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Summary / Sumario

The prescription of physical exercise. We all need to row together in the same direction

La prescripción de ejercicio físico. En este barco remamos todos

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It is now a year since the Digitalization Plan for the Sports Sector (Resolution of 4 July 2022 of the Presidency of the Supreme Council for Sports) was set in motion. A plan which, among other objectives, proposes establishing a common strategy for the prescription of physical exercise and activity. Although we should congratulate ourselves, this plan is not something new in Spain, given that a number of autonomous communities have had physical exercise prescription (PEP) programmes in place for many years now, whereby medical personnel prescribe physical exercise based on standardised guidelines. These prescriptions are a primary therapeutic tool and form part of the healthcare strategies for patients suffering from a chronic disease.

Specifically, the Regional Centre for Sports Medicine of Castilla y León (CEREMEDE) already has extensive experience in PEP. Since 2015, we have been treating patients with different chronic pathologies and we aim to pass on our experience and knowledge to other healthcare centres, particularly with regard to the design and development of protocols, healthcare guides and forms that facilitate the implementation of PEP in the surgeries of other specialties, and in the area of primary healthcare in particular.

Moreover, at the end of 2021, in point 28 of the Conclusions of the European Council and of the representatives of the Governments of the Member States, meeting within the Council, on lifelong physical activity (OJEU of 13/12/2021), there is strong insistence on the need to "strengthen collaboration, where possible, with the health sector in providing exercise prescription and counselling given by healthcare and specialised professionals".

And the fact is that there are increasingly more scientific publications in the area of physical exercise and its contribution to health. Molecular biology has helped to clarify some of the mechanisms by which physical exercise represents a beneficial intervention not only for the prevention but also for the treatment of the most common metabolic, musculoskeletal, cardiovascular disorders and, in general, chronic non-communicable diseases (CNCDs). Given that many of these diseases are among the main reasons for using the healthcare services, they are one of the most decisive factors in healthcare spending as a whole, as well as being a major factor in the loss of years and quality of life. In parallel, over the last few decades, medicine and nutrition have endeavoured to reduce the prevalence of excess weight and obesity as well as the problems resulting from these conditions (diabetes, high cholesterol, high blood pressure, etc.). However, the prevalence of many of the CNCDs has progressively increased in the different age segments and in both sexes.

We are aware that physical inactivity is one of the major preventable causes of mortality with a greater relative risk of 30-50% as opposed to active individuals. Despite the fact that the strong relationship existing between physical activity and health is well documented, a considerable percentage of the population is either not sufficiently active or is completely inactive. This normalization of a lack of physical activity in our society has led to the conclusion that physical exercise is a necessary intervention at all levels: social, political, healthcare, educational.... and medical.

We are continuing to take as a basis the criteria of the WHO, which define an active individual as one who does more than 150 minutes of moderate physical activity a week or more than 75 minutes of intense physical activity a week, or an equivalent combination throughout the week; while the amount of time dedicated to sedentary activities should also be limited. However, if we persist in considering that any level of physical activity is positive (even if the quantity and quality are below

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the proposed thresholds), given that the benefits of physical activity are dose dependant, we are not prescribing physical exercise but are recommending physical exercise which, although it is a first step towards resolving this situation, is not sufficient.

We are aware that disease alters and reduces the quality of life of individuals. Progress in healthcare has extended life expectancy, thereby increasing the prevalence of chronic diseases. An improvement in lifestyle is one of the key tools available to us, in order to intervene in the prevention and treatment of numerous chronic diseases.

The outcomes of investigations show us that interventions with physical exercise, if correctly designed, are safe and meet the prevention and treatment objectives of CNCDs.

PEP must be understood to be a therapeutic tool and the recommended way to provide exercise instructions, given that it delivers greater benefits as opposed to generic, non-specific recommendations. In the same way as for the prescription of medicines, PEP is a structured practice in which we systematically indicate on an individual basis, a dose of exercise for the purpose of benefiting the patient's health. The prescription must contemplate a dose (intensity), frequency, duration, etc., all dependent on the patient's clinical condition, physical capabilities and tastes. Likewise, consideration must be given to any contraindications and side effects.

Physical exercise has a clear beneficial effect on the prevention of multiple pathologies and it is also a useful tool in many stages of disease, reducing the appearance of treatment-related complications and side effects. Furthermore, it clearly improves the psychological aspects relating to the disease, and also enhances vitality, level of functionality and the functioning of the cardiovascular, respiratory, muscular and immunological systems.

We are in no way proposing to medicalize physical exercise, but to obtain results, to prevent and treat diseases and, to do so, as in any medical practice, we need to diagnose and establish a prescription, in this case, for physical exercise. To prescribe and train ourselves. To train ourselves to prescribe. Diagnosis and treatment are part of our very essence, and in this case as well.

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Original article

Influence of the menstrual cycle on physical and cognitive performance in eumenorrheic women

Inés Piñas Bonilla[1], Pablo Abián[2], Alfredo Bravo-Sánchez[3], María Ramírez-de la Cruz[1], Fernando Jiménez[1], Javier Abián-Vicén[1]

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Summary

Introduction: The female sexual hormones typical of the menstrual cycle not only have reproductive functions, they also influence other physiological systems and can affect sports and cognitive performance. The purpose of this study has been to evaluate different aspects such as body composition, endurance, muscle strength and some cognitive abilities at different stages of the menstrual cycle.

Material and method: Eight young eumenorrheic women (age = 23.1 ± 4.4 years) with regular menstrual cycles participated in the study. A densitometry and bioimpedance test were performed to study body composition, a short-term visual memory test and a reaction time test to assess cognitive abilities, and muscle characteristics (thickness and stiffness of the anterior rectus and muscle strength) along with a progressive test to exhaustion were analyzed to assess performance during the mid-follicular (FF) and mid-luteal (FL) phases of the participants' menstrual cycle.

Results: During the follicular phase, the participants registered a greater total time (FF = 488.5 ± 93.18 s vs. FL = 468.6 ± 81.29 s; $P = 0.015$) and a lower initial heart rate (FF = 83.3 ± 10.23 PPM vs. FL = 92.9 ± 7.67 PPM; $P = 0.034$) in the progressive test to exhaustion. Regarding cognitive abilities, in the follicular phase, better results were obtained in reaction time both with the right hand (FF = 0.426 ± 0.082 s vs. FL = 0.453 ± 0.087 s; $P = 0.036$) and with the left hand (FF = 0.435 ± 0.096 s vs. FL = 0.466 ± 0.077 s; $P = 0.034$). On the other hand, a higher percentage of fat (FF = 27.3 ± 5.1% vs. FL = 27.9 ± 5.0%; $P = 0.041$) was found in the luteal phase.

Conclusion: Performance in endurance and in cognitive test, such as reaction time was better in the Follicular Phase, while a higher percentage of fat was observed in the Luteal Phase. However, memory, strength and muscular characteristics were not affected by the hormonal fluctuations of the menstrual cycle.

Key words:
Menstrual cycle. Woman. Cognitive aspects. Performance. Physical activity.

Influencia del ciclo menstrual en el rendimiento físico y cognitivo en mujeres eumenorreicas

Resumen

Introducción: Las hormonas sexuales femeninas propias del ciclo menstrual no solo tienen funciones reproductivas, también influyen en otros sistemas fisiológicos pudiendo afectar al rendimiento deportivo y cognitivo. El propósito del presente estudio ha sido evaluar distintos aspectos como la composición corporal, la resistencia, la fuerza muscular y algunas capacidades cognitivas en diferentes etapas del ciclo menstrual.

Material y método: En el estudio participaron ocho mujeres jóvenes eumenorreicas (edad = 23,1 ± 4,4 años) con ciclos menstruales regulares. Se realizó una prueba de densitometría y una bioimpedancia para estudiar la composición corporal, una prueba de memoria visual a corto plazo y un test de tiempo de reacción para evaluar habilidades cognitivas y se analizaron características del músculo (grosor y rigidez del recto anterior y fuerza muscular) junto a una prueba de esfuerzo para evaluar el rendimiento durante las fases folicular media (FF) y lútea media (FL) del ciclo menstrual de las participantes.

Resultados: Durante la fase folicular las participantes registraron un mayor tiempo total (FF = 488,5 ± 93,18 s vs. FL = 468,6 ± 81,29 s; p = 0,015) y una frecuencia cardiaca inicial menor (FF = 83,3 ± 10,23 PPM vs. FL = 92,9 ± 7,67 PPM; p = 0,034) en la prueba de esfuerzo. Además, Respecto a las habilidades cognitivas, en la fase folicular se obtuvieron mejores resultados en el tiempo de reacción tanto con la mano derecha (FF = 0,426 ± 0,082 s vs. FL = 0,453 ± 0,087 s; p = 0,036) como con la mano izquierda (FF = 0,435 ± 0,096 s vs. FL = 0,466 ± 0,077 s; p = 0,034). Por otro lado, se encontró un mayor porcentaje de grasa (FF = 27,3 ± 5,1% vs. FL = 27,9 ± 5,0%; p = 0,041) en la fase lútea.

Conclusión: El rendimiento en resistencia y en aspectos cognitivos como es el tiempo de reacción fue mejor en la Fase Folicular mientras que se observó un mayor porcentaje de grasa en la Fase Lútea. Sin embargo, la memoria, la fuerza y las características musculares no se vieron afectadas por las fluctuaciones hormonales propias del ciclo menstrual.

Palabras clave:
Ciclo menstrual. Mujer. Aspectos cognitivos. Rendimiento. Actividad física.

Award for the best communication of the Conference of Badajoz

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Introduction

In recent years, the participation of women in sport has increased, creating the need to understand exercise physiology in the female athlete in detail[1]. In the 1980s, it was accepted that physiological responses to exercise did not differ between men and women[2]. With more research, it has been shown in recent decades that in the early stages of childhood there are no differences between the sexes and that discrepancies appear from puberty, coinciding with the beginning of testosterone production in men[3]. In adulthood, men secrete thirty times more testosterone than women, giving them a significant advantage in terms of strength, speed and endurance[4,5].

Women start their menstrual cycle (MC), one of the most important biological rhythms of human physiology, when they reach puberty[6]. It is a physiological process generated by the interaction of the hypothalamus with pituitary hormones, which cause various changes not only in the female reproductive system but also in other body tissues[7]. The ovarian cycle lasts from 25 to 30 days and is divided into two phases according to the ovarian function in each: the follicular phase (FP) and luteal phase (LP)[8]. The follicular phase begins with menstruation, which usually lasts 4 to 6 days[9]. From day 6, the hypothalamus secretes gonadotropin-releasing hormone (GnRH) more frequently to produce follicle-stimulating hormone (FSH) and luteinising hormone (LH)[10]. FSH stimulates the growth of follicles in the ovary and, as a result, drives the production of oestradiol. LH reaches its peak on day 14 of the cycle, causing the release of the mature follicle from the ovary to the fallopian tube, i.e. ovulation[11]. The luteal phase is characterised by the formation of the corpus luteum and the secretion of progesterone[12]. The luteal phase ends with the death of the corpus luteum, causing a decrease in progesterone, and the degradation of the endometrium through menstrual bleeding, bringing the menstrual cycle to an end[13].

There are a variety of mechanisms that suggest that cyclical fluctuations of oestrogen and progesterone during the MC could affect athletic performance. Oestrogens modulate body composition by increasing fat mass[14] and provoking water retention[15]. Interestingly, oestrogens also increase muscle glycogen storage capacity[16], which improves oxidative capacity and decreases dependence on anaerobic pathways for adenosine triphosphate (ATP) production. Therefore, high oestrogen levels are associated with lower blood lactate levels and decreased muscle fatigue[17]. In turn, progesterone influences other parameters, such as resting heart rate, which increases markedly in the luteal phase[18]. As a result, the subjective perception of effort increases, attenuating sports performance[19]. It also promotes protein catabolism, which in turn reduces the stimulation of muscle protein synthesis[20]. Therefore, the increase in oestrogens and a decrease in progesterone which occurs in the follicular phase should be related to greater results in terms of strength and power. Focusing on muscle stiffness, Yim *et al.*[21] suggest that the increase in oestrogens in certain phases of the MC reduces the stiffness of different muscle and connective tissues. In recent years, consideration has been given to the possibility that the menstrual cycle, and specifically progesterone, might have a negative effect on some cognitive skills, such as short-term memory[22] or reaction time, but other studies have concluded that altered perceptions and sociocultural expectations, rather than identifiable cognitive deficits, may play a significant role[23].

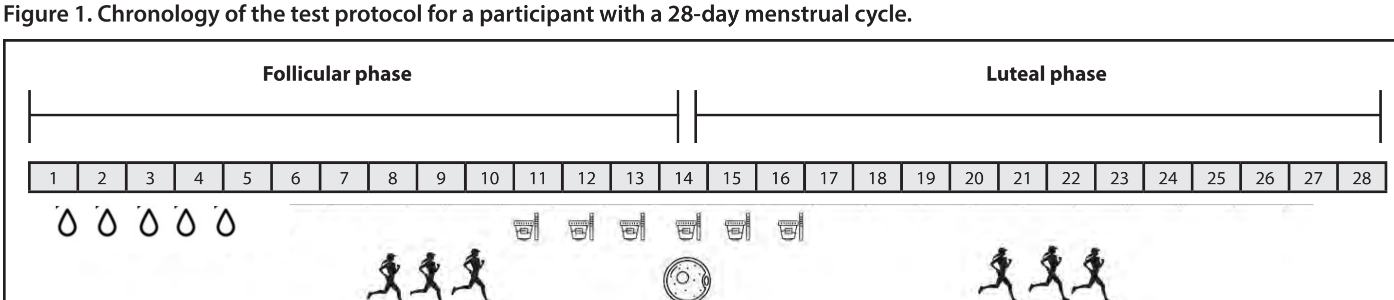
Taking into account the above, it would not be correct to apply studies carried out in men directly to women, given the physiological and endocrinological differences between the sexes[24]. From this evidence, a line of research focused on studying the effects of female physiology was developed[25], concluding that to carry out an ideal study on sports performance in women, the effects of hormonal fluctuations in the menstrual cycle should be taken into consideration. Therefore, the purpose of this study was to evaluate the effect of the menstrual cycle on body composition, resistance, different cognitive aspects (memory and reaction time) and muscle characteristics (muscle strength, thickness and stiffness) in young eumenorrheic women. It was hypothesised that in the luteal phase greater body mass and water percentage would be observed, and that greater physical performance and a better response of cognitive skills such as short-term memory would be seen in the follicular phase.

Material and method

Research design

The experimental design of this study was repeated measures. The dependent variables were measured at two different points in the participants' menstrual cycle, specifically in the middle of the follicular phase and the middle of the luteal phase (Figure 1). According to recent

Figure 1. Chronology of the test protocol for a participant with a 28-day menstrual cycle.



studies, these two moments represent preovulation and peak progesterone concentration, respectively[9]. The start of menstruation was taken as day 1 of the cycle and the middle of the follicular phase between eight and ten days after the first day of menstruation. The middle of the luteal phase was taken as days 20-22 for a regular 28-day cycle. The choice of these moments was made following the methodology in the study by Carmichael *et al.*[9]. First, the participants were familiarised with the protocol one week before the start of the experimental stage in order to minimise any effects related to learning during the measurements. The measurements were taken during two consecutive phases (FP and LP), but in which of the two phases each of the subjects began was randomised in such a way that half of the subjects started with the FP and the other half with the LP. On each measurement day, the tests were performed in the same order: dual-energy X-ray absorptiometry (DXA) and bioimpedance to assess body composition; a reaction time and short-term memory test; an ultrasound to study the thickness of the rectus femoris muscle and a muscle stiffness test on the same muscle; a maximum knee extension and flexion strength test; and finally a stress test (Figure 2).

Participants

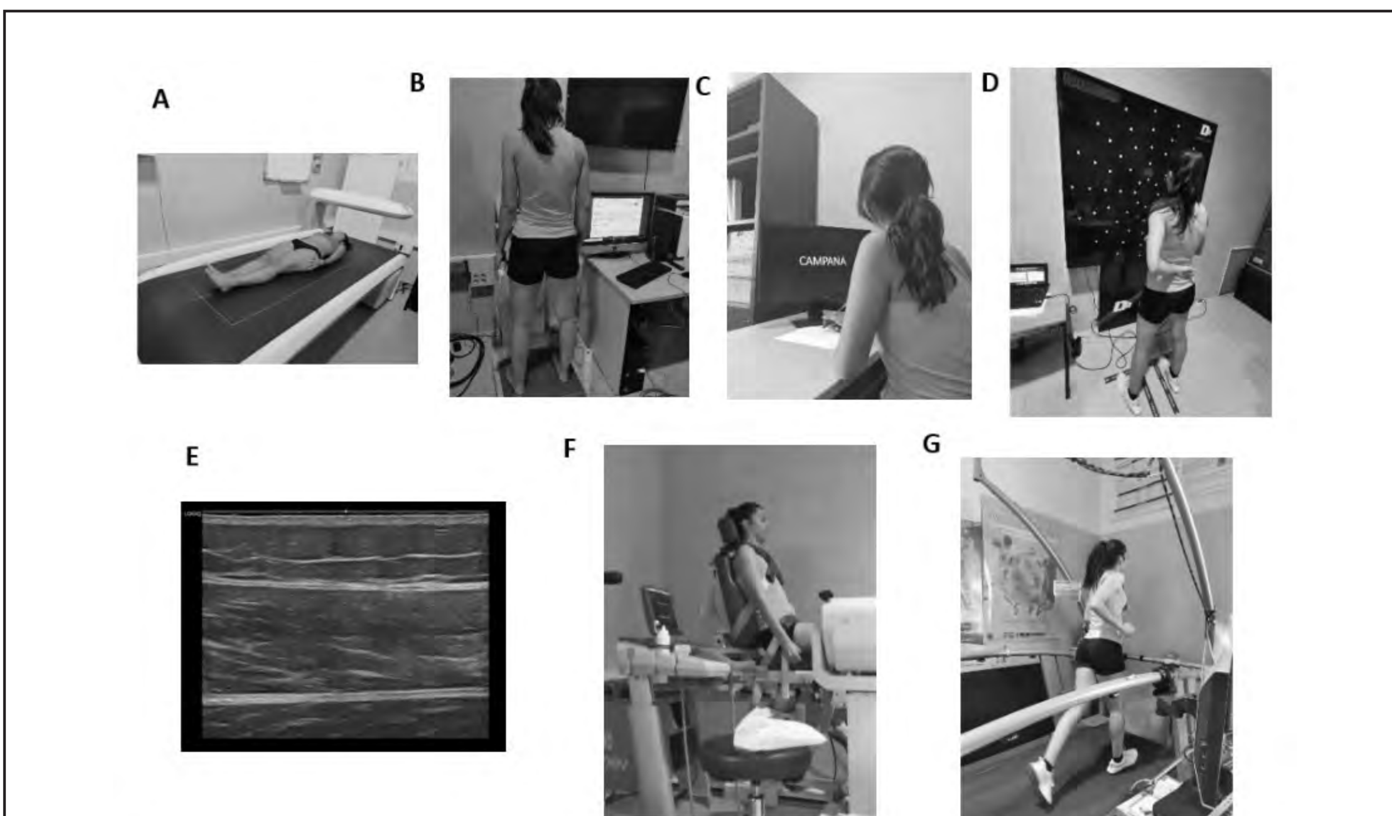
Eight young eumenorrheic women (age = 23.1 ± 4.4 years; total mass = 56.33 ± 6.65 kg; height = 165.5 ± 4.7 cm) with regular menstrual cycles voluntarily participated in the study. The inclusion criteria for all participants were: being of legal age, being physically active (performing physical activity at least three days a week) and the absence of menstrual disorders. The participants had no experience with hormonal contraceptives or supplements for at least 6 months prior to the test and had a history of clinically normal menstrual cycles. Subjects were excluded if they reported any type of injury within the 6 months prior to the start of the study, a positive smoking status, use of oral contraceptives or hormonal supplements, or any type of menstrual disorders, such as dysmenorrhea or amenorrhea, or severe symptoms associated with PMS[26].

