et al.* 2021[4] Spain	Press (kg)	↑* MG ↑* CG	↔
	Deadlift (kg)	↑ MG ↑ CG	↔
	Squat (kg)	↑* MG ↑ CG	↔
	Crossfit Total (kg)	↑* MG ↑* CG	↔
	Grace (seconds)	↓* MG ↓* CG	↔
	RPE (BORG CR-10)	↔ MG ↔ CG	↔

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; VO_{2max}: maximal oxygen uptake; PPO: peak power output; RCT: respiratory compensation threshold; PO: power output; VT: ventilatory threshold; Max HR: maximal heart rate; La^+: plasma lactate concentration; No. rep.: number of repetitions; RPE: rate of perceived exertion; kg: kilogram.

(Hb) or haematocrit (Hct) in healthy participants after 6 weeks of cycling training with the ETM[13] or physically active subjects during 20 minutes of exercise on a cycle ergometer at 60% maximum power[19]. Therefore, any hypoxemia with the ETM is probably not caused by the simulation of altitude but is likely due to its modest dead space and the deterioration of alveolar ventilation[19]. Hypoxemia could also be intensified by re-inhaling carbon dioxide (CO $_2$) and the subsequent shift of the O_2 dissociation curve[8]. However, at 'real' altitudes such as those that the ETM is able to simulate (914 to 5,486 metres), saturation levels typically fall from 97-95% to 79-63%, much greater drops than those reported when using the ETM at those same altitudes[9]. This suggests that, if the ETM induced hypoxic conditions, the exposure stimulus was not sufficient to achieve haematological adaptations. In addition, the generation of hypoxia with the ETM is not clear because Barbiere *et al.*[19] and Boyle *et al.*[20] found no modifications in SpO_2 between the different conditions in their studies.

On the other hand, hypoxia affects the function of the hypothalamic-pituitary-adrenal (HPA) axis, increasing the levels of adrenocorticotropic hormone (ACTH) in plasma, and expression of the steroidogenic acute regulatory (StAR) protein, increasing the secretion of glucocorticoids such as cortisol[21,22]. Hu *et al.*[23] demonstrated that testosterone secretion is suppressed during exercise in hypoxia. However, Fernández-Lázaro *et al.*[4] reported modest increases in testosterone (3.6±0.52%) and a minimal decrease in cortisol (-0.18±4.01%) in Crossfit® athletes during 12 weeks of ETM training, with similar hormonal adaptations in the CG. Therefore, this hormonal response would not appear to be related to the use of the ETM but would rather reflect the high levels of physical fitness of the athletes[24] and an optimal training programme because in the ratio rest times/physical routines these are enough to restore the function of the HPA axis[25]. An optimised endocrine response to resistance training is of great importance for muscle adaptations and performance improvement[26]. In this sense, both groups (MG and CG) show improvements in muscle recovery and the 'Workout of the Day' (WODs), without significant differences between them[4].

These results could lead to a change in the marketing of the ETM, which originally focused on simulating altitude[14]. The ETM has been proposed as a respiratory muscle resistance training device[9,19,20]. In a meta-analysis[27], we recently described that inspiratory muscle training (IMT) in isolation improves lung function associated with increases in aerobic and anaerobic performance. However, there were no significant changes between groups (MG vs. CG) or in the ETM condition during the study in the lung function parameters of forced vital capacity (FVC)[6,13], forced inspiratory vital capacity (FIVC)[6], forced expiratory volume in the first second (FEV1)[13] or maximum inspiratory pressure (MIP)[13]. These results agree with those reported by Kido *et al.*[28], who did not inform as to any significant improvement in lung function after using the ETM. These differences between IMT and the ETM on lung function monitoring parameters could be due to the different musculature which is worked with the ETM and in IMT. The ETM does not train the diaphragm musculature or the inspiratory intercostal muscles, which are the ones that carry out the work of inspiration[14]. Furthermore, the scalene and sternocleidomastoid muscles, which are also involved in inspiratory mechanics during more intense exercise, also have to be trained through IMT[27]. Another cause could be the respiratory resistive load applied to the athletes. The working resistance should be > 30% MIP with incremental application up to 50-70% MIP, considering that loads <15% MIP are ineffective[27]. Therefore, the respiratory resistive loading (by means of a valve system) applied with the ETM may not reach the ideal working thresholds to generate an ergogenic effect on the strength of the respiratory muscles. This could explain why no effects are achieved on respiratory fatigue, the metabolic reflex mechanism of the respiratory musculature 'metaboreflex' (RMMR), hypertrophy of the diaphragm, modification of the composition of muscle fibres towards type I and increase of type II intercostal muscle fibres, optimisation of neuro-motor control of the respiratory musculature, and greater economy of the respiratory musculature[27]. These results call into question the application of the ETM as a respiratory muscle resistance training tool.

The popularity of the ETM is fundamentally based on improving sports performance by generating hypoxia[14]. However, the study by Fernández-Lázaro *et al.*[4] did not report significant changes in WODs in Crossfit® athletes, and Porcari *et al.*[13] did not describe significant improvements in VO_{2max} in highly trained athletes. Furthermore, the ETM has been shown to reduce performance during incremental exercise [7] and attenuate the ability to maintain working speed in back squat, bench press, and sprint[12]. These results are consistent with other studies not included in this review which used the ETM in constant load 29 and incremental load until exhaustion[20] exercises. Therefore, the ETM limits sports performance probably because increasing the respiratory load simultaneously during resistance training decreases overall exercise performance compared to resistance training without adding respiratory resistance. This could occur due to the significant increase in transdiaphragmatic pressure[20] and the possible fatigue of the respiratory muscles[30], which could reduce the total training load of the locomotor muscles by decreasing the time and/or intensity of exercise. The increase in respiratory muscle fatigue means that RMMR requires a lower intensity before activation, thus decreasing the tolerance to exercise[30]. Increased dyspnoea could also influence a reduction in exercise time/intensity and, therefore, the training load on the skeletal muscle system during respiratory load combined with physical activity[20,30]. Moreover, as described above, there are no improvements in lung function, thereby preventing improvements in sports performance. It has been shown that the effectiveness of the EMI on aerobic and anaerobic performance requires an increase in IMP of 20% and 6.8% respectively post EMI[27]. Even the modest hypoxemia produced by the use of the ETM[7,12,13] seems insufficient to achieve improvements in sports performance compared with hypoxia exposure programmes[1–3]. Therefore, the ETM has little influence on sports performance.

The use of the ETM in athletes increased the rate of perceived respiratory effort [7], and negatively influenced alertness and focus during exercise[13]. However, the mask caused an increase in cerebral oxygenation compared with the CG[9] while not conditioning the total training schedule of the athletes, because there were no significant differences in the MG between the study times or in the group-by-time interaction on the Borg-10 scale[4,9]. Given these discrepancies, future studies are needed to determine the comfort and convenience of the ETM during exercise, assessing whether it alters the perception of exertion or conditions performance through psychological and/or subjective factors related to the attention process in sports activity.

The use of the ETM as an altitude simulation device induces, if anything, a slight hypoxic stimulus which is clearly insufficient to trigger adaptive physiological responses in the target organ systems. However, it could serve a useful purpose as a respiratory training system in isolation (without combined exercise load) by properly adjusting the working loads (valve resistance) on the respiratory muscles to achieve gains in lung function which contribute to sports performance as an alternative to resistive loading IMT devices (PFlex, TrainAir), voluntary isocapnic hyperpnea devices (SpiroTiger) and threshold devices (PwB, Powerlung, Threshold IMT, Respifit-S) in those individuals or situations which make it impossible to use IMT devices, such as a lack of handling skills, cognitive impairment impeding their use or disabling pathologies affecting the upper limbs.

Conflict of interest

The authors declare that they are not subject to any type of conflict of interest.

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Original article

Cardiorespiratory response to high intensity interval exercise in endurance-trained postmenopausal women

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Summary

Objectives: To evaluate the cardiorespiratory response to high-intensity interval exercise in endurance-trained postmenopausal women and compare it with their counterparts eumenorrheic females.
Material and method: Twenty-one eumenorrheic (30.5±6.5 years, 58.4±8.7 kg, 25.2±6.7% fat mass, 48.4±4.4 ml/kg/min $\dot{V}O_{2peak}$) and thirteen postmenopausal (51.3±3.6 years, 54.1±4.1 kg, 24.2±5.2% fat mass, 46.01±9.8 ml/kg/min $\dot{V}O_{2peak}$) endurance-trained women performed a high-intensity interval running protocol consisted of 8 bouts of 3-min at 85% with 90-s recovery at 30% of their maximal aerobic speed. It was carried out in the early-follicular phase for the eumenorrheic group and at any time for the postmenopausal group. Cardiorespiratory variables were continuously monitored throughout the protocol.
Results: The Mann–Whitney U test reported lower values in postmenopausal women compared to eumenorrheic females for ventilation (66.9±10.1 vs 78.6±11.1 l/min; p<0.001), oxygen consumption (33.7±3.9 vs 38.6±4.1 ml/kg/min; p<0.001), % maximal oxygen consumption (79.6±5.3 vs 76.0±10.6 %; p=0.003), heart rate (154.6±9.5 vs 167.3±11.4 bpm; p<0.001) and carbon dioxide production (1914.8±248.9 vs 2127.5±296.8 ml/min; p<0.001). On the contrary, % maximal carbon dioxide production (60.6±15.0 vs 65.3±8.9 %; p=0.010), respiratory exchange ratio (1.03±0.08 vs 0.96±0.06; p<0.001) and % maximal respiratory exchange ratio (75.4±19.0 vs 83.3±8.2 %; p<0.001) were higher in the postmenopausal group. Finally, % maximal heart rate (91.9±1.7 vs 91.1±2.4 %, p=0.443) and % maximal ventilation (71.9±6.7 vs 71.1±8.4 %, p=0.138) lacked of difference between study groups.
Conclusions: Postmenopausal women appear to have a lower cardiorespiratory response to high-intensity interval exercise than eumenorrheic females, because of the age-related physiological changes, along with the chronic sex hormone decrease. Nonetheless, trained postmenopausal women present a similar cardiac strain when comparing to eumenorrheic females in relative values, which could be associated to the regular practice of physical activity.

Key words:
Eumenorrheic. Exercise. Heart rate. Menopause. Oxygen consumption. Sex hormones.

Respuesta cardiorrespiratoria en mujeres postmenopáusicas deportistas durante un ejercicio interválico de alta intensidad

Resumen

Objetivo: Analizar la respuesta cardiorrespiratoria en mujeres deportistas postmenopáusicas y compararla con la de las eumenorreicas.
Material y método: Veintiuna mujeres eumenorreicas (30,5±6,5 años, 58,4±8,7 kg, 25,2±6,7% masa grasa, 48,4±4,4 ml/kg/min $\dot{V}O_{2peak}$) y trece postmenopáusicas (51,3±3,6 años, 54,1±4,1 kg, 24,2±5,2% masa grasa, 46,01±9,8 ml/kg/min $\dot{V}O_{2peak}$) entrenadas realizaron un protocolo de interválico de alta intensidad. Éste consistió en 8 series de 3 minutos al 85% con descansos de 90 segundos al 30% de su velocidad aeróbica máxima. Las mujeres eumenorreicas realizaron el protocolo en su fase folicular temprana. Las variables cardiorrespiratorias fueron constantemente monitorizadas a lo largo del protocolo.
Resultados: El test de U Mann-Whitney mostró que la respuesta cardiorrespiratoria en el protocolo interválico fue menor en las mujeres postmenopáusicas comparado con las eumenorreicas para la ventilación (66,9±10,1 *vs* 78,6±11,1 l/min; p<0,001), consumo de oxígeno (33,7±3,9 *vs* 38,6±4,1 ml/kg/min; p<0,001), porcentaje del consumo máximo de oxígeno (79,6±5,3 *vs* 76,0±10,6 %; p=0,003), frecuencia cardiaca (154,6±9,5 *vs* 167,3±11,4 lpm; p<0,001) y producción de dióxido de carbono (1914.8±248,9 vs 2127,5±296,8 ml/min; p<0,001). Por el contrario, el porcentaje de la máxima producción de dióxido de carbono (60.6±15.0 vs 65,3±8,9 %; p=0,010), cociente respiratorio (1,03±0,08 *vs* 0,96±0,06; p<0,001) y el porcentaje del máximo cociente respiratorio (75,4±19,0 *vs* 83,3±8,2 %; p<0,001) fue mayor en el grupo de postmenopáusicas. Por último, el porcentaje de la frecuencia cardiaca máxima (91,9±1,7 *vs* 91,1±2,4 %, p=0,443) y el porcentaje de la ventilación máxima (71,9±6,7 *vs* 71,1±8,4 %, p=0,138) no mostraron diferencias entre grupos.
Conclusión: Las mujeres postmenopáusicas presentan una respuesta cardiorrespiratoria menor en ejercicio interválico de alta intensidad que la de las mujeres eumenorreicas, debido a los cambios fisiológicos asociados con la edad y el descenso de las hormonas sexuales. Sin embargo, ambas presentan un trabajo cardíaco similar en valores relativos, lo que podría estar asociado a la práctica regular de ejercicio.

Palabras clave:
Eumenorrea. Ejercicio. Frecuencia cardiaca. Menopausia. Consumo de oxígeno. Hormonas sexuales.

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2021 SEMED Research Award

Introduction

Physical fitness performance is reduced with aging. However, its pattern differs by sex showing women a more rapid decline than men during middle age[1]. This sex difference might be related to the hormonal changes that women experience during their menopausal years. Menopause is characterised by the loss of the ovarian function along with dramatic changes in endogenous sex hormones secretion[2]. Based on previous research, follicle-stimulating hormone (FSH) concentrations rises approximately 68% the following 7 to 10 months after the last menstruation, with a concomitant drop of 60% in 17β-estradiol (E2) level[3].

Endogenous sex hormones change after menopause, specially E2 decrease, may have an impact on women´s physiology. Previous research reported body composition adaptations such as an increase in fat mass[4] as well as a decrease in muscle mass[1,5] and bone mineral density[6] in postmenopausal women. Besides, some cardiorespiratory shifts have also been observed in this population such as a rise in arterial stiffness and blood pressure as well as a drop in heart rate (HR) and oxygen consumption ($\dot{V}O_2$)[1,7,8]. Indeed, literature showed a HRmax reduction of 6 beats/min per decade[9] and a maximal oxygen consumption ($\dot{V}O_{2max}$) decrease of 1% per year after the third decade of life in women[10]. Apart from sex hormones influence, it has been suggested that postmenopausal women have a more sedentary lifestyle than premenopausal females[11]. Hence, the reduction in cardiorespiratory fitness observed in this population may partially occur because of the decrease in E2[3,12,13] as well as the decline in physical activity level[11]. All these factors that postmenopausal women experience at this stage enhance the risk of suffering cardiovascular diseases and several types of cancer[14,15]. However, impairments on cardiorespiratory system caused by both, age and sex hormones change after menopause, may be partially offset in trained females because of the positive effect that physical activity has on these systems, especially high intensity exercise[16-21].

In this regard, few authors have analysed the cardiorespiratory response to high intensity interval exercise in postmenopausal sedentary women[7,22] and, as far as we are concerned, none has evaluated it in endurance-trained postmenopausal women. Therefore, the aim of the present study was to assess the cardiorespiratory response to high intensity interval exercise in endurance-trained postmenopausal women and compare it with their counterparts premenopausal females.

Material and method

Participants

A total of twenty-one eumenorrheic females and thirteen postmenopausal women (at least one year without menstruation[23]) participated in this study. All of them were healthy and well-trained in endurance activities such as running, obstacle races, triathlon, and cycling. Eumenorrheic females had regular menstrual cycles (MC), occurring from 23 to 38 days in length, during the six months prior the study[24]. Characteristics of the study population are described in Table 1.

Participants were required to meet the following criteria: (a) healthy adult females between 18 and 40 years old for the eumenorrheic group and under 60 years old for the postmenopausal group; (b) presenting healthy iron parameters (serum ferritin >20µg/l, haemoglobin >115 µg/l and transferrin saturation >16%); (c) performing endurance training at least 3 h per week. Exclusion criteria included (a) oral contraceptive users; (b) smoking; (c) metabolic or hormonal disorder; (d) medication or dietary supplements that alter vascular function (e.g., tricyclic antidepressants, α-blockers, β-blockers, etc.); (e) any surgery interventions (e.g. ovariectomy); (f) pregnancies in the year preceding; (g) any musculoskeletal injury in the last six months. At the start of the data collection, all participants conducted a questionnaire gathering information about training experience, health status and dietary supplements. All participants were informed about the procedures and risks involved and informed consent was provided by each participant. The experimental protocol was approved by the institutional Ethics Committee board of the Universidad Politécnica de Madrid and is in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki)[25].

Study design

The present work is part of the IronFEMME study, an observational cross-sectional study performed by physically active and healthy women which methodology has been recently published (Contract DEP2016-75387-P)[26].

Participants came to our laboratory on two occasions. To avoid diurnal variability[27], participants came to the laboratory between 8 and 10 a.m., abstaining from alcohol, caffeine and any intense physical activity or exercise practice the 24 hours prior the testing day. Nutritional recommendations were provided to the participants by a nutritionist to standardize the diet, and volunteers followed them 24h prior every protocol. Volunteers underwent a screening (first visit) and interval running protocol (second visit), which were conducted any time for postmenopausal women and during the early follicular phase for the eumenorrheic group (i.e., between 2nd and 5th day of the menstrual cycle with day 1 being the onset of menstrual bleeding), to measure them under similar hormonal environments (low estrogen and progesterone levels). Regarding postmenopausal women, at least one rest day was between the first and the second visit.

On the first visit, volunteers came to our laboratory between 8 and 10 a.m. in a rested and overnight fasted state. Volunteers did not perform moderate or vigorous physical activity, intake caffeine or any supplementation 24 h prior to the test. Firstly, they signed all the informed consents and participant´s weight and height were recorded. Then, baseline blood samples were collected, for a complete blood count, genetic testing, biochemistry, and hormonal analyses. Subsequently, a dual-energy X-ray absorptiometry was done with a GE Lunar Prodigy apparatus using GE Encore 2002 software (version 6.10.029; GE Healthcare, Madison, WI). Finally, after eating and resting for a minimum of 2 hours, participants completed a maximal aerobic ramp test on a computerized treadmill (H/P/COSMOS 3PW 4.0, H/P/Cosmos Sports & Medical, Nussdorf-Traunstein, Germany) to determine their $\dot{V}O_{2peak}$. Expired gases were measured breath-by-breath with the gas analyser Jaeger Oxycon Pro (Erich Jaeger, Viasys Healthcare, Germany), which validity and reliability has been previously demonstrated[28,29], whilst heart response was continuously monitored with a 12-lead ECG. Participants began with a warm-up of 3 min at 6 km/h. Once the warm-up finished, the speed was set at 8 km/h and then increased by 0.2 km/h every 12 s until exhaustion. A slope of 1% was set throughout the test to simulate air resistance[30]. To verify that $\dot{V}O_{2peak}$ was reached, a confirmatory test was carried out as suggested in previous studies[31,32] after a 5 min recovery of the maximal aerobic test[32]. The confirmatory test consisted of a 3 min warm-up (2 min at 50% and 1 min at 70% of the maximal speed reached in the maximal aerobic test). Then, speed was set at 110% of the maximal speed reached in the maximal aerobic test until volunteers´ exhaustion. The $\dot{V}O_{2peak}$ was determined as the mean of the three highest $\dot{V}O_2$ measurements in the maximal aerobic test if it was not less than 3% compared to the one obtained in the confirmatory trial. If the value was less than 3%, $\dot{V}O_{2peak}$ was calculated as the mean of the three highest $\dot{V}O_2$ values recorded during the last 30-s of the confirmatory trial. The maximal aerobic speed ($v\dot{V}O_{2peak}$) was recorded as the minimum speed required to elicit $\dot{V}O_{2peak}$[33]. Then, the speed equivalent to 85% of the $v\dot{V}O_{2peak}$ was calculated to use in the interval running protocol.

Interval running protocol

After this screening day, eumenorrheic participants attended to the laboratory to perform the interval running protocol. The protocol of the testing procedure day has been previously described[34,35]. Firstly, a blood sample was collected to analyze sex hormones, followed by a resting blood pressure (BP) measurement, using the auscultatory method with a calibrated sphygmomanometer. Subsequently, participants started the interval running protocol, which consisted of a 5 min warm-up at 60% of the $v\dot{V}O_{2peak}$ followed by 8 bouts of 3 min at 85% of the $v\dot{V}O_{2peak}$, with 90-second recovery at 30% of the $v\dot{V}O_{2peak}$ between bouts. Finally, 5 min cool down was performed at 30% of the $v\dot{V}O_{2peak}$. During exercise, ventilation ($\dot{V}e$), $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), and HR among others ventilatory variables were continuously measured using the same apparatus as mentioned for the maximal aerobic test. Besides, maximal cardiorespiratory values percentage ($\%\dot{V}e_{max}$, $\%\dot{V}O_{2max}$, $\%\dot{V}CO_{2max}$, %RER max and %HR max) throughout the interval running protocol was calculated considering maximal values, previously obtained in the maximal aerobic test, as 100%. Cardiorespiratory values were obtained as the mean of the 5 min warm-up, as well as the mean of the 5 min cool down. Likewise, values over the interval running protocol were elicited as the mean of the 3 min high intensity bouts and the mean of the 90-second recovery intervals.