Procedure

Determination of the phases of the menstrual cycle

The regularity and duration of the menstrual cycle were monitored in each participant during the 6 months prior to the start of the research

Figure 2. Pictures taken during testing. A. Densitometry test. B. Bioimpedance test. C. Memory Test. D. Reaction Time test. E. Ultrasound of the rectus femoris. F. Isokinetic strength test. G. Stress test.



using a mobile application (Mycalendar®, Period-tracker, USA). With this app, the participants completed a menstrual diary that included: the start and end of bleeding, ovulation day and the total duration of the cycle. The cycle was assessed individually in each subject and the average was 29.3 ± 1.5 days[27]. During the familiarisation tests, they were told that they should measure basal body temperature (BBT) and mass every morning immediately after waking up. Temperature increases of at least 0.3°C, body mass changes of at least 0.5% and the information provided by the period tracking app also helped identify the phases of the menstrual cycle[28]. They were given test strips (Ovulation LH Test Strip; Cuckool. China) to assess the increase in luteinising hormone (LH) in the first morning urine sample and thus determine the day of ovulation. Thanks to all this information, it was possible to determine the times at which the measurements were made, the follicular phase 25-30% and the luteal phase 70-75% of the duration of the individual menstrual cycle. This protocol allowed tests to be performed at the same points in the cycle for all participants, despite differences in the durations of their MC[29] (Figure 1).

Body composition analysis

First, body mass with as little clothing as possible and height were measured using scales with a stadiometer (Seca 711, Seca, Germany). Subsequently, the participants underwent a bone mineral density examination by means of DXA (GE Lunar IDXA, GE Healthcare, Madison, WI, USA), which allowed us to record bone mass, fat percentage and soft tissue composition[30]. The densitometry was performed using the whole body protocol, where the subject lay in supine position with their arms extended alongside their body and their feet together. Body composition analysis was completed with a bioimpedance examination with an InBody 720 (Biospace Inc. Tokyo, Japan), which analysed parameters such as body fat percentage, skeletal muscle mass, total body water and basal metabolic rate. To do this, the patient had to get onto the Inbody, hold the upper handlebars with both hands, placing her thumbs on the specific contacts and holding the position without moving until the instrument finished measuring[31].

Cognitive aspects

First, reaction time was measured using a Dynavision™ D2 Visuomotor Device (Dynavision International LLC, West Chester, OH, USA). This device consists of a board (1.21 m × 1.21 m) containing 64 buttons that serve as visual stimulus. They are arranged in 5 concentric circles around a central screen which should be at eye level. The test was standardised by having the subjects stand 40 cm from the screen with their feet 15 cm apart. The protocol used was the Reaction time protocol developed by Wells *et al.*[32]. The test consisted of pressing the "home" button which was lit up red and, after a new red light lit up on the board, pressing the button to turn off the light as quickly as possible. The protocol was performed three times with each hand and the best time between the button lighting up and the participant pressing it was taken.

The other cognitive variable was short-term memory using a visual test similar to the one developed by Nelson *et al.*[33] to study the modulation of memory storage processes. It consisted of three lists, one for each data collection (familiarisation, FP and LP), containing very specific words with concreteness and imagery ratings of >6.40 on a scale of 1 to 7 from the Paivio *et al.* norms[34]. Each of the 20 words on the list was shown for 5 seconds, the presentation lasting 100 seconds in all. There was then a 100-second consolidation period. After that, the subjects had 120 seconds to write down as many words as they could remember, regardless of the order in which they were shown[35].

Muscle characteristics (strength, thickness and stiffness)

For muscle characteristics, first of all, we studied the thickness of the rectus femoris muscle by ultrasound, using a Logiq® S8 ultrasound (GE Healthcare, Milwaukee, WI, USA). To do this, the participants sat with a knee flexion of 20°, and the midpoint between the anterior superior iliac spine and the upper edge of the patella was marked with a marker pen to locate ourselves on top of the rectus femoris. The distance between the superficial and deep aponeurosis of the rectus femoris was measured perpendicular to the muscle fibres. Subsequently, passive muscle stiffness in a relaxed state was measured using a manual myotonometry device, the MyotonPRO (Myoton AS, Tallinn, Estonia), which applies a brief mechanical pulse for 5 ms to cause damped oscillations. Stiffness was measured at the same location as the earlier ultrasound.

Finally, maximum knee extension and flexion strength were measured with a unilateral isometric test, measuring the dominant leg with Biodex System 3 (Biodex Medical Systems; Shirley, NY, USA). Prior to this test, the participants warmed up for 5 minutes on a cycle ergometer at 50 watts. Then the participants sat in the isokinetic chair with the knee joint flexed at 90°and were secured in position with different straps. Once in the test position, the participants performed several submaximal knee flexion and extension repetitions to complete the warm-up. The protocol used consisted of a maximal knee extension for 5 seconds, 10 seconds of rest, and then 5 seconds of maximal knee flexion. This test was performed 3 times with one minute of rest in between[36].

Resistance

A stress test was performed on an HP Cosmos Saturn Med 4.0 treadmill (Saturn, Traunstein, Germany). The protocol consisted of a two-minute warm-up phase walking on the treadmill at 4 km/h. After one minute of warming up, the participants' heart beats were recorded and taken as initial rate using the Polar H9 heart rate monitor (Polar Electro Oy, Kempele, Finland). After the warm-up, the stress test began. The participants started running at 6 km/h and the speed was increased by one km/h each minute, At the end of the stress stage, the total time, maximum speed achieved and final heart rate were recorded. To finish the test, the participants recovered by walking at 4 km/h for 3 minutes. Their heart rate was recorded at the end of the first minute of recovery.

Statistical analysis

The software used for statistical analysis was: a Microsoft Excel spreadsheet (Microsoft, Redmond, WA, USA) for storing measurement data and SPSS v. 22.0 (SPSS Inc., Chicago, IL, USA) to perform statistical calculations. The normality of the variables was initially checked with the Shapiro-Wilk test. As all variables showed a normal distribution, Student's t-test was used for related samples to analyse the differences between the two time points in the cycle analysed (FP vs. LP). The relationships between variables were analysed with the Pearson correlation coefficient. The effect sizes for all pairwise comparisons were calculated using the d-Cohen test. The magnitude of the effect size was interpreted using the scale proposed by Cohen: An effect size (ES) of 0.2 was considered small, around 0.5 was considered medium, and around 0.8 was considered large. *P*<0.05 was taken as the significance level.

Results

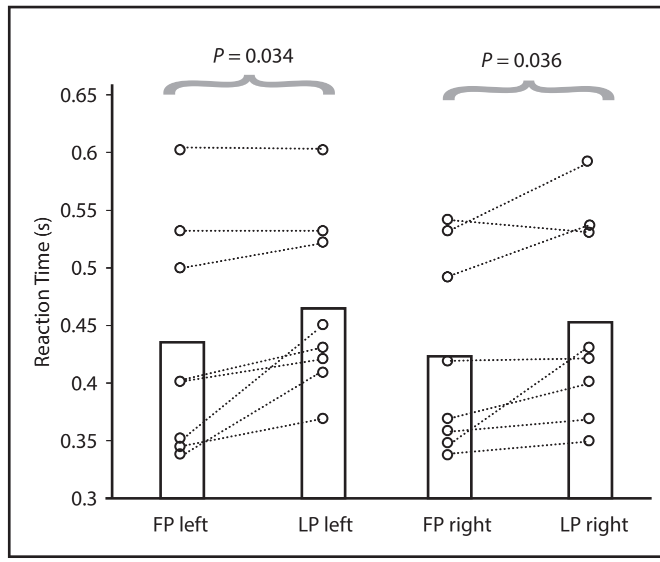
The data for the body composition variables are shown in Table 1. An increase (*P* <0.05) of total fat and fat percentage was found in the luteal phase compared with the follicular phase. On the other hand, no significant differences were found in total mass, BMD or skeletal muscle mass between the two phases analysed (Table 1).

No significant differences were observed during the phases of the menstrual cycle in terms of short-term memory (FP = 15.5 ± 3.9 words vs. LP = 14.7 ± 3.1 words; *P* = 0.468; 95% confidence interval (CI): -1.6 to 3.1 words; ES = 0.1). However, an improvement in reaction time was observed in the follicular phase, both with the right hand (FP = 0.426 ± 0.082 s vs. LP = 0.453 ± 0.087 s; *P* = 0.036; 95% CI: -0.050 to -0.002 s; ES = 0.9) and the left hand (FP = 0.435 ± 0.096 s vs. LP = 0.466 ± 0.077 s; *P* = 0.034; 95% CI: -0.059 to -0.003 s; ES = 0.9) (Figure 3).

No significant differences were found when comparing the two phases of the menstrual cycle in terms of rectus femoris morphology and stiffness or maximal knee extension and flexion strength (Table 2).

Regarding resistance, we found a higher heart rate before starting the test in the luteal phase compared with the follicular phase (FP = 83.3 ± 10.2 beats/min vs. LP = 92.9 ± 7.7 beats/min; *P* = 0.034; 95% CI: from -10.0 to -1.2 beats/min; ES = 0.8). However, participants lasted longer in

Figure 3. Right and left hand reaction time in the Dynavision™ Reaction Time test.



FP: follicular phase; LP: luteal phase.

Table 1. Effects of the menstrual cycle on body composition.

	Follicular phase	Luteal phase	Δ	p-value	95% CI	ES
Total mass (kg)	54.4 ± 7.7	55.0 ± 7.9	-1.1	0.349	-2.3 to 0.2	0.4
BMD (g/cm²)	1.13 ± 0.14	1.14 ± 0.13	-0.9	0.554	-0.08 to 0.01	0.4
Fat percentage (%)	27.3 ± 5.1	27.9 ± 5	-2.2	0.041	-0.6 to -0.3	0.7
Total fat (g)	14.9 ± 4.2	15.4 ± 4.4	-3.4	0.036	-0.45 to -0.04	0.7
Skeletal muscle mass (kg)	23.54 ± 3.23	23.49 ± 3.42	0.2	0.695	-0.2 to 0.3	0.1

ES: effect size; CI: confidence interval; BMD: bone mineral density.

Table 2. Effects of the menstrual cycle on muscle characteristics.

	Follicular phase	Luteal phase	Δ	p-value	95% CI	ES
Rectus femoris thickness (mm)	1.53 ± 0.37	1.58 ± 0.19	-3.3	0.515	-0.22 to 0.12	0.2
Stiffness (N/m)	197.43 ± 15.83	193.43 ± 15.54	2.0	0.300	-4.64 to 12.64	0.4
Maximal extension strength (N)	174.1 ± 58.5	168.4 ± 47.6	3.3	0.589	-18.15 to 29.58	0.2
Maximal flexion strength (N/m)	73.3 ± 9.8	80.4 ± 22.8	-9.7	0.742	-33.5 to 10.1	0.2

ES: effect size; CI: confidence interval.

the test in the follicular phase (FP = 488.5 ± 93.2 s vs. LP = 468.6 ± 81.3 s; $P = 0.029$; 95% CI: from 2.7 to 37.1 s; ES = 0.9). We found no difference in heart rate at the end of the test (189.1 ± 8.8 beats/min vs. 189.5 ± 10.8 beats/min; $P = 0.807$; 95% CI: from -3.8 to 3.1 beats/min; ES = 0.1) or after one minute of recovery (170.1 ± 11.9 beats/min vs. 171.8 ± 11.2 beats/min; $P = 0.650$; CI 95%: from -9.7 to 6.5 beats/min; ES = 0.2).

Discussion

The purpose of this study was to examine the effect of the menstrual cycle on body composition, resistance, different cognitive aspects (memory and reaction time) and muscle characteristics (muscle strength, thickness and stiffness) in young eumenorrheic women. The most important findings of the study were: 1) Total body fat and fat percentage were higher in the luteal phase, 2) In resistance, a longer total exertion time and a lower basal heart rate in the follicular phase, 3) Reaction time was better in the follicular phase and, finally, 4) Short-term memory, muscle strength and muscle characteristics were not affected by the menstrual cycle and the hormones involved.

Analysis of the body composition variables throughout the menstrual cycle showed higher values in total fat mass and fat percentage in the LP. These variations in total fat could be one of the causes of variations in sports performance in women. Many women claim to experience physical changes during the menstrual cycle, highlighting weight gain, notably in the luteal phase in the days prior to menstrual flow[14]. Carmichael *et al.*[9] found higher fat mass in DXA analysis in the LP in comparison with the FP. They controlled the subjects' diet for 24 hours and carried out a hydration analysis beforehand in order to eliminate any variables that could influence the results. In our study, we did not find significant differences in body water, although it should be taken into account that we did not control the degree of hydration of the subjects. The participants were asked, however, to come to the laboratory on the two days in the same preceding conditions and all the participants carried out both tests at the same time of the day. It is understandable that BMD does not change at different points in the menstrual cycle because it is a parameter that varies very little over time[6].

Regarding resistance, the total time of the stress test shows results similar to those recorded in recent research which concludes that responses to submaximal exercise are significantly different during the phases of the menstrual cycle[19]. Some studies suggest a possible slight increase in aerobic capacity or exercise efficiency during the follicular phase[6]. These claims may be related to the high oestrogen levels characteristic of the follicular phase and their relationship with low lactate levels[17]. An inverse relationship has been observed where higher oestrogen levels correspond to lower lactate levels, resulting in decreased muscle fatigue and thus improved performance. In this study, we recorded a higher initial heart rate in the luteal phase, which may be related to the high levels of progesterone which are typical of it[18]. Nevertheless, plenty of studies do not confirm this hypothesis and argue that there are no differences in aerobic and anaerobic capacity over the course of the menstrual cycle[6].

Henderson[22] studied the effect of progesterone on women's cognitive performance and observed that the difference was minimal in women of reproductive age but that progesterone had a detrimental effect on short-term memory after menopause and hormone therapy. In our study, we found no differences between the two phases analysed in terms of short-term memory, in line with recent studies that, similarly, have not observed any clinically significant important and consistent effects of progesterone on cognitive function in women[37].

Regarding reaction time, we found significant differences in both the right and the left hand, with participants in the follicular phase showing better reaction times. Although Karia[38] concluded that reaction time is a skill that depends on a wide variety of factors such as age, sex and the number, intensity and duration of the stimuli, other studies have found relationships between fluctuating oestrogen and progesterone levels during the normal menstrual cycle and reaction time[39]. Kumar *et al.*[40] attributed the prolongation of reaction time in women during the luteal phase to the female sex hormones, which cause salt and water retention, which in turn influence the process of axonal conduction and availability of neurotransmitters at the synapse. Morgan and Rapkin[23] have shown a positive correlation between reaction time and body mass index in women: the greater the body mass, the longer the reaction time.

The variables related to muscle strength analysed in this study remain constant over the phases of the menstrual cycle despite the fluctuations in concentrations of circulating levels of oestrogen and progesterone that occur during them[41]. This can be seen in different studies where eumenorrheic women who participate in sports or activities that depend on strength seem not to be disadvantaged by the menstrual phase they are in[29]. However, the comparison of results is difficult due to the lack of research with strength measurements similar to those taken in this study and the use of different methodologies to determine the phases of the menstrual cycle. The study by Birch and Reilly[42] in which they analysed the isometric strength of the lower limb muscles in FP and LP concluded that the production of maximal voluntary force did not appear to be influenced by menstrual phases. Muscle strength, power and speed were not affected either. Although the results point to no significant differences in the mechanical variables, we know that hormonal fluctuations during the menstrual cycle are indisputable and these should be controlled for clearer results. Some studies where serological tests were performed to control hormone levels observed that muscle strength changed, proving to be greater in the follicular phase[43]. These results support the idea that skeletal muscle is sensitive to changes in oestrogen concentration and should be taken into account when planning training and developing strategies to prevent injuries to the lower extremities during sports activities[43].

Study limitations

There were several limitations in this study which should be acknowledged. First, the sample size was small, so the results should be treated with caution. Consequently, finding significant relationships between the variables analysed is complex because statistical tests require a certain sample size to ensure representativeness. It is also important to highlight the problems associated with the precise identification of the menstrual phases in each participant. Although false-positives are highly unlikely in urine LH tests, the tests depended on participants performing them correctly. To minimise the bias produced by self-measurement, the participants received precise indications prior to measuring. Despite these limitations, the study provides some indications on the effects of the phases of the menstrual cycle on the physical and cognitive abilities of eumenorrheic women.

Conclusions

We can conclude that body composition, reaction time and resistance test performance are different in the phases of the menstrual cycle analysed (luteal phase and follicular phase). In the luteal phase, a higher fat percentage and more total fat are found than in the follicular phase, while performance in reaction time and the resistance test is better in the follicular phase. On the other hand, short-term memory, muscle thickness and stiffness, and strength are not been affected by the hormonal changes that occur during the menstrual cycle.

Conflict of interest

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

Bibliography

1. Hulteen RM, Smith JJ, Morgan PJ, Barnett LM, Hallal PC, Colyvas K, *et al.* Global participation in sport and leisure-time physical activities: A systematic review and meta-analysis. *Prev Med.* 2017;95:14-25.
2. Joyner MJ. Physiological limits to endurance exercise performance: influence of sex. *J Physiol.* 2017;595(9):2949-54.
3. Handelsman DJ, Hirschberg AL, Bermon S. Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. *Endocr Rev.* 2018;39(5):803-29.
4. Southren AL, Tochimoto S, Carmody NC, Isurugi K. Plasma production rates of testosterone in normal adult men and women and in patients with the syndrome of feminizing testes. *J Clin Endocrinol Metab.* 1965;25(11):1441-50.
5. Handelsman DJ. Sex differences in athletic performance emerge coinciding with the onset of male puberty. *Clin Endocrinol (Oxf).* 2017;87(1):68-72.
6. Constantini NW, Dubnov G, Lebrun CM. The menstrual cycle and sport performance. *Clin Sports Med.* 2005;24(2):e51-82, xiii-xiv.
7. Richards JS. The Ovarian Cycle. *Vitam Horm*. 2018;107:1-25.
8. Reed BG, Carr BR. *The Normal Menstrual Cycle and the Control of Ovulation: MDText*.com, Inc., South Dartmouth (MA); 2000.
9. Carmichael MA, Thomson RL, Moran LJ, Wycherley TP. The Impact of Menstrual Cycle Phase on Athletes' Performance: A Narrative Review. *Int J Environ Res Public Health*. 2021;18(4).
10. Holesh JE, Bass AN, Lord M. *Physiology, Ovulation.* StatPearls. Treasure Island (FL): StatPearls Publishing; 2022.
11. Anderson RC, Newton CL, Anderson RA, Millar RP. Gonadotropins and Their Analogs: Current and Potential Clinical Applications. *Endocr Rev.* 2018;39(6):911-37.
12. Tanski D, Skowronska A, Tanska M, Lepiarczyk E, Skowronski MT. The In Vitro Effect of Steroid Hormones, Arachidonic Acid, and Kinases Inhibitors on Aquaporin 1, 2, 5, and 7 Gene Expression in the Porcine Uterine Luminal Epithelial Cells during the Estrous Cycle. *Cells.* 2021;10(4).
13. Piette P. The history of natural progesterone, the never-ending story. *Climacteric.* 2018;21(4):308-14.
14. Ziomkiewicz A, Ellison PT, Lipson SF, Thune I, Jasienska G. Body fat, energy balance and estradiol levels: a study based on hormonal profiles from complete menstrual cycles. *Human Reproduction.* 2008;23(11):2555-63.
15. Stachenfeld NS, Keefe DL, Palter SF. Estrogen and progesterone effects on transcapillary fluid dynamics. *Am J Physiol Regul Integr Comp Physiol.* 2001;281(4):R1319-29.
16. Hackney AC. Effects of the menstrual cycle on resting muscle glycogen content. *Horm Metab Res.* 1990;22(12):647.
17. Oosthuyse T, Bosch AN. Oestrogen's regulation of fat metabolism during exercise and gender specific effects. *Curr Opin Pharmacol.* 2012;12(3):363-71.
18. Sedlak T, Shufelt C, Iribarren C, Merz CN. Sex hormones and the QT interval: a review. *J Womens Health (Larchmt)*. 2012;21(9):933-41.
19. Janse-DE-Jonge XA, Thompson MW, Chuter VH, Silk LN, Thom JM. Exercise performance over the menstrual cycle in temperate and hot, humid conditions. *Med Sci Sports Exerc.* 2012;44(11):2190-8.
20. Lamont LS, Lemon PW, Bruot BC. Menstrual cycle and exercise effects on protein catabolism. *Med Sci Sports Exerc.* 1987;19(2):106-10.
21. Yim J, Petrofsky J, Lee H. Correlation between Mechanical Properties of the Ankle Muscles and Postural Sway during the Menstrual Cycle. *The Tohoku Journal of Experimental Medicine.* 2018;244(3):201-7.
22. Henderson VW. Progesterone and human cognition. *Climacteric*. 2018;21(4):333-40.
23. Morgan M, Rapkin A. Cognitive flexibility, reaction time, and attention in women with premenstrual dysphoric disorder. *J Gend Specif Med.* 2002;5(3):28-36.
24. Cable NT, Elliott KJ. The Influence of Reproductive Hormones on Muscle Strength. *Biological Rhythm Research*. 2004;35(3):235-44.
25. Edwards DA, Turan B. Within-person coupling of estradiol, testosterone, and cortisol in women athletes. *Peer J.* 2020;8:e8402.
26. Tenan MS, Hackney AC, Griffin L. Maximal force and tremor changes across the menstrual cycle. *Eur J Appl Physiol.* 2016;116(1):153-60.
27. Janse-DE-Jonge XA, Thompson B, Han A. Methodological Recommendations for Menstrual Cycle Research in Sports and Exercise. *Med Sci Sports Exerc.* 2019;51(12):2610-7.
28. Lara B, Gutiérrez-Hellín J, García-Bataller A, Rodríguez-Fernández P, Romero-Moraleda B, Del Coso J. Ergogenic effects of caffeine on peak aerobic cycling power during the menstrual cycle. *Eur J Nutr.* 2020;59(6):2525-34.
29. Romero-Moraleda B, Coso JD, Gutiérrez-Hellín J, Ruiz-Moreno C, Grgic J, Lara B. The Influence of the Menstrual Cycle on Muscle Strength and Power Performance. *J Hum Kinet*. 2019;68:123-33.
30. Shepherd JA, Ng BK, Sommer MJ, Heymsfield SB. Body composition by DXA. *Bone.* 2017;104:101-5.
31. Churchill SJ, Wang ET, Bhasin G, Alexander C, Bresee C, Pall M, *et al.* Basal metabolic rate in women with PCOS compared to eumenorrheic controls. *Clin Endocrinol (Oxf).* 2015;83(3):384-8.
32. Wells AJ, Hoffman JR, Beyer KS, Jajtner AR, Gonzalez AM, Townsend JR, *et al*. Reliability of the dynavision™ d2 for assessing reaction time performance. *J Sports Sci Med.* 2014;13(1):145-50.
33. Nelson DL, McEvoy CL, Schreiber TA. The University of South Florida free association, rhyme, and word fragment norms. *Behav Res Methods Instrum Comput*. 2004;36(3):402-7.
34. Paivio A, Yuille JC, Madigan SA. Concreteness, imagery, and meaningfulness values for 925 nouns. *J Exp Psychol.* 1968;76(1):Suppl:1-25.
35. VanArsdall JE, Blunt JR. Analyzing the structure of animacy: Exploring relationships among six new animacy and 15 existing normative dimensions for 1,200 concrete nouns. *Mem Cognit*. 2022;50(5):997-1012.
36. Bravo-Sánchez A, Abián P, Sánchez-Infante J, Esteban-García P, Jiménez F, Abián-Vicén J. Objective Assessment of Regional Stiffness in Vastus Lateralis with Different Measurement Methods: A Reliability Study. *Sensors (Basel)*. 2021;21(9).
37. Gloe LM, Kashy DA, Jacobs EG, Klump KL, Moser JS. Examining the role of ovarian hormones in the association between worry and working memory across the menstrual cycle. *Psychoneuroendocrinology.* 2021;131:105285.
38. Karia D. Effect Of Gender Difference On Visual Reaction Time: A Study On Medical Students Of Bhavnagar Region. *IOSR Journal of Pharmacy (IOSRPHR).* 2012;2:452-4.

39. Nene AS, Pazare PA. A study of auditory reaction time in different phases of the normal menstrual cycle. *Indian J Physiol Pharmacol.* 2010;54(4):386-90.

40. Kumar S, Mufti M, Kisan R. Variation of reaction time in different phases of menstrual cycle. *J Clin Diagn Res*. 2013;7(8):1604-5.

41. Blagrove RC, Bruinvels G, Pedlar CR. Variations in strength-related measures during the menstrual cycle in eumenorrheic women: A systematic review and meta-analysis. *J Sci Med Sport*. 2020;23(12):1220-7.

42. Birch K, Reilly T. The diurnal rhythm in isometric muscular performance differs with eumenorrheic menstrual cycle phase. *Chronobiol Int*. 2002;19(4):731-42.

43. Rodrigues P, Correia M, Wharton L. Effect of Menstrual Cycle on Muscle Strength. *Journal of Exercise Physiology Online*. 2019;22:89-97.

Original article

Influence of ACTN3 R577X on injury risk: systematic review

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Summary

Regular physical activity is recommended as part of a healthy lifestyle to reduce the risk of disease and improve quality of life. However, sport can also increase the risk of tendon, muscle, and bone injuries. Among the risk factors that can predispose the human body to suffer this type of injuries, genetics, and in particular, the presence of single nucleotide polymorphisms (SNPs), can play a key role. However, studies analyzing the risk of injury associated with the genetic component are currently scarce and in many cases contradictory. In this regard, the ACTN3 gene, coding for the α-actin-3 protein, is one of the most studied genetic markers. The aim of this systematic review was to analyze and synthesize the state of knowledge on the relationship between the ACTN3 R577X polymorphism and the risk of injury in the sports practice. Therefore, an exhaustive review of all works published up to 28th January 2020 that analyzed the relationship between the ACTN3 R577X polymorphism and the risk of injury was carried out using the PubMed database. Eleven articles that met the inclusion criteria were selected. Although the number of studies analyzed is relatively low, it seems that carriers of the XX genotype may have a higher tendency to suffer lesions compared to the RX and RR genotypes. This increased risk of injury appears to be associated with α-actin-3 protein deficiency. These results can be useful in developing prevention programs to reduce the risk and severity of sports injuries.

Key words:
Polymorphism. Genotype. Athletic injuries. Physical exercise. Injury. Muscle damage

Influencia de ACTN3 R577X sobre el riesgo de lesión

Resumen

La práctica de actividad física regular se encuentra dentro de las recomendaciones para seguir un estilo de vida saludable con el fin de reducir el riesgo de enfermedades y mejorar la calidad de vida. Sin embargo, el deporte también puede aumentar el riesgo de sufrir lesiones tendinosas, musculares u óseas. Entre los factores de riesgo que pueden predisponer al cuerpo humano a sufrir lesiones de este tipo se encuentra el componente genético y, en particular, la presencia de polimorfismos de un solo nucleótido (SNPs). Sin embargo, actualmente los estudios que se han llevado a cabo sobre el riesgo de lesión asociado al componente genético son escasos y en muchos casos contradictorios. En este sentido, el gen ACTN3 que codifica para la proteína α-actina-3 es uno de los marcadores genéticos más estudiados. El propósito de la presente revisión sistemática fue analizar y sintetizar la información existente sobre la relación entre el polimorfismo ACTN3 R577X y el riesgo de lesión muscular en la práctica deportiva. Para ello, se realizó una revisión exhaustiva de todos los artículos publicados hasta el 28 de enero de 2020 que analizaban la relación entre el polimorfismo ACTN3 R577X y el riesgo de lesión, utilizando la base de datos PubMed. Se seleccionaron 11 artículos que cumplían con los criterios de inclusión. Aunque el número de estudios analizados es relativamente bajo, parece que los portadores del genotipo XX pueden presentar una mayor tendencia a sufrir lesiones en comparación con los genotipos RX y RR. Este mayor riesgo de lesión parece estar asociado a la deficiencia de la proteína α–actina-3. Estos resultados pueden ser de utilidad a la hora de elaborar programas de prevención de cara a disminuir el riesgo de las lesiones deportivas y su gravedad.

Palabras clave:
Polimorfismo. Genotipo. Lesión. Daño muscular. Ejercicio físico. Lesiones deportivas

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Introduction

An injury is damage to some part of the human body caused by a blow or fall. If the injury is caused when doing sport or exercise, it can be of two types: acute injuries which occur suddenly, such as ankle sprain, produced mainly during middle age and one of the most common injuries to the joints of the musculoskeletal system during physical activity, and chronic injuries that occur with doing exercise over time[1,2]. Several risk factors can predispose the human body to tendon, muscle and bone injuries; of these, the importance attached to the genetic component has grown in recent years and this factor has been studied with the aim of developing prevention programmes and reducing the risk of injuries and their severity[3-5]. Within this intrinsic factor, the presence of single nucleotide genetic polymorphisms (SNPs) can cause predisposition to injury[6,7].

SNPs are single-base alterations in DNA sequence and are present in all individuals. Some studies seem to indicate that SNPs can predispose the human body to behave differently in response to the same injury. Of the SNPs related to muscle injury, the R577X (rs1815739) of the ACTN3 gene is one of the most studied[6,7].

ACTN3 is the gene that encodes for a muscle protein, α-actinin-3 (a sarcomeric actinin-binding protein with a fundamental role in muscle structure and metabolism), which is expressed in muscle fibres, especially in type II or fast-twitch fibres[8-10].

The ACTN3 R577X polymorphism consists of a transition from cytosine (R allele, the ancestral allele) to thymine (X allele), resulting in a premature termination codon, which is associated with the absence of α-actinin-3 expression in individuals with the XX genotype. Some studies seem to indicate that individuals with the XX genotype present a reduction in muscle mass associated with a greater tendency to injury, meaning that interindividual differences in vulnerability to exercise-induced damage may be, in part, genetically determined by ACTN3 R577X[10-13]. However, studies conducted on the risk of injury associated with the genetic component are scarce and, in many cases, contradictory. Therefore, in this review we have compiled all those studies that have analysed the relationship between the ACTN3 R577X polymorphism and the risk of injury with the aim of providing an overview of the findings to date and elucidating any possible relationship which may exist. In this way, individuals with a greater predisposition to injury could be identified and personalised prevention programmes and treatments for individual athletes could be developed in the future.

Objectives

The main objective of this systematic review was to analyse and summarise the information from the studies available to date on the association between the different genotypes of the ACTN3 R577X polymorphism and the risk of injury in sport.

Material and method

A comprehensive review of all published articles related to the ACTN3 R577X polymorphism and risk of injury until 28 January 2020 was conducted using the PubMed database. The search criteria used were as follows: ((((((((((("rs1815739"[All Fields] AND "injurie"[All Fields] OR "injuried"[All Fields]) OR "injuries"[MeSH Subheading]) OR "injuries"[All Fields]) OR "wounds and injuries"[MeSH Terms]) OR ("wounds"[All Fields] AND "injuries"[All Fields])) OR "wounds and injuries"[All Fields]) OR "injurious"[All Fields]) OR "injury s"[All Fields]) OR "injuryed"[All Fields]) OR "injurys"[All Fields]) OR "injury"[All Fields])) OR ("R577X"[All Fields] AND (((((((((("injurie"[All Fields] OR "injuried"[All Fields]) OR "injuries"[MeSH Subheading]) OR "injuries"[All Fields]) OR "wounds and injuries"[MeSH Terms]) OR ("wounds"[All Fields] AND "injuries"[All Fields])) OR "wounds and injuries"[All Fields]) OR "injurious"[All Fields]) OR "injury s"[All Fields]) OR "injuryed"[All Fields]) OR "injurys"[All Fields]) OR "injury"[All Fields]))) OR ("rs1815739"[All Fields] AND ((("damage"[All Fields] OR "damaged"[All Fields]) OR "damages"[All Fields]) OR "damaging"[All Fields]))) OR ("R577X"[All Fields] AND ((("damage"[All Fields] OR "damaged"[All Fields]) OR "damages"[All Fields]) OR "damaging"[All Fields]))) OR ("rs1815739"[All Fields] AND ((((("ruptur"[All Fields] OR "rupture"[MeSH Terms]) OR "rupture"[All Fields]) OR "ruptured"[All Fields]) OR "ruptures"[All Fields]) OR "rupturing"[All Fields]))) OR ("R577X"[All Fields] AND ((((("ruptur"[All Fields] OR "rupture"[MeSH Terms]) OR "rupture"[All Fields]) OR "ruptured"[All Fields]) OR "ruptures"[All Fields]) OR "rupturing"[All Fields]))) OR ("rs1815739"[All Fields] AND ((("lesion"[All Fields] OR "lesion s"[All Fields]) OR "lesional"[All Fields]) OR "lesions"[All Fields]))) OR ("R577X"[All Fields] AND ((("lesion"[All Fields] OR "lesion s"[All Fields]) OR "lesional"[All Fields]) OR "lesions"[All Fields])).

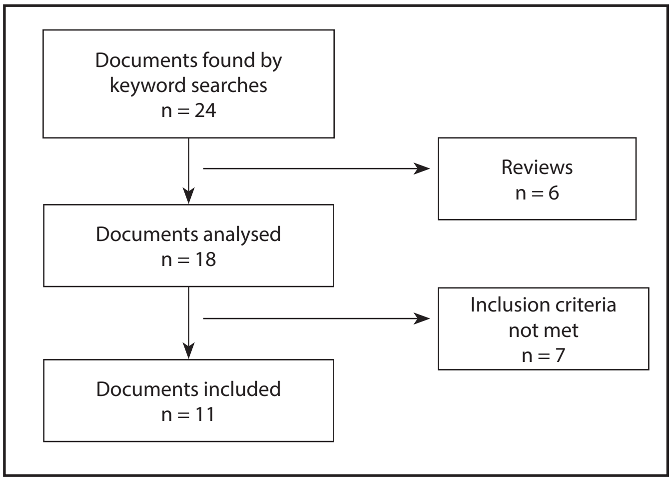
The inclusion criteria for the study were: studies carried out on healthy individuals without ruling anybody out for reasons of sex, ethnicity, age or country. We included only those studies that analysed the ACTN3 R577X polymorphism individually and not as part of a score, as a haplotype or in genome-wide association studies (GWAS).

Results and discussion

Figure 1 shows the flowchart of the search details and selection process used in the systematic review. After the initial search applying the aforementioned criteria, 24 articles were found. Subsequent analysis excluded 6 publications because they were reviews and another 7 for not meeting the inclusion criteria defined. After the whole process, 11 papers were included in the final analysis (Table 1).

Of the 11 documents included, studies were found that addressed the influence of the different genotypes (RR, RX, XX) of the ACTN3 R577X polymorphism on the risk of injury in patients both before and after doing different types of exercise or sports (football, marathon, half-ironman). Specifically, they analysed both the incidence of injuries and the levels of hormones associated with these injuries (creatine

Figure 1. Flowchart. Search and selection details for the systematic review process.



kinase (CK), myoglobin (Mb), cortisol or testosterone) in the different genotypes of the athletes.

In the 11 studies, the association of the participants' genotype with having a higher risk of injury or protecting them against the incidence of injuries was analysed. In their study on the role of the ACTN3 R577X polymorphism in the response to exercise-induced muscle damage, the researcher Barbara Vicent and her team14 concluded that the XX genotype was associated with an increased risk of injury compared to the RR genotype. In the study, a blood sample was taken from 19 healthy young men before and 6, 24 and 48 hours after performing an eccentric exercise that consisted of 4 sets of 20 knee extensions on both legs. A significant increase in CK levels was observed in the entire sample, but this increase was significantly greater in individuals with the XX genotype compared to those with RR. CK is an enzyme that participates in cellular energy metabolism and is composed of three isoenzymes distributed in skeletal muscle, cardiac muscle and the brain. CK is normally found

Table 1. Summary of studies on the association of the different ACTN3 R577X genotypes and the risk of injury.