Additionally, Rate of Perceived Exertion (RPE) and Perceived Readiness (PR) were measured by RPE Borg 6-20 scale[36] and PR Nurmekivi 1-5 scale[37]. Participants were asked for RPE in the last 5 s of warm-up, of every running bout, and at the end of the cool-down. PR scale was applied in the last 5 s of warm-up, of every active recovery interval, and at the end of the cool down.

Blood samples analyses

Blood samples were obtained with venepuncture into a vacutainer containing clot activator. Following inversion and clotting, the whole blood was centrifuged (Biosan LMC-3000 version V.5AD) for ten minutes at 1610 g to obtain the serum (supernatant). After that, serum was transferred into eppendorf tubes and stored at -80ºC until further analysis. Within 1 to 15 days after testing, the serum samples were delivered to the clinical laboratory of the Spanish National Centre of Sport Medicine (Madrid, Spain) to determine sex hormones and verify hormonal profiles. Total E2, progesterone, FSH and luteinizing hormone (LH) were measured via ADVIA Centaur® solid-phase competitive chemiluminescent enzymatic immunoassay (Siemens city, Germany). Inter- and intra-assay coefficients of variation (CV) reported by the laboratory for each variable were previously described[35].

Statistical analysis

Data are presented as mean and standard deviation (±SD). A Saphiro-Wilk test to assess the normality of the variables was conducted. The Mann–Whitney U test was applied to analyze differences in sex hormones (FSH, LH, E2 and progesterone) and cardiorespiratory variables (BP, $\dot{V}e$, $\dot{V}O_2$/kg, $\dot{V}CO_2$, RER, HR, RPE, PR) throughout the interval running protocol between both groups tested. Then, Cohen´s d[38] and their 95% confidence intervals (CI) were calculated to assess the magnitude of effect on the changes found. Threshold values were set as small (≥0.2 and <0.5), moderate (≥0.5 and <0.8) and large (≥0.8)[38]. Statistical significance was set at p<0.05 and all procedures were conducted with SPSS software 21 version (IBM Corp., Armonk, NY, USA).

Results

Firstly, it is worth mentioning that a homogeneous group of females have been studied since no differences in descriptive variables (height, weight, FM percentage, LM percentage, training status and $\dot{V}O_{2peak}$), other than age, were observed between eumenorrheic and postmenopausal women (Table 1). Regarding sex hormone concentrations in the testing day, significant differences between groups were observed, presenting postmenopausal women higher values of LH and FSH, whereas eumenorrheic females reported higher E2 and progesterone levels (Table 1). Eumenorrheic volunteers´ menstrual cycles ranged from 28±2 to 31±2 days in length, and their early follicular phase was at day 3.43±0.93.

Speed throughout the interval running protocol was lower for the postmenopausal group compared to eumenorrheic females in the warm-up (8.2±0.7 and 9.0±0.7 km/h, respectively; Z=-2.463; p=0.014; d=1.14; CI=0.40 to 1.89), high intensity intervals (11.7±1.1 and 12.8±0.9 km/h, respectively; Z=-2.428; p=0.015; d=1.12; CI=0.38 to 1.86), active recovery intervals (4.2±0.5 and 4.6±0.5 km/h, respectively; Z=-2.218; p=0.027; d=0.80; CI=0.08 to 1.52) and cool down (4.2±0.4 and 4.5±0.4 km/h, respectively; Z=-2.304; p=0.021; d=0.75; CI=0.04 to 1.46).

Secondly, neither resting systolic blood pressure (eumenorrheic group: 106.15±8.44 and postmenopausal group: 107.85±8.09 mmHg; Z=-1.004; p=0.316; d=0.21; CI=-0.49 to 0.90) nor diastolic blood pressure (eumenorrheic group: 65.75±7.66 and postmenopausal group: 68.57±7.48 mmHg; Z=-1.815; p=0.070; d=0.37; CI=-0.33 to 1.07) showed differences between both groups tested.

Table 1. Characteristics of the study population (mean±SD).

	Eumenorrheic in the EFP	Postmenopausal	Z	*p*	d	CI
Age (years)	30.5±6.5	51.3±3.6	-5.059	<0.001	3.37	2.31 to 4.43
Height (cm)	163.1±6.4	160.8±5.6	-0.755	0.450	-0.49	-1.19 to 0.21
Weight (kg)	58.4±8.7	54.1±4.1	-0.562	0.574	-0.55	-1.25 to 0.16
Fat mass (%)	25.2±6.7	24.2±5.2	-0.471	0.637	-0.16	-0.86 to 0.53
Lean mass (%)	70.4±6.5	72.9±5.6	-1.145	0.252	0.41	-0.29 to 1.10
Experience (years)	7.4±5.3	7.9±3.3	-1.297	0.195	0.11	-0.59 to 0.80
Training volume (mins/week)	295.9±183.6	258.5±90.45	-0.273	0.785	-0.24	-0.94 to 0.45
$\dot{V}O_{2peak}$ (ml/kg/min)	48.4±4.4	46.01±9.8	-1.577	0.115	-0.35	-1.04 to 0.35
LH (mIU/ml)	6.70±2.71	41.22±12.26	-4.790	<0.001	4.42	3.16 to 5.68
FSH (mIU/ml)	7.15±2.36	81.99±38.20	-4.739	<0.001	3.19	2.16 to 4.22
E2 (pg/ml)	48.60 ±32.23	33.03±57.34	-2.433	0.015	-0.36	-1.06 to 0.34
Progesterone (ng/ml)	0.32±0.19	0.17±0.13	-2.250	0.024	-0.88	-1.61 to -0.16

EFP: early-follicular phase; $\dot{V}O_{2peak}$: peak oxygen consumption; FSH: follicle-stimulating hormone; LH: luteinizing hormone; E2: 17 β-estradiol.

Regarding the warm-up, $\dot{V}e$, $\dot{V}O_2$/Kg, $\dot{V}CO_2$ and HR exhibited lower values in postmenopausal women than in eumenorrheic females; while RER, RPE and PR did not show differences between study groups. However, when comparing relative values, only %HR max was lower in postmenopausal women throughout the warm-up, since %$\dot{V}e$ max, %$\dot{V}O_2$/Kg max, %$\dot{V}CO_{2\,max}$ and %RER max reported no differences between study groups (Table 2). Lastly, cool down outcomes showed lower values for $\dot{V}e$ and $\dot{V}O_2$/Kg in the postmenopausal group compared to the eumenorrheic one, whereas RER was higher. Besides, no differences between study groups were observed for $\dot{V}CO_2$, HR, RPE, PR, %$\dot{V}e$ max, %$\dot{V}O_2$/Kg max, %$\dot{V}CO_2$ max and %RER max and %HRmax (Table 2).

According to the interval running protocol (Table 3) postmenopausal women exhibited lower values of $\dot{V}e$, $\dot{V}O_2$/Kg, %$\dot{V}O_2$/Kg max, $\dot{V}CO_2$, HR and RPE, whereas %$\dot{V}CO_2$ max, RER and %RER max were higher for this group throughout the high intensity bouts compared to the premenopausal one. Nonetheless, no differences in %$\dot{V}e$ max and %HRmax were reported between study groups across the high intensity bouts. Moreover, postmenopausal women reported lower values of $\dot{V}e$, $\dot{V}O_2$Kg, %$\dot{V}O_2$/Kg max, $\dot{V}CO_2$, and HR while %$\dot{V}CO_2$ max, RER, %RER max and PR were higher for this group during the active recovery. Finally, no differences in %$\dot{V}e$ max, %$\dot{V}CO_2$max and %HRmax were observed between study groups during the active recovery intervals.

Discussion

The purpose of this study was to examine cardiorespiratory response to high intensity interval exercise in postmenopausal endurance-trained women and compare it with their counterparts eumenorrheic females. The findings of the present work suggest a lower aerobic fitness in postmenopausal women than in premenopausal females. However, it is wort mentioning the similar cardiorespiratory response between groups when comparing relative values.

The lack of difference in %HRmax means a similar cardiac strain between eumenorrheic and postmenopausal endurance-trained women. This finding might be explained by the positive effect exercise has on cardiac function. It is well known that cardiac myocytes are increased and strengthened due to the regular practice of exercise, leading to a better cardiac function and lower myocardial stiffness in this population[17]. Although very few studies have evaluated this variable, a recent study carried out with active (3 times per week during the last 3 months) postmenopausal (62 years old) women reported a 65% HRmax throughout a cycle ergometer test at 75% of their $\dot{V}O_{2max}$, while postmenopausal volunteers from the present study reported a 91% HRmax throughout a high intensity interval running protocol[39]. Discrepancies in %HRmax between studies could be explained by differences in exercise protocols as well as volunteers´ training status and age.

The lower cardiovascular response with aging previously documented[7,9,40,41], is in line with the findings from the present study since postmenopausal women reported lower HR response throughout the interval running protocol compared to premenopausal females. An age-related decline in heart function has been long time accepted[42,43]. On the one hand, a pivotal aspect of the aging heart is the increase in myocardial stiffness, leading to a drop in myocardial distensibility and, thereby, cardiac filling is impaired[44]. Meanwhile, the decrease in cardiac compliance limits the recruitment of the Franck-Starling mechanism and reduces the possibility of increasing the systolic volume and, therefore, cardiac output[44]. On the other hand, E2 enhances cardiac contractility[45] as well as vasodilation of the coronary and peripheral arteries[46]; thereby, its drastic decrease after menopause may compromise cardiac function.

Turning on to the respiratory system in elderly women, the lower values observed in relative and absolute values observed in the postmenopausal group from the present study agrees with previous research[7,9,40,41]. This system also undergoes a measurable decline in the physiological function. With advancing age, the thoracic cage stiff and airways resistance increase, and this in turn elevates the work of

Table 2. Performance variables (Mean±SD) throughout the warm-up and cool down between eumenorrheic females and postmenopausal women.

		Eumenorrheic in the EFP	Postmenopausal	Z	*p*	d	CI
Warm-up	$\dot{V}$e (l/min)	48.24±8.65	39.38±6.58	-2.746	0.006	-1.12	-1.86 to -0.38
	$\dot{V}$e max (%)	44.71±5.49	42.65±5.63	-1.085	0.291	-0.37	-1.09 to 0.34
	$\dot{V}O_2$/Kg (ml/kg/min)	29.07±2.56	23.41±2.19	-3.739	<0.001	-2.33	-3.22 to -1.45
	%$\dot{V}O_2$/Kg max (%)	60.18±3.87	55.86±7.20	-1.683	0.096	-0.82	-1.55 to -0.08
	$\dot{V}CO_2$ (ml/min)	1481.21±215.57	1235.88±131.10	-2.395	0.017	-1.30	-2.06 to -0.54
	%$\dot{V}CO_2$ max (%)	42.23±10.86	44.65±6.85	-0.112	0.927	0.25	-0.46 to 0.96
	RER	0.88±0.05	0.94±0.11	-1.953	0.051	0.65	-0.06 to 1.36
	%RER max (%)	69.20±18.26	76.69±9.75	-1.235	0.228	0.48	-0.24 to 1.19
	HR (bpm)	135.95±12.83	117.50±16.03	-2.208	0.027	-1.31	-2.07 to -0.55
	%HR max (%)	75.62±8.57	70.10±7.77	-2.533	0.011	-0.73	-1.44 to -0.02
	RPE	9.33±1.77	10.86±1.68	-1.822	0.068	0.85	0.13 to 1.57
	PR	4.86±0.28	4.70±0.49	-0.573	0.566	-0.43	-1.13 to 0.27
Cool down	$\dot{V}$e (l/min)	43.19±6.35	42.58±6.06	-2.463	0.014	-0.10	-0.79 to 0.59
	%$\dot{V}$e max (%)	39.61±5.11	39.76±6.66	-0.299	0.782	0.03	-0.68 to 0.74
	$\dot{V}O_2$/Kg (ml/kg/min)	19.49±2.67	19.01±2.47	-2.948	0.003	-0.19	-0.88 to 0.51
	%$\dot{V}O_2$/Kg max (%)	38.44±9.91	37.66±6.13	-1.045	0.309	-0.09	-0.80 to 0.62
	$\dot{V}CO_2$ (ml/min)	1069.41±180.80	1058.41±164.94	-1.658	0.097	-0.06	-0.76 to 0.63
	%$\dot{V}CO_2$ max (%)	30.44±8.05	31.94±5.24	0.000	1.000	0.21	-0.50 to 0.92
	RER	0.94±0.06	0.97±0.08	-2.505	0.012	0.33	-0.37 to 1.02
	%RER max (%)	73.64±18.75	81.01±7.49	-1.385	0.175	0.47	-0.25 to 1.19
	HR (bpm)	137.91±15.16	138.54±13.55	-1.239	0.215	0.04	-0.65 to 0.74
	%HR max (%)	75.99±7.51	74.65±6.91	-0.713	0.476	-0.28	-0.97 to 0.42
	RPE	9.81±2.91	9.44±1.97	-0.921	0.357	-0.14	-0.84 to 0.55
	PR	4.09±1.13	4.28±0.71	-0.343	0.732	0.19	-0.50 to 0.88

EFP: early-follicular phase; $\dot{V}$e: ventilation; %$\dot{V}$e max: maximal ventilation percentage; $\dot{V}O_2$: oxygen consumption; %$\dot{V}O_2$ max: maximal oxygen consumption percentage; $\dot{V}CO_2$: carbon dioxide production; %$\dot{V}CO_2$ max: maximal carbon dioxide production percentage; RER: respiratory exchange ratio; %RER max: maximal respiratory exchange ratio percentage; HR: heart rate; %HR max: maximal heart rate percentage; RPE: rate of perceived exertion; PR: perceived readiness.

breathing[47]. In addition, sex hormones shift occurring in women at this stage have also been linked to impairment of respiratory function[48]. For instance, a cross-sectional study found a significantly lower spirometric measures and more respiratory symptoms in postmenopausal women compared to women of the same age but with regular menstruations[49]. Besides, it appears that E2 concentrations can increase pulmonary blood volume and pulmonary diffusion capacity[50,51]; thus, its fall after menopause could compromise pulmonary function.

Nonetheless, it should be pointed out that, in the present study the interval running protocol speed was lower for the postmenopausal group. Consequently, the lower respiratory response observed in this group might be related to this factor. Besides, a recent publication carried out with these eumenorrheic and postmenopausal endurance-trained women reported no differences in most cardiorespiratory values either at resting or at peak values[52]. Thus, outcomes from the present study should be taken with cautious since resting and peak values lack of differences between eumenorrheic and postmenopausal women[52] and the cardiorespiratory response to a high intensity interval exercise might be altered by differences in speed.

Finally, according to RER and %RER max, the present study showed higher values in the postmenopausal group throughout the high intensity interval protocol, indicating a higher glycogen consumption and a lower fat oxidation in this population. Women´s metabolism could also be affected by the fall in E2 levels after menopause, since this sex hormone enhances glycogen sparing and fat oxidation by promoting lipolysis in the muscles[51,53-55].

The current study attempts to address a gap in the research through the investigation of important cardiorespiratory variables in endurance-trained postmenopausal women. The strengths of our study included the recruitment of a homogeneous group, regardless the age, of premenopausal and postmenopausal endurance-trained women, since most of previous research have evaluated healthy sedentary women. Thus, longitudinal studies with an intra-subject design should be carried out to explore the influence of the hormonal changes over the life span.

Table 3. Performance variables (Mean±SD) throughout the interval running protocol.

		Eumenorrheic in the EFP	Postmenopausal	Z	*p*	d	CI
Bouts	$\dot{V}$e (l/min)	78.61±11.09	66.95±10.08	-7.906	<0.001	-1.09	-1.83 to -0.35
	%$\dot{V}$e max (%)	71.91±6.65	71.11±8.36	-1.485	0.138	-0.11	-0.82 to 0.60
	$\dot{V}O_2$/Kg (ml/kg/min)	38.62±4.04	33.74±3.95	-8.270	<0.001	-1.22	-1.97 to -0.47
	%$\dot{V}O_2$/Kg max (%)	79.64±5.26	75.98±10.64	-2.980	0.003	-0.48	-1.20 to 0.24
	$\dot{V}CO_2$ (ml/min)	2127.48±296.78	1914.77±248.91	-5.634	<0.001	-0.76	-1.48 to -0.05
	%$\dot{V}CO_2$ max (%)	60.62±15.04	65.33±8.91	-2.564	0.010	0.36	-0.36 to 1.07
	RER	0.962±0.060	1.031±0.083	-6.623	<0.001	1.03	0.29 to 1.76
	%RER max (%)	75.35±19.02	83.33±8.21	-4.499	<0.001	0.50	-0.22 to 1.22
	HR (bpm)	167.29±11.44	154.59±9.48	-7.578	<0.001	-1.18	-1.93 to -0.44
	%HR max (%)	91.86±1.73	91.07±2.44	-0.767	0.443	-0.39	-1.09 to 0.31
	RPE	15.15±3.18	13.97±1.81	-4.753	<0.001	-0.43	-1.13 to 0.27
Active recovery intervals	$\dot{V}$e (l/min)	64.34±8.77	55.06±9.47	-6.669	<0.001	-1.03	-1.76 to -0.29
	%$\dot{V}$e max (%)	58.96±6.33	58.54±8.53	-0.033	0.974	-0.06	-0.77 to 0.65
	$\dot{V}O_2$/Kg (ml/kg/min)	30.23±3.60	26.05±3.12	-8.395	<0.001	-1.22	-1.97 to -0.47
	%$\dot{V}O_2$/Kg max (%)	62.36±5.59	58.39±9.36	-3.296	0.001	-0.56	-1.28 to 0.17
	$\dot{V}CO_2$ (ml/min)	1801.27±257.15	1615.70±220.42	-5.878	<0.001	-0.76	-1.48 to -0.05
	%$\dot{V}CO_2$ max (%)	51.30±12.72	54.20±8.22	-0.555	0.579	0.26	-0.46 to 0.97
	RER	1.050±0.075	1.121±0.104	-5.579	<0.001	0.80	0.08 to 1.51
	%RER max (%)	82.11±20.36	90.51±9.83	-3.680	<0.001	0.48	-0.23 to 1.20
	HR (bpm)	156.17±13.12	142.96±13.93	-6.607	<0.001	-0.98	-1.71 to -0.25
	%HR max (%)	84.86±2.24	82.63±5.17	-0.889	0.374	-0.62	-1.32 to 0.09
	PR	4.00±0.99	4.15±0.82	-2.979	0.003	0.16	-0.53 to 0.85

$\dot{V}$e: ventilation; %$\dot{V}$e max: maximal ventilation percentage; $\dot{V}O_2$: oxygen consumption; %$\dot{V}O_2$ max: maximal oxygen consumption percentage; $\dot{V}$CO2: carbon dioxide production; %$\dot{V}CO_2$ max: maximal carbon dioxide production percentage; RER: respiratory exchange ratio; %RER max: maximal respiratory exchange ratio percentage; HR: heart rate; %HR max: maximal heart rate percentage; RPE: rate of perceived exertion; PR: perceived readiness.

Conclusions

This investigation suggests that postmenopausal cardiorespiratory response to exercise cannot be as high as premenopausal one when performing a high intensity interval training. This fact appears to be associated with age-related physiological changes, along with the chronic sex hormone decrease after menopause. Nonetheless, postmenopausal women present a similar cardiac strain when comparing to eumenorrheic females in relative values, which could be associated to the regular practice of physical activity. Further research is recommended to provide a better understanding of the potential effects of different hormonal profiles in cardiorespiratory system when studying physically active women.

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Conflict of interest

The authors do not declare a conflict of interest.

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Psychological intervention programs in sports injury rehabilitation processes

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Summary

Introduction: This paper aims to review the publications regarding the psychological interventions applied in the rehabilitation processes of injured athletes until 2020.
Material and method: A datasearch were conducted in Web of Science (WoS) databases according to the recommendations and criteria established in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement guidelines. To do this, the search terms sport injur*, psycho* and rehabilitation were used. The inclusion criteria used were: 1) to have as an object of study the measurement of psychological variables during the rehabilitation phase of a sports injury; 2) be empirical in nature and; 3) the application of a psychological training program as part of the treatment in the rehabilitation of the sports injury.
Results: After applying the search strategies, a total of 394 articles were obtained, of which after eliminating those that did not meet the exclusion criteria were reduced to 15 articles.
Conclusions: The results show that the most used psychological intervention programs in the rehabilitation of injured athletes have been relaxation, guided imagery, goal-setting and mindfulness. On the other hand, the most studied psychological variables were pain, adherence to rehabilitation and self-efficacy. Finally, the application of psychological intervention in the rehabilitation process of the injured athlete was effective, for the objective pursued, in 13 of the 15 works under study.

Key words:
Sport injur. Rehabilitation. Psychology. Psychological training. Sport.