Study	Aim	Characteristics of the sample	Results	Conclusion
Clarkson PM, *et al.* 2005	To study variations in genes coding two myofibrillar proteins (ACTN3 and MLCK) and their response to muscle damage produced by exercise.	208 healthy subjects. Male and female. USA.	The subjects with the XX genotype had a lower baseline CK and Mb compared to RX group but no different from that of the RR group. However, there was no association between ACTN3 XX and increased CK in response to eccentric exercise.	The subjects with the XX genotype showed a lower risk of injury than the RX subjects.
Vicent B, *et al.* 2010	To investigate the possible role of the ACTN3 R577X polymorphism in the response to muscle damage and recovery after eccentric exercise.	19 young healthy subjects. Male. Belgium.	After eccentric exercise, the participants with the XX genotype had greater CK activity. Participants with the RR genotype showed higher repair responses compared to those with the XX genotype.	The XX genotype was associated with an increased risk of injury compared to the RR genotype.
Venckunas T, *et al.* 2012	To compare the impact of and recovery from exercise-induced muscle damage between the different genotypes of the ACTN3 R577X polymorphism.	18 young healthy subjects. Male. Country not specified.	There were no significant differences between the different genotypes of the ACTN3 R577X polymorphism.	There was no association between the different genotypes and the risk of injury.
Shang X, *et al.* 2015	To investigate if the ACTN3 R577X polymorphism is associated with non-contact acute ankle sprains.	142 subjects with non-contact acute ankle sprain and a control group of 280 without ankle sprain. Male. China.	The XX genotype was significantly greater among participants with ankle sprain compared to the RX and RR genotypes.	Participants with the RR genotype had less risk of ankle sprains than those with the XX and RX genotypes.
Qi B, *et al.* 2016	To study the association between the ACTN3 R577X polymorphism and the incidence of non-acute ankle sprain in a Han Chinese population.	100 patients with ankle sprain and a healthy control group of 100 with no history of ankle injuries. Male and female. China.	The frequency of the RR genotype in ankle sprain was significantly lower than in the control group.	The RR genotype protected against ankle sprain in the Han Chinese population.
Del Coso J, *et al.* 2017a	To investigate the influence of the ACTN3 R577X polymorphism on the level of exercise-induced muscle damage during an official half-ironman race.	23 experienced athletes. Male and female. Spain.	At the end of the half-ironman, the athletes with the XX and RX genotypes had higher concentrations of CK and Mb than those with the RR genotype.	Athletes with the XX and RX genotypes had a higher risk of muscle injury during a half-ironman race than those with RR.

(continued on next page)

Table 1. Summary of studies on the association of the different ACTN3 R577X genotypes and the risk of injury *(continuation)*.

Study	Aim	Characteristics of the sample	Results	Conclusion
Del Coso J, *et al.* 2017b	To determine the influence of the ACTN3 R577X polymorphism on exercise-induced muscle damage during a marathon.	71 runners. Male and female. Country not specified.	Mb and CK levels were higher in marathoners with the XX and RX genotypes than in those with the RR genotype.	Marathoners with the XX and RX genotypes had higher exercise-induced muscle injury marker values than marathoners with the RR genotype.
Moreno V, *et al.* 2017	To determine the influence of the genotypes of the ACTN3 R577X polymorphism on marathoner injury incidence during the year prior to participation in a competitive marathon race.	139 amateur marathoners. Male and female. Spain.	The likelihood of suffering a muscle injury during the year prior to the competition was twice as high in runners with the XX genotype compared to those with RR and RX.	The XX genotype showed a greater incidence of injuries than the RX and RR genotypes.
Miyamoto N, *et al*. 2018	To study if the ACTN3 R577X polymorphism may have an influence on muscle stiffness.	76 university students. Male. Japan.	Greater hamstring muscle stiffness was detected in participants with the RR and RX genotypes than in those with the XX genotype. However, the frequency of injury episodes among the 3 genotypes was the same.	The RR and RX genotypes were associated with increased muscle stiffness, although they do not appear to be linked to more episodes of injury.
Massidda M, *et al.* 2019	To investigate the association between the ACTN3 R577X polymorphism and indirect muscle disorders/injuries in professional football players.	257 professional football players. Male. Italy.	The players with the XX and RX genotypes were 2.66 and 1.63 more likely to be injured than players with the RR genotype, respectively.	The X allele showed a greater risk of injury compared to the RR/RX genotypes.
Coelho DB, *et al.* 2019	To assess muscle damage indicators and hormonal responses after football matches and their relationship to the expression of the ACTN3 R577X polymorphism (XX vs RR/RX).	0 U16 football players. Male. Brazil.	The concentration of CK, testosterone and cortisol after the game was higher in players with the RR/RX genotype compared to players with the XX genotype.	The RR and RX genotypes were associated with an increased risk of injury compared to the XX genotype.

CK: creatine kinase; MLCK: myosin light-chain kinase.

in blood at very low levels and comes mainly from skeletal muscle. In the event of an injury or muscle damage, significant amounts of CK are released into the blood, its concentration being proportional to the intensity, severity and duration of the damage. The peak in plasma is reached 24 hours after finishing exercise and the presence of CK may remain high for 48-72 hours[15,16]. In the same study, the subjects were asked to rate their perception of muscle pain after repeating the sets of eccentric muscle contractions using an analogue visual scale (EVA scale) and the individuals with the RR genotype indicated lower levels of muscle pain.

In two studies carried out on Chinese and Han Chinese populations of both sexes[17,18], clinical questionnaires, anthropometric measurements and analytical tests were used to analyse the possible association between the different genotypes and ankle sprain (the most frequent injury in musculoskeletal joints). No significant differences in age, sex, height, weight or overall health were found between the clinical questionnaires and physical examinations. However, when comparing the distribution of the 3 possible genotypes of the ACTN3 R577X polymorphism among the group of participants with ankle sprain and a control group (healthy), it was observed that healthy people manifested a greater presence of the RR genotype while the XX genotype prevailed among the people with ankle sprain. These differences in genomic DNA led the researchers to the conclusion that the participants with the RR genotype were less at risk of suffering ankle sprain than those with XX and that RR was a protective genotype.

In the studies carried out by Del Coso, J., *et al*. in 2017[19,20] based on endurance sports, a half-ironman race and a marathon, a greater risk of injury was observed in individuals with the XX and RX genotypes after analysing two indicators of injury risk, CK and Mb, in 23 and 71 participants, respectively. Mb is a protein composed of a polypeptide chain present in all striated muscle fibres, the highest concentrations being in cardiac and skeletal muscle. It is not found in smooth muscle. Its main function is to transport and store oxygen in the muscle for energy and it also helps muscles to contract. Like CK, in the event of an injury, its blood concentration increases in response to high oxygen demand and hypoxia, and the destruction of muscle tissue[21,22]. Two groups were created in both studies, one with individuals with the RR genotype and the other with individuals with the XX and RX genotypes, the latter two showing very similar phenotypic responses. Blood samples were collected both before and after the race. Before the race, the test showed higher concentrations of serum CK and Mb in the XX+RX group compared to the RR group. After the race, the increase in CK and Mb concentrations was more pronounced in the XX+RX group than in the RR genotype group. Therefore, in both studies it was concluded that marathon and half-ironman athletes with the XX+RX genotypes of the ACTN3 R577X polymorphism showed higher levels of exercise-induced muscle damage than their RR counterparts.

The same result was obtained in another study published that same year[23] in which, through a cross-sectional study, the association between the genotypes of the ACTN3 R577X polymorphism and the risk of sports-related injury in a group of 139 Spanish female and male marathon runners was analysed. To do this, the participants completed a questionnaire about the injuries they had suffered during the year prior to competing in a race and a DNA swab test was performed on them. Those individuals with the XX genotype were seen to have had twice as many injury episodes during the year prior to the marathon compared to runners with the RR and RX genotypes. It was also observed that the most common cause of injury was an excessive training load. This result may suggest that the fact that participants with the XX genotype have an α-actinin-3 deficit in their fast-twitch muscle fibres causes decreased muscle function, exposing them to a greater risk of injury.

However, other studies have obtained results contrary to those mentioned above, observing an increased risk of injury in individuals with the RR genotype. In the Clarkson *et al*. study, the blood samples of 208 subjects were analysed before and after performing an eccentric elbow flexion exercise in two sessions of 25 repetitions each[24]. Contrary to expectations, there was no association between the XX genotype and a higher blood concentration of CK and Mb in response to eccentric exercise. The individuals with the XX genotype showed lower CK and Mb concentrations in the blood in response to eccentric exercise compared to the RX genotype and did not differ from the RR genotype.

A subsequent study[25] sought to study the association of the ACTN3 R577X polymorphism with muscle stiffness and the risk of muscle strain injury. To this end, the medical histories and different measurements of 76 university students were analysed. It was one of the first studies to ask whether there was an association between genotypes and hamstring strain injury. At the time, it was known that muscle stiffness mainly affected joint flexibility and was related to muscle strain injury. At the end of the study, it was concluded that the RR and RX genotypes were associated with greater muscle stiffness and, therefore, had a greater risk of injury compared to the XX group.

In another study conducted on male football players[26], the relationship between the ACTN3 R577X polymorphism and muscle injury after a football match was examined. Muscle damage was assessed using muscle microtrauma and hormonal stress markers, analysing hormonal indicators such as cortisol, testosterone and CK. Cortisol is a steroid hormone produced by the adrenal gland which has an effect on virtually every organ and tissue in the body. Faced with a stressful situation such as muscle damage, the level of cortisol in the blood increases. If this increase is protracted, it leads to a greater need for glucose, which the body obtains from the amino acids in the muscle, which can lead to the loss of muscle mass[27,28]. Meanwhile, testosterone is a hormone produced by the adrenal glands which influences the development of the sexual organs, bone maintenance and increases in muscle mass. When muscle damage occurs after intense exercise, the concentration of testosterone increases[27-29]. Immediately after finishing the football match, a significantly higher increase in CK, cortisol and testosterone levels was observed in players with the RR and RX genotypes compared to those with the XX genotype.

Like the previous study by Coelho, D.B., *et al.* 2019[26], the study by Massidda, M., *et al.* was also conducted on professional football players. This time participants were grouped by genotype and compared to a control group (healthy non-athletes). No differences were found in the frequencies of the different genotypes between the non-athletes and the football players. However, a greater tendency to suffer muscle injuries was observed among players with the XX genotype compared to RR[30].

Only one study[31], conducted on 18 healthy young men, found no significant differences between the different genotypes of the ACTN3 R577X polymorphism when studying different parameters related to injury risk. The participants performed two episodes of 50 jumps, separated by two weeks, each jump from a height of 40 cm to a 90-degree knee bend. Muscle pain was reported using an ordinal scale of 0-10, where 0 meant no pain and 10 very intense pain, and muscle damage percentages were obtained by collecting blood samples and analysing CK. CK increased immediately after exercise with no significant differences between genotype groups and decreased on finishing the two sets of 50 jumps with no significant differences between the different groups. The differences between the RR, RX and XX genotypes could be called modest and no association was found between the different genotypes and the risk of injury.

Conclusion

The SNP ACTN3 R577X expressed in fast-twitch muscle fibres and its protein α-actinin-3 play an important role in muscle metabolism, injury severity and incidence. Despite the heterogeneity and low number of studies, it is hypothesised that individuals with the XX genotype have an increased risk of injury because the X allele is associated with an α-actinin-3 deficiency in the muscle. α-actinin-3 is a protein necessary for the formation of fast-twitch muscle fibre, and its absence seems to negatively affect muscle capacity, leading to a greater propensity to injury. By contrast, the RR genotype of the ACTN3 R577X polymorphism is likely to play a protective role in skeletal muscle functions, which would be reflected in a lower risk of injury.

Conflict of interest

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

Bibliography

1. Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, Ekstrand J, English B, McNally S, *et al*. Terminology and classification of muscle injuries in sport: The Munich consensus statement. *Br J Sports Med*. 2013;47(6):342-50.
2. Pollock N, James S, Lee J, Chakraverty R. British athletics muscle injury classification: A new grading system. *Br J Sports Med*. 2014;48(18):1347-51.
3. Schwellnus MP, September AV, Collins M, Gibson W. Tendon and ligament injuries: The genetic component. *British Journal of Sports Med.* 2007; 41(4):241-6.
4. Raleigh SM, Van Der Merwe L, Ribbans WJ, Smith RK, Schwellnus MP, Collins, M. Variants within the MMP3 gene are associated with Achilles tendinopathy: Possible interaction with the COL5A1 gene. *Br J Sports Medicine*. 2009;43(7):514-20.
5. Bramah C, Preece SJ, Gill N, Herrington L. Is There a Pathological Gait Associated With Com- mon Soft Tissue Running Injuries? *Am J Sports Med*. 2018;46:3023-31.
6. Kathry N, Beggs AH. Deficiency of a Skeletal Muscle Isoform of Alpha-Actinin (alpha-actinin-3) in Merosin-Positive Congenital Muscular Dystrophy. *Neuromuscul Disord.* 1996; 6(4):229-35.
7. Yamima, B, Kathryn N. A Gene for Speed: The Emerging Role of alpha-actinin-3 in Muscle Metabolism. *Physiol* (Bethesda). 2010;25(4):250-9.
8. Ispirlidis I, Fatouros IG, Jamurtas AZ, Nikolaidis MG, Michailidis I, Douroudos I, *et al*. Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sportst Med*. 2008;18(5):423-31.
9. Coelho DB, Pimenta EM, Rosse IC, Veneroso CE, Becker LK, Carvalho MRS, *et al*. The alpha-actinin-3 R577X polymorphism and physical performance in soccer players. *J Sports Med Phys Fitness.* 2016;56(3):241-8.
10. Houweling PJ, Papadimitriou ID, Seto JT, *et al.* Is evolutionary loss our gain? The role of ACTN3 p.Arg577Ter (R577X) genotype in athletic performance, ageing, and disease. *Hum Mutat*. 2018;39(12):1774-87.
11. Yang N, MacArthur DG, Gulbin JP, Gulbin PJ, Hahn AG, Beggs AH, *et al.* ACTN3 Genotype Is Associated with Human Elite Ath- letic Performance. *Am J Hum Genet*. 2003; 73(3):627-31.
12. Eynon N, Duarte JA, Oliveira J, Sagiv M, Yamin C, Meckel Y, *et al.* ACTN3 R577X polymorphism and israeli top-level athletes. *Int J Sports Med.* 2009;30(9):695-8.
13. Pimenta E, Coelho D, Cruz I, Morandi R, Veneroso C, Pussieldi G, *et al.* The ACTN3 genotype in soccer players in response to acute eccentric training. *Eur J Appl Physiol.* 2012;112(4):1495-503.
14. Vicent B, Windelinckx A, Nielens H, Ramaekers M, Van Leemputte M, Hespel P, *et al*. Protective role of alpha-actinin-3 in the response to an acute eccentric exercise bout. *J Appl Physiol.* 2010;109(2):564-73.
15. Brancaccio P, Limongelli FM, Maffulli N. Monitoring of serum enzymes in sport. *Br J Sports Med*. 2006;40(2):96-7.
16. Vasan RS. Biomarkers of cardiovascular disease. Molecular basis and practical considerations. *Circulation.* 2006;113(19):2335-62.
17. Shang X, Li Z, Cao X, Xie C, Gu M, Chen P, *et al.* The association between the ACTN3 R577X polymorphism and noncontact acute ankle sprains. *J Sports Sci.* 2015; 33(17): 1775-9.
18. Qi B, Liu JQ, Liu GL. Genetic association between ACTN3 polymorphism and risk of non-acute ankle sprain. *Genetic Mol Res.* 2016;15(4).
19. Del Coso J, Salinero JJ, Lara B, Gallo-Salazar C, Areces F, Puente C, *et al.* ACTN3 X- allele carriers had greater levels of muscle damage during a half-ironman. *Eur J Appl Physiol.* 2017a;117(1):151-8.
20. Del Coso J, Valero M, Salinero JJ, Lara B, Díaz G, Gallo-Salazar C, *et al.* ACTN3 genotype influences exercise-induced muscle damage during a marathon competition. *Eur J Appl Physiol.* 2017b;117(3):409-16.
21. Murphy MJ, Berding CB. Use of measurements of myoglobinand cardiac troponins in the diagnosis of acute myocardial in-farction. *Critical Care Nurse.* 1999;19(1):58-66.
22. Masson JF, Obando L, Beudoin S, Booksh K. Sensitive and real-time fiber-optic-based surface plasmon resonance sensors for myoglobin and cardiac troponin I. *Talanta.* 2004; 62(5):865-70.
23. Moreno V, Areces F, Ruiz-Vicente D, Ordovás JM, Del Coso J. Influence of the ACTN3 R577X genotype on the injury epidemiology of marathon runners. *PLoS One.* 2020; 15(1):e0227548.
24. Clarkson PM, Hoffman EP, Zambraski E, Gordish-Dressman H, Kearns A, Hubal M, *et al.* ACTN3 and MLCK genotype associations with exertional muscle damage. *J Appl Physiol.* 2005;99(2):564-9.
25. Miyamoto N, Miyamoto-Mikami E, Hirata K, Kimura N, Fuku N. Association analysis of the ACTN3 R577X polymorphism with passive muscle stiffness and muscle strain injury. *Scand J Med Sci Sports.* 2018;28(3):1209-14.
26. Coelho DB, Pimenta EM, Rosse IC, Veneroso C, Pussieldi GA, Becker LK, *et al.* Alpha-Actinin-3 R577X Polymorphism Influences Muscle Damage and Hormonal Responses After a Soccer Game. *J Strength Cond Res.* 2019;33(10):2655-64.
27. Derbre´ F, Vincent S, Maitel B, Jacob C, Delamarche P, Zouhal H. Androgen responses to sprint exercise in young men. *Int J Sports Med*. 2010;31(5):291-7.
28. Canali E, Kruel L. Hormonal responses in the year. *Rev Paul Educ Fis*. 2001;15:141-53.
29. Lu SS, Lau CP, Tung YF, Huang SW, Chen YH, Shih HC, *et al.* Lactate and the effects of exercise on testosterone secretion: Evidence for the involvement of a cAMP-mediated mechanism. *Med Sci Sports Exer.* 1997;29:1048-54.
30. Massidda M, Voisin S, Culigioni C, Piras F, Cugia P, Yan X, *et al.* ACTN3 R577X Polymorphism Is Associated With the Incidence and Severity of Injuries in Professional Football Players. *Clin J Sport Med.* 2019;29(1):57-61.
31. Venckunas T, Skurvydas A, Brazaitis M, Kamandulis S, Snieckus A, Moran CN. Human alpha- actinin-3 genotype association with exercise-induced muscle damage and the repeated-bout effect. *Appl Physiol Nutr Met.* 2012;37(6):1038-46.