Programas de intervención psicológica en procesos de rehabilitación de lesiones deportivas

Resumen

Introducción: El presente trabajo tiene como objetivo revisar las publicaciones respecto de las intervenciones psicológicas aplicadas en los procesos de rehabilitación de deportistas lesionados hasta el año 2020.
Material y método: Se realizó una búsqueda bibliográfica en la base de datos electrónica Web of Science (WoS) de acuerdo con las líneas de recomendación para revisiones sistemáticas y meta-análisis de la guía PRISMA. Para ello, se utilizaron los términos de búsqueda *sport injur**, *psycho** y rehabilitation. Los criterios de inclusión utilizados fueron: 1) tener como objeto de estudio la medición de variables psicológicas durante la fase de rehabilitación de una lesión deportiva; 2) ser de carácter empírico y; 3) la aplicación de un programa de entrenamiento psicológico como parte del tratamiento en la rehabilitación de la lesión deportiva.
Resultados: Tras aplicar las estrategias de búsqueda, se obtuvieron un total de 394 artículos, de los cuales tras eliminar los que no cumplían los criterios de exclusión se redujeron a 15 artículos.
Conclusiones: Los resultados muestran que los programas de intervención psicológica más utilizados en la rehabilitación de deportistas lesionados han sido la relajación, la visualización, el establecimiento de objetivos y el Mindfulness. Por su parte, las variables psicológicas más estudiadas fueron el dolor, la adherencia a la rehabilitación y la autoeficacia. Finalmente, la aplicación de intervención psicológica en el proceso de rehabilitación del deportista lesionado se mostró eficaz, para el objetivo que perseguía, en 13 de los 15 trabajos objeto de estudio.

Palabras clave:
Lesión deportiva. Rehabilitación. Psicología. Entrenamiento psicológico. Deporte.

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2021 SEMED Research Award

Introduction

An injury can constitute a catastrophic break that calls for major reflection and reconsideration, which athletes, at times, do not have sufficient resources to do in the best possible way[1-3]. In addition, such occasions can sometimes entail negative consequences on athletes' physical, neurological[4-8], and psychological health[9-11].

The Wiese-Bjornstal *et al.*[12] Model allows us to understand the relationships between sports injuries and psychological factors. Like the models of Andersen and Williams[13] and Williams and Andersen[14], this model dynamically integrates personal and situational factors into the response components to the injury[15]. The authors explain that an overarching emotional and behavioural response appears in the injured athlete that is caused by the situation and the cognitive assessments that they subsequently arrive at. Thanks to this model, it is understood that stress is not only a risk factor in sports injury, but also an obstacle to recovery.

As Olmedilla and García-Mas[2] explain, five fundamental lines of research are observed on the relationship between psychological factors and sports injuries. One of them focuses on the study of athletes' emotional and psychological reactions to injuries, associating them to behaviours vis-à-vis adherence to rehabilitation. In this line of research, notable works are Brewer *et al.*[16], Abenza *et al.*[17], and Chan and Hagger[18], which explain that factors such as stress, fear of pain, level of motivation, confidence, and others, are key in the rehabilitation process. In light of such works, it is important to take psychological techniques into account, both to improve adherence to treatment and to control anxiety levels, and to increase injured athletes' self-confidence[19-21]. To know which techniques are the most appropriate when carrying out psychological work with athletes in a rehabilitation process, one must know which psychological variables are the most affected or the most important to improve.

Based on the excellent systematic review of Cavanna and Chang[22], the objective of which was to identify the psychological problems considered most relevant by sports doctors for the rehabilitation process, the following can be highlighted: anxiety, stress, depression, level of adherence, and social support. In this sense, there is research that also highlights anxiety control, self-confidence, motivation and concentration[10,23-25]. Junichi and Hajime[26] emphasise aspects such as stress control or anxiety reduction. Yang *et al.*[27], emphasise social support, understanding it as athletes' assessment of the help that could be available from their social network, and their satisfaction with such support. Other studies have focused on analysing the relationship between personality traits and sports performance[28,29], where aspects such as competitiveness, team spirit, self-confidence and analytical disposition appear as significant predictors of sports performance.

In this sense, there are several studies that focus their psychological intervention on the use of techniques such as relaxation, goal setting or visualisation[30-34]. Specifically, different studies associate visualisation and relaxation with an improvement in psychological coping[33,34] and reduced anxiety over fear of re-injury[30,33,3]4. Also, although to a lesser extent, these techniques have additionally proven to be effective in reducing negative psychological consequences, improving psychological coping and reducing anxiety over fear of re-injury, psychological counselling, written sharing, and acceptance and commitment therapy[33].

In line with the proven importance of psychological intervention in the rehabilitation process of injured athletes, several research projects have begun to use them. Framed within a psychological training program, as part of an injured athlete's rehabilitation[35-37], they increasingly integrate psychological work into athletes' training.

Smith *et al.*[38] conducted a systematic review of the various coping strategies used by athletes recovering from sports injuries. In this review, it is noted that depression can be partially mitigated by setting short-term goals. Several studies[39,40] using psychological techniques as part of the rehabilitation of a sports injury demonstrated the treatment's efficacy.

In this sense, the following affirmations can be made: a) the reviews carried out are either very old, or were not focused exclusively on psychological intervention programs[22]; and b) there is a corpus of literature on psychological interventions in the rehabilitation processes of sports injuries, and it has been increasing in recent years.

In the light of the above, the objective of this paper is to review the existing publications until 2020 which aim to apply psychological intervention programs in the rehabilitation processes of injured athletes.

Materials and method

Search strategy

To search for the information studied herein, the Clarivate Analytics Web of Science (WoS) electronic database (https://webofknowledge.com) was used.

WoS is a powerful platform of the ISI *(Institute for Scientific Information)* that integrates different bibliographic databases and other resources covering all fields of scientific knowledge. The fields of analysis contained in the database are: topic, title, author, author identifiers, publisher, joint authorship, publication name, DOI, year of publication and address.

Procedure

A systematic review of the literature was carried out following the pre-defined protocol for the stages of identification, screening, selection, and inclusion, as described in the PRISMA[41] guide.

The *Social Science Citation Index* (SSCI) and *Science Citation Index* (SCI) databases were selected in the WoS database to perform data queries.

A detailed search of original articles was carried out using a series of keywords in order to filter the articles dealing with this subject. To do this, we used the advanced search using a topic with the descriptors (topic= *sport injur**) and (topic=*psycho**) and (topic=*rehabilitation*). All articles published up to and including 2020 were analysed.

The initial search yielded a total of 394 articles that matched the defined keywords. This total was reduced after applying the exclusion criteria to properly analyse the information.

Exclusion criteria

Of the works identified (n=394) the following exclusion criteria were applied:

- The research subject was the validation of an instrument.
- The research subject was a bibliographic review.
- The research was not of an empirical nature.
- The research did not address at least one psychological variable.
- The research did not apply a psychological training program.

Following these criteria, a total of 15 articles were included in the review. Figure 1 details the excluded works according to the aforementioned criteria.

Data analysis

After selecting the articles that made up the analytical corpus of the study, they were analysed according to a series of variables such as: complete citation; research objectives; applied psychological intervention program; psychological variables studied in the research; assessment tools used and; research results.

Results

In the aforementioned way, and in keeping with the exclusion criteria, 15 articles were selected in the end.

Table 1 below lists the studies that incorporated a psychological intervention program in the rehabilitation process of sports injuries in athletes.

Figure 1. Selection process of the articles included in the review.

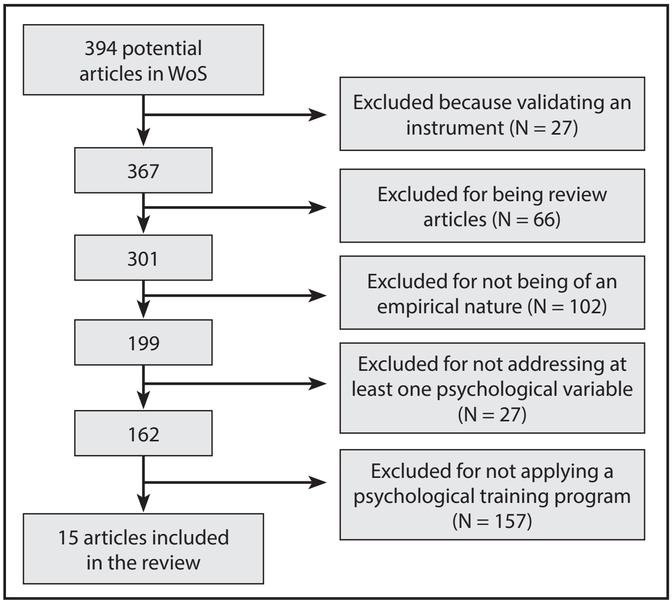

Table 2 shows the most relevant aspects of each of the publications, specifically: the complete citation of the article, the research objectives, the psychological intervention program used in the study, the psychological variables studied in the research, the psychological assessment instruments and, finally, the research results.

The most commonly used psychological technique in the intervention programs was visualisation, followed by goal setting and relaxation, psychological counselling and mindfulness. The psychological variables that attracted the most interest in the studies were pain, adherence to rehabilitation and self-efficacy. Self-reports predominated as an assessment instrument and the results showed the effectiveness of the psychological intervention program that was adopted in 13 of the 15 studies under investigation.

Discussion

The objective of this work was to review, in the current state of the literature, the existing publications in which psychological training programs were applied in the rehabilitation processes of injured athletes.

Taking into account the search source, the keywords and the exclusion criteria used in obtaining the articles of interest to this research, it was observed that few studies (N=15) focused on the application of a psychological training program as part of the rehabilitation process in injured athletes.

Table 1. Studies that incorporate a psychological intervention program in the rehabilitation process.

Authors	Psychological intervention program
Brinkman *et al.* 2020	Goal setting
Arvinen-Barrow *et al*. 2020	Active video games (AVG)
Podlog *et al.* 2020	Cognitive Behavioural Therapy (CBT)
Mohammed *et al.* 2018	Mindfulness
Palmi *et al.* 2018	Mindfulness
Pazit *et al.* 2017	Communication and information
Carson *et al.* 2014	Visualisation
Mankad and Gordon, 2010	Pennebaker's writing paradigm
Vergeer, 2006	Visualisation
Christakou y Zervas, 2007	Relaxation and visualisation
Thatcher *et al.* 2007	Reversal theory
Rock and Jones, 2002	Psychological counselling
Evans and Hardy, 2002	Goal setting
Cupal and Brewer, 2001	Relaxation and visualisation
Brewer *et al*. 1994	Goal setting, visualisation and psychological counselling

Table 2. Analysis of the selected articles as a sample of the systematic review.

<table>
<tr><td colspan="3">Use of goal setting to enhance self-efficacy after sports-related injury: a critically appraised topic
(Brinkman <i>et al.</i> 2020)</td></tr>
<tr><td>Objectives
To know if goal setting is effective in improving self-efficacy after a sports injury</td><td>Psychological Intervention Program
Goal setting</td><td>Psychological variables
Efficacy</td></tr>
<tr><td colspan="3">Psychological Assessment Instruments
<i>Sports Injury Rehabilitation Beliefs Survey</i></td></tr>
<tr><td colspan="3">Results
The results support improved self-efficacy for athletes undergoing rehabilitation for sports injuries when using goal setting</td></tr>
<tr><td colspan="3">Functional outcomes and psychological benefits of active video games in the rehabilitation of lateral ankle sprains: a case report
(Arvinen-Barrow <i>et al</i>. 2020)</td></tr>
<tr><td>Objectives
Examine the functional outcomes and psychological benefits of the active video game (AVG) rehabilitation program in injured athletes</td><td>Psychological Intervention Program
Active Video Games (AVG)</td><td>Psychological variables
Adherence to rehabilitation, perception of pain, perception of readiness for RTP and mood</td></tr>
<tr><td colspan="3">Psychological assessment instruments
Measure of adherence to training rehabilitation in athletes
Pain Visual Analog Scale (VAS)
Injury-Psychological Readiness to Return to Sport Scale
Brunel Mood Scale</td></tr>
<tr><td colspan="3">Results
The results are favourable at the functional level of the injury, but the application of AVG does not produce improvement in the psychological variables of the study</td></tr>
<tr><td colspan="3">A cognitive behavioural intervention for college athletes with injuries
(Podlog <i>et al</i>. 2020)</td></tr>
<tr><td>Objectives
Examine the efficacy of a CBT intervention in improving psychological well-being, rehabilitation adherence and outcomes</td><td>Psychological Intervention Program
Cognitive Behavioural Therapy (CBT)</td><td>Psychological variables
Positive and negative affect, vitality and self-esteem</td></tr>
<tr><td colspan="3">Psychological assessment instruments
Self-reports</td></tr>
<tr><td colspan="3">Results
The results show improvements in the emotional well-being of the study subjects compared to the control group.</td></tr>
<tr><td colspan="3">Effect of Mindfulness Bases Stress Reduction (MBSR) in increasing pain tolerance and improving the mental health of injured athletes
(Mohammed <i>et al.</i> 2018)</td></tr>
<tr><td>Objectives
Evaluate the role of MBSR in reducing perceived pain and decreasing anxiety and stress, and increasing tolerance to stress and mindfulness</td><td>Psychological Intervention Program
Mindfulness Based Stress Reduction (MBSR) Program</td><td>Psychological variables
Pain, anxiety, and stress</td></tr>
<tr><td colspan="3">Psychological Assessment Instruments
Cold Pressor Test (CPT)
Visual Analogue Scale (VAS)
Mindful Attention Awareness Scale (MAAS) (Brown and Ryan, 2003)
Depression Anxiety and Stress Scale (DASS) (Lovibond and Lovibond, 1995)
Profile of Mood States (POMS) (Terry <i>et al</i>. 2003)</td></tr>
<tr><td colspan="3">Results
The results show increased tolerance to pain and increased awareness
Anxiety and stress decreased as the sessions went on</td></tr>
<tr><td colspan="3">Mindfulness rehabilitation intervention of an injured athlete: professional football case
(Palmi <i>et al</i>. 2018)</td></tr>
<tr><td>Objectives
Evaluate the effectiveness of a mindfulness intervention in the rehabilitation of an injured athlete</td><td>Psychological Intervention Program
Mindfulness</td><td>Psychological variables
States of mood, full self-awareness, and emotions</td></tr>
<tr><td colspan="3">Assessment Instruments
Profile of Mood States (POMS)
Mindful Attention Awareness Scale (MAAS)
Positive and Negative Affect Schedule (PANAS)</td></tr>
<tr><td colspan="3">Results
The results demonstrate the efficacy of this intervention in improving subjective perception of mood during rehabilitation</td></tr>
</table>

(continuation)

Table 2. Analysis of the selected articles as a sample of the systematic review. (continuation).

A novel web-support intervention to promote recovery following Anterior Cruciate Ligament Reconstruction: a pilot randomised controlled trial (Pazit *et al*. 2017)		
Objectives Evaluate the efficacy of an internet-based intervention regarding perceptions of knee pain, function, self-efficacy and fear of pain	**Psychological Intervention Program** Communication and Information	**Psychological variables** Perception of pain, self-efficacy and fear of pain
Assessment tools Semi-structured telephone interviews Fear-Avoidance Beliefs questionnaires Tampa Scale for Kinesiophobia Knee Self Efficacy Scale (K-SES)		
Results The results show the effectiveness of the internet-based intervention as an information tool		
A case study of technical change and rehabilitation: intervention design and interdisciplinary team interaction (Carson *et al*. 2014)		
Objectives Research an interdisciplinary team's approach to technical change and rehabilitation of an injured athlete	**Psychological Intervention Program** Visualisation and Self-Efficacy	**Psychological variables** Visualisation and self-efficacy
Assessment tools Instruments created *ad hoc*		
Results The results show that self-reporting measures of self-efficacy and visualisation were considered essential to facilitate change, highlighting the multifactorial nature of the intervention		
Psycholinguistic changes in athletes grief response to injury after written emotional disclosure (Mankad y Gordon, 2010)		
Objectives Examine the effectiveness of Pennebaker's standard writing paradigm in improving psychological response	**Psychological Intervention Program** Pennebaker Standard Writing Paradigm	**Psychological variables** Psychological responses, self-efficacy and writing
Assessment tools Psychological Responses to Sport Injury Inventory[31] (PRSII) The 19-item Sport Injury Rehabilitation Beliefs Survey[12] Linguistic Inquiry Word Count[32] (LIWC2007)		
Results The results demonstrated that the writing paradigm was effective in improving psychological rehabilitation by contributing to a better personal understanding of the injury event and attenuating the grief-related response		
Exploring the mental representation of athletic injury: a longitudinal case study (Vergeer, 2006)		
Objectives Improve the knowledge and use of visualisation, thoughts, and sensations related to the injury during the rehabilitation process	**Psychological Intervention Program** Visualisation	**Psychological variables** Visualisation, thoughts and sensations
Assessment tools Unspecified		
Results The results indicate the importance of consciousness, mental images, the mental model of the injury, the mental "itinerary" of the future and the self-concept desired by the athlete as interdependent dimensions in the visualisation of injuries		
The effectiveness of imagery on pain, edema, and range of motion in athletes with a grade II ankle sprain (Christakou y Zervas, 2007)		
Objectives Examine the effectiveness of visualisation and relaxation training	**Psychological Intervention Programa** Relaxation and Visualisation	**Psychological variables** Visualisation and pain
Assessment tools Visual Analog Scale (EAV)		
Results No significant differences in pain were found between the two groups after performing visualisation		

(continuation)

Table 2. Analysis of the selected articles as a sample of the systematic review. (continuation).

<table>
<tr><td colspan="3">A reversal theory analysis of psychological responses during sports injury rehabilitation
(Thatcher <i>et al.</i> 2007)</td></tr>
<tr><td>Objectives
Evaluate the effectiveness of reversal theory in the emotional and psychological process of rehabilitation from injury</td><td>Psychological Intervention Program
Reversal Theory</td><td>Psychological variables
Motivational states, injury beliefs, emotional and psychological responses</td></tr>
<tr><td colspan="3">Assessment tools
Motivational Style Profile (MSP)
Sports Injury Rehabilitation Beliefs Survey (SIRBS)
Structured interviews <i>ad hoc</i> to assess emotional and psychological responses to injury</td></tr>
<tr><td colspan="3">Results
The results demonstrate the efficacy of Reversal Theory in this context</td></tr>
<tr><td colspan="3">A preliminary investigation into the use of counselling skills in support of rehabilitation from sport injury
(Rock y Jones, 2002)</td></tr>
<tr><td>Objectives
Analyse the usefulness of psychological counselling in the rehabilitation of injured athletes</td><td>Psychological Intervention Program
Psychological Counselling</td><td>Psychological variables
Social support, adherence, mood and pain</td></tr>
<tr><td colspan="3">Assessment tools
Semi-structured interviews created <i>ad hoc</i>
Social Support Behaviours Survey (SSBS)
Sport Injury Rehabilitation Adherence Scale (SIRAS)
Emotional Responses of Athletes to Injury Questionnaire (ERAIQ)
Patient Information Questionnaire (PIQ)</td></tr>
<tr><td colspan="3">Results
The results show the beneficial impact of psychological counselling on outcomes of rehabilitation from injury, especially during setbacks</td></tr>
<tr><td colspan="3">Injury rehabilitation: a goal-setting intervention study
(Evans y Hardy, 2002)</td></tr>
<tr><td>Objectives
Examine the effects of an intervention based on goal-setting</td><td>Psychological Intervention Program
Goal-setting</td><td>Psychological variables
Adherence, self-efficacy, hopelessness, time management</td></tr>
<tr><td colspan="3">Assessment tools
<i>Ad hoc</i> self-reporting to assess adherence to rehabilitation
Sports Injury Rehabilitation Beliefs Survey (SIRBS)
Psychological Responses to Injury (20item PRSII)</td></tr>
<tr><td colspan="3">Results
In the study group that received goal-setting treatment, increased levels were observed of adherence to rehabilitation, self-efficacy, improved time management and decreased hopelessness, compared to the control group.</td></tr>
<tr><td colspan="3">Effects of relaxation and guided imagery on knee strength, reinjury anxiety, and pain following anterior cruciate ligament reconstruction
(Cupal y Brewer, 2001)</td></tr>
<tr><td>Objectives
Examine the effects of relaxation and visualisation on knee strength, anxiety toward a new injury, and pain from surgery</td><td>Psychological Intervention Program
Relaxation and Visualisation</td><td>Psychological variables
Anxiety toward a new injury and pain</td></tr>
<tr><td colspan="3">Assessment tools
<i>Ad hoc</i> self-report instrument to assess anxiety toward a new injury
<i>Ad hoc</i> self-report instrument to assess perceived pain</td></tr>
<tr><td colspan="3">Results
A decrease was appreciated in anxiety toward a new injury and perceived pain in the treatment group versus the control group</td></tr>
</table>

(continuation)

Table 2. Analysis of the selected articles as a sample of the systematic review. (continuation).

Perceptions of psychological interventions in the context of sport injury rehabilitation (Brewer *et al.* 1994)		
Objectives Evaluate the perception of three different psychological interventions in the context of rehabilitation from a sports injury	**Psychological Intervention Program** Goal-setting, visualisation, psychological counselling	**Psychological variables** Perceived satisfaction, adherence, beliefs, motivation
Assessment tools Intervention Perceptions Questionnaire (IPQ) Treatment Acceptability Questionnaire (TAQ)		
Results The results show that goal setting, visualisation and psychological counselling are effective to be used in the treatment of injured athletes		

The interest in studying the relationship between sports injuries and psychological factors has led to rehabilitations more frequently combining physical and psychological aspects, which has given rise to interesting works[32]. In this study, the research studies identified were carried out in the last 20 years. Specifically, 9 articles were published between 2010 and 2020 and 6 articles between 2001 and 2006.

The main objective of the 15 analysed studies was to assess the effectiveness of the psychological training program applied in the injured athlete's rehabilitation. The most applied psychological intervention program was visualisation (used in 5 of the 15 publications), followed by goal setting and psychological techniques such as relaxation, psychological counselling and mindfulness.