Original article

Effects of the use of foam rollers by high-performance athletes on range of motion, flexibility, strength and delayed onset muscle soreness

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Summary

Introduction: The Foam Roller (FR) is a self-induced myofascial release instrument to apply pressure directly on the target musculature. FR is widely used by athletes as a self-massage tool.
Objective: We evaluate the current evidence on the impact of FR on the musculoskeletal system in athletes, trying to identify the mechanisms that influence myofascial tissues.
Material and method: Based on the Preferred Reporting Item Guidelines for Systematic Reviews and Meta-Analyses (PRISMA), we systematically reviewed studies indexed in Web of Science, Cochrane, and PubMed to evaluate the effects of FR on joint range of motion (ROM), flexibility, strength, and delayed onset muscle soreness (DOMS) in high-performance athletes. Original articles published from 2018 through September 30, 2022, with controlled trial or pre-post intervention design, in which the FR intervention was compared to a control group, were included. The PEDro scale was used to assess methodological quality.
Results: Among the 141 records identified in the search, a total of 10 studies met the inclusion and exclusion criteria. In general, the use of FR, in high performance athletes, showed significant improvements on ROM and flexibility, and markedly beneficial effects on DOMS and strength, with no adverse effects on myofascial tissue. FR may act by improving myofascial tissue architecture, attenuating the inflammatory and nociceptive effect.
Conclusion: The use of FR seems to be safe; it is an effective tool for the improvement of the physical qualities of mobility, strength, and flexibility, and to decrease DOMS and increase sports performance.

Key words:
Foam roller. Myofascial induction. Flexibility. Range of motion. Strength. DOMS.

Efectos del rodillo de espuma o *foam roller* sobre el rango de movimiento, la flexibilidad, la fuerza y el dolor muscular de inicio retardado en deportistas de alto rendimiento

Resumen

Introducción: El rodillo de espuma o *Foam Roller (FR)* es un instrumento de liberación miofascial autoinducida, para aplicar presión de forma directa sobre la musculatura diana. *FR* es ampliamente empelado por deportistas como herramienta de auto-masaje.
Objetivo: Evaluar la evidencia actual sobre el impacto del *FR*, sobre el sistema musculoesquelético, en deportistas, tratando de identificar los mecanismos que influyen sobre los tejidos miofasciales.
Material y método: Basándonos en las directrices de los Elementos de Información Preferidos para Revisiones Sistemáticas y Metaanálisis (PRISMA), revisamos sistemáticamente estudios indexados en Web of Science, Cochrane y PubMed, para evaluar los efectos del *FR* en el rango articular de movimiento (ROM), la flexibilidad, la fuerza y el dolor muscular de inicio retardado (DOMS) en deportistas de alto rendimiento. Se incluyeron artículos originales publicados desde el 2018 hasta el 30 de septiembre de 2022, con diseño de ensayo controlado o pre-post intervención, en los que se comparó la intervención de *FR* con un grupo control. Se utilizó la escala PEDro para evaluar de la calidad metodológica.
Resultados: Entre los 141 registros identificados en la búsqueda, un total de 10 estudios cumplieron los criterios de inclusión y exclusión. En general, el uso de *FR*, en los deportistas de alto rendimiento, mostró mejoras significativas sobre el ROM y flexibilidad, y efectos notablemente beneficiosos sobre el DOMS y la fuerza, sin efectos adversos en el tejido miofascial. El *FR* puede actuar mejorando la arquitectura tisular miofascial, atenuando el efecto inflamatorio y nociceptivo.
Conclusión: El uso *FR*, parece seguro, es un instrumento efectivo para la mejora de las cualidades físicas de movilidad, fuerza y flexibilidad, y disminuir el DOMS incrementando del rendimiento deportivo.

Palabras clave:
Rodillo de espuma. Inducción miofascial. Flexibilidad. Rango de movimiento. Fuerza. DOMS.

SEMED (Spanish Society of Sports Medicine) Award for investigation 2022

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Introduction

Optimal musculoskeletal recovery is the key factor that will permit an athlete to train day after day and to assimilate the training loads with guarantees of increased performance[1]. Good musculoskeletal health is achieved by motivating the athlete to train flexibility, strength and maintenance of a correct Range of Motion (ROM) in a way that is functional and specific to the sport practised[2]. However, the more demanding physical training periods put the athlete at the limit of muscle dysfunction and sub-clinical pain[3]. Musculoskeletal alterations are progressively established and the athlete exhibits muscle stiffness, restriction and alteration of motion[4], conditioning their physical and sports activity. However, training loads are necessary in order to increase athletic performance[5] and they are associated with homeostatic biological processes of adaptation that not only include muscle tissue remodelling processes[6], but also affect the viscoelastic properties of the myofascial tissue, modifying its mechanical qualities[7]. In order to address the muscle and fascial disorders induced by the psycho-physical stresses resulting from strenuous, intense exercise, and to recover adequately, athletes use prevention, treatment and re-adaptation processes. These techniques promote the restoration of the musculoskeletal mechanical and physiological performance[1]. In the context of this entire process, intervention on the myofascial tissue could potentially permit the tolerance of intense athletic activity by modulating muscle adaptation[7].

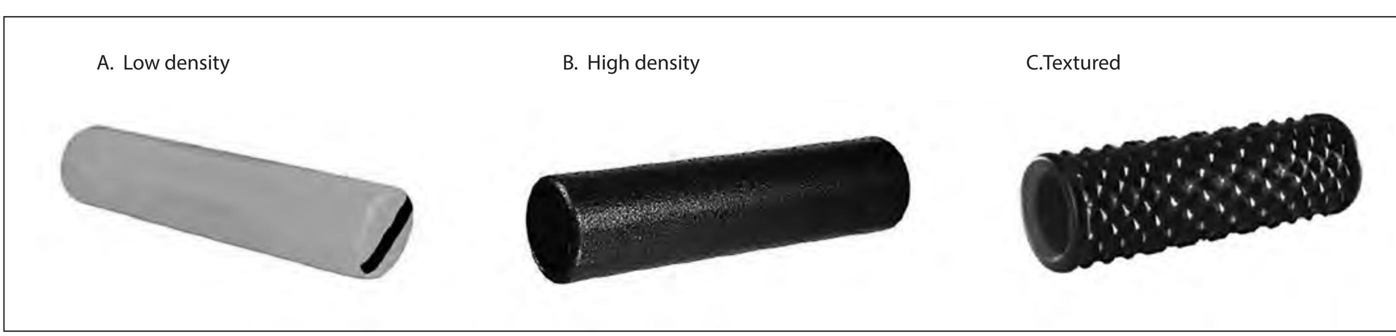
The Foam Roller (FR) (Figure 1) is a device that makes it possible to implement self-myofascial release, a technique by which the athlete can use the FR to directly self-apply pressure on the targeted musculature[8]. An FR is either a hollow or solid core cylinder covered in foam, available in different sizes and densities (Table 1). The FR allows the user to apply pressure, which is directly dependent on body weight, and to roll it over the target musculature to be treated, considering that direct pressure can change the viscoelastic properties of the myofascial tissue[9]. The FR is currently a device that is widely-used as a simulation therapy for myofascial release by elite and recreational athletes, although since the nineteen-eighties it has also been used as a self-massage tool[10].

It has been reported that the use of FR permits certain improvements in physically active, healthy adults with regard to flexibility[11,12], Delayed Onset Muscle Soreness (DOMS)[13,14], and ROM[15], although the gains in muscle strength were more limited following self-applied FR treatment[16]. However, elite athletes demand levels of mobility, strength and flexibility which, on occasions, exceed natural human capacity, and are determining physical factors on performance. The potential improvements on these physical capacities and DOMS could be

Table 1 Characteristics and recommendations for use of the different types of Foam Roller.

Types of *Foam Rollers*	Characteristics and recommendations for use
Low density	- Lightweight and soft contact with the body. Possible to use without feeling very intense pressure. - Recommended application in muscle areas with great muscle stiffness, delicate or painful areas. - For muscle groups such as those on the lateral thigh (vastus lateralis and tensor fasciae latae), the back, avoiding pressing down on the vertebral apophysis.
Firm density	- Hard contact with the body, and may even be painful due to the high pressure. - Application recommended for rapid recovery, given that it produces a very deep massage with a more effective muscle release, making it equivalent to days of recovery and specific masotherapy sessions. - For muscle groups that are more difficult to massage and requiring depth, such as the soleus muscles, hamstrings and/or the anterior tibialis.
Textured	- Featuring moderate ridges and knobs that distribute the pressure exerted over the FR. They are quite pleasant to use given that they have an intermediate density. - Application recommended for daily use in training sessions due to their low weight and small size. - They make it possible to release the fascial tissue and, specifically, to work on specific trigger points.

Figure 1. Foam roller



related to the changes in the stiffness of the muscle tissue and on its morphological structures[17,18]. Unfortunately, to date, the use of FR has been insufficiently studied and/or there is no critical review of the literature on the effects of the FR on high-performance athletes. Therefore, this study aimed to conduct a systematic review of the effects of the FR on the musculoskeletal system, ROM, flexibility, strength and DOMS, of highly-trained athletes, trying to identify the mechanisms that exert an influence on the myofascial tissues. We used the PICO model in accordance with the standard methods proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[19] as follows: Population: healthy male adults, competitive athletes or highly-trained; Intervention: self-myofascial release through the FR; Comparison: control/placebo group or group of before/after comparative data; Results: ROM, flexibility, strength and DOMS. The study followed the recommendations for the ethical publication of systematic reviews proposed by Wager and Wiffen[20] and the review protocol is published in the Prospective Register of Systematic Reviews (PROSPERO); reference CRD CRD42022367950.

Material and method

Search strategy

For the selection of articles, a structured search was conducted using the following electronic databases: M*edline (PubMed), Scopus, Cochrane and Web of Science (WOS)* for studies published from 2018 onwards up to 30 September 2022. The search strategy contained a combination of *Medical Subject Headings (MeSH)* and free words for related key concepts which included: *("foam rolling" OR "self-myofascial release" OR "roller massage" OR "foam roller") AND ("range of motion" OR "ROM" OR "flexibility) AND ("strength" OR "muscle strength") AND ("DOMS" OR "Delayed Onset Muscle Soreness") AND ("athletes" OR "elite athletes" OR" "high performance athletes" OR "high trained athletes") AND ("warm up OR "pre-exercise" OR "post-exercise".* Two authors (D.F.L. and C.I.F.-L.) independently performed the search of the studies published while a third reviewer (J.S.-C.) resolved any disagreements on the records. All the studies obtained in the 3 databases were compared in order to delimit the search as far as possible and to avoid the repetition of studies. A review was made of all the meta-analyses and systematic reviews existing in order to avoid a loss of studies due to the absence of search terms.

Selection of articles: inclusion criteria

For the selection of studies, we established the following inclusion criteria: a) healthy adults, elite or high-performance athletes, with no acute and/or chronic pathologies (excluding studies made on animals and *in vitro*); b) isolated use of the FR device, before, during or after exercise; c) original records with random and non-random trials, controlled double-blind or parallel design (not considering reviews, meta-analyses, editorials and non-original studies); d) studies that assess the relationship between the use of the FR for myofascial release and the physical factors (ROM, flexibility, strength and DOMS) either as the primary outcome of the study or secondary outcomes; e) studies with clear information on the intervention with FR, total duration of the myofascial treatment, precise moment of the intervention and the muscle area to which is was applied; f) documents published from 2018 onwards up to 30 September 2022; g) studies ≥6 points on the methodological quality scale of the *Physiotherapy Evidence Database* (PEDro)[21]. Any studies not meeting these criteria were excluded.

Data extraction and synthesis

The following information was extracted from each study included in the systematic review: the name of the first author, year of publication; country in which the study was conducted; study design; sample size; sex and age of the participants; height; body weight; intervention of FR, that is: duration, moment of the intervention, area of application; parameters analysed; and final outcomes. Two investigators (D.F.L. and C.I.F.-L.) performed the data extraction process using a spreadsheet. In the event of disagreements relating to the data extraction, a third reviewer author (J.S.-C.) took part in the process.

Evaluation of the methodological quality

The evaluation of the methodological quality of the records selected was conducted using PEDro[21]. The aim of this evaluation was to exclude any studies with poor methodology.

Results

Selection of studies

A total of 141 studies were identified, 134 studies came from 3 electronic databases, Cochrane, SCOPUS and PubMed, and 7 came from additional sources such as ResearchGate (n = 2) and reference lists of relevant studies (n = 5). Following the exclusion of 44 duplicates, a total of 90 articles identified in databases were examined. Following the assessment of the title and abstract, 31 articles were considered to be potential records. Following a review of the complete text and the assessment of the potential database records, 1022-31 studies were included in the systematic review (Figure 2).

Assessment of the methodological quality

Once the articles had been selected, their methodological quality was assessed using the PEDro scale[21]. With regard to the 10 studies included[22-31], 1 study 24 was rated as excellent while the methodological quality of the other 9 studies[22,23,25-31] was rated as good. Items number 5 and 6 were the least met, referring to the masking of the participant and the masking of the therapist, respectively (Table 2).

Characteristics of the participants and interventions

The characteristics of the participants are shown in Table 3. The total number of volunteers was 215 (111 men and 84 women), although one

Figure 2. Flow diagram showing the processes for the identification and selection of relevant studies based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

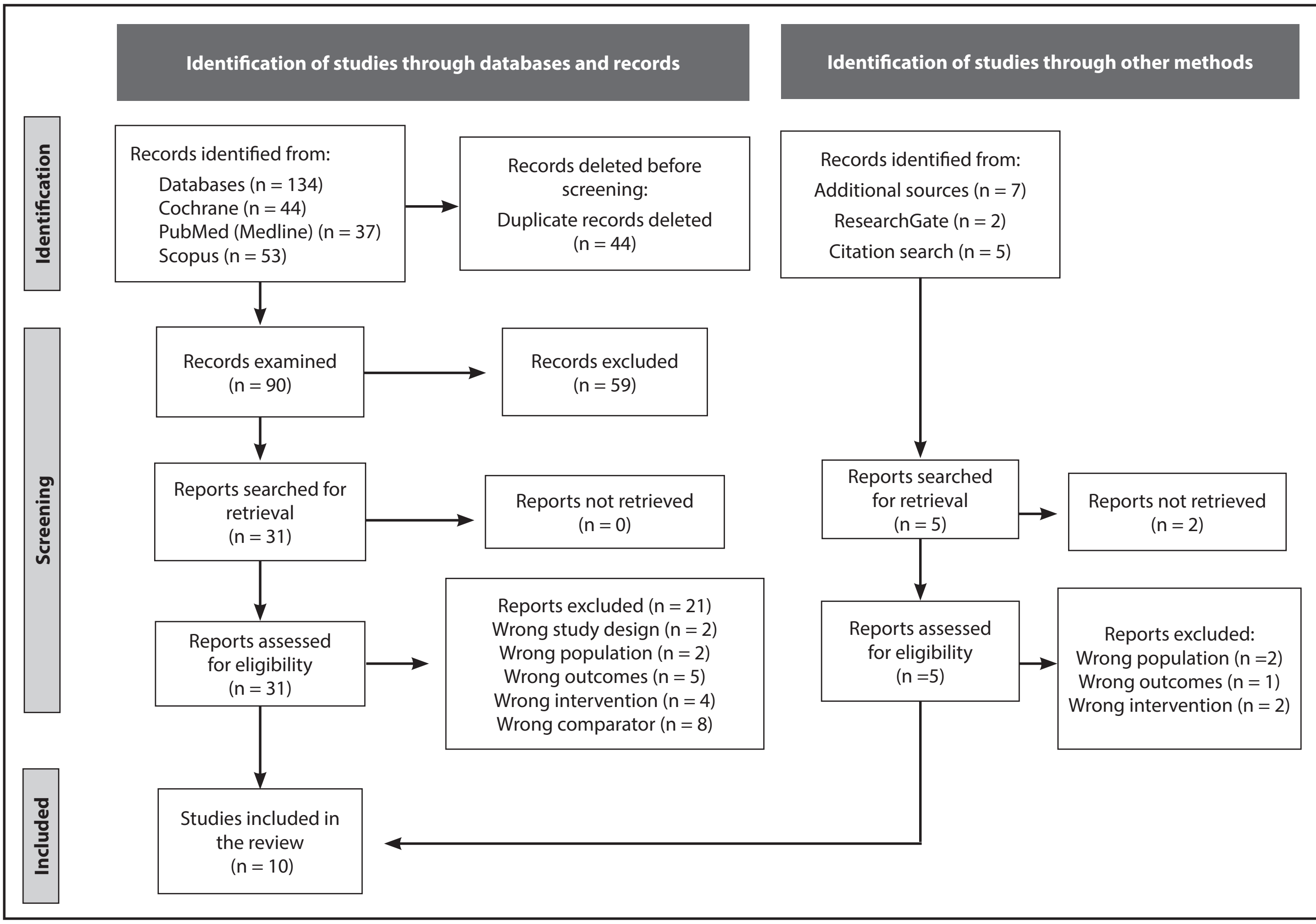


Table 2. PEDro scale for the assessment of the methodological quality.

Reference	Items											T_E	Quality
	1	2	3	4	5	6	7	8	9	10	11		
Lopez-Samanes *et al.*, 2021[29]	1	1	0	1	0	0	0	1	1	1	1	7	B
Maniatakis *et al.*, 2020[26]	1	1	0	1	0	0	1	1	1	1	1	8	B
Oranchuk *et al.*, 2019[25]	0	1	1	1	0	0	1	1	1	1	1	8	B
Rey *et al.*, 2017[27]	1	1	0	1	0	0	0	1	1	1	1	8	B
Richman *et al.*, 2018[31]	0	1	0	1	0	0	0	1	1	1	1	6	B
Romero *et al.*, 2019[24]	1	1	1	1	1	0	1	1	1	1	1	10	E
Scudamore *et al.*, 2021[23]	1	1	0	1	0	0	0	1	1	1	1	7	B
Siebert *et al.*, 2020[28]	1	1	0	1	0	0	0	1	1	1	1	7	B
Souza *et al.*, 2020[30]	1	1	0	1	0	0	0	1	1	1	1	7	B
Sulowska-Daszyk *et al.*, 2022[22]	1	1	1	1	0	0	0	1	1	1	1	8	B

Abbreviations: TE: Total items met per study: E: Excellent; G: Good; 1: Criterion met; 0: Criterion not met.

study did not specify the sex of its 20 subjects[23], all are healthy athletes (with no chronic conditions that would prevent the intensive practice of sport) with a high training level. The studies included high-performance athletes practising athletics[22,24] basketball[26,28,31], volleyball[25,28,31], tennis[28,29], football[27,28], lacrosse[25] and military competitions[23]. 7 studies were based on the intervention with the FR used in the pre-exercise warm-up[2,24,26,28-31], 2 studies used it in the post-training cool-down[23,27] and only Oranchuk *et al*.[25] used it between exercise sessions. The muscle groups targeted with the FR were mainly the lower extremities (LE), primarily the hamstrings, quadriceps, gluteals and gastrocnemius[22-25,27-31], and in the study made by Maniatakis *et al*.[26] on volleyball players, the FR was used in 3 areas of the shoulder. None of the studies included in this systematic review reported the density, length and texture of the FR[22-31]. No adverse effects resulting from the use of the FR were reported[22-31].

Evaluation of the outcomes

Table 3 summarises the outcomes of the studies included in this systematic review.

Range of Motion (ROM)

In the 5 studies measuring the ROM[24-26,28,29] and included in this review, significant improvements (*P* <0.05) were observed in the intervention group (IG) after the use of the FR for the muscle groups assessed: passive dominant leg raise (hip test))[25,29], shoulder external rotation and flexion[26], ankle dorsiflexion, hip extension and knee flexion 24 and flexion of the longitudinal section of the hip[28]. However, only the ROM significantly improved (*P* <0.05) in the longitudinal section of the hip extensors (femoral biceps and semitendinosus)[28] and in the knee flexion[24] when compared to the condition with no use of the FR. Furthermore, Romero *et al.*[24] found no significant differences (*P* >0.05) in the proprioceptive capacity of the knee joint.

Flexibility

Three of the studies included in the systematic review[22,27,31], assessed muscle flexibility following application of the FR. Two studies[27,31] used the Sit and Reach test and reported significant increases (*P* <0.05) in the IG. When the IG was compared with the control group (CG), flexibility only improved significantly in football players[27] and no changes were observed in basketball players[31]. Sulowska-Daszyk *et al.*[22] reported a significant increase (*P* <0.05) in the flexibility of the tensor fasciae latae muscles, and substantial non-significant increases (*P* >0.05) in the piriformis and adductor muscles in the IG following use of the FR. However, the flexibility in the IG was significantly lower (*P* <0.05) in the iliopsoas and rectus femoris muscles compared to the control group and for the iliopsoas from the start up to the end of the FR treatment.

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported.

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
López-Samanes *et al.,* 2021, Spain[29]	Rando-mised crossover	9 ♂ professional women tennis players ATP ranking Age (mean ± SD): 20.64 ± 3.56 years Height (mean ± SD): 1.83 ± 0.05 metres Weight (mean ± SD): 75.55 ± 5.03 kg IG (n = 9): warm-up + TMT with FR CG (n = 9): warm-up + TMT with DE With no loss of participants	FR rolling massage on muscle groups: - Quadriceps - Hamstrings - Gluteals - Calves. 8 mins: 60 s x muscle group x each LE Warm-up	ROM hip test; - PSLR, DL - PSLR, NDL - TT, DL - T, NDL attempts maximum x test; 20 s rest between attempts Measurement inclinometer (º)	IG vs CG ↔ ROM hip test: PSLR & TT (NDL / DL) IG: Changes from baseline ↑^ EPSLR, DL ↔^ PSLR, NDL ↔ TT, DL ↔TT, NDL
Maniatakis *et al.,* 2020, Greece[26]	Piloto pre / post test	15 ♂ elite volleyball players Greek 1st division and competition in Europe Age (mean ± SD): 24 ± 4.54 years Height (mean ± SD): 177 ± 0.08 cm Weight (mean ± SD): 81 ± 7.71 kg The 15 players are treated simultaneously. Comparison with the baseline (pre / post- test)	FR self-mobilizations 3 areas of shoulder: - Anterior - Lateral - Posterior for 10 mins: 3 rep x 60 s x part of shoulder Rest x 20 s x part of shoulder Warm-up	ROM (º): - Flexion - IR - ER Both UE were measured, and the mean was calculated Measured with goniometer (º)	IG vs Changes from baseline ↑* Flexion ↑ IR ↑* ER

(continues)

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported (continued).

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
Oranchuk *et al.*, 2019, United States[25]	Cross-over, randomized single blind	11 ♀ Lacrosse players + 11 ♀ basketball players. Competition NCAA II Age (mean ± SD): 19.4 ± 1.7 years; height (mean ± SD): 164.8 ± 9.2 cm Weight (mean ± SD): 61.4 ± 8.9 kg IG: TMT with FR CG: Passive rest	*FR* rolling massage on muscle group: - Hamstrings 3 sets x 1 min; 30 s rest between sets Between training sessions	Acute flexibility hamstrings using ROM in the hip flexion (º) Assessed with PSLR test using goniometer (º)	IG vs CG ↑ PSLR IG: Changes from baseline ↑* PSLR ↑*Δ % change: 7.3% +
Rey *et al.*, 2017, Spain[27]	Randomised control	18 ♂ football players. Professional Football League (1st and 2nd division) Experience 14.8 ± 2.6 years Age (mean ± SD): 26.6 ± 3.7 years; height (mean ± SD): 180.5 ± 4.55 cm Weight (mean ± SD): 75.8 ± 4.7 kg Body fat (mean ± SD): 10.2 ± 0.8% 1 x RM squat: 156.7 ± 24.9 kg VO_2 maximum: 61.2 ± 4.2 ml/kg/min CG (n = 9) 20 mins seated IG (n = 9): *FR* 20 mins	*FR* rolling massage on muscle group: - Quadriceps - Hamstrings - Adductors - Gluteals - Calves 2 rep of 45 s x muscle group x each LE 15 s rest On both legs After training	Flexibility - Lumbar spine - Hamstrings (Sit & Reach test" (cm) DOMS: - TQR - VAS	IG vs CG Flexibility ↑ Sit & Reach test DOMS: ↑ TQR ↓ VAS IG: Changes from baseline Flexibility: ↑* Sit & Reach test ↑*Δ % change: 18.79% + DOMS: ↑ TQR ↓ VAS
Richman *et al.*, 2018, United States[31]	Randomised crossover	14 ♀ n = 8 volleyball players + n = 6 basketball players. Competition NCAA II Age (mean ± SD): 19.8 ± 1.3 years; height (mean ± SD): 172 ± 24 cm Weight (mean ± SD): 69.3 ± 10.9 kg IG (n = 7) TMT with *FR* + DE CG (n = 7): light aerobic foot running + DE	*FR* rolling massage at constant pressure on muscle groups - Hip flexors - Quadriceps - Adductors - TFL - Gluteals - Hamstrings - Plantarflexors - Dorsiflexors 6 mins: 30 s x muscle group on each LE Warm-up	Flexibility (Sit & reach test (cm)) 3 times T1, T2, T3	IG vs CG ↔ T2 ↔ T3 IG: Changes from baseline ↑* T1 vs. T2 ↑* T1 vs. T3 ↑ T2 vs. T3
Romero *et al.*, 2019, Spain[24]	Randomised control	30 athletes; ♂ n = 18; ♀ n = 12 IG (n = 15; 8♂, 7♀): TMT with *FR* + aerobic foot running Age (mean ± SD): 24.2 ± 4.2 years; height (mean ± SD): 177.0 ± 7.0 cm Weight (mean ± SD): 70.1 ± 14.2 kg CG (n = 15; 10♂, 5♀): Aerobic foot running Age (mean ± SD): 25.0 ± 4.7 years; height (mean ± SD): 175.0 ± 8.0 cm Weight (mean ± SD): 67.5 ± 5.6 kg	*FR* rolling massage on muscles: - Anterior muscle - Posterior muscle - Gastrocnemius 6 mins: 45 s x muscle x each LE 15 s rest between each LE Warm-up	ROM Ankle: Dorsiflexion: Knee Extension / Flexion Hip: Extension Measured with inclinometer (º) Proprioception: Knee AAE, RAE, VAE 10 minutes later	IG vs CG ROM Ankle: ↑ Dorsiflexion: Knee: ↑ Extension / ↑* Hip Flexion: ↑ Extensión Proprioception: Knee ↔ (AAE, RAE, VAE) GI: changes from baseline ROM: Ankle: ↑* Dorsiflexion Knee: ↑ Extension / ↑* Flexion Hip: ↑* Extension Proprioception: Knee ↔ (AAE, RAE, VAE)

(continues)

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported (continued).

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
Scudamore, *et al.*, 2021, United States[23]	Rando-mised crossover	20 soldiers ♂and ♀ CMilitary resistance competitions ≥1 year Age (mean ± SD): 23.6 ± 4.1 years; height (mean ± SD): 176.4 ± 5.6 cm Weight (mean ± SD): 84.7 ± 13.4 kg IG: *FR* CG: passive in seated position	*FR* mrolling massage on muscle groups: - Gluteals - Hamstrings - Iliotibial band - Quadriceps - Adductors 20 mins: 45 s x 2 x muscle group for each LE; 15 s rest between LE After training	DOMS DOMS-inducing exercise protocol (DIP) 10 x 10 squats# 60% 1*RM #squat 5 s eccentric 1 s pause 2 2s concentric 1 s pause DOMS ratio (DR) (CR-11)	IG vs CG ↓ DOMS IG: Changes from baseline ↔ DOMS
Siebert *et al.*, 2020, Germany[28]	Rando-mised crossover	14 ♂ athletes (tennis, swimming, gymnastics, basketball) national training level ≥3 days x week Age (mean ± SD): 23.7 ± 1.3 years Height (mean ± SD 182 ± 8 cm Weight (mean ± SD): 79.4 ± 6.9 kg IG: FR on bench CG: passive in seated position	Position of athlete seated on bench with horizontal rolling movement of FR on muscles - Biceps femoris - Semitendinosus 6 mins: 10 / 12 complete passes on hamstring x 30 s each Warm-up	Hip flexion ROM measured in sagittal plane with subjects lying in a lateral position Surface (EMG) of 2 representative hip extensors (biceps femoris and semitendinosus)	IG vs CG ↑* ROM longitudinal section ↔ ROM transverse section IG: Changes from baseline ↑* ROM longitudinal section ↔ ROM transverse section
Souza *et al.,* 2020, Brazil[30]	Randomi-sed control	14♀ female professional footballers 1st division, Esporte Club Vitoria IG (n = 7) FR + specific warm-up Age (mean ± SD): 22.3 ± 2.3 years; height (mean ± SD): 170 ± 0.1cm Weight (mean ± SD): 64 ± 10 kg CG (n = 7): football-specific warm-up Age (mean ± SD): 28.8 ± 4.3 years; Height (mean ± SD): 170 ± 0.1cm Weight (mean ± SD): 62 ± 7.6 kg	*FR* rolling massage on muscle groups: - Quadriceps - Hamstrings - Sural triceps 2 weeks TMT: 3 x week. 3 sets x 1 min x muscle; 30 s rest between muscles Warm-up	MS Peak torque of Extension on: - NDL - DL Flexion on: - NDL - DL Angular speed 60º/s.	IG vs CG Extension ↑ NDL ↑ DL Flexion ↑ NDL ↑ DL IG: Changes from baseline Extension ↔ NDL ↔ DL Flexion ↔ NDL ↔ DL
Sulowska-Daszyk *et al.*, 2022, Poland[22]	Randomi-sed control	62 ♂ and ♀ Long-distance runners competing at national level IG (n = 30) (n = 18 ♂; n = 12 ♀): *FR* Age (mean ± SD): 34.09 ± 7.73 years Height (mean ± SD): 175.81 ± 8.73 cm Weight (mean ± SD): 69.88 ± 9.55 kg IG (n = 32) (n = 22 ♂; n = 10 ♀): passive in seated position Age (mean ± SD): 33.46 ± 7.33 years Height (mean ± SD): 177.60 ± 7.63 cm Weight (mean ± SD): 70.70 ± 8.79 kg	*FR* balance massage on muscle groups: - Hamstrings - Major gluteal - Hip Adductors - Quadriceps - TFL - Gastrocnemius On both LE: 2 mins x muscle group 2.5 cm/s, 10 x muscle Warm-up	Flexibility - ER (piriformis) - Iliopsoas - TFL - Rectus femoris - Adductors Measured with a tape measure (cm)	IG vs CG ↑ ER ↓* Iliopsoas ↑ TFL ↓ Rectus femoris ↑ Adductors IG: Changes from baseline ↑ ER ↓* Iliopsoas ↑* TFL ↓* Rectus femoris ↑ Adductors

Abbreviations: ↑: Non-significant increase; ↓: Non-significant decrease; ↔: no significant change. ↑*: Significant increase; ↓*: significant decrease; GC: control group; GI: intervention group; ^significant interaction between group-time; ²significant principal temporary effect; ¹significant principal effect of the group; SD: standard deviation; ♂: Male; ♀: Female; Kg: kilogrammes; cm: centimetres; ml: millilitres; *FR: foam roller*; ROM: joint Range of Motion ER: external rotation; IR: internal rotation; TFL: tensor fasciae latae; LE: lower extremities; UE: upper extremities; mins: minutes; s: seconds; rep: repetitions; PSLR: passive straight leg raise; DL: dominant limb; NDL: non-dominant limb; TMT: treatment; DE: dynamic exercises; TT: Thomas test; DOMS: delayed onset muscle soreness; AAE: absolute angular error; RAE: relative angular error; VAE: variable angular error; TQR: total quality recovery; VAS: visual analogue scale; NCAA: National Collegiate Athletic Association; RM: Repetition Maximum; CR-11: 11 item category rating scale; EMG: electromyography; ATP: Asociación Tenistas Profesionales (Professional Tennis Players Association); DIP: DOMS-inducing exercise protocol; DR: DOMS ratio.

Strength

Souza *et al.*[30] assessed the use of the FR on football players during the warm-up session, on the quadriceps, hamstrings and sural triceps muscle groups, achieving substantial improvements in extension strength in both limbs (dominant and non-dominant) after 2 weeks of treatment.

Delayed Onset Muscle Soreness (DOMS)

The 2 studies included in this systematic review[23,27] reported notable decreases in DOMS in the IG compared to the CG, rated using the visual analogue scale (VAS) for pain intensity[27] and an 11-item category rating scale (CR-11).

Discussion

With regard to the ten studies that met the pre-specified inclusion / exclusion criteria, the use of FR as a self-release therapy in high-performance athletes showed significant improvements for ROM and flexibility, and considerable beneficial effects for DOMS and strength, with no adverse effects or pathological alterations in the myofascial tissue.

The physical activity of highly trained athletes includes high-intensity workloads that induce alterations in the mechanical properties of the soft tissue that reduce the load tolerance threshold of the musculoskeletal system and promote a mechanical deterioration of the myofascial tissue that is particularly recurrent in sports that require a high density of movements with a high eccentric component[3,4]. Furthermore, the biological processes of the mechano-adaptation of the extracellular matrix of the connective tissue, in the face of repetitive strenuous physical loads that induce an inflammatory response mediated by inflammatory Interleukins (IL) such as IL-1β, IL-6 and the alpha tumoral necrosis factor (TNF-α). Additionally, transforming growth factor beta-1 (TGFβ-1) is released, which favours tissue fibrosis and stiffness through the differentiation and proliferation of fibroblasts and the excessive synthesis of collagen[32,33]. These adaptations lead to a pathological alteration of the mechanical behaviour of the connective tissue due to fascial restrictions, causing a loss of elasticity, increased stiffness and dehydration. When this occurs, fascia anastomosis occurs around the traumatised areas, causing fibrous adhesion. The adhesions interfere with functional development, impairing normal muscle mechanics and they can cause trigger points with muscle hyperactivity and a loss of: ROM, elasticity, strength, flexibility and muscle resistance[7,34]. These sub-clinical studies could be decisive in situations of high athletic demand.

To reverse this situation, myofascial techniques have been used to modulate muscle involvement and to take advantage of the thixotropic nature of fascia to return it to a softer and more pliable state[7,35]. The FR is a self-myofascial release tool that could potentially increase flexibility and biotensegrity in the short term[36]. This review included 2 studies[27,31] that significantly improved flexibility, assessed using the Sit and Reach test in the post-training of female football players[27] and in the warm-up of professional basketball players[31]. These results are consistent with those reported for healthy volunteers[37], using the same flexibility test, and those obtained with static stretching[15]. The improvement in flexibility could be due to the effect of the FR on the restoration of the fascial structure of the intermuscular septa, anchors and partitions, which would achieve optimal mechanical properties and alleviate muscle tightness[7,35]. Furthermore, the myofascial technique using the FR could stimulate the inverse myotatic reflex, which could provide a relaxation signal, facilitating flexibility[35]. However, in a study on volunteers practising physical activity, no effect on flexibility was observed in the Sit and Reach test[38]. The limitations of the Sit and Reach test that measures hamstring flexibility through flexion of the hip[39], could account for these differences in results. The study conducted by Sulowska-Daszyk *et al.*[22] showed contradictory results with regard to flexibility, with improvements in the tensor fasciae latae muscles, piriformis and adductor muscles with moderate decreases in the iliopsoas and rectus femoris muscles in long-distance athletes. Seco *et al.*[40] reported that, while muscle activation may influence training-induced hypertrophy, the mode of contraction seems to be a stronger driver of architectural changes in hamstrings, with excessive muscle stiffness, which could lead these athletes to exhibit ischiofemoral impingement, which causes extra-articular hip syndrome accompanied by compression between the less trochanter and the ischial tuberosity. This extra-articular hip syndrome is the most common injury suffered by athletes, restricting the action of these muscle groups[40], and may explain the differences found by Sulowska-Daszyk *et al*[22].

The pressure exercised by the FR on all the myofascial structures could cause changes in fascial adhesion, myofascial trigger points and viscoelastic tissue properties due to collagen and elastin remodelling[41], resulting in an increase of the tissue distensibility, facilitating the ability to slide between planes and, therefore, improving the ROM[7,35]. Furthermore, the increased blood flow due to vasodilation, by stimulating the release of nitric oxide and reducing vascular stiffness [42], could reintegrate the interstitial fluid into the systemic circulation, inducing a heating effect and facilitating motion[43]. Such mechanisms could be potentially responsible for the significant improvements in the ROM in the IG following the intervention with FR on the different muscle groups[24-26,28,29]. These results are similar to those described in 2 studies[44,45] and a review[35] in a non-athletic population that achieved significantly positive results in ROM with the use of FR (≥2 weeks). Furthermore, similar effects on the ROM were observed following conventional masotherapy techniques[46].

Analgesic neurophysiological[35] mechanisms have also been described, following self-myofascial release therapy and leading to a shift from the sympathetic to parasympathetic tone, which has been associated with increases in ROM. Moreover, pain tolerance may also play a part in improving ROM. This increase in the pain threshold could be due to the diffuse noxious inhibitory control that is activated by the reception of a sustained nociceptive stimulus that is able to suppress the nociception of the local and distant areas. In other words, the self-myofascial release using FR could combat pain in one area by creating it in another[7,47]. This contra-irritation phenomenon occurs in cryotherapy[1], and in the application of electric muscle stimulation (EMS) currents[48]. Although this mechanism would probably play a more significant role in the modulation of DOMS.