Although the different treatments applied were effective in the rehabilitation processes, visualisation proved to be the most used and the most effective technique. It obtained favourable results in 4 of the 5 studies where it was used as the main psychological intervention program. It is also worth mentioning the effectiveness of mindfulness, which achieved positive results after application in the two studies where it was used. These techniques were effective in improving different states of anxiety and concentration[42], increasing self-esteem and promoting coping and stress management strategies[43] and, therefore, in improving sports performance[44].

On the other hand, the most studied psychological variables were pain, adherence to rehabilitation, and self-efficacy, followed by others such as anxiety, mood, perceived satisfaction, motivation or stress. In keeping with the scientific evidence, with decreased anxiety comes better performance[45] and, by extension, better coping strategies[43].

Different assessment instruments were used in the different studies, proving to be very specific for each study. The most used method was self-reports. The fact that most of the instruments used were self-reported demonstrated the importance and consistency of this instrument in the analysis of psychological variables.

In sum, in accordance with the results, the interventions that were carried out helped the injured athletes in their rehabilitation processes. Although not in all cases—but in most—it was possible to improve the indicators of the psychological variables under analysis (decreased anxiety, pain control, improved mood, or improved self-efficacy with respect to recovery). The results obtained, as well as the intervention proposals, could be useful tools for sports psychologists both to develop working hypotheses and more appropriate interventions.

Conclusions

The following conclusions were drawn in relation to this review's objective of grasping the current state of the literature as relates to the application of psychological training programs as intervention tools in the rehabilitation of sports injuries:

– The most commonly used technique was visualisation, which was used in 5 of the 15 publications that were analysed.
– Goal setting was used in 3 studies, followed by psychological counselling, mindfulness and relaxation, which were used in two publications (each).
– The most studied psychological variables were pain, adherence to rehabilitation and self-efficacy.
– The assessment instruments used were very different, the most used being self-reports.
– The results showed the efficacy of the psychological intervention in 13 of the 15 articles analysed.

Limitations and future lines of research

The WoS electronic database is the most important database and includes almost all prestigious journals. Despite this, it would perhaps be interesting to expand the search to other databases, thus recovering articles that were not identified in this search.

According to the results, in future lines of research, it would be important to publish the application of professional interventions, either focused on psychological aspects or as interdisciplinary interventions that improve the proper understanding of injured athletes' rehabilitation processes. This is specifically so in the case of applying psychological techniques such as visualisation or psychological establishment in pain treatment or adherence to rehabilitation treatment.

Conflict of interest

The authors do not declare any conflict of interest.

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Analysis of the variations in balance and proprioception in relation to the practice of surfing: a pilot study

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Summary

Introduction: Surfing is a sport that requires a level of balance since it takes place in a changing environment. Hypothesis: Exercises that value proprioception are expected to show better results in advanced surfers than in beginners and non-surfers.
Objective: To assess how the practice of surfing intervenes in proprioception by comparing beginners and advanced surfers with each other, and with non-surfers.
Material and method: A sample of 30 participants, 10 surf beginners, 10 advanced surfers and 10 non-surfers, was tested in Valencia ("Mediterranean Surf School") and Zarautz ("ESSUS"). A questionnaire and 6 tests were performed evaluating: the static balance, Balance Error Scoring System (BESS) and dynamic, Y-Balance Test (YBT); back flexibility, Schober's Modified-modified-Test, and lumbar strength and resistance, Biering-Sorensen test (BSTT); perceived effort, the Borg scale; and quadriceps strength, ChronoJump® kit.
Results: In the BESS test there were significant differences ($p = 0.02$) in the total result of errors on unstable surface, being lower in advanced surfers than in non-surfers. In the total scores of the YBT, in the Schober test and in the BSTT, we did not obtain differences. Surfers improved in quadriceps isometric strength and on the Borg test ($p = 0.008$).
Conclusions: No differences in balance strategies were obtained. We observed improvement of the static balance in advanced surfers compared to non-surfers, when the demand for balance is at its highest.

Key words:
Surf. Balance. Water Sports. Proprioception. Postural balance.

Análisis de las variaciones del equilibrio y propiocepción en relación con la práctica del surf: estudio piloto

Resumen

Introducción: El surf es un deporte que requiere un nivel de equilibrio ya que se desarrolla en un entorno cambiante. Hipótesis: Se espera que los ejercicios que valoran la propiocepción muestren mejores resultados en surfistas avanzados que en principiantes y no surfistas.
Objetivo: Evaluar cómo la práctica del surf interviene en la propiocepción comparando a los surfistas principiantes y avanzados entre sí, y con los no surfistas.
Material y método: Una muestra de 30 participantes, 10 surfistas principiantes, 10 surfistas avanzados y 10 no surfistas, fue analizada en Valencia ("Mediterranean Surf School") y Zarautz ("ESSUS"). Se realizó un cuestionario y 6 pruebas que evaluaban: el equilibrio estático, Balance Error Scoring System (BESS) y el dinámico, Y-Balance Test (YBT); la flexibilidad de la espalda, Schober's Modified-modified-Test, y la fuerza y resistencia lumbar, Biering-Sorensen test (BSTT); el esfuerzo percibido, la escala de Borg; y la fuerza del cuádriceps, ChronoJump® kit.
Resultados: En el test BESS hubo diferencias significativas ($p = 0{,}02$) en el resultado total de errores en superficie inestable, siendo menor en los surfistas avanzados que en los no surfistas. En las puntuaciones totales del YBT, en el test de Schober y en el BSTT, no se obtuvieron diferencias. Los surfistas mejoraron en la fuerza isométrica del cuádriceps y en el test de Borg ($p = 0{,}008$).
Conclusiones: No se obtuvieron diferencias en las estrategias de equilibrio. Observamos una mejora del equilibrio estático en los surfistas avanzados en comparación con los no surfistas, cuando la demanda de equilibrio es máxima.

Palabras clave:
Surf. Equilibrio. Deportes acuáticos. Propiocepción. Equilibrio postural

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Best Paper Honourable Mention Award at the Congress

Introduction

As a sport, surfing is currently experiencing a boom, attracting an increasing number of enthusiasts. Balance is an essential performance quality of this sport, while muscle strength, cardiorespiratory endurance and aerobic and anaerobic power also play an important part[1,2]. However, the fact that it is necessary to stand up on an unstable surface makes the athlete's balance the fundamental basis for practising surfing. Furthermore, unlike other sports, external factors come into play, given that it is performed in an ever changing environment that requires surfers to continuously adapt their balance to the conditions of the moment[3].

Balance is fundamental to what are considered to be the Basic Activities of Daily Living (BADL), for both maintaining one's position and also for performing a daily movement or learning new, more specific movements. This requires the interaction of different systems such as the sensitive vestibular, visual and proprioceptive system, the central nervous system and the musculoskeletal system[4,5].

Balance is directly related to proprioception. This system in turn is supported by muscles, joints and cutaneous receptors that incorporate information on the status of the effector system (force, tension, orientation, position of limbs) and environmental information (distribution of pressure, contact with the surface and others)[4]. This information is transmitted to the brain where it is processed, subsequently preparing and sending position adjustment responses[4,6].

These systems, which are essential for balance, provide us with somatosensory information. Damage to these systems, which occurs in certain pathologies, represents a difficulty for the BADL. Therefore, a joint injury will affect this proprioceptive system and, consequently, this will lead to an alteration of the somatosensory information. These alterations on the system may subsequently make an individual prone to further injury[6]. In the same way as for the proprioceptive system, it is possible to train, for example, to perform specific movements in certain sports, it is also possible to train to improve proprioception following an injury or in certain pathologies such as those resulting from certain injuries of the central nervous system.

Like in any other learning context, brain neuroplasticity is also involved in this balance training process[8,9]. So that the repetition of movements generates new circuits or adaptations in the nervous system, this produces a response base that we can use whenever required10. Factors such as exercising outdoors or with social contact, stimulate the nervous system in its training[11].

Therefore, balance and proprioception could generate this neuroplasticity that is essential in pathologies such as stroke, autism and others. Neuronal plasticity and the importance of sport are already being taken into account in rehabilitation therapies[8,12]. We can therefore highlight the importance of surfing. Currently, the adaptive surfing category exists as a professional sport, showing us that those with some kind of difficulty for practising surfing are able to surf by adapting surfing to their disability. Therefore, it could be thought that surfing could give them a better quality of life related to the development of balance, strength, among others.

The hypothesis of this work was that surfing is an effective stimulus on all those factors underpinning balance. The objective of this study was to evaluate whether the practice of surfing plays a part in the balance and proprioception of athletic subjects, making a comparison between beginner and advanced surfers and with a control group who did not practice sport.

Material and method

This is a correlational/analytical, cross-sectional, descriptive study. All participants gave their consent to participate in the study, and it was approved by the ethics committee of the Universidad Católica of the UCV/2018-2019/110 (Catholic University of Valencia). The entire study complies with the provisions of the Declaration of Helsinki for research involving human subjects. 30 subjects aged from 18 to 30 years of both sexes voluntarily took part in the study, recruited from the "Mediterranean Surf School" in Valencia and "ESSUS" (Surf School) in Zarautz (Guipúzcoa), and university students of Valencia. Of these, 20 individuals were surfers (10 beginners and 10 advanced) and 10 individuals did not practice any sport at all (control group).

The inclusion criteria were: be aged between 18 and 30 years; the control group did not routinely practice sport; the beginner surfers had surfed for 1 year to date; and the advanced surfers for at least 5 years. The exclusion criteria were: taking medication that could affect balance; musculoskeletal injuries that could make it impossible to perform the tests; and disorders affecting balance. In order to evaluate the proprioception of the participants more completely, we conducted a static balance BESS test and a dynamic Y-Balance Test. Due to the fact that different systems are involved in balance and to the difficulty to measure balance as a whole, further tests were conducted in order to evaluate back strength (Biering-Sorensen Test), quadriceps strength (isometric strength- *ChronoJump BoscoSystem*) and flexibility (*Modified-modified Schober Test*) as well as cardiopulmonary strength (Borg Scale) (Figure 1).

The sampling size was determined by the number of volunteers willing to participate in the study. The IBM® SPSS® Statistics version 22 statistical package was used to analyse the results. The graphics design was made with the Microsoft® Excel® 2019 processor. We performed a descriptive analysis of the test results and we studied the mean averages. For the comparative analysis, we used non-parametric tests due to the fact that the sample data were not normally distributed. We studied the relationship of the ranges between the groups and performed a statistical analysis to compare the data of the continuous variables between the different independent groups with the Mann-Whitney U test, taking 5% as the significance level.

Results

The demographic data are shown in Table 1 and Table 2. Data were collected from the 30 participants with a mean age of 22

Table 1. Demographic characteristics of participants.

	N	Mean	Standard deviation
Age			
Control	10	21.7	2.50
Beginner surfer	10	21.6	1.17
Advanced surfer	10	22.6	2.32
Total	30	21.97	2.06
Height (cm)			
Control	10	170.1	11.81
Beginner surfer	10	173.9	7.71
Advanced surfer	10	170.2	9.66
Total	30	171.4	9.69
Weight (kg)			
Control	10	63.75	15.32
Beginner surfer	10	67.84	11.58
Advanced surfer	10	67.07	13.45
Total	30	66.22	13.19

(range: 20-27 years), 10 women and 20 men, with a mean height of 171.4 cm (range: 160-180 cm) and mean weight of 66.22 kg (range: 51-77 kg). 10 subjects did not practice any sport, 10 were beginner surfers and 10 were professional surfers.

The results obtained in the BESS test are provided in Figure 2. The advanced surfers group showed a total of 11.5 errors (9.1 on foam Surface and 2.4 on *firm Surface*), the beginner surfers group showed 12.7 errors (9.6 on *foam Surface* and 3.1 on *firm Surface*) while the control group showed 14.7 errors (11.6 on foam Surface and 3.1 on firm Surface). There were significant differences in the total number of errors between the control group and the advanced surfers group (p= 0.02), in tandem stance on the foam (p=0.01) and the total number of errors on the foam (p=0.03).

The results measured using the Y-Balance Test test are shown in Figure 3. The greatest mean scores were obtained for the Composite Reach Distance (%) in the surfer groups, with a higher score for the

Table 2. Absolute and relative frequencies of questionnaire variables.

	Control		Beginner		Advanced		Total	
Sex	AF	RF	AF	RF	AF	RF	AF	RF
Female	5	0.50	2	0.20	3	0.30	10	0.33
Male	5	0.50	8	0.80	7	0.70	20	0.67
	10	1.00	10	1.00	10	1.00	30	1.00
Location								
Valencia	10	1.00	8	0.80	2	0.20	20	0.67
Zarautz	0	0.00	2	0.20	8	0.80	10	0.33
	10	1	10	1	10	1	30	1
Age								
18-20 years	4	0.4	1	0.1	1	0.1	6	0.2
21-23 years	5	0.5	9	0.9	6	0.6	20	0.6667
24-27 years	1	0.1	0	0	3	0.3	4	0.1333
	10	1	10	1	10	1	30	1
Height								
150-160 cm	2	0.2	1	0.1	2	0.2	5	0.1667
161-170 cm	3	0.3	3	0.3	4	0.4	10	0.3333
171-180 cm	4	0.4	3	0.3	3	0.3	10	0.3333
181-190 cm	1	0.1	3	0.3	1	0.1	5	0.1667
	10	1	10	1	10	1	30	1
Weight								
40-50 Kg	1	0.1	1	0.1	2	0.2	4	0.1333
51-60 Kg	5	0.5	1	0.1	1	0.1	7	0.2333
61-70 Kg	1	0.1	4	0.4	2	0.2	7	0.2333
71-80 Kg	0	0	2	0.2	3	0.3	5	0.1667
81-90 Kg	3	0.3	2	0.2	2	0.2	7	0.2333
	10	1	10	1	10	1	30	1
Dominance								
Right	5	0.5	10	1	8	0.8	23	0.7667
Left	5	0.5	0	0	2	0.2	7	0.2333
	10	1	10	1	10	1	30	1
Smokers								
No	9	0,9	8	0,8	8	0,8	25	0,8333
Yes	1	0,1	2	0,2	2	0,2	5	0,1667
	10	1	10	1	10	1	30	1
Years/Smoking								
No	9	0.9	8	0.8	8	0.8	25	0.8333
Yes	1	0.1	2	0.2	2	0.2	5	0.1667
	10	1	10	1	10	1	30	1
Sport								
No	2	0.2	0	0	1	0.1	3	0.1
Yes	8	0.8	10	1	9	0.9	27	0.9
	10	1	10	1	10	1	30	1

Figure 1. A) Bess Test. B) YBT Test. C) *ChronoJump*.

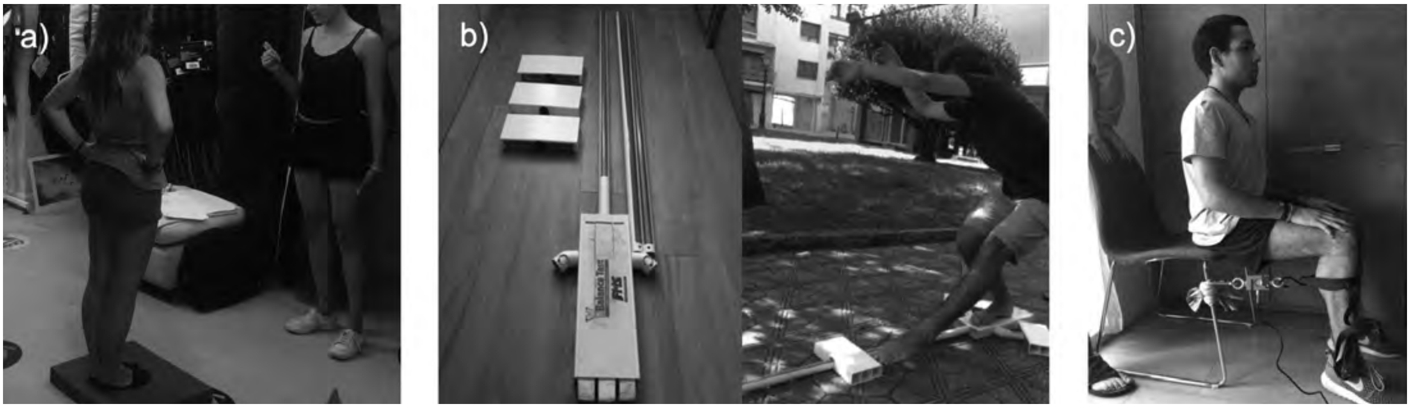


Figure 2. Comparison or number of errors between a firm and unstable surface. BESS Test

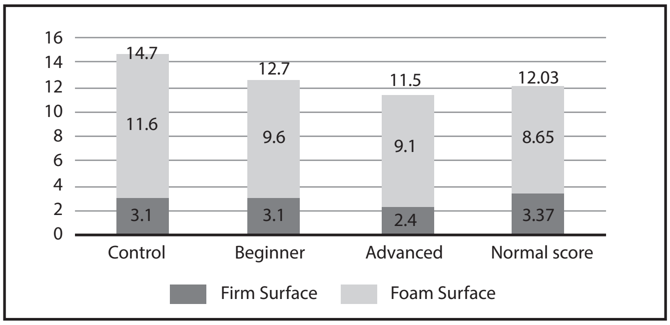
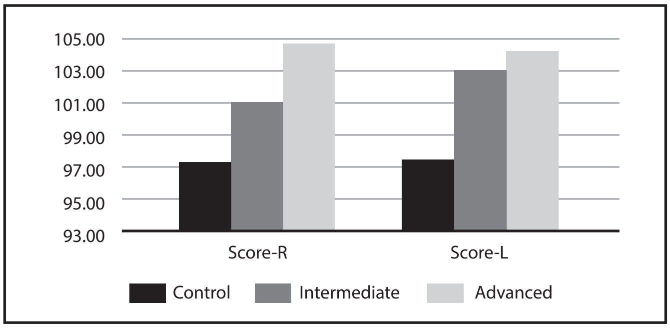


Figure 3. YBT comparison of Scores between right and left legs between the groups.



R: *Right;* L: *Left.*

Figure 4. BST comparison of groups at 1st, 2nd attempt, mean and the difference between the 1st and 2nd attempt.

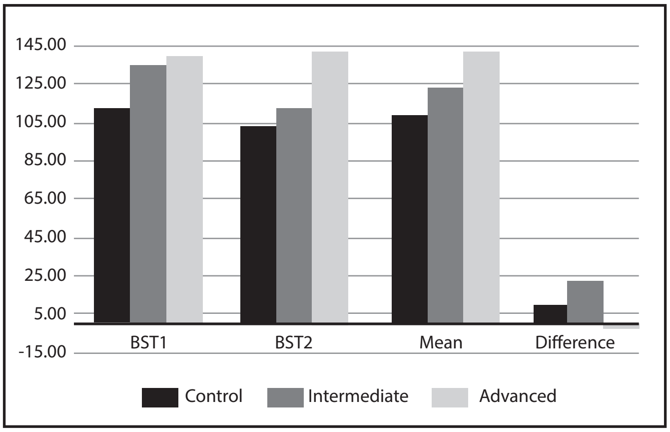
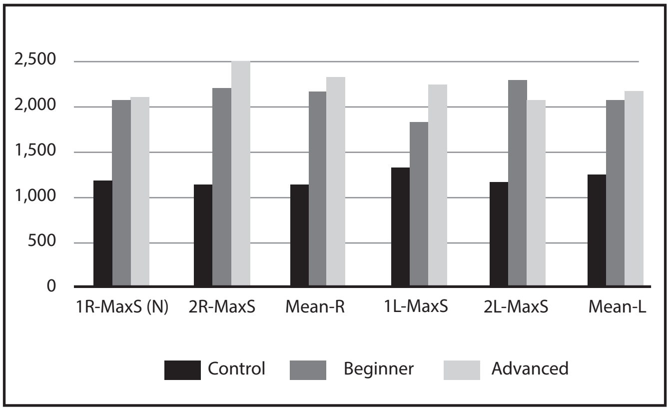


Figure 5. Maximum quadriceps strength *(ChronoJump)*.



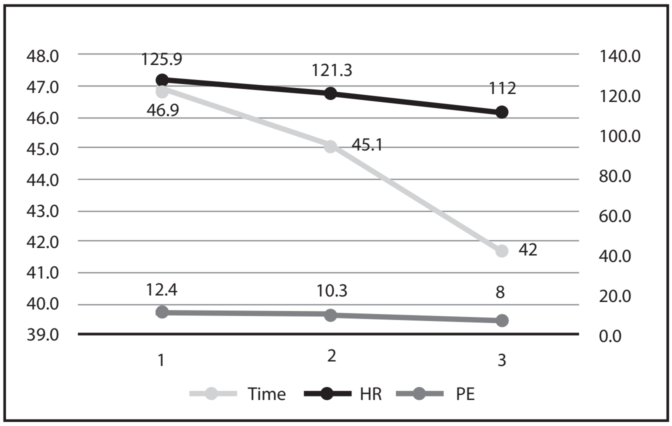
R: *Right*, L: *Left*; MaxS: maximum strength; 1: first attempt; 2: Second attempt: N: Newtons.

advanced surfers. Significant differences were observed in the comparison between advanced surfers and non-surfers, in two of the directions with the right leg, the posteromedial (p= 0.03) and the posterolateral (p= 0.03). When comparing beginner surfers with non-surfers, significant differences were obtained in the posteromedial direction, for both the right leg (p= 0.03) and the left one (p= 0.001), and in the posterolateral direction with the right leg (p= 0.017).