DOMS-related pain and muscle stiffness are a result of the inflammatory response generated by the continuous and intense physical loads on athletes[32,33]. The release of pronociceptive mediators such as bradykinin and substance *P* also contribute to DOMS, as they activate peripheral sensitization at a peripheral level, in the mechanical environment of the free nerve endings and at a spinal level[32]. Therefore, the effect of FR on DOMS would be determined by the synergic influence of self-release on tissue architecture and mechanics, inflammatory and pro-inflammatory molecular mediators and neurophysiological mechanisms of nociceptive control[18,49]. Of particular importance is the neurophysiological mechanism of diffuse noxious inhibitory control, a mechanism that utilises FR to reverse myofascial trigger point pain, known as Gate Control, where various stimuli are directed to the same level of the medulla, the pain and the pressure caused by the use of the FR, and there is a compromise for entry given that the information coming from the nociceptors lacks superiority over another stimulus, so that they are finally inhibited, although temporarily[50].

The different myofascial techniques[51], including FR, are able to re-establish and increase ROM, flexibility and reduce DOMS without affecting the intensity of activity or muscle performance[36]. In fact, Souza *et al.*[30] reported considerable improvements in the strength of the LE in the quadriceps, hamstrings and sural triceps muscle groups. These increases could confirm that myofascial release is responsible for improvements in strength, given that the transmission of strength to the tendon depends on muscle integrity during contraction and also on the mechanical properties of the connective tissue and the degree of pretension of the fascial system[52]. Additionally, the effects of the FR on increased blood flow[42] could provide a greater delivery of oxygen and substrates to perform muscle actions.

The authors of this review acknowledge a few limitations. Firstly, there were a limited number of articles that met the inclusion criteria. Despite this, our systematic approach followed the PRISMA method[19], the search was made using 3 key databases and covered grey literature. Furthermore, we used the PEDro tool for the assessment of the methodological quality[21] in order to ensure that all the records selected met the minimum quality criteria and included a series of outcomes that are commonly used in the assessment of sports medicine to explain the physiopathology of the intense and repetitive sports activity processes. Secondly, the studies are extremely heterogeneous with regard to the results, sport discipline, muscle groups of the intervention, and duration. We were therefore unable to make a meta-analysis. Although the great variability in the use of FR demands caution when interpreting the results, it has been suggested that it improves the physical qualities of ROM, strength and flexibility, providing benefits to the health and performance of athletes, and is extremely useful for high-performance athletes with regard to prevention, treatment and return to training.

In conclusion, the evidence presented in this systematic review showed that the use of the FR is safe. Given the significant improvements in ROM and flexibility, and the considerable beneficial effects on DOMS and strength, with no adverse effects or pathological alterations in the myofascial tissue, the use of FR could also be beneficial to adults with musculoskeletal pathologies. The pleiotropic effect of FR can act by improving the myofascial tissue mechanics and architecture, alleviating the effect of the pro-inflammatory cytokines and activating the neurophysiological nociceptive control mechanisms[18,49]. However, more investigation is required in order to confirm the possible benefits of the use of FR as a self-release tool with regard to the physical qualities of high-performance athletes.

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Bibliography

1. Fernández-Lázaro D. Estrategias ergogénicas para optimizar el rendimiento y la salud en participantes de actividad física regular: evaluación de la eficacia de la crioterapia compresiva, la exposición a la hipoxia intermitente en reposo y el entrenamiento sectorizado de los músculos inspiratorios. Tesis doctoral, Universidad de León, León, España, 2020. Disponible en: https://dialnet.unirioja.es/servlet/tesis?codigo=286163&info=resumen&idioma=SPA (citado 12 octubre 2022).
2. Afonso J, Ramirez-Campillo R, Moscão J, Rocha T, Zacca R, Martins A, *et al*. Strength training versus stretching for improving range of motion: A systematic review and meta-analysis. *Healthcare.* 2021;9:427.
3. Ferraro E, Giammarioli AM, Chiandotto S, Spoletini I, Rosano G. Exercise-Induced Skeletal Muscle Remodeling and Metabolic Adaptation: Redox Signaling and Role of Autophagy. *Antioxid Redox Signal.* 2014;21:154-76.
4. El-Tallawy SN, Nalamasu R, Salem GI, LeQuang JAK, Pergolizzi JV, Christo PJ. Management of Musculoskeletal Pain: An Update with Emphasis on Chronic Musculoskeletal Pain. *Pain Ther*. 2021;10:181-209.
5. Macinnis MJ, Gibala MJ, Macinnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. *J Physiol.* 2017;595:2915-30.
6. Franchi MV, Reeves ND, Narici MV. Skeletal muscle remodeling in response to eccentric vs. concentric loading: Morphological, molecular, and metabolic adaptations. *Front Physiol.* 2017;4:447.
7. Wheeler AH. Myofascial Pain Disorders: Theory to Therapy. *Drugs.* 2004;64:45-62.
8. Freiwald J, Baumgart C, Kühnemann M, Hoppe MW. Foam-Rolling in sport and therapy – Potential benefits and risks: Part 2 – Positive and adverse effects on athletic performance. *Sport Orthop Traumatol.* 2016;32:267-75.
9. Hughes GA, Ramer LM. Duration of myofascial for optimal recovery, range of motion, and performance: A systematic review of the literature. *Int J Sports Phys Ther.*

2019;14:845-59.

10. Romero-Moraleda B, López-Rosillo A, González-García J, Morencos Martínez E. Efectos del foam roller sobre el rango de movimiento, el dolor y el rendimiento neuromuscular: revisión sistemática. *Retos.* 2020;38:879-85.
11. Boguszewski D, Falkowska M, Adamczyk JG, Białoszewski D. Influence of foam rolling on the functional limitations of the musculoskeletal system in healthy women. *Biomed Hum Kinet*. 2017;9:75-81.
12. Griefahn A, Oehlmann J, Zalpour C, von Piekartz H. Do exercises with the Foam Roller have a short-term impact on the thoracolumbar fascia? - A randomized controlled trial. *J Bodyw Mov Ther.* 2017;21:186-93.
13. Romero-Moraleda B, Touche R, Lerma-Lara S, Ferrer-Peña R, Paredes V, Peinado AB, *et al.* Neurodynamic mobilization and foam rolling improved delayed-onset muscle soreness in a healthy adult population: a randomized controlled clinical trial. *PeerJ.* 2017;5:e3908.
14. Romero-Moraleda B, González-García J, Cuéllar-Rayo Á, Balsalobre-Fernández C, Muñoz-García D, Morencos E. Effects of Vibration and Non-Vibration Foam Rolling on Recovery after Exercise with Induced Muscle Damage. *J Sports Sci Med.* 2019;18:172-80.
15. Su H, Chang NJ, Wu WL, Guo LY, Chu IH. Acute Effects of Foam Rolling, Static Stretching, and Dynamic Stretching During Warm-ups on Muscular Flexibility and Strength in Young Adults. *J Sport Rehabil.* 2017;26:469-77.
16. Grabow L, Young JD, Alcock LR, Quigley PJ, Byrne JM, Granacher U, *et al.* Higher quadriceps roller massage forces do not amplify range-of-motion increases nor impair strength and jump performance. *J Strength Cond*. 2018;32:3059-69.
17. Baumgart C, Freiwald J, Kühnemann M, Hotfiel T, Hüttel M, Hoppe MW. Foam Rolling of the Calf and Anterior Thigh: Biomechanical Loads and Acute Effects on Vertical Jump Height and Muscle Stiffness. *Sport.* 2019;7:27.
18. Wiewelhove T, Döweling A, Schneider C, Hottenrott L, Meyer T, Kellmann M, *et al.* A meta-analysis of the effects of foam rolling on performance and recovery. *Front Physiol*. 2019;10:376.
19. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372:n71.
20. Wager E, Wiffen PJ. Ethical issues in preparing and publishing systematic reviews. *J Evid Based Med.* 2011;4:130-4.
21. Moseley AM, Elkins MR, Van der Wees PJ, Pinheiro MB. Using research to guide practice: The Physiotherapy Evidence Database (PEDro). *Brazilian J Phys Ther.* 2020;24:384-91.
22. Sulowska-Daszyk I, Skiba A. The Influence of Self-Myofascial Release on Muscle Flexibility in Long-Distance Runners. *Int J Environ Res Public Health.* 2022;19:457.
23. Scudamore EM, Sayer BL, Church JB, Bryant LG, Přibyslavská V. Effects of foam rolling for delayed onset muscle soreness on loaded military task performance and perceived recovery. *J Exerc Sci Fit.* 2021;19:166-70.
24. Romero-Franco N, Romero-Franco J, Jiménez-Reyes P. Jogging and Practical-Duration Foam-Rolling Exercises and Range of Motion, Proprioception, and Vertical Jump in Athletes. *J Athl Train*. 2019;54:1171-78.
25. Oranchuk DJ, Flattery MR, Robinson TL. Superficial heat administration and foam rolling increase hamstring flexibility acutely; with amplifying effects. *Phys Ther Sport.* 2019;40:213-7.
26. Maniatakis A, Mavraganis N, Kallistratos E, Mandalidis D, Mylonas K, Angelopoulos P, *et al.* The effectiveness of Ergon Instrument-Assisted Soft Tissue Mobilization, foam rolling, and athletic elastic taping in improving volleyball players' shoulder range of motion and throwing performance: a pilot study on elite athletes. *J Phys Ther Sci.* 2020;32:611-4.
27. Rey E, N-Cabo AP, Costa PB, Barcala-Furelos R. Effects of Foam Rolling as a Recovery Tool in Professional Soccer Players. *J strength Cond Res*. 2019;33:2194-201.
28. Siebert T, Donath L, Borsdorf M, Stutzig N. Effect of Static Stretching, Dynamic Stretching, and Myofascial Foam Rolling on Range of Motion During Hip Flexion: A Randomized Crossover Trial. *J strength Cond Res.* 2022;36:680-85.
29. Lopez-Samanes A, Del Coso J, Hernández-Davó JL, Moreno-Pérez D, Romero-Rodriguez D, Madruga-Parera M, *et al.* Acute effects of dynamic versus foam rolling warm-up strategies on physical performance in elite tennis players. *Biol Sport*. 2021;38:595-601.
30. Souza SM, Costa Neto JFP, Santos JET. Revista Pesquisa em Fisioterapia. *Rev Pesqui em Fisioter*. 2020;10:188-94.
31. Richman ED, Tyo BM, Nicks CR. Combined Effects of Self-Myofascial Release and Dynamic Stretching on Range of Motion, Jump, Sprint, and Agility Performance. *J strength Cond Res*. 2019;33:1795-803.
32. Zügel M, Maganaris CN, Wilke J, Jurkat-Rott K, Klingler W, Wearing SC, *et al*. Fascial tissue research in sports medicine: from molecules to tissue adaptation, injury and diagnostics: consensus statement. *Br J Sports Med.* 2018;52:1497.
33. Barbe MF, Gallagher S, Massicotte VS, Tytell M, Popoff SN, Barr-Gillespie AE. The interaction of force and repetition on musculoskeletal and neural tissue responses and sensorimotor behavior in a rat model of work-related musculoskeletal disorders. *BMC Musculoskelet Disord.* 2013;14:1-26.
34. Wong TL, Huang CF, Chen PC. Effects of Lower Extremity Muscle Fatigue on Knee Loading During a Forward Drop Jump to a Vertical Jump in Female Athletes. *J Hum Kinet*. 2020;72:5-13.
35. Beardsley C, Škarabot J. Effects of self-myofascial release: A systematic review. *J Bodyw Mov Ther.* 2015;19:747-58.
36. Hendricks S, Hill H, Hollander S den, Lombard W, Parker R. Effects of foam rolling on performance and recovery: A systematic review of the literature to guide practitioners on the use of foam rolling. *J Bodyw Mov Ther.* 2020;24:151–74.
37. Sullivan KM, Silvey DBJ, Button DC, Behm DG. Roller-massager application to the hamstrings increases sit-and-reach of motion within five to ten seconds without performance impairments. *Int J Sports Phys Ther*. 2013;8:228-36.
38. Peacock CA, Kerin DD, Silver TA, Sanders GJ, VON Carlowitz KA. An Acute Bout of Self-Myofascial Release in the Form of Foam Rolling Improves Performance Testing. *Int J Exerc Sci*. 2014;7:202-11.
39. Crotti M, Bosio A, Invernizzi PL. Validity and reliability of submaximal fitness tests based on perceptual variables. *J Sports Med Phys Fitness.* 2018;58:555-62.
40. Seco-Calvo J, Palavicini M, Rodríguez-Pérez V, Sánchez-Herráez S, Abecia-Inchaurregui LC, Mielgo-Ayuso J. The Role of Hip Joint Clearance Discrepancy as Other Clinical Predictor of Reinjury and Injury Severity in Hamstring Tears in Elite Athletes. *J Clin Med.* 2021;10:1-16.
41. Schleip R. Fascial plasticity – a new neurobiological explanation: Part 1. *J Bodyw Mov Ther.* 2003;7:11-9.
42. Hotfiel T, Swoboda B, Krinner S, Grim C, Engelhardt M, Uder M, *et al.* Acute Effects of Lateral Thigh Foam Rolling on Arterial Tissue Perfusion Determined by Spectral Doppler and Power Doppler Ultrasound. *J Strength Cond Res.* 2017;31:893-900.
43. MacDonald GZ, Penney MDH, Mullaley ME, Cuconato AL, Drake CDJ, Behm DG, *et al.* An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res.* 2013;27:812-21.
44. Junker DH, Stöggl TL. The Foam Roll as a Tool to Improve Hamstring Flexibility. *J Strength Cond Res.* 2015;29:3480-5.
45. Mohr AR, Long BC, Goad CL. Effect of Foam Rolling and Static Stretching on Passive Hip-Flexion Range of Motion. *J Sport Rehabil.* 2014;23:296-9.
46. Eriksson Crommert M, Lacourpaille L, Heales LJ, Tucker K, Hug F. Massage induces an immediate, albeit short-term, reduction in muscle stiffness. *Scand J Med Sci Sports.* 2015;25:e490-6.
47. Aboodarda S, Spence A, Button DC. Pain pressure threshold of a muscle tender spot increases following local and non-local rolling massage. *BMC Musculoskelet Disord.* 2015;16:265.
48. Leone C, Truini A. The CPM Effect: Functional Assessment of the Diffuse Noxious Inhibitory Control in Humans. *J Clin Neurophysiol.* 2019;36:430-6.
49. Monteiro ER, Cavanaugh MT, Frost DM, Novaes J da S. Is self-massage an effective joint range-of-motion strategy? A pilot study. *J Bodyw Mov.* 2017;21:223-6.
50. Braz J, Solorzano C, Wang X, Basbaum AI. Transmitting pain and itch messages: A contemporary view of the spinal cord circuits that generate Gate Control. *Neuron.* 2014;82:522-36.
51. Ajimsha MS, Al-Mudahka NR, Al-Madzhar JA. Effectiveness of myofascial release: systematic review of randomized controlled trials. *J Bodyw Mov Ther.* 2015;19:102-12.
52. Bernabei M, van Dieën JH, Maas H. Altered mechanical interaction between rat plantar flexors due to changes in intermuscular connectivity. *Scand J Med Sci Sports.* 2017;27:177-87.

Original article

Autonomic responses and internal load analysis through acute assessment of heart rate variability after a high-intensity functional training session

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Summary

Backgroud: Heart rate variability (HRV) measurement is an important tool that may help indicate possible physiological changes, and HRV monitorization could be a great strategy for clinical analysis (autonomic control) and performance (internal load).
Objective: The aim of the present study was to evaluate autonomic responses and internal load through HRV during a high-intensity functional training (HIFT) session.
Material and method: Thirty-three individuals (22 men and 11 women) participated in the study (Age: Mean = 34.9 ± 7.2 years; Weight: Mean = 72.3 ± 13.7 kg; Height: Mean = 1.72 ± 0.1 m; BMI: Mean = 24.4 ± 3.0 kg/m²). All participants engaged in a 60-to-90-minute HIFT session. HRV analysis was performed during the specific warm-up period (targeted warm-up or skill training that followed the general mobility and light cardiovascular warm-up), during exercise (approximately 50 minutes), and in the recovery phase (10 minutes post-training). A Polar H10 heart rate monitor chest strap (Kempele, Finland®) was used to collect HRV and was connected to the Elite HRV mobile application. The data were further transferred to Kubios HRV Standart software, version 3.3.1, in order to process the acquired data.
Results: For isolated analyzes (pre- and post-), differences were found for SDNN ($P<0.001$), RMSSD ($P<0.001$) and HF ($P=0.041$), yet not for LF / HF ($P=0.483$). In the analysis of HRV kinetics, significant results were found between moments for RR, SDNN, RMSSD, LF and HF ($P<0.05$). In the analysis of the internal load, the highest level of stress was identified in 40 ($P=0.010$) and 50 minutes of exercise ($P=0.001$), as well as in recovery ($P<0.001$), this assessment being carried out through HRV through the LnRMSSD index. A negative correlation was observed between maximum heart rate (HRmax) and LnRMSSD at 40 (r=-0.51) and 50 minutes of exercise (r=-0.58). In recovery, the correlation was positive, yet insignificant (r=0.032).
Conclusion: The present study observed that HIFT could alter HRV and thus cause changes in autonomic behavior. In addition, this type of modality can offer significant levels of training loads, thus affecting the physiological responses and consequently the individual's functional efficiency.

Key words:
Heart Rate Variability. Autonomic Response. Training Load. High-Intensity Functional Training. CrossFit.

Respuestas autonómicas y análisis de la carga interna mediante la evaluación aguda de la variabilidad de la frecuencia cardíaca tras una sesión de entrenamiento funcional de alta intensidad

Resumen

Introducción: La medición de la variabilidad de la frecuencia cardiaca (HRV) es una herramienta importante que puede ayudar a indicar posibles cambios fisiológicos. La monitorización de la HRV podría ser una gran estrategia para el análisis clínico (control autonómico) y el rendimiento (carga interna).
Objetivo: El objetivo del presente estudio fue evaluar las respuestas autonómicas y la carga interna a través de la VFC durante una sesión de entrenamiento funcional de alta intensidad (HIFT).
Material y método: Treinta y tres individuos (22 hombres y 11 mujeres) participaron en el estudio (Edad: Media = 34,9 ± 7,2 años; Peso: Media = 72,3 ± 13,7 kg; Altura: Media = 1,72 ± 0,1 m; IMC: Media = 24,4 ± 3,0 kg / m²). Todos los participantes participaron en una sesión HIFT de 60 a 90 minutos. El análisis de la VFC se realizó durante el periodo de calentamiento

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específico (calentamiento dirigido o entrenamiento de habilidades que seguía al calentamiento cardiovascular ligero y de movilidad general), durante el ejercicio (aproximadamente 50 minutos) y en la fase de recuperación (10 minutos después del entrenamiento). Se utilizó una banda de pecho con pulsómetro Polar H10 (Kempele, Finlandia®) para recoger la VFC y se conectó a la aplicación móvil Elite HRV. Los datos se transfirieron posteriormente al software Kubios HRV Standart, versión 3.3.1, para procesar los datos adquiridos.