The results measured using the Biering-Sorensen Test are shown in Figure 4. We observed for the advanced surfers an increase in the mean time in the study stance of the second attempt in relation to the first, as well as a greater mean time in both attempts compared to the beginner surfers and non-surfers.

In the descriptive analysis of the maximal isometric quadriceps strength test (Figure 5), it can be seen how the mean strengths of the

Figure 6. Borg Test with the means for frequency after completing the circuit.



1: Control; 2: Beginner; 3: Advanced; HR: heart rate; PE: Perceived effort.

control group remained below those of the surfer groups. Significant differences were observed when comparing the results of the attempts of the control group with the right foot, with the beginner surfer group (p<0.05) and advanced surfers (p<0.05); and the second attempt with the left leg, when comparing these same groups (p<0.05).

Finally, in the comparative analysis of the Borg test (Figure 6), significant differences were observed in the perceived effort scale when comparing non-surfers with advanced surfers (p=0.008). We also observed significant differences in the heart rate after completing the circuit for the first time and the minute of rest for non-surfers (p=0.02) and beginner surfers (p=0.03) in relation to the advanced surfers, who exhibited lower values.

Discussion

For the BESS test, we obtained significant differences that reflect better results for the group of advanced surfers compared to the beginner and control groups, both for the foam testing surface and for total errors. This leads us to think that, with increased balance demands, on an unstable surface and without the visual system, advanced surfers have better postural control and intrinsic proprioception. There were no significant differences between the control group and the beginner group. This could be due to the fact that they were performing this exercise for the first time. For future studies, it could be of interest to test whether, following a minimum practice time, the difference in errors increases, as well as the influence of the visual system by repeating the exercise with the subject's eyes open, given that other studies have obtained different results by varying the state of this sensitive system[3,5]. It could also be of interest to observe the variations in balance between groups when having to concentrate on another mental task.. When comparing advanced surfers with swimmers, Chapman *et al.*[5] concluded that when a balance test was performed together with another cognitive test, expert surfers adapted their posture more easily. The participant who obtained less errors (5 errors) in this test, had an extremely advanced slackline level. To the best of our knowledge, there is no prior literature in which this test has been used on surfers.

The dynamic balance was evaluated with the Y-Balance Test, a test that requires strength, flexibility, neuromuscular control and proprioception, which are characteristics that play a part in balance[13]. Neither has this test been previously used on surfers to evaluate balance. However, a study in which the YBT test was conducted on football players recorded a mean Composite Reach Distance (%) for amateur football players (98.8±9.2%, left; 99.2±8.8%, right) and professionals (96.9±8%, left; 98.5±8.5%, right) that was less than that recorded in this study for beginner surfers (103% left; 101.1% right) and advanced surfers (104.3% left; 104.8% right)[14]. The same thing happens when comparing the results with another study on healthy young adults[13,14].

The Modified-Modified Schober Test was used to measure the flexibility of surfers and non-surfers, finding no significant differences. With regard to the mean, we could interpret the reduction in the average for the beginner group as the result of overexertion in the first attempt, leading to exhaustion or discomfort in the hamstrings, antagonist hip flexor muscles. Renneker *et al.*[1] described a limited flexibility of the shoulder, back and hamstrings of surfers. Prior literature indicates that flexibility may be reduced as a result of the repetition of movements and intense training, although back pain may also be a factor related to the above[14,15]. In our study, no subject suffered from lumbago at the time of the tests, given that this was included in the exclusion criteria.

We have found no studies that evaluate the back strength of surfers. We considered the Biering-Sorensen Test (BST) to be a suitable test to measure back strength and resistance. Despite the fact that no significant differences were obtained between groups, when the mean averages were compared we observed that the advanced surfers had greater back strength and resistance, slightly increasing from one attempt to the next with a mean time of 140 seconds, while for the control group (107 seconds) and the beginners group (123 seconds) the mean duration is lower with a decreasing slope.

During the test, the participants were asked about the site where they first noticed fatigue, the control group referred to the back area while the surfers indicated the gluteus.

Due to the novelty of the Chrono-Jump programme and the lack of articles using this test, of all the variable provided by this programme, we decided to use only the maximum strength. This evaluation is of interest given that it "is valid in evaluating the influence of strength on dynamic performance"[16]. We obtained a higher maximum strength for the surfers. The literature consulted highlights the importance and the development of the quadriceps musculature when surfing the waves as well as its benefit on balance[3,7].

Finally, for the Borg test, when comparing the means, we reached the conclusion that cardiovascular capacity improves as the surfer becomes more skilled. Surfers considered exercise to be light or very light while non-surfers considered it to be hard or very hard. Prior literature also supports the idea that the practice of surfing improves cardiopulmonary resistance[17-19].

Therefore, surfing could be a sport with great potential in the field of rehabilitation. Furthermore, the improvements demonstrated in psychological studies may help to achieve more effective rehabilitation.

And not only could surfing be included, but a study could be made of the exercises used in training in order to include them in rehabilitation programmes[20].

In conclusion, surfers obtained better results in the balance tests evaluated, on the foam pad in the BESS test and in some of the YBT directions. Likewise, surfers exhibited greater back strength and quadriceps strength, which are essential muscles to maintain balance and stance. Finally, surfers exhibited a greater tolerance to effort, evaluated using the Borg scale.

Conflict of interest

The authors have no conflict of interest at all.

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Effects of heat on performance in resistance sports in the various intensity-duration domains: review article

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Summary

Physical exercise induces an increase in body temperature that is influenced by the exercise intensity, as well as by the heat stress conditions in which it is performed. Power/velocity-duration relationship (PD-VD) shows how long an exercise can be sustained depending on the power output or the velocity output. Four intensity domains can be differentiated, which will be delimited by the lactic threshold (LT), the critical power/velocity (CP/CV) and the maximum oxygen consumption (VO_{2max}). This review aims to analyze the effects of heat stress on performance in the different intensity-duration domains, as well as to identify the main physiological mechanisms responsible. In the moderate (below LT) and hard (between LT and CP/CV) intensity domains, heat impairs the performance of exercises ranging from ~40min to over 3h, with central mechanisms and glycogen depletion being the major contributors to this fatigue. In the severe domain (above CP/CV), heat negatively affects the performance of maximum exercises ranging from ~25 to ~2 min duration, with cardiovascular and peripheral factors being the main limitations. However, in the extreme domain (above VO_{2max}), heat has been considered as a key element in achieving better performance records in maximum efforts of less than 2 min, associating these improvements with central and energy availability factors. Heat greatly influences the performance of endurance sports, accelerating task failure in those efforts longer than ~2 min, and favoring those with shorter durations. Knowing these mechanisms of action can help us to identify different strategies to reduce or take advantage of their effects during training and competition.

Key words:
Endurance. Performance. Fatigue. Hyperthermia. Physiology. Review.

Efectos del calor en el rendimiento en deportes de resistencia en los diferentes dominios de intensidad-duración: artículo de revisión

Resumen

El ejercicio físico induce un aumento de la temperatura corporal que se ve influenciado por la intensidad de este, además de por las condiciones de estrés térmico en las que se realice. La relación potencia/velocidad-duración (PD/VD) muestra cómo el tiempo que un ejercicio puede ser mantenido depende de la potencia o velocidad producida, pudiendo diferenciarse 4 dominios de intensidad que estarán delimitados por el umbral láctico (LT), la potencia/velocidad crítica (PC/VC) y el consumo máximo de oxígeno (VO_{2max}). Esta revisión tiene como objetivo analizar los efectos del estrés térmico sobre el rendimiento en los diferentes dominios de intensidad-duración, así como identificar los principales mecanismos fisiológicos responsables. En los dominios de intensidad moderado (por debajo del LT) y duro (entre LT y PC/VC), el calor perjudica el rendimiento en los ejercicios que comprenden duraciones de ~40 min hasta por encima de 3h, siendo los mecanismos centrales y la depleción del glucógeno los principales contribuyentes a esa fatiga. En el dominio severo (por encima de la PC/VC), el calor afecta negativamente al rendimiento de los ejercicios máximos que van de los ~25 a ~2 min de duración, siendo los factores cardiovasculares y periféricos los limitantes principales. Sin embargo, en el dominio extremo (por encima del VO_{2max}), el calor se ha visto como un elemento clave en la consecución de mejores registros de rendimiento en esfuerzos máximos inferiores a ~2 min de duración, debiéndose estas mejoras a factores centrales y de disponibilidad energética. El calor influye en gran medida en el rendimiento de los deportes de resistencia, acelerando el fracaso de la tarea en aquellos que tienen duraciones superiores a los ~2 min, y favoreciendo aquellos de duraciones inferiores. Conocer estos mecanismos de actuación puede ayudarnos a identificar distintas estrategias para reducir o aprovechar sus efectos durante el entrenamiento y la competición.

Palabras clave:
Resistencia. Rendimiento. Fatiga. Hipertermia. Fisiología. Revisión.

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Introduction

Resistance is defined as the time limit over which work at a determined intensity can be maintained,[1] as the energy contribution from aerobic means increases over 50% of the total as exercise extends beyond one minute.[2] Various authors subsequently defined it with greater precision arguing that, in the same way, the capability to resist both physical and psychological fatigue should be distinguished from the capacity to recover quickly from the effort.[3,4] In this way, it seems that the capability to resist a determined effort should not be associated with a minimum duration and could therefore be applied both to continuous and intermittent exercises.[5]

In resistance sports, we find 5 main physiological factors that determine performance: maximum oxygen consumption (VO_{2max}), the speed or power associated with it, energy efficiency, position ($\%VO_{2max}$) of metabolic thresholds (VT1 and VT2), and the reserve of anaerobic speed or power (RVA/RPA).[6,7] The effects of these physiological factors on performance is represented by the power-duration (PD) or speed-duration (VD) ratio.

In particular, the hyperbolic nature of the power-duration or speed-duration curve (PD/VD) shows the ratio between the power or speed produced and the time that it can be sustained. Skinner and Mclellan[8] already classified intensities into three phases related to the physiological responses observed during exercise with progressively increasing intensity. However, Burnley and Jones[9] are currently proposing four intensity domains to explain bioenergetic responses to exercise and how they relate to task failure. This refers to the point that a participant cannot or does not want to continue a physical task.[9]

These four intensity domains are marked out by three physiological milestones (lactate threshold (LT), critical power/velocity (PC/VC) and maximum oxygen consumption (VO_{2max})), that will separate the sustainable entities for hours, even minutes or seconds: moderate intensity (power or velocity below the LT), heavy (power or speed between LT and PC/VC), severe (power or speed over the PC/VC that can be sustained until the VO_{2max} is reached), and extreme (power or velocity over VO_{2max}).[9]

The moderate intensity field includes intensities under the LT (between 50-60% of the VO_{2max} in young subjects and between 70-80% in highly-trained subjects).[10] These intensities can be sustained beyond 3 hours (e.g. ultra-marathon, trail race, road cycling or long distance triathlon), because the intensity is so low that the blood lactate concentration levels and the respiratory exchange rate (RER) remain at base levels during the stable exercise.[11] As the exercise continues over time, the incapacity to produce muscular strength due to a drop in activation of the motor neurons (central fatigue)[12] is proposed as one of the main limiting factors for ultra-resistance performance,[13–15] and bioenergetic alterations might occur in the muscle, as well as an increase in the recruitment of motor units to maintain the task in hand.[16] On the other hand, peripheral fatigue associated with these intensities is most probably caused by depletion of glycogen.[10,17] In addition, dehydration and thermal stress can also adversely affect performance and the athlete's perception of their own effort during long-duration exercise.[18,19] Although fatigue is multi-factorial in the moderate intensity domain, Burnley and Jones[9] mention that central fatigue is the main determining factor.

In turn, the heavy intensity domain includes intensities from the LT to the PC/VC (70-80% of the VO_{2max} in young subjects and 80-90% of the VO_{2max} in highly-trained subjects.10 The PC or VC reflects a critical metabolic rate from which exercise is defined in a stable metabolic status (heavy and moderate intensity) of the exercise in the metabolic instability phase (severe and extreme intensity).[20.21] This gives the hyperbolic relationship between the developed power/velocity and its sustainable time. The PC/VC is highly correlated with resistance performance, associated with the respiratory compensation point (RCP)[22] and the maximum lactate stable state (MLSS),[23] although there is quite a lot of controversy on this matter.[24–26] This review does not aim to assess the terminological and methodological differences between the PC and the MLSS (for review, see[21,27]). Therefore, we will use the terms PC or CS as the maximum metabolic stable status point that separates the heavy and severe intensity domains. The exercise in PC/VC can be sustained between 25-30 min,[10,21] and it has been estimated that elite marathon runners compete at ~96% of their critical velocity.[20] Therefore, when the LT is exceeded, tolerance for exercise is limited between ~40 min and ~3 h,[28] including tests in this domain such as a marathons, cycling time trials of around an hour and Olympic distance triathlons, among others. The characteristics of the physiological response to exercise in this domain are development of the slow component of VO_2 and an increase in the blood [lactate], that will stabilise eventually.[8] Jones *et al.*[29] observed that during exercise 10% below the PC/VC, muscular phosphocreatine (PCr) and concentrations of inorganic phosphate (Pi) and the pH attained constant values within the first 2 min of exercise and remained stable during the following 20 min. However, the slow component of the VO_2 will cause the muscular glycogen to be used as the exercise goes on, both for type I fibres and type II fibres, recruiting additional fibres necessary to maintain the intensity of the exercise, and depleting the muscular glycogen at a greater velocity.[9,16,28,30] Therefore, depletion of the musculoskeletal glycogen can be key in the fatigue processes in this domain of intensity. In this respect, Burnley, Vanhatalo and Jones[31] have also proved that central fatigue can limit performance at these intensities, and there is no single mechanism that is responsible for task failure.

The severe intensity domain includes action models that range from PC/VC to VO_{2max}. Beyond the PC/VC, the muscular metabolites (PCr and H^+), blood lactate and also the VO_2 lose homoeostasis,[32] reducing muscular efficiency, which boosts the slow component of the VO_2 to its maximum, associating task failure with achieving the VO_{2peak} and an "intolerable" muscular metabolic environment.[33,34] These work intensities above the CP/CS also recruit type II muscular fibres with low oxidative capacity, where the QO_2/VO_2 ratio (and therefore $PmvO_2$) is less than in the type I fibres.[10] Furthermore, the drop in pH means that the ventilation, and so also the respiratory frequency, increase,[35] also raising the demand on the respiratory muscles, that, out of necessity, or due to fatigue, can compromise blood flow to the active musculature,[36] which causes intramuscular metabolic stress.[37] Despite not having been tested, the reduction in the excitability of the motor neuron as the contractions progress in severe intensity exercise could contribute to central fatigue.[10] Therefore, this intensity domain considers resistance events in the range of approximately 2 to 25 min,[20] covering a very wide range of events, such as in athletics, from approximately 800 m maybe even up to 10,000 m, depending on sporting prowess and gender.

The extreme intensity domain considers all intensities over the VO_{2max}, where efforts are mainly dependent on the glycolysis and the phosphagen means. In this type of effort, high ATP production rates are fundamentally associated with developing high speed or power. The maximum rate of PCr degradation comes immediately after the start of the contraction and starts to fall after 1.3 s, while glycolysis reaches its maximum rate of ATP production after 5 s and it is maintained for several seconds before it subsequently falls.[2] Consequently, the production of force will be affected as the resynthesis and ATP use rates drop. The almost complete emptying of the PCr reserves, the gradual drop in PH, the reduction in activity of the glycolysis enzymes, and problems in the transmission and inhibition mechanisms for the motor neurons will be the factors limiting the extreme intensity performance, among many others that have yet to be determined.[2,38] Therefore, the athlete will fail the task before they can reach VO_{2max}. Athletics disciplines between 60 m and 400-800 m fall within this domain, just like some specific key moments in many resistance sport disciplines such as changes in pace, sprint finishes.

Therefore, there are many factors limiting performance that play a major role in task failure in each intensity domain. However, this review does not aim to analyse them all. The aim of this review is to analyse the acute responses from the organism to exercise in hot conditions and assess its effects on the different intensity-duration domains. It has been scientifically demonstrated that thermal stress reduces a human's capability to do exercise,[39] and it is a determining factor in certain competitions that are held each year in adverse weather conditions.[40]

Acute responses from the organism when exercising in heat

We must differentiate between the terms thermal stress and thermal tension.[41] We talk about thermal stress as environmental conditions that lead to an increase in body temperature.[42] However, thermal tension is the physiological consequence of thermal stress.[43] The interaction between the two is a complex mechanism that depends on environmental variables (temperature, humidity, wind speed, solar radiation, the clothes worn, etc.) and the type of exercise (running, cycling, swimming, etc.), individuals (aerobic condition, body size, acclimatisation status, hydration status, etc.) and intensity, duration and strategy of exercise pace.[41]

This multi-factorial interaction will cause core temperature to rise excessively over basal resting values (37ºC) for moderate intensity exercise in a cold-temperate environment (38ºC),[44] thereby accelerating the fatigue induced by hyperthermia (H) and reducing the time to task failure. Intense physical exercise can cause an increase in the core temperature (Tn) over 38ºC (H), altering the activity of the pre-frontal area of the brain (central fatigue)[45] and reducing the time to exhaustion during exercise in a warm environment.[39] Although the skin, muscle and brain temperatures are also affected, the core temperature seems to have the greatest impact on physiological thermoregulation.[46]

Cheung and Sleivert[47] conclude that there are at least two homoeostasis disturbances that affect exercise performance in H conditions, mainly affecting the Central Nervous System (CNS) and cardiovascular tension. However, Nybo *et al*.[41] propose an integrating model to understand the complexity of fatigue induced by H, that includes cardiovascular tension, central fatigue, peripheral fatigue and changes in ventilation.

Consequently, thermal stress will harm exercise performance at both high and moderate intensities, manifesting as lower power or speed production during the time trials,[48–53] reducing the time to task failure at set intensities,[54–57] or in standardised protocols such as an incremental test.[50,58,59]

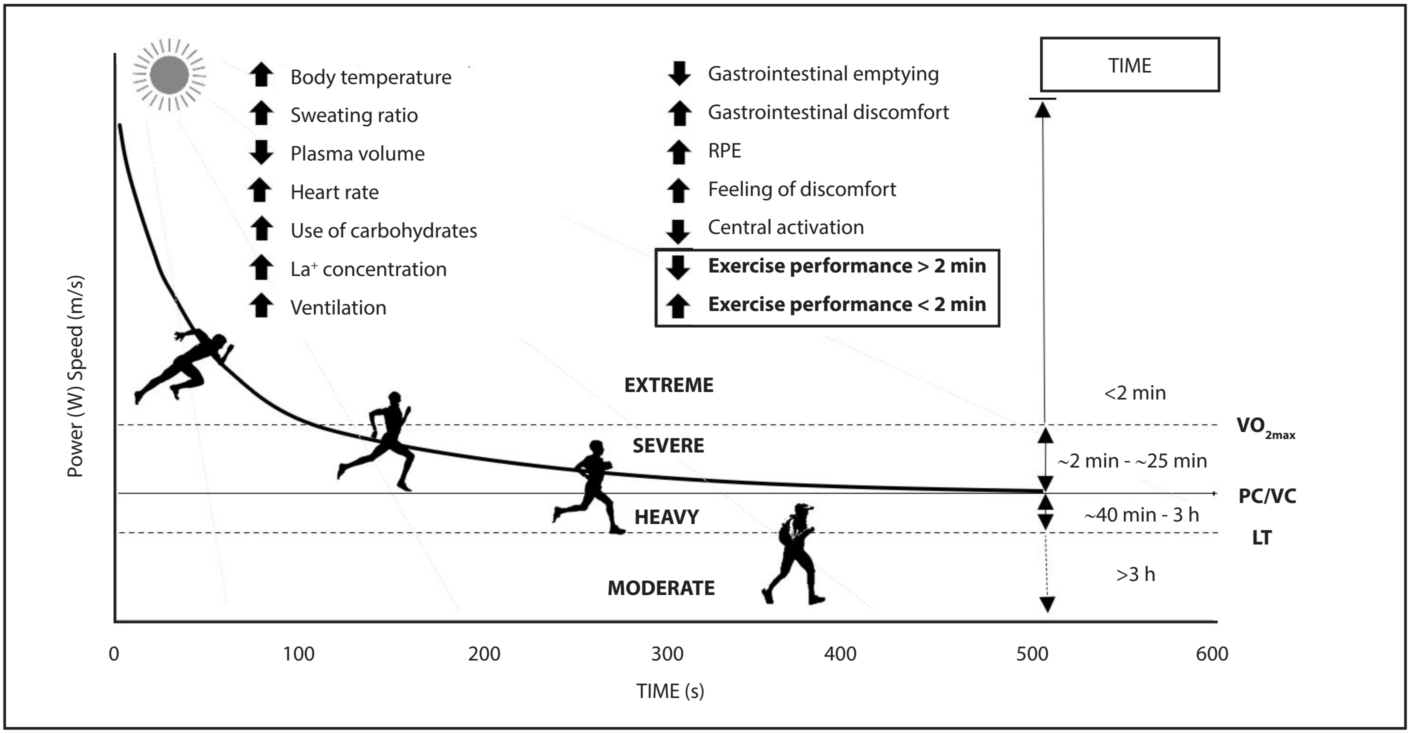
Although the fatigue induced by H is multi-factorial and many factors change in parallel or are inter-related, we will try to describe the possible causes that might induce fatigue in each intensity domain in a hot environment.

Moderate intensity domain

To the best of our knowledge, no studies have been described that compare performance in the laboratory during efforts over 3 h in control and hot conditions. However, other studies can be referenced such as Parise and Hoffman,[60] that compare data from 50 runners in a 161 km Trail event over two consecutive years, with hot conditions the first year and temperate conditions the second year, demonstrating a 7% drop in performance when competing in hot conditions. As this competition lasts around 24 h, performance was affected more for faster runners than slower ones, because they were running for a higher percentage of the race in hot conditions than runners who came further back. However, studies by Ely, Cheuvront, Roberts and Montain61 and Vihma[62] show how the lower-level runners who took more than 3 h to complete the marathon distance were more affected, as the thermal stress increased, than the runners who finished the race in a shorter time. Therefore, as these articles demonstrate, heat plays a fundamental role in developing fatigue during sub-maximal long duration races.

Factors that affect performance in the moderate intensity domain due to hyperthermia do not seem to be associated with either cardiovascular or peripheral factors.[41] Changes have barely been found in cardiac output during sub-maximal intensity exercise, due to the fact that, despite the rise in blood flow from the skin being associated with a lower systolic volume, the rise in heart rate can compensate the

Figure 1. Acute effects of the heat on exercise and the intensity-duration domains.



deterioration in cardiac filling.63 Furthermore, the increase in cardiac output will make it possible for blood to flow both to the skin and to the active skeletal muscles,[64,65] thereby helping thermoregulation and the use of oxygen to sustain the intensity of the exercise.

Thermal stress also produces changes at a metabolic level in the muscle, with a greater dependency on glycogen in hot conditions, thereby increasing blood lactate concentration levels.[59,66,67] There are several studies which state that depletion of glycogen deposits is not the main factor for task failure at sub-maximal intensities.[41,68-70] However, to the best of our knowledge, it has not been demonstrated in such long duration tests, so it will be a factor to consider in ultra-resistance competitions.

Ventilation will also be increased during the sub-maximal exercise in heat regarding the normothermia conditions,[71] but there is no mention that the respiratory musculature fatigue at these intensities causes a redistribution of the blood flow from the active skeletal musculature to the respiratory musculature,[65] so performance will not be affected by this increase in ventilation.

Therefore, the central factors seem to induce the appearance of fatigue during exercise carried out in the moderate intensity domain. The high brain temperature, the dopaminergic system activity,[72] low brain oxygen levels,[73] and feedback from the skeletal musculature[45] can affect motor activation. Furthermore, it is well documented that exercise in heat causes perceptions of greater effort than in temperate conditions.[48,72,74] The high skin temperature, associated with thermal discomfort, and the increase of ventilation, that can alter feelings of dyspnea, can also modify how exercise is performed and perceived.[37,75]

Splanchnic and gastrointestinal blood volume will also be reduced, causing the release of endotoxins that are associated with gastrointestinal discomfort, and a lower production of strength.[41,76] Gastrointestinal emptying will also be reduced by the heat,[77] accelerating dehydration and depletion of the muscular glycogen, affecting long-duration performance.

All these factors will accelerate the fatigue process in hot conditions. However, it is very complicated to separate the effects of heat from the effects of actual dehydration.

Heavy intensity domain

Ely *et al*.,[61] analysed the data from several marathons that were held at different temperatures, and they compared the results against the race records, showing a progressive drop in performance among elite marathon runners as the ambient temperature rises. Furthermore, Guy *et al*.[78] analysed the marathon times for the World Championships of the International Association of Athletics Federations (IAAF) from 1999 to 2011, and they saw a drop in performance of 3.1% and 2.7%, in men and women respectively, when the races were held in ambient temperatures >25 ˚C. Recent statistical analysis shows how, between 5ºC and 25ºC, for every 1ºC that the ambient temperature increases,

Table 1. Comparison of performance in sub-maximal aerobic exercise during time trials (TT) and time to exhaustion (TTE) in hot conditions vs. Control Temperature.

Study	N	Test	Exercise	Control	Heat	Intensity	Performance
Peiffer and Abbiss[48]	9	TT 40 km	Cycling	17°C	32°C	Self-paced	-3%
Periard *et al.*[49]	8	TT 40 km	Cycling	20°C	35°C	Self-paced	-7%
Lorenzo *et al.*[50]	12	TT 60 min	Cycling	13°C	38°C	Self-paced	-18%
Racinais *et al.*[52]	8	TT 43 km	Cycling	8°C	36°C	Self-paced	-16%
Periard and Racinais[53]	12	TT 750-Kj	Cycling	18°C	35°C	Self-paced	-14%
Periard and Racinais[86]	11	TT 750-Kj	Cycling	20°C	35°C	Self-paced	-14%
Keiser *et al.*[87]	8	TT 30 min	Cycling	18°C	38°C	Self-paced	-13%
Schlader *et al.*[88]	9	TT 30 min	Cycling	20°C	40°C	Self-paced	-21%
Romer *et al.*[89]	7	TT ~30 min	Cycling	15°C	35°C	Self-paced	-24%
VanHaitsma*et al.*[90]	20	TT 40 km	Cycling	21°C	35°C	Self-paced	-5%
Roelands *et al.*[81]	8	TT Kj 30 min	Cycling	18°C	30°C	Self-paced	-25%
Roelands *et al.*[82]	11	TT Kj 30 min	Cycling	18°C	30°C	Self-paced	-15%
Watson *et al.*[83]	8	TT Kj 30 min	Cycling	18°C	30°C	Self-paced	-30%
Supinget *et al.*[84]	10	Marathon	Running	8°C	29°C	Self-paced	-10%
Paula Viveiros *et al.*[85]	14	TT 10 km	Running	20°C	40°C	Self-paced	-21%
		TTE 90% MMP10 km		20°C	40°C	90% MMP10 km	-48%
Galloway and Maughan[54]	8	TTE	Cycling	4°C	31°C	70% VO_{2max}	-36%
				11°C	31°C	70% VO_{2max}	-44%
				21°C	31°C	70% VO_{2max}	-36%
Ftaiti *et al.*[55]	7	TTE	Cycling	22°C	35°C	60% VO_{2max}	-34%
Rowland *et al.*[56]	8	TTE	Cycling	20°C	31°C	65% VO_{2max}	-29%
Girard and Racinais[57]	11	TTE	Cycling	22°C	35°C	66% VO_{2max}	-35%
Parkin *et al.*[68]	8	TTE	Cycling	3°C	40°C	70% VO_{2max}	-64%
				20°C	40°C	70% VO_{2max}	-50%
MacDougall *et al.*[91]	6	TTE	Running	23°C	39°C	70% VO_{2max}	-36%

Km: Kilometres; Kj: Kilojoules; MMP: Personal best; VO_{2max}: Maximum Oxygen Consumption and performance reduction (%) during the tests. Dry-bulb temperature (ºC) of the control environment (temperate) and in thermal stress conditions.

marathon performance is affected by 38 s among the 100 best times, and by 20 s for the race winner.[79,80] Many studies have compared how the heat affects performance in the heavy intensity domain compared to temperate environmental conditions, distinguishing between self-paced protocols[48–50,52,53,81–90] and set intensity protocols.[54–57,68,85,91] The fixed intensity exercise protocols provide information on the time to exhaustion, while self-paced exercise protocols show the fatigue appearance process, and both protocols are based on different theories.[88] During the fixed intensity exercise, there is a progressive and not self-regulated increase in core temperature, which will lead to voluntary exhaustion of exercise when core temperature values reach ~40°C[39,45,54] or exceed them in the case of some high level athletes during competition.[92] However, during self-paced exercise, the athlete regulates the production of metabolic heat, and thereby avoids reaching this critical core temperature too soon, making it possible to finish the race (Table 1).

In this domain, the factors that produce the fatigue are the same as in the moderate intensity domain (see moderate intensity domain). The increase in dependency on carbohydrates in thermal stress conditions can accelerate the appearance of fatigue in this domain, where depletion of the muscular glycogen deposits is one of the main limiting factors, along with the central factors,[41,72,73] of the exercise between LT and PC/VC.[9]

Severe intensity domain

Several studies have seen maximum power production values fall during incremental intensity tests (VO_{2max}) in thermal stress conditions.[58,93–101] Nybo *et al.*,[41] show how VO_{2max} fell by 11% on average in 10 out of 11 studies analysed. These drops in VO_{2max} have also been seen in previously acclimatised subjects (~7%), compared with VO_{2max} in temperate conditions (21°C).[58] During timed tests or tests to exhaustion mainly

Table 2. Comparison of performance in maximum aerobic exercise during time trials (TT) and time to exhaustion (TTE) in hot conditions vs. Control Temperature.

Study	N	Test	Exercise	Control	Heat	Intensity	Performance
Periard and Racinais[86]	10	TT 15 min + 1 min 30 s max.	Cycling	18˚C	35˚C	Self-paced	-18%
Altareki *et al.*[102]	9	TT 4 km	Cycling	13˚C	35˚C	Self-paced	-2%
Ely *et al.*[103]	8	TT 15 min	Cycling	21˚C	40˚C	Self-paced	-17%
Tatterson *et al.*[104]	11	TT 30 min	Cycling	23˚C	32˚C	Self-paced	-6%
Tuckeret *et al.*[105]	10	TT 20 km	Cycling	15˚C	35˚C	Self-paced	-6%
Tyler and Sunderland[106]	9	TT 15 km	Cycling	14˚C	30˚C	Self-paced	-10%
Marino *et al.*[107]	16	TT 8 km	Cycling	15˚C	35˚C	Self-paced	-12%
Marino *et al.*[108]	12	TT 8 km	Cycling	15˚C	35˚C	Self-paced	-14%
Mitchell *et al.*[109]	11	TTE	Cycling	11˚C	37˚C	80% VO_{2max}	-48%
			Cycling	11˚C	37˚C	100% VO_{2max}	-3%

Km: Kilometres; VO_{2max}: Maximum Oxygen Consumption and performance reduction (%) during the tests. Dry-bulb temperature (ºC) of the control environment (temperate) and in thermal stress conditions.

run over the PC/VC, performance was also affected in hot conditions compared to control conditions[86,102–109] (Table 2).

During exercise in the severe intensity domain in H conditions, it seems widely accepted that cardiovascular mechanisms are responsible for the drop in VO_{2max} and performance.[41] Intense exercise is associated with high production levels of endogenous heat that, in a thermal stress environment, will compromise the capacity of the Cardiovascular System to dissipate heat to the environment,[94] thereby developing an H and compromising the capacity to diffuse arterial oxygen to the muscles that are working. The combined effect of the drop in the central blood volume,[110] and a lower diastolic filling time,[111] will cause a drop in the systolic volume and cardiac output.[63] Therefore, the muscular oxygen supply will not be sufficient for the oxygen extraction demands required by high intensity exercise, and to support thermoregulation, so performance will be affected.[41]

Therefore, the energy contribution of the anaerobic metabolism will increase to maintain the exercise intensity,[112] decreasing ATP and PCr levels in the muscles more quickly and increasing the accumulation of blood lactate and H^+, inducing peripheral fatigue.[94]

The increase in the work of the respiratory muscles during high intensity exercise will compromise the flow of blood to the musculature for the exercise due to vasoconstriction,[113,114] so it will be a relevant factor in the performance both in normothermia and hyperthermia conditions.

Furthermore, the lower oxygen delivery to the muscle and changes in the muscular metabolism will influence the inhibitory afferent feedback of the CNS, increasing the athletes' feeling of fatigue and influencing the pace,[115] limiting the development of peripheral fatigue to a critical threshold, probably to protect the organism from the extenuation and any possible damage.[116]

During the severe intensity domain, the periphery and cardiovascular factors are the main limiting factors for performance in heat, but as mentioned previously, fatigue is multi-factorial[41,47] and central fatigue can also play an important role in performance.

Extreme intensity domain

Back in 1945, Asmussen and Bøje[117] demonstrated that performance during maximum effort of 12-15 s on a static bike benefited from a greater muscular temperature, regardless of whether this was achieved by active or passive warming. Subsequently, other authors have confirmed these results on short duration maximum efforts.[118-121] However, it is not clear that performance is enhanced in severe intensity efforts in warm environment laboratory conditions. Dotan and Bar-Or[122] and Backx *et al.*[123] did not find significant differences in Wingate test performance, or several consecutive tests, between temperate and hot environments, as opposed to Ball, Burrows and Sargeant.[124] Other papers have reported greater performances in repeated short sprint protocols in thermal stress conditions.[125,126] In field conditions, Haïda *et al.*,[127] and Guy *et al.*[78] used statistical analysis of results from major international championships for sprint and middle distance races to find that there is a relationship between the best results and a greater ambient temperature. Haïda *et al.*[127] found that performances in athletics races between 100 m and 1,500 m were better in events held during the first week in July and usually coincided with important sporting events in the northern hemisphere where the average temperatures are usually high. They associate these better results with environmental conditions. Guy *et al.*[78] analysed the 6 best performances in sprint races (100-200 m) during the IAAF World Championships between 1999 and 2011, and they found that the athletes performed ~2% better in hot conditions compared to temperate conditions.

Currently, the mechanisms for causing this improved performance during short term efforts in hot conditions are not known exactly, although there are some theories. Asmussen *et al*.[117] attributed this improved performance to the fact that the increase in muscle temperature would provide a greater rate of forming cross-linkages. Gray *et al*.[120] propose a faster rate of using phosphocreatine (PCr), and a greater conduction speed for muscular fibres. For greater knowledge of heat mechanisms on sprint performance, please refer to Girard, Brocherie and Bishop.[128]

Conclusion

This review has described how thermal stress influences performance in the different intensity-duration domains described, and the physiological mechanisms that produce these variations. Analysis of competition results demonstrates how heat influences moderate intensity performance, and that it is complicated to separate the effects of heat from the effects of dehydration. There is a lot of evidence on how heat affects performance during heavy and severe intensity exercises, both in laboratory conditions and during competition. However, in the extreme intensity domain, hot conditions seem to be more favourable to develop greater power or speed than a temperate or cold environment. In sub-maximal exercises (moderate and heavy domains), central factors and dependency on muscular glycogen seem to be the main limiting factors on performance in temperate conditions and these mechanisms will be more affected as thermal stress increases, thereby accelerating the appearance of fatigue. During maximal exercises (severe domain) in hyperthermia conditions, it will be the cardiovascular and peripheral factors that cannot sustain intensity and so limit performance. Supra-maximal exercise (extreme domain) will achieve improved performance due to central factors and energy availability that increases in the heat. It is difficult to talk about isolated physiological mechanisms that determine performance in each intensity-duration domain. We talk about mechanisms that mainly influence the performance of each one, but it should be considered that many factors interact to cause the fatigue process, not just one. This review demonstrates that tests ranging from 3-4 min up to more than 3 h can benefit from cooling strategies before and during competition in hot conditions, while in races lasting <2min, cooling might compromise performance.

Conflict of interests

The authors do not declare any conflict of interests.

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Improving hamstring flexibility through physical education based interventions: a systematic review and meta-analysis

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Summary

Flexibility is recognized as a strong marker of physical health in children. Scientific research has indicated that there is a worldwide decline in children's physical fitness, including a reduction in flexibility levels. It has been suggested that a lack of flexibility in youth may be responsible for several health complications, including back pain, injury risk, and posture problems. Physical education (PE) classes are part of the school curriculum, which are an ideal setting to improve children physical fitness levels. The purpose of this systematic review and meta-analysis was to investigate whether incorporating a stretching component during regular PE classes can improve flexibility in school children. Three electronic databases were searched systematically until June 2019 for studies analysing the effects of interventions performed during PE classes aimed to improve the flexibility levels of school children (6-18 years). The critical appraisal was carried using PEDro and MINORS scales and a meta-analysis was performed. Seventeen studies of moderate-to-high methodological quality were included in the review and 14 in the meta-analysis, pooling 874 participants. The interventions showed significant improvements in the flexibility of the children, although the relative influence of genre could not be further analysed, due to the fact that insufficient data was reported. The meta-analysis for the hamstring flexibility resulted in a significant moderate effect. Flexibility levels can be improved through the incorporation of stretching interventions during PE classes, since flexibility is a key health-related physical fitness componentFurther research is needed on the effects of such interventions on trunk and upper body flexibility.

Key words:
Children. Health. Physical education. Flexibility.

Mejora de la flexibilidad de isquiotibiales a través de intervenciones basadas en educación física: una revisión sistemática y un meta-análisis

Resumen

La flexibilidad es un fuerte indicador de la salud física de los niños. La investigación científica ha indicado que hay una disminución mundial en la condición física de los niños, incluida una reducción en los niveles de flexibilidad. Las clases de educación física (EF) que forman parte del curriculum, son un entorno ideal para mejorar los niveles de aptitud física de los niños. El propósito de esta revisión sistemática y metanálisis fue investigar si la incorporación de estiramientos durante las clases regulares de educación física puede mejorar la flexibilidad en los niños en edad escolar. Se realizaron búsquedas sistemáticas en tres bases de datos electrónicas hasta junio de 2019 en busca de estudios que analizaran los efectos de las intervenciones realizadas durante las clases de EF destinadas a mejorar los niveles de flexibilidad de los escolares (6-18 años). La valoración crítica se realizó mediante escalas PEDro y MINORS y se realizó un metaanálisis. En la revisión se incluyeron 17 estudios de calidad metodológica de moderada a alta y 14 en el metanálisis, que agruparon a 874 participantes. Las intervenciones mostraron mejoras significativas en la flexibilidad de los niños, si bien la influencia del género no se pudo analizar en profundidad, debido a la existencia de insuficiente información al respecto. El metanálisis de la flexibilidad de los isquiotibiales resultó en un efecto moderado significativo. Los niveles de flexibilidad se pueden mejorar mediante la incorporación de intervenciones de estiramiento durante las clases de educación física. Se necesitan más investigaciones sobre los efectos de tales intervenciones en la flexibilidad del tronco y la parte superior del cuerpo.

Palabras clave:
Niños. Salud. Educación física. Flexibilidad.

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Introduction

Flexibility is recognized as a strong marker of physical health in children, representing one of the main components of health-related physical fitness[1]. Indeed, it has been suggested that a lack of flexibility in youth may be responsible for several health complications, including back pain, injury risk, and posture problems[2]. For instance, reduced hamstring flexibility has been shown to negatively affect pediatric posture in children[3], while reduced trunk flexibility has been identified as a risk factor for developing lumbar vertebrae stress[4]. A lack of flexibility in younger people has also been associated with a higher risk of developing low back pain[5]. Finally, it has been reported that children with limited joint flexibility exhibit lower levels of motor competence[6], which is considered a key factor for developing a healthy lifestyle[7].

Scientific research has indicated that there seems to be a worldwide decline in children's physical fitness[8], including a reduction in flexibility levels. Indeed, secular trends have demonstrated that youth in the present day are less flexible than those in the 1980s[9] 90s and 00s[10]. These findings highlight the importance of developing and promoting adequate flexibility among children. However, current guidelines developed by the government and institutions for promoting fitness development in this population are mainly focused on aerobic and muscular fitness, resulting in flexibility often being overlooked[11]. Therefore, alternative strategies must be found to increase the motivation for children to improve their flexibility levels.

Physical education (PE) classes are part of the school curriculum, which are an ideal setting to improve children physical fitness levels. Indeed, PE is the most effective time to promote physical activity during the school day, and most countries have legal requirements to incorporate PE during at least part of the compulsory schooling years[12]. As a result, PE classes may be a useful opportunity to implement interventions aimed to improve the flexibility of children. To the best of the authors' knowledge, however, no study has critically reviewed the existing scientific evidence and assessed the potential benefits of these interventions. Thus, the purpose of this systematic review and meta-analysis was to investigate whether incorporating a stretching component during regular PE classes can improve flexibility in school children.

Material and method

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The selected search strategy and methods of analysis were registered in the PROSPERO database.

Search strategy

Three electronic databases (MEDLINE/PubMed, SPORTDiscuss and Scopus) were searched systematically from their inception until June 2019. The following search terms, Boolean operators, and combinations were used: "Flexibility" OR "Stretching" AND "Physical Education" OR "School".

Eligibility criteria

Studies that provided information regarding the effects of interventions performed during PE classes aimed to improve the flexibility levels of school children (6-18 years) were considered eligible. Investigations were excluded if: a) the intervention included other activities performed outside PE classes; b) the intervention was based on the performance of a single exercise training session; and c) the research was not written in English, Portuguese or Spanish.

Study selection

Two authors screened the titles and abstracts of the identified studies for eligibility. After independently reviewing the selected studies for inclusion, these were compared by both authors to reach an agreement. Once the agreement had been reached, a full-text copy of every potentially relevant study was obtained. If it was unclear whether the study met the selection criteria, advice was sought from a third author and a consensus was reached.

Data extraction

Information on participants' characteristics, training program details, drop-outs and outcomes were extracted from the original reports by one researcher and checked by a second investigator. Missing data were obtained from the study authors, whenever possible.

Quality appraisal

The methodological quality of the selected RCTs was directly retrieved from the Physiotherapy Evidence Database (PEDro). The quality appraisal of those RCTs not rated in PEDro was performed by two authors independently with discrepancies in ratings arbitrated by a third author. In case of disagreement, advice was sought for a third author. The suggested cut-points to categorize studies by quality were excellent[9–10], good[6–8], fair[4–5] and poor (≤ 3)[13].

The methodological index for non-randomized studies (MINORS)[14] was used to perform the quality appraisal of those investigations in which the participants were not randomly assigned to intervention and control groups. These studies were evaluated as comparative investigations by two independent authors. For these cases, the MINORS includes 12 items with a maximum score of 24 points. Quality for these scores were interpreted as high[19–24], moderate[13–18], low[7–12], and very low (≤ 6)[14].

Data analysis

A meta-analysis was performed on all the studies in which the results obtained by the experimental and the control groups were compared, provided that the same outcomes had been assessed in at least two studies in a comparable way[15]. In addition, a sensibility analysis was performed analyzing the results separately for the RCTs and non-RCTs. Pre- and post-intervention data were presented for the intervention and control groups as mean ± standard deviation (SD). Standardized mean differences (SMD) and their 95% confidence intervals (CIs) were calculated to assess the change for each outcome variable. For studies with multiple comparison groups, the Cochrane Handbook of Systematic Reviews of Interventions recommendations and its formula to combine groups were used to merge the data into a single effect size, in order to avoid double-counting.

To obtain the pooled effects, both a fixed effect and a random effects model were applied. In cases with a heterogeneity level (I-squared) over 30%, the random effects model was used. Forest plots displaying SMD and 95% CIs were used to compare the effects between the pre- and post-intervention measurements in the intervention and control groups. SMDs were significant when their 95% CIs excluded zero, while pooled SMD values of less than ± 0.2, ranging from ± 0.2 to ± 0.8, or greater than ± 0.8 indicated the existence of small, medium, or large effects, respectively. Meta-regression was used for moderator analysis because it reduces the probability of Type I error by computing concurrent estimates of independent effects by multiple moderators on the variation in effect size across trials. All statistical analyses were performed using Stata 13.

Results

A total of 49,659 references were initially obtained. Duplicates were removed, and then the titles and abstracts of 62 investigations were screened for eligibility. After assessing the full texts for inclusion and exclusion criteria, a total of 17 investigations[16-33] were finally included in qualitative analysis and 12 were included in the meta-analysis (Figure 1).

Study characteristics

All studies included children or adolescents, with ages ranging between 5 and 17 years old. The full characteristics of each study can be found in (Table 1).

In general, participants were free from preexisting conditions such as orthopedic, musculoskeletal, and/or spinal pathologies (n = 14). Only three studies excluded participants if they were already engaging in another form of structured physical activity[16,17] or sport[18]. The length of

Figure 1. Flow diagram.

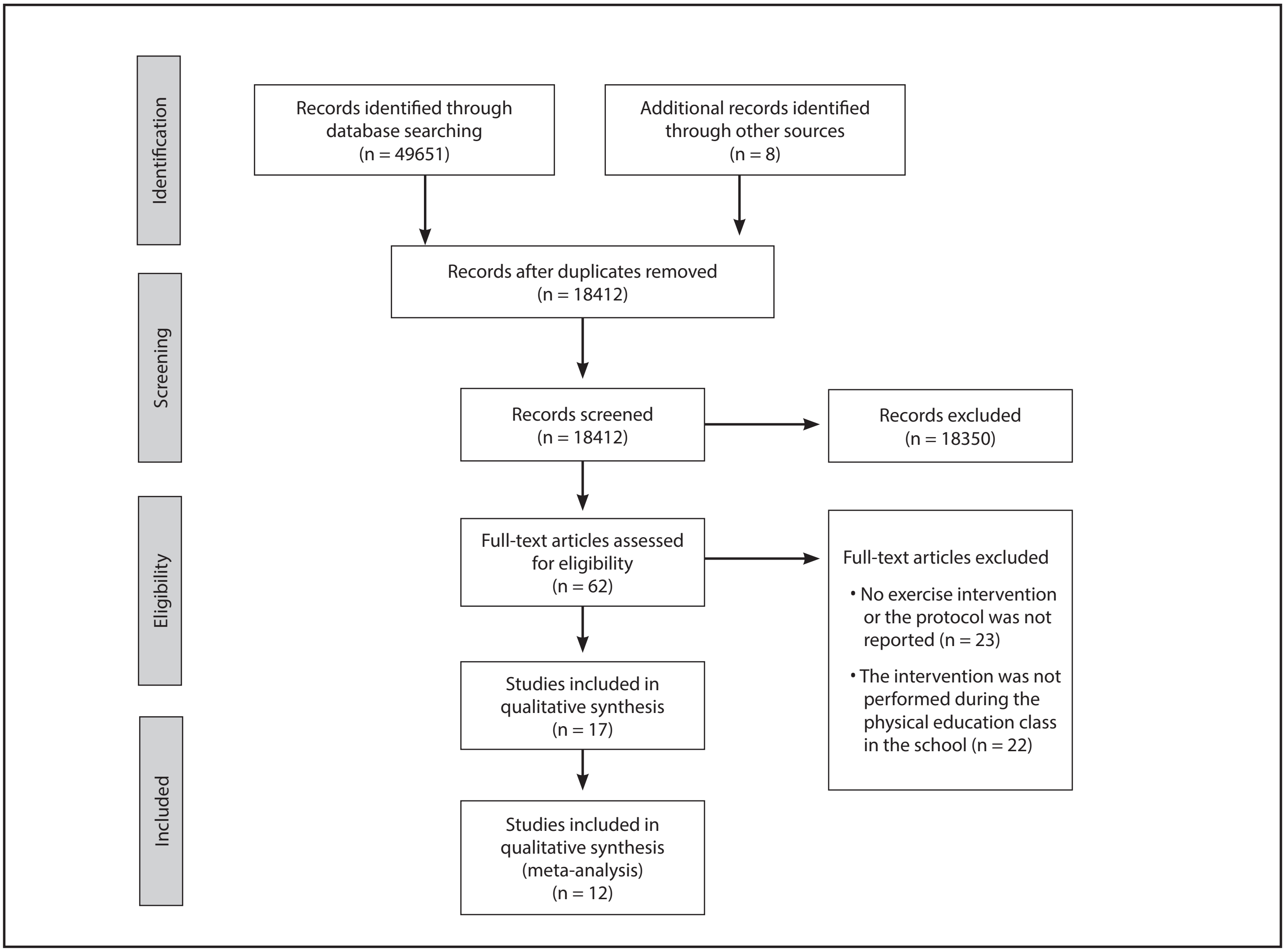


Table 1. Characteristics of the Studies Included in the Systematic Review.

Author (Year)	Participants	Intervention and Control Groups	Responsive Outcomes	Flexibility Scores	Flexibility Differences
Useros-García, 2010[18]	IG1: *n* = 12 (16-17 years) IG2: *n* = 12 (16-17 years) CG: *n* = 9 (16-17 years) Inclusion Criteria: N/R Exclusion Criteria: Practice regular sports; pathology or pain.	Length: 5 weeks IG1: 30 minutes, twice per week of active global stretching. Stretches were held for 4-10 minutes, depending on the characteristics of the postures. IG2: 30 minutes of moderate-intensity analytical stretching on a wide range of muscle groups (15 seconds per stretch). CG: Standard PE classes.	Recruitment: N/R IG1 Attrition Rate: 0% (12 to 12) IG2 Attrition Rate: 25.0% (12 to 9) CG Attrition Rate: 11.1% (9 to 8) IG1 & IG2 Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility (M_{diff}): (Toe-Touch Test) IG1: 6.9±4.9 IG2: 3.9±1.2 CG: 0.4±4.5 Dorsal-Lumbar Flexibility (M_{diff}): (Wall-Heel Distance) IG1: 13.5±8.6 IG2: 2.2±5.9 CG: 1.8±9.9 Trunk Flexibility (M_{diff}): (Deep Bending Test) IG1: 6.4±5.0 IG2: 3.1±2.4 CG: 1.6±2.9 Hamstring Flexibility (M_{diff}): (Leg Raise Test) IG1: 9.3±9.3 IG2: 7.4±11.4 CG: -0.3±7.3	Intergroup Difference (Toe-Touch Test): Post IG1* vs. Post CG Post IG2* vs. Post CG Post IG1* vs. Post IG2 Intergroup Difference (Wall-Heel Distance): Post IG1* vs. Post CG Post IG2 vs. Post CG (NS) Post IG1* vs. Post IG2 Intergroup Difference (Deep Bending Test): Post IG1* vs. Post CG Post IG2* vs. Post CG Post IG1* vs. Post IG2 Intergroup Difference (Leg Raise Test): Post IG1* vs. Post CG Post IG2* vs. Post CG Post IG1* vs. Post IG2
Becerra-Fernandez, 2016[22]	IG: *n* = 55 (16-17 years) CG: *n* = 53 (16-17 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions; missing an evaluation session.	Length: 8 weeks IG: 4 minutes, twice per week of hamstring stretches using a dynamic technique during warm-up and cooldown of PE classes (60 seconds per stretch). Detraining was performed for 4 weeks after the intervention. CG: Standard PE classes.	Recruitment: 100% (108 out of 108) IG Attrition Rate: 10.9% (55 to 49) CG Attrition Rate: 0% (53 to 53) IG Adherence Rate: >95% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 31.4±5.8 CG: 31.5±6.9 Post-Test: IG: 34.0±5.3 CG: 29.6±7.3	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG*** Pre CG*** vs. Post CG
Bohajar-Lax, 2015[32]	IG1: *n* = 30 (16-17 years) IG2: *n* = 29 (16-17 years) Inclusion Criteria: N/R Exclusion Criteria: Surgery on the spine or hamstring; diagnosed spinal abnormality.	Length: 5 weeks IG1: 5 minutes, twice per week of hamstring stretches using a static technique during warm-up of PE classes on consecutive days (20 seconds per stretch). IG2: 5 minutes, twice per week of hamstring stretches using a static technique during warm-up of PE classes on non-consecutive days (20 seconds per stretch).	Recruitment: N/R IG1 Attrition Rate: N/R IG2 Attrition Rate: N/R IG1 & IG2 Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility (M_{diff}): (Sit-and-Reach Test) Pre-Test: IG1: -1.4 ± 8.8 IG2: 3.4 ± 10.4 Post-Test: IG1: 0.8 ± 7.9 IG2: 5.7 ± 10.2	Intergroup Difference: Post IG1 vs. Post IG2 (NS) Intragroup Differences: Pre IG1 vs. Post IG1** Pre IG2 vs. Post IG2***

(continued)

Table 1. Characteristics of the Studies Included in the Systematic Review (continuation).

Author (Year)	Participants	Intervention and Control Groups	Responsive Outcomes	Flexibility Scores	Flexibility Differences
Coledam, 2012[16]	IG1: *n* = 15 (9.5±0.6 years) IG2: *n* = 16 (9.5±0.6 years) CG1: *n* = 15 (9.7±0.7 years) CG2: *n* = 15 (9.3±0.5 years) Inclusion Criteria: No participation in any kind of systematized physical training. Exclusion Criteria: Attendance rate of less than 85% for sessions.	Length: 12 weeks IG1 & IG2: 7 minutes of lower body stretches using a static technique during cooldown of PE classes. CG1 & CG2: Standard PE classes.	Recruitment: N/R IG1 & IG2 Attrition Rate: N/R CG1 & CG2 Attrition Rate: N/R IG & IG2 Adherence Rate: >85% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG1: 24.0±5.6 IG2: 24.7±6.7 CG1: 25.4±4.8 CG2: 25.5±6.1 Post-Test: IG1: 26.4±6.9 IG2: 27.9±6.3 CG1: 24.2±6.7 CG2: 26.2±5.6	Intragroup Differences: Pre IG1 vs. Post IG1* Pre IG2 vs. Post IG2*** Pre CG1 vs. Post CG1 (NS) Pre CG2 vs. Post CG2 (NS)
Gonzalez-Galvez, 2015[19]	IG: *n* = 39 (14.4±0.6 years) CG: *n* = 27 (14.0±0.5 years) Inclusion Criteria: Assertion that each student was free of musculoskeletal, neurological, cardiac, metabolic or rheumatic conditions. Exclusion Criteria: Prior history of spine pathologies/injuries or who had received previous treatment for back injuries; missing more than one session.	Length: 6 weeks IG: 55 minutes, twice per week of Pilates Method exercises. CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: N/R CG Attrition Rate: N/R IG Adherence Rate: 91.7% Adverse Events: N/R	Hamstring Flexibility (M_{diff}): (Sit-and-Reach Test) Pre-Test (Females): IG: 4.6±9.9 CG: 1.0±5.7 Post-Test (Females): IG: 8.5±8.4 CG: 1.1±7.3 Pre-Test (Males): IG: -2.2±8.5 CG: -8.9±5.8 Post-Test (Males): IG: 1.2±8.14 CG: -8.9±5.9	Intergroup Difference: Girls: Post IG** vs. Post CG Boys: Post IG** vs. Post CG Intragroup Differences: Girls: Pre IG vs. Post IG** Girls: Pre CG vs. Post CG (NS) Boys: Pre IG vs. Post IG** Boys: Pre CG vs. Post CG (NS)
Schawanke, 2016[17]	IG: *n* = 29 (7-17 years) CG: *n* = 32 (7-17 years) Inclusion Criteria: No participation in exercise program other than physical education classes or physical therapy treatment. Exclusion Criteria: No orthopedic disorders or history of orthopedic surgery.	Length: 16 weeks IG: 30 minutes, three times per week of stretching and strengthening exercises. CG: Usual care.	Recruitment: 47.3% (61 out of 129) IG Attrition Rate: 20.7% (29 to 23) CG Attrition Rate: 28.1% (32 to 23) IG Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test (Females): IG: 23.3±9.9 CG: 18.3±6.7 Post-Test (Females): IG: 28.8±7.3 CG: 20.2±6.0 Pre-Test (Males): IG: 20.4±7.1 CG: 15.6±7.6 Post-Test (Males): IG: 22.3±5.5 CG: 16.2±7.4	Intergroup Difference: Girls: Post IG* vs. Post CG Boys: Post IG** vs. Post CG Intragroup Differences: Girls: Pre IG vs. Post IG** Girls: Pre CG vs. Post CG (NS) Boys: Pre IG vs. Post IG (NS) Boys: Pre CG vs. Post CG (NS)
Mayorga-Vega, 2014[23]	IG: *n* = 22 (9.9±0.3 years) CG: *n* = 23 (9.9±0.3 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions; missing an evaluation session.	Length: 8 weeks IG: 5 minutes, twice per week of hamstring stretches using a static technique during cooldown of PE classes (20 seconds per stretch). Detraining was performed for 5 weeks after the intervention. CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: 0% (22 to 22) CG Attrition Rate: 0% (23 to 23) IG Adherence Rate: >90% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 17.1±5.6 CG: 14.2±4.2 Post-Test: IG: 18.6±5.7 CG: 14.6±4.1	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG*** Pre CG vs. Post CG (NS)

(continued)

Table 1. Characteristics of the Studies Included in the Systematic Review (continuation).

Author (Year)	Participants	Intervention and Control Groups	Responsive Outcomes	Flexibility Scores	Flexibility Differences
Mayorga-Vega, 2014[24]	IG: *n* = 22 (10.9±0.3 years) CG: *n* = 23 (10.9±0.3 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions.	Length: 8 weeks IG: 6 minutes, twice per week of hamstring/lumbar stretches using a static technique during cooldown of PE classes (20 seconds per stretch). Detraining was performed for 5 weeks after the intervention. CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: 0% (22 to 22) CG Attrition Rate: 0% (23 to 23) IG Adherence Rate: >95% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 15.7±7.0 CG: 13.4±8.5 Post-Test: IG: 18.2±7.7 CG: 13.1±8.5	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG*** Pre CG vs. Post CG (NS)
Mayorga-Vega, 2015[25]	IG1: *n* = 60 (12.7±0.7 years) IG2: *n* = 59 (12.7±0.6 years) CG: *n* = 61 (12.6±0.6 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions; incorrect performance of flexibility evaluation.	Length: 8 weeks IG1: 4 minutes, once per week of hamstring stretches using a static technique during cooldown of PE classes (30 seconds per stretch). IG2: 4 minutes, twice per week of hamstring stretches using a static technique during cooldown of PE classes (30 seconds per stretch). CG: Standard PE classes.	Recruitment: 100% (180 out of 180) IG1 Attrition Rate: 11.7% (60 to 53) IG2 Attrition Rate: 11.9% (59 to 52) CG Attrition Rate: 4.9% (61 to 58) IG1 & IG2 Adherence Rate: >90% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG1: 20.2±6.7 IG2: 20.7±7.7 CG: 20.4±7.0 Post-Test: IG1: 21.7±6.6 IG2: 22.6±8.2 CG: 20.7±7.4	Intergroup Difference: Post IG1** vs. Post CG Post IG2*** vs. Post CG Post IG1 vs. Post IG2 (NS) Intragroup Differences: Pre IG1 vs. Post IG1** Pre IG2 vs. Post IG2*** Pre CG vs. Post CG (NS)
Mayorga-Vega, 2016[26]	IG1: n = 51 (8.5±0.8 years) IG2: n = 51 (8.4±0.8 years) CG: n = 49 (8.4±0.6 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions; incorrect performance of flexibility evaluation.	Length: 9 weeks IG1: 4 minutes, twice per week of hamstring stretches using a static technique during cooldown of PE classes (30 seconds per stretch). Detraining was performed for 5 weeks after the intervention performing the same stretches for 4 minutes. IG2: 4 minutes, twice per week of hamstring stretches using a static technique during cooldown of PE classes (30 seconds per stretch). Detraining was performed for 5 weeks after the intervention performing a maintenance program for 1 minute. CG: Standard PE classes.	Recruitment: 100% (150 out of 150) IG1 Attrition Rate: 13.7% (51 to 44) IG2 Attrition Rate: 0% (51 to 51) CG Attrition Rate: 8.2% (49 to 45) IG1 & IG2 Adherence Rate: >90% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG1: 16.8±5.7 IG2: 16.8±5.5 CG: 15.3±5.2 Post-Test: IG1: 19.5±6.0 IG2: 19.1±5.1 CG: 15.4±4.9	Intergroup Difference: Post IG1** vs. Post CG Post IG2*** vs. Post CG Post IG1 vs. Post IG2 (NS) Intragroup Differences: Pre IG1 vs. Post IG1** Pre IG2 vs. Post IG2*** Pre CG vs. Post CG (NS)
Mayorga-Vega, 2017[27]	IG: *n* = 19 (9 years) CG: *n* = 18 (9 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions; incorrect performance of flexibility evaluation.	Length: 32 weeks IG: 3 minutes, once per week of hamstring stretches using a static technique during cooldown of PE classes (20 seconds per stretch). CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: 0% (19 to 19) CG Attrition Rate: 0% (18 to 18) IG Adherence Rate: >90% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 24.0±5.5 CG: 24.2±7.2 Post-Test: IG: 25.5±5.8 CG: 23.9±7.7	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG** Pre CG vs. Post CG (NS)

(continued)

Table 1. Characteristics of the Studies Included in the Systematic Review (continuation).

Author (Year)	Participants	Intervention and Control Groups	Responsive Outcomes	Flexibility Scores	Flexibility Differences
Merino-Marban, 2014[28]	IG: *n* = 23 (5.9±0.3 years) CG: *n* = 22 (5.9±0.3 years) Inclusion Criteria: No orthopedic disorders over the past six months. Exclusion Criteria: Attendance rate of less than 90% for sessions.	Length: 8 weeks IG: 1 minute, twice per week of hamstring stretches using a static technique during cooldown of traditional games (30 seconds per stretch). Detraining was performed for 5 weeks after the intervention. CG: Traditional games.	Recruitment: N/R IG Attrition Rate: 0% (23 to 23) CG Attrition Rate: 0% (22 to 22) IG Adherence Rate: >90% Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 16.4±4.9 CG: 16.9±5.0 Post-Test: IG: 18.8±5.8 CG: 16.9±4.9	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG*** Pre CG vs. Post CG (NS)
Sainz de Baranda, 2009[20]	IG: *n* = 26 (13.7±0.4 years) CG: *n* = 24 (13.7±0.4 years) Inclusion Criteria: N/R Exclusion Criteria: Prior history of spine pathologies.	Length: 31 weeks IG: Lower body stretches twice per week after warm-up for 5 minutes and after cooldown for 2 minutes during PE classes (15 seconds per stretch). CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: 0% (26 to 26) CG Attrition Rate: 0% (24 to 24) IG Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility: (Leg Raise Test) Pre-Test (Right Leg): IG: 79.7±7.0 CG: 79.2±12.7 Post-Test (Right Leg): IG: 87.3±5.5 CG: 77.3±8.0 Pre-Test (Left Leg): IG: 79.6±6.0 CG: 78.5±11.8 Post-Test (Left Leg): IG: 86.7±3.3 CG: 76.8±6.5	Intergroup Difference: Post IG*** vs. Post CG Intragroup Differences: Pre IG vs. Post IG*** Pre CG vs. Post CG (NS)
Rodriguez-García, 1999[29]	IG1: *n* = 23 (10.3±0.3 years) IG2: *n* = 23 (13.5±0.7 years) CG1: *n* = 18 (10.3±0.3 years) CG2: *n* = 13 (13.5±0.7 years) Inclusion Criteria: N/R Exclusion Criteria: N/R	Length: 32 weeks IG1 & IG2: Hamstring stretches twice per week after warm-up for 5 minutes and after cooldown for 2 minutes during PE classes. CG1 & CG2: Standard PE classes.	Recruitment: 92.8% (77 out of 83) IG1 & IG2 Attrition Rate: N/R CG1 & CG2 Attrition Rate: N/R IG1 & IG2 Adherence Rate: N/R Adverse Events: N/R		
Rodriguez-García, 2008[30]	IG1: *n* = 25 (10.3±0.3 years) IG2: *n* = 24 (13.5±0.7 years) CG1: *n* = 21 (10.3±0.3 years) CG2: n = 20 (13.5±0.7 years) Inclusion Criteria: No musculoskeletal disorders or lower-back pain. Exclusion Criteria: N/R	Length: 32 weeks IG1 & IG2: Hamstring stretches twice per week after warm-up for 3 minutes and after cooldown for 2 minutes during PE classes (20 seconds per stretch). CG1 & CG2: Standard PE classes.	Recruitment: N/R IG1 & IG2 Attrition Rate: N/R CG1 & CG2 Attrition Rate: N/R IG1 & IG2 Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility (M_{diff}): (Sit-and-Reach Test) Pre-Test: IG1: -0.7±6.1 IG2: -4.0±7.7 CG1: 0.4±8.5 CG2: -0.4±6.2 Post-Test: IG1: 1.3±7.8 IG2: 3.2±7.8 CG1: -3.9±9.9 CG2: -2.7±7.3	Intergroup Difference: Post IG1*** vs. Post CG1 Post IG2*** vs. Post CG2 Intragroup Differences: Pre IG1 vs. Post IG1 (NS) Pre IG2 vs. Post IG2*** Pre CG1*** vs. Post CG1 Pre CG2 vs. Post CG2 (NS)
Sanchez-Rivas, 2014[31]	IG: *n* = 22 (7.8±0.4 years) CG: *n* = 22 (7.9±0.5 years) Inclusion Criteria: Prior history of pathologies that could be aggravated. Exclusion Criteria: Missing an evaluation session or more than two sessions.	Length: 9 weeks IG: 3 minutes, twice per week of hamstring stretches using a static technique during cooldown of PE classes (20 seconds per stretch). CG: Standard PE classes.	Recruitment: N/R IG Attrition Rate: 0% (22 to 22) CG Attrition Rate: 0% (22 to 22) IG Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility: (Sit-and-Reach Test) Pre-Test: IG: 17.1±3.6 CG: 16.6±5.6 Post-Test: IG: 18.2±3.7 CG: 16.0±5.5	Intergroup Difference: Post IG** vs. Post CG

(continued)

Table 1. Characteristics of the Studies Included in the Systematic Review (continuation).

Author (Year)	Participants	Intervention and Control Groups	Responsive Outcomes	Flexibility Scores	Flexibility Differences
Santonja-Medina 2007[21]	IG1: *n* = 25 (10-11 years) IG2: *n* = 20 (10-11 years) CG: *n* = 18 (10-11 years) Inclusion Criteria: N/R Exclusion Criteria: N/R	Length: 31 weeks IG1: Hamstring stretches twice per week after warm-up for 3 minutes and after cooldown for 2 minutes during PE classes (20 seconds per stretch). IG2: Hamstring stretches four times per week after warm-up for 3 minutes and after cooldown for 2 minutes during PE classes and extracurricular physical activity (20 seconds per stretch). CG: Standard PE classes.	Recruitment: N/R IG1 Attrition Rate: 0% (25 to 25) IG2 Attrition Rate: 0% (20 to 20) CG Attrition Rate: 0% (18 to 18) IG1 & IG2 Adherence Rate: N/R Adverse Events: N/R	Hamstring Flexibility (Mdiff): (Leg Raise Test) Pre-Test (Right Leg): IG1: 77.7±12.0 IG2: 76.7±11.5 CG: 79.2±12.7 Post-Test (Right Leg): IG1: 86.7±7.5 IG2: 93.7±8.5 CG: 77.7±12.0 Pre-Test (Left Leg): IG1: 77.6±9.0 IG2: 76.6±10.2 CG: 78.5±11.8 Post-Test (Left Leg): IG1: 85.7±8.5 IG2: 93.5±5.0 CG: 76.4±9.5	Intergroup Difference: Post IG1*** vs. Post CG Post IG2*** vs. Post CG Post IG1 vs. Post IG2*** Intragroup Differences: Pre IG1 vs. Post IG1*** Pre IG2 vs. Post IG2*** Pre CG vs. Post CG (NS)

Note. Statistics are reported as means ± standard deviations unless otherwise specified; Mdiff: mean difference; N/R: not reported; NS: non-significant; IG: intervention group; CG: control group; PE: physical education.
*p < .05. **p < .01. ***p < .001

the stretching interventions lasted between 5 and 32 weeks (M = 15.3, SD = 2.7), with sessions lasting 1-55 minutes each (M = 10.4, SD = 2.9) and performed at a frequency of 1-4 times per week (M = 2.0, SD = 0.1).

Three of the included studies used a full stretching intervention as a replacement for the participants' physical education classes[17-19], whereas the remaining 14 studies incorporated the stretching intervention into the warm-up and/or cooldown of their physical education classes. Control groups were used in 16 out of 17 studies, including standard physical education classes (n = 14), traditional games (n = 1), and a usual care group (n = 1).

No major or minor adverse events were reported in any studies and the attrition rate was 7.1% across twelve studies, ranging between 0-25%. The remaining five studies did not report the attrition rate in the intervention group. Nine studies reported an adherence rate above 85%, while eight studies did not report adherence rates.

Quality appraisal

Quality assessment criteria for the 17 included studies can be found in (Table 2)[18] was evaluated as an RCT according to the PEDro scale, which was given a score of 5/10 and considered fair quality. The remaining 16 studies were evaluated as non-RCTs using the MINORS scale. The average score of the non-RCTs was 17.4 out of 24, with scores ranging from 15 to 21. Overall, this indicated that the included studies have moderate-to-high methodological quality.

Results of the individual studies

The included studies reported outcome data across five outcomes: Sit-and-Reach (SR) test (n = 13), Leg Raise (LR) test (n = 3), Toe-Touch (TT) test (n = 1), Wall-Heel Distance (n = 1), and Deep Bending test (n = 1). In a comparison of active global stretching (4-10 minutes per stretch), analytical stretching (15 seconds per stretch), and standard physical education classes, the active global stretching group had significantly greater improvements in hamstring, trunk, and dorsal-lumbar flexibility compared to the other comparison groups[18]. The analytical stretching group also had significantly greater improvements in hamstring and trunk flexibility compared to standard physical education.

Intergroup differences were found for hamstring flexibility. All three studies using the LR test demonstrated significantly greater improvements for left and right legged hamstring flexibility in the stretching intervention when compared to control conditions[18,20,21]. Similarly, significant greater improvements in hamstring flexibility were observed between intervention and control groups on the Sit-and-Reach test for all 11 studies that reported intergroup differences[17,19,22-28,30,31].

Two studies examined intragroup differences between pre- and post-intervention scores in male and female participants separately[17,19]. Although female participants showed significant post-treatment improvements in hamstring flexibility for both studies, male participants only reported significant improvements in one of the two studies.

Results of the meta-analysis

A total of 761 participants were included in the meta-analysis for hamstring flexibility using the SR and TT tests (Figure 2). A significant medium effect was found in favour of the intervention groups (random effects model SMD = 0.46; 95% CI = 0.22, 0.70; I-squared heterogeneity = 56.9%). The meta-analysis for the LR test resulted in a significant and large effect in favour of the intervention groups (n = 113; fixed effect model SMD = 1.22; 95% CI = 0.80, 1.64; I-squared heterogeneity = 0%). Data was pooled from 874 participants when the analysis included SR,

Table 2. Quality Assessment.

PEDro scale		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Useros-García (2010)[18]		Y*	Y	N	N	N	N	Y	Y	N	Y	Y	5 / 10
MINORS scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Becerra-Fernandez (2016)[22]	2	2	2	1	0	2	2	0	2	2	2	2	19 / 24
Bohajar-Lax (2015)[32]	2	2	2	1	0	2	0	0	0	2	2	2	15 / 24
Coledam (2012)[16]	2	2	2	1	0	2	2	2	2	2	2	2	21 / 24
Gonzalez-Galvez (2015)[19]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Schwanke (2016)[17]	2	2	2	1	0	2	2	2	2	2	1	2	20 / 24
Mayorga-Vega (2014)[23]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Mayorga-Vega (2014)[24]	2	2	2	1	0	2	2	0	2	2	2	2	19 / 24
Mayorga-Vega (2015)[25]	2	2	2	1	0	2	2	0	2	2	2	2	19 / 24
Mayorga-Vega (2016)[26]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Mayorga-Vega (2017)[27]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Merino-Marban (2014)[28]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Sainz de Baranda (2009)[20]	2	2	2	1	0	2	2	0	2	2	0	2	17 / 24
Rodriguez-García (1999)[29]	2	0	2	1	0	2	2	0	2	2	0	2	15 / 24
Rodriguez-García (2008)[30]	2	0	2	1	0	2	0	0	2	2	2	2	15 / 24
Sanchez-Rivas (2014)[31]	2	2	2	1	0	2	0	0	2	2	2	2	17 / 24
Santonja-Medina (2007)[21]	2	0	2	1	0	2	2	0	2	2	2	2	17 / 24

Note. Y = yes; N = no.
*Not included in total score.

TT and LR tests, which found a significant moderate effect in favour of the intervention groups (random effects model SMD = 0.58; 95% CI = 0.32, 0.83; I-squared heterogeneity = 66.7%).

Discussion

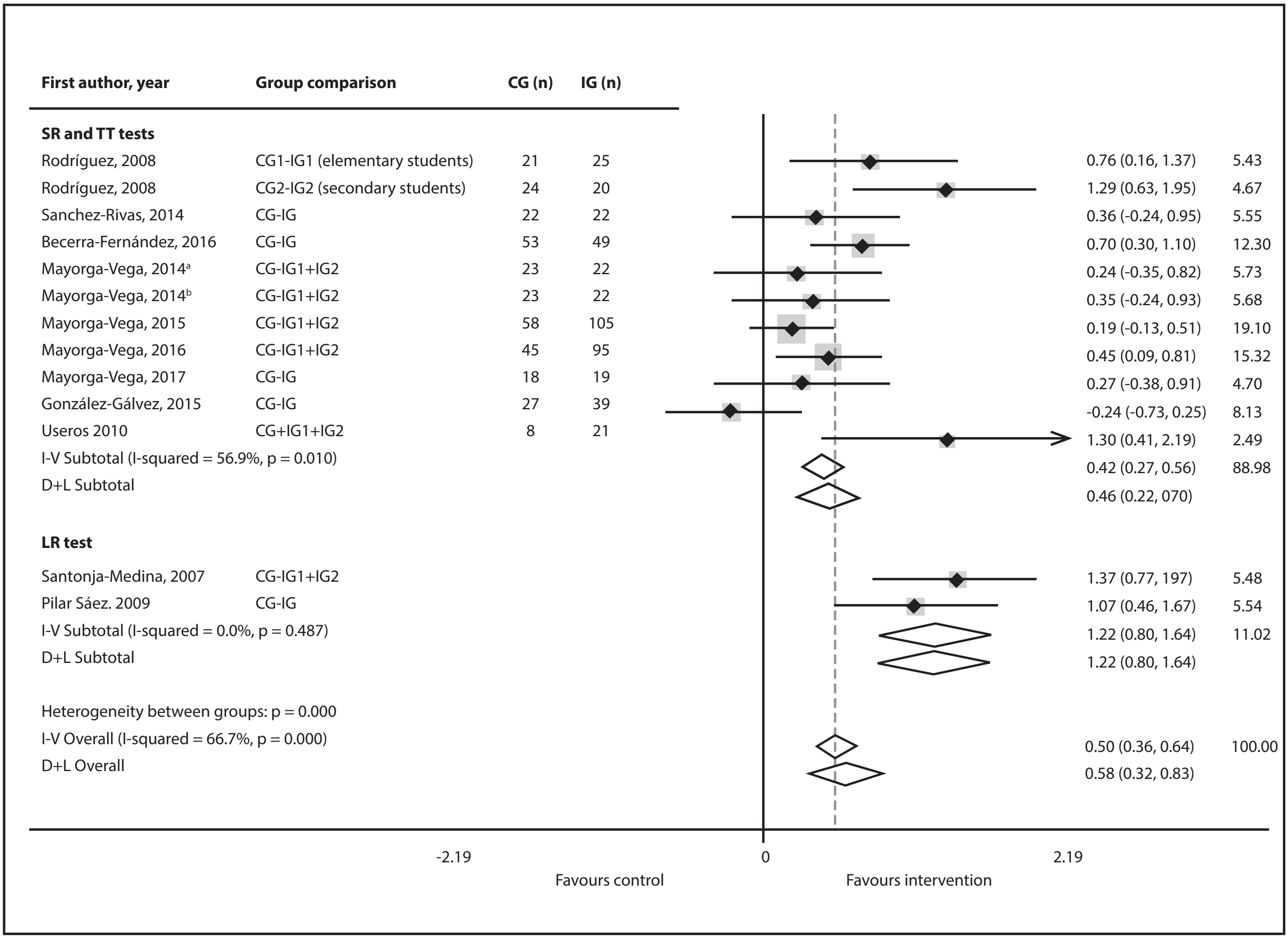
In the present research, the existing scientific evidence on the effects of stretching interventions carried out during PE classes on the flexibility of school students were synthesized and summarized. After a thorough investigation of the literature, a published review with a similar topic was found[33]. However, this work was closer to a narrative review than to a systematic review, since no methodological quality assessment of the included studies was carried out. Moreover, no meta-analysis was performed to quantitatively assess the benefits of stretching interventions on flexibility in school children. Instead, this work was specifically focused on a unique variable (hamstring extensibility) and in a specific population (primary children). Therefore, the present review provides a greater foundation of evidence for PE teachers who wish to improve the flexibility level of their students during PE classes.

Notably, the current review identified a substantial number of investigations published on the research topic that have been shown to possess acceptable methodological quality. In this regard, it should be highlighted that some of the investigations reviewed were described by the authors as cluster randomize trials. However, given the small number of schools included these studies (generally only two) and the low number of participants considered eligible for each cluster, they were appropriately treated as comparative investigations.

According to the results of the included studies, stretching interventions performed during PE classes are a feasible strategy for improving flexibility in all educational levels. This includes preschool, primary and secondary (high school) students. Even interventions involving just a few minutes of stretching during warm-up and/or cooldown of PE classes seemed to be effective. These observations indicate that flexibility can be gradually improved as long as it is progressively continued. This is an interesting finding since schools provide an ideal setting for children to maintain their flexibility levels throughout their schooling, which tend to gradually decrease with age[34].

Most importantly, the current meta-analysis focused on hamstring extensibility and included a large sample of children tested on three flexibility assessments procedures[35]. This supports the implementation of stretching as key element of PE sessions, since reduced hamstring flexibility is a common clinical concern in children and adolescents that can often lead to low-back pain, postural problems and a higher risk of muscle injury[36]. However, it should be noted that the SR was a field-based test used for assessing hamstring extensibility on a majority of the investigations, and it has been suggested that the score of this test is strongly influenced by low back (pelvic tilt and lumbar spine) range of motion[37]. Therefore, it is possible that some of these interventions

Figure 2. Meta-analysis.



could have a greater impact on the pelvic and lumbar spine than on the hamstring muscles.

Despite these findings, there are certain characteristics of the included studies that should be mentioned, since they may potentially affect the interpretation of the results. Firstly, most of the investigations did not gather information regarding students' participation on exercise training or sporting activities. This is potentially a confounding factor that could have influenced the obtained results. Secondly, only two investigations reported separate outcome data for each sex, resulting in mixed findings. Therefore, it is not clear whether the effects of the stretching interventions were different between boys and girls. It has been noted that sex has a substantial influence on flexibility levels during school years, with girls generally outperforming boys[38]. In particular, it has been proposed that females have less passive tissue resistance to angular motion, resulting in females having greater knee flexor extensibility and less passive knee flexor stiffness compared to males[39]. It is therefore plausible that boys and girls may respond differently to stretching interventions. Further research is needed to investigate these flexibility differences between school-aged boys and girls.

In summary, the present review provides valuable information regarding the beneficial effects of implementing stretching interventions during PE classes. It is important to note, however, that there are some inherent limitations that should be acknowledged in the current literature. In particular, there are very few RCTs that have been conducted on this topic, research has not considered sex as a potential moderating factor on the efficacy of stretching interventions, and that most investigations only focus on hamstring extensibility. In addition, a considerable amount of studies administered the "sit and reach" test for this purpose. In this regard, it should be acknowledged that this is a linear test whose results might be affected by anthropometric factors and range of motion of the lumbar spine[40]. These factors limit the applicability of the scientific evidence provided in the current review. In addition, some limitations inherent to this research design such us language restrictions and not having reviewed the grey literature, should also be acknowledged.

Conclusion

This review provides preliminary scientific evidence indicating that flexibility levels can be improved through the incorporation of stretching interventions during PE classes. Further research is needed on the effects of such interventions on trunk and upper body flexibility. Future studies should take into account exercise and sport performed outside the school setting, as well as the influence of sex as potential confounding factors.

Implications for school health

Physical education (PE) programs are evolving from a traditional skill-centered model to a health-centered model that focuses on improving fitness. Consequently, activities aimed to increase health-related physical fitness should be performed during PE class, including stretching routines, since flexibility is a key health-related physical fitness component. Flexibility training is not often included in the physical activity guidelines for the general population[11]. However, for active people who are motivated towards exercising, the inclusion of stretching routines is considered an important strategy, as it reduces muscle injuries and increases joint range of motion[41]. One of the goals of PE is the development of positive attitudes towards active lifestyles among students. Thus, including flexibility training during PE class is an approach that can assist in achieving this goal.

Physical education policies have received increased attention as a means for improving physical activity levels. In this regard, performing activities such ball play, playing games, gymnastics, dance or fitness during PE class, it is considered a useful strategy for helping to reach children the amount of physical activity recommended[42]. The results of our study shows that if PE teachers decide to include stretching routines, even if is only for a short period of time (i.e. before and after the performance of these activities), they would increase the potential contribution that PE can make for meeting public health goals.

Conflict of interest

The authors do not declare a conflict of interest.

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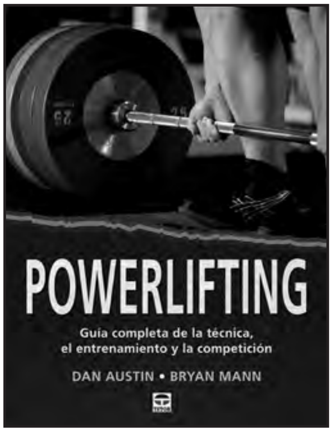

POWERLIFTING

Guía completa de la técnica, el entrenamiento y la competición

ISBN: **978-84-18655-06-7**
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Encuadernación: **Rústica cosida**

Basado en los estudios e investigaciones más recientes sobre la Ciencia del ejercicio, y con su enfoque práctico del entrenamiento y la competición en este deporte, este libro ofrece más de 100 ejercicios para desarrollar los tres movimientos principales: sentadilla, *press* banca y peso muerto. Las rutinas de calentamiento dinámico y las técnicas de recuperación te ponen a punto para el entrenamiento, lo que convierte este libro en una guía única hacia el éxito en el *powerlifting*.

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PERIODIZACIÓN DEL ENTRENAMIENTO DE FUERZA APLICADA A LOS DEPORTES

Programas de entrenamiento contrastados para 30 deportes

ISBN **978-84-18655-08-1**
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Encuadernación: **Rústica cosida**

Tudor O. Bompa, científico del deporte de renombre mundial y la mayor autoridad en periodización, y Carlo Buzzichelli, experto internacional en fuerza y acondicionamiento, van más allá de la simple aplicación de programas de culturismo o *powerlifting* para enseñarte qué tipo de entrenamiento programar, y cuándo, para aumentar la fuerza y maximizar el rendimiento deportivo en el momento adecuado.

Este libro demuestra cómo utilizar planes de entrenamiento periodizados para alcanzar el pico de forma física en los momentos adecuados. Para ello, manipulan las variables del entrenamiento de fuerza durante seis fases: adaptación anatómica, hipertrofia, fuerza máxima, conversión a fuerza específica, mantenimiento y pico. Los entrenadores y deportistas de 30 disciplinas tienen ahora al alcance de la mano programas contrastados que consideran las fases específicas y las exigencias únicas de su deporte, junto con información acerca del sistema energético predominante, los factores que limitan el rendimiento y los objetivos del entrenamiento de fuerza.

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La **Sociedad Española de Medicina del Deporte**, en su incesante labor de expansión y consolidación de la Medicina del Deporte y, consciente de su vocación médica de preservar la salud de todas las personas, viene realizando diversas actuaciones en este ámbito desde los últimos años.

Se ha considerado el momento oportuno de lanzar la campaña de gran alcance, denominada **CAMPAÑA DE APTITUD FÍSICA, DEPORTE Y SALUD** relacionada con la promoción de la actividad física y deportiva para toda la población y que tendrá como lema **SALUD – DEPORTE – DISFRÚTALOS**, que aúna de la forma más clara y directa los tres pilares que se promueven desde la Medicina del Deporte que son el practicar deporte, con objetivos de salud y para la mejora de la aptitud física y de tal forma que se incorpore como un hábito permanente, y disfrutando, es la mejor manera de conseguirlo.