Resultados: En los análisis aislados (pre y post), se encontraron diferencias para SDNN (p <0,001), RMSSD (p <0,001) y HF (p = 0,041), pero no para LF / HF (p = 0,483). En el análisis de la cinética de la VFC, se encontraron resultados significativos entre momentos para RR, SDNN, RMSSD, LF y HF (p <0,05). En el análisis de la carga interna, el mayor nivel de estrés se identificó en 40 (p = 0,010) y 50 minutos de ejercicio (p = 0,001), así como en la recuperación (p <0,001), realizándose esta valoración mediante la VFC a través del índice LnRMSSD. Se observó una correlación negativa entre la frecuencia cardiaca máxima (FCmáx) y el LnRMSSD a los 40 (r = -0,51) y 50 minutos de ejercicio (r = -0,58). En la recuperación, la correlación fue positiva, aunque insignificante (r = 0,032).

Conclusiones: En el presente estudio se observó que el HIFT podía alterar la VFC y, por tanto, provocar cambios en el comportamiento autonómico. Además, este tipo de modalidad puede ofrecer niveles significativos de cargas de entrenamiento, afectando así a las respuestas fisiológicas y, en consecuencia, a la eficiencia funcional del individuo.

Palabras clave:
Variabilidad de la frecuencia cardíaca. Respuesta autonómica. Carga de entrenamiento. Entrenamiento funcional de alta intensidad. CrossFit.

Introduction

Heart rate variability (HRV) is an important parameter for analyzing autonomic behavior and might be an excellent tool for physiological assessment[1]. As known, HRV is a time (measured in milliseconds) between two adjacent heartbeats (rate a rate — RR)[2]. Higher values determine better cardiac conditions and, consequently, indicate a greater balance of the autonomic nervous system[3]. For this matter, it is possible to have a prognosis of an abnormality related to the cardiovascular system through HRV, as well as for other systems, and also to assess the physiological and functional condition of a certain individual[4].

Traditionally, HRV is widely used to assess autonomic responses (sympathetic and parasympathetic interaction) and thus identify certain unwanted reactions, preserving health and functional integrity[5]. Additionally, HRV can change because of intrinsic reasons such as aging[6] and according to sex characteristics[7,8], as well as extrinsic factors such as supplementation[9] and type of training[10]. However, HRV seems to be an easily accessible tool for clinical assessment[11] and for determining physical condition[12].

In the identification of better autonomic responses, different HRV indices (commonly time and frequency domain) can detect physiological changes that could serve for important adjustments favoring cardiovascular health[4]. On the other hand, HRV could also be useful for analyses of physical performance[13] and, consequently, help control stress and fatigue[14], preventing individuals from getting injured[15] and providing a greater assessment of an individual's adaptation to a given training sequence[16].

In a sports environment, HRV has been used for analyzing not only the autonomic balance (cardiovascular health) but also internal load (performance), providing greater efficiency of an individual, regardless of their level[15]. In terms of internal load assessment, HRV has already been used as an important strategy for the assessment of possible stresses and high levels of fatigue resulting from overtraining[13,14,17]. In order to assess clinical condition and performance, studies have used HRV to identify changes that can generate negative responses in exercisers/athletes of different modalities[18].

One of the modalities that have been gaining popularity is high intensity functional training (HIFT), supported by the well-known CrossFit® brand. Due to the high physiological demand of this activity[19], studies with physiological behavioral analyzes are extremely useful for better understanding of the repercussions caused by the training load in exercisers or athletes. Studies on HRV in HIFT are still scarce[20], therefore, it is extremely viable to further analyze this variable in exercisers or athletes of this modality. In this activity, the control of the training load (mainly internal) is indispensable since it is a type of training with high physiological demand, thus avoiding possible disorders and even the risk of injuries. Therefore, the aim of the present study was to evaluate the autonomic and internal load responses through HRV in a HIFT session.

Material and method

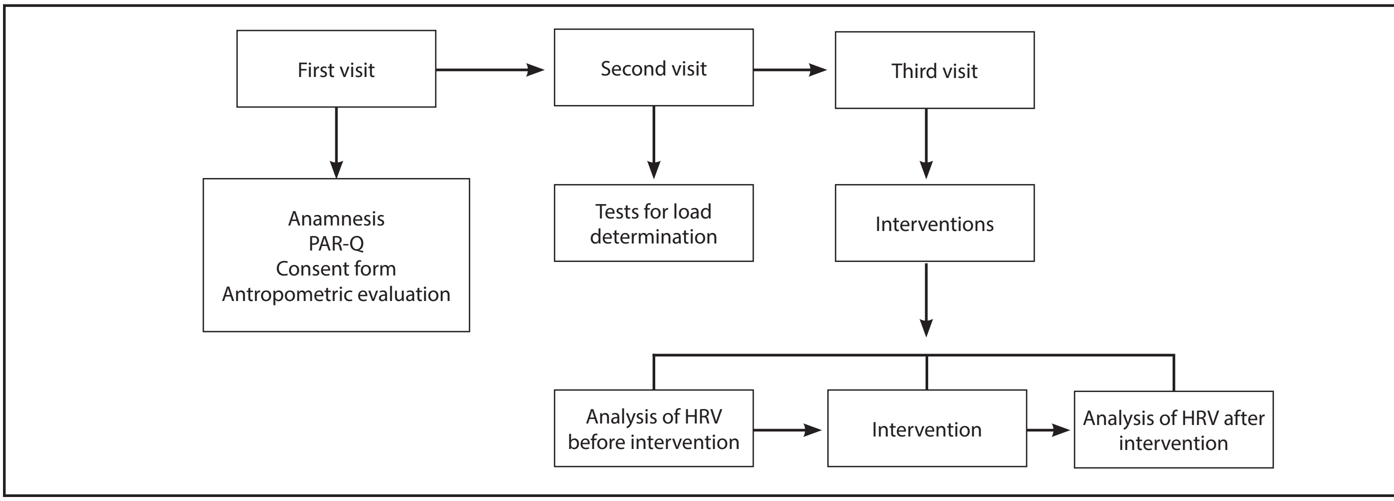
Participants

33 individuals participated in the study (22 men and 11 women) (Table 1), all of them were HIFT exercisers with regular practice of at least 3 months, with training frequency of at least 3 times per week. The exclusion criteria were medication use and / or ergogenic resources that could influence the expected results (i.e., pharmacological drugs for blood pressure control, beta-blockers, drugs related to cardiovascular control, performance enhancers, among others) and presenting musculoskeletal disorders that would compromise the interventions. In

Table 1. Anthropometric characteristics of the participants.

Variables	Participants (n=33) M±SD
Age (years)	34.9 ± 7.2
Weight (kg)	72.3 ± 13.7
Height (m)	1.72 ± 0.1
BMI (kg/m^2)	24.4 ± 3.0

Figure 1. Experimental design flowchart.



addition, all participants received a recommendation not to eat foods that could interfere with cardiovascular responses (excessive consumption of salt, caffeine, alcohol, high-calorie foods, among others).

Experimental design

Further on (Figure 1), the entire organization of the phases of the experimental activities of the present study follows. The research was carried out in a cross-sectional experimental manner.

Procedures

Before the start of the training session, the participants filled out the sociodemographic questionnaires. The Polar H10 was paired with the Elite HRV application. In the application, at the beginning of the warm-up, the activity recording started.

After performing joint mobility exercises and the warm-up with light to moderate intensity, the participant went on to the fundamental part of the training (technical/strength part) and then to the workout of the day (WOD). The 10 minutes after the end of the training were complete rest or light stretching. After the end of the measurement, the txt file was transferred to the computer with the participant's code. On average, the session lasted for 1 hour and 10 minutes.

Training protocol

The training session lasted for up to 70 minutes and consisted of the physiological adaptation phase (mobility exercises and light warm-up), the fundamental part, the WOD, and the recovery. The training session used was the one prescribed by the head coach of the CrossFit box for the very day, being in accordance with the CrossFit® training methodology.

Since the research protocol was based on time, the exercises were performed by running time (minutes) rather than distance or repetitions: Thus, the WOD was performed as follows: Initial phase: 10 min warm-up, using mobility exercises and dynamic stretching. Main phase: 5 rounds of 10 min, composed of: 5 min of out door running in flat space (in high effort zone), 1 min squats, 1 min burpee, 1 min mountain climbers, 1 min push ups and 1 min passive recovery. Final phase: 10 min. stretching and relaxation exercises. All participants were asked to perform the exercises in the greatest possible bearable effort zone. And throughout the series, everyone was recommended to perform the movements with the highest level of quality.

Heart rate variability analyzes

HRV analysis was performed during the warm-up period (10 minutes - pre-time). For the moments between exercises (50 minutes) and recovery (10 minutes - post time). During the complete session (70 minutes), HRV was monitored continuously. A Polar H10 heart rate monitor chest strap was used to collect HRV. For analyzing HRV data, the data were transferred to the computer for their posterior uploading to Kubios HRV Standart Software, version 3.3.1.

For the analysis of data acquired from HRV, for all moments, windows of 5 minutes (300s inter-beats interval) were used, the moments with the highest stable level of HRV were used[1]. All analyzes were performed manually by a researcher with experience for a certain type of analysis. For greater reliability of the collected data, a percentage of up to 2% of artifacts (possible interferences in the collected data) as considered at all times evaluated.

The calculation of the mean of the time domain indices (RR, RMSSD, SDNN and PNN50) and the frequency (LF, HF and LF / HF) was used[4]. In the time domain normal RR (time between two adjacent heartbeats) and, based on statistical or geometric methods (mean, standard deviation and indexes derived from the histogram of RR intervals), the fluctuation indexes of the duration of cardiac cycles were calculated, with RMSSD (square root of the square mean of successive differences between adjacent normal RR intervals, in a time interval, expressed in ms), SDNN (standard deviation of all normal RR) intervals recorded in one time interval, expressed in ms) and the PNN50% (represents the percentage of adjacent RR intervals with a difference in duration greater than 50 ms). The RMSSD and PNN50% represent parasympathetic activity, while the SDNN represents sympathetic and parasympathetic activity (global index), yet does not allow to distinguish when changes in HRV are due to increased sympathetic tone or withdrawal of vagal tone, thus indicating an interaction between sympathetic and parasympathetic[11].

For the analysis of HRV in the frequency domain, low frequency components (Low Frequency — LF) were used, which correspond to the joint action of the parasympathetic and sympathetic systems in the heart, with a predominance of the sympathetic and high-frequency component (High Frequency — HF) which corresponds to respiratory modulation and represents the activation of the vagus nerve. Finally, the LF/HF ratio was used, which, despite several limitations in its use in the autonomic balance[21], could indicate the sympathetic-vagal balance[2]. In this sense, all the data collected were calculated and presented in accordance with different standards so that there are broad interpretations in relation to HRV. For data presentation, a pre- (rest) and post- (recovery) comparison using the SDNN (global index), RMSSD (parasympathetic index), HF (parasympathetic index), and LF/HF (a possible indicator of sympathovagal balance) was performed. The objective was to understand the influence of the type of intervention on parasympathetic activation or reactivation of these individuals. Additionally, an analysis of the HRV kinetics (rest, 10, 20, 30, 40, 50 minutes of exercise and recovery) was performed before the entire experimental session (rest, exercise and recovery) using all indexes and, thus, assessing the complete autonomic behavior in relation to the type of effort.

Load training analyzes

The internal load analysis was performed using the HRV RMSSD index[22]. For this assessment, the RMSSD values were transformed into logarithms (LnRMSSD)[17] and the same HRV collection moments were used for general calculations of this variable. In the presentation of the data, kinetics (rest, 10, 20, 30, 40, 50 minutes of exercise and active recovery) of the LnRMSSD index (rest, exercise, and active recovery) was elaborated in order to identify the possible point of greater intensity of the internal load for this type of training, which was determined when there were major reductions in the values of the lnRMSSD index.

Statistical analyzes

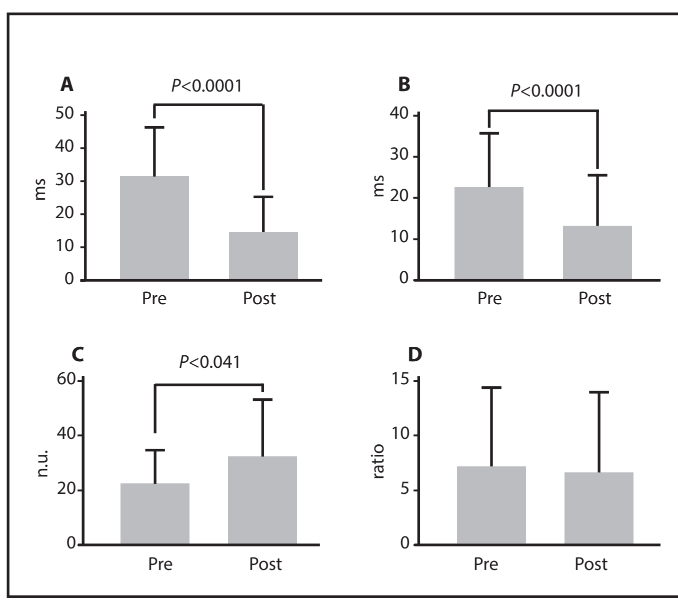
In the descriptive analysis, the means and standard deviation of the variables were calculated. The normality of the data was not rejected by the Shapiro-Wilk test. For isolated analyzes (pre-and post-) of HRV (SDNN, RMSSD, HF, and LF / HF) the T-Test was used. For analysis of the kinetics (all index) of each index (moment) the ANOVA (one-way) was applied repeatedly. Tukey's test was used to perform multiple comparisons, when necessary. Finally, the Pearson test (parametric data) was used for correlation analysis (HR with lnRMSSD). All statistical analyzes were performed using the GraphPrism software version 8.0.1, with a significance level of 5% ($P<0.05$).

Results

For isolated analyzes, the SDNN (Figure 2 A), RMSSD (Figure 2 B), HF (Figure 2 C) and LF/HF (Figure 2 D) indices were used. A significant difference was observed for the pre (warm up) and post (recovery) condition in the SDNN index ($P<0.001$), meaning that, when there were reductions in the values, there was a significant vagal withdrawal. In the RMSSD, there was a reduction in this index after effort ($P<0.001$), indicating a high sympathetic activation resulting from exercise. However, in the evaluation of the HF index, an increase of this index was observed at the time of recovery ($P=0.041$), which means that even under high stimuli, in the post-effort moment, there was a significant capacity for parasympathetic reactivation, which is important in post-activity cardiovascular recovery. Finally, no significant difference was observed in the pre-and post- LF/HF evaluation ($P=0.483$).

An assessment of HRV kinetics (Table 2) was carried out throughout the experimental session (rest, exercise, and recovery) using time domain (RR, SDNN, RMSSD, and PNN50%) and frequency (LF, HF, and LF/HF) (Table 2). The objective of this evaluation was to propose an analysis of the sympathetic-vagal behavior at different times, such as warm-up, exercise, and recovery. In the RR index, significant reductions were observed, in relation to the pre-moment, in 30 ($P=0.010$), 40 ($P=0.000$) and 50 minutes of exercise ($P<0.001$), as well as in recovery ($P<0.001$). For SDNN, there was a significant reduction in this index compared to pre-, in 40 and 50 minutes of exercise ($P=0.002$ and $P<0.001$, respectively) and in the post-effort moment ($P<0.001$). In comparison with 10 minutes of exercise, there was a difference in 40 ($P=0.018$) and 50 minutes ($P<0.001$), as well as in the post time ($P<0.001$). When compared to 20 minutes of exercise, a difference was also observed in relation to 40 ($P=0.044$) and 50 minutes ($P<0.001$), as well as in recovery ($P=0.000$). Still, for SDNN, there was a difference between the 30 and 50 minutes of exercise ($P=0.018$). These findings (RR and SDNN) demonstrated that the inter-

Figure 2. Pre- and post-effort, for SDNN (A), RMSSD (B), HF (C), and LF/HF (D).



vention promoted a high sympathetic activation, thus significantly inhibiting the parasympathetic system, especially in the final phase of the session.

Summarizing the results above, in assessing the behavior of the RMSSD index, the wide vagal withdrawal was notorious. In comparison with the pre-moment, there was a reduction in moments 40 (P=0.001) and 50 minutes of exercise (P<0.001), as well as after the effort (P=0.00). Regarding 10 minutes of exercise, for the same moments, significant reductions were observed (P=0.010, P=0.000 and P=0.001, respectively). In the same way, when compared to 20 minutes of activity, there was a reduction in 40 (P=0.036) and 50 minutes (P=0.000) of exercise, as well as in recovery (P=0.007). In addition, there was also a significant difference between the 30 and 50 minutes of exercise (P=0.023). Analytically, these findings were similar to the RR and SDNN indices for the same time points., which affirms a high discrepancy in the sympathetic vagal performances due to the high-intensity nature of the exercise. However, for PNN50%, no difference was found (P>0.05), and this may indicate a positive ability of the parasympathetic to act during the effort, as there was no significant reduction in the values related to this index.

Nevertheless, it could be suggested that the sympathetic-vagal interaction of these individuals was positive. In the frequency domain, for LF (high sympathetic activation) there was a difference (reduction of values) between 10 and 50 minutes of exercise (P=0.045). This difference was also observed when compared to 20 minutes of exercise for 50 minutes (P=0.003) and recovery (P=0.012). Interestingly, in the HF (parasympathetic), the differences (increase in values) were for the same LF moments, 10 and 50 minutes (P=0.045) and 20 minutes compared to 50 minutes of exercise (P=0.003) and after effort (P=0.017). These findings may suggest that, at the end of the particular session (even with fatigued subjects), there was excellent parasympathetic control over sympathetic activity. However, in the evaluation of a possible sympathetic-vagal balance (LF/HF), no significant difference was observed (P=0.262). It could imply that, even with its limitations, the LF/HF showed results that could sustain a positive behavior between sympathetic and parasympathetic, as there was no significant increase in this value compared to rest.

Additionally, the internal load of the individuals during a HIFT session was evaluated. For this evaluation, the RMSSD index transformed into logarithm values (LnRMSSD) was used. Thus, it was possible to identify at which moments of the training session there was a more significant internal load (Figure 2). The findings of the present study demonstrated that the peak internal load was in the final phase of training, including the recovery phase. This demonstrated a high fatigue index after exercise. With regard to the pre-moment, significant differences were observed at moments 40 (P=0.010) and 50 minutes of exercise (P=0.001), as well as in the recovery phase (P<0.001).

To complement the internal load assessment, an analysis of the maximum heart rate kinetics (HR_{max}) and LnRMSSD (Figure 3) was performed. The use of HR_{max} can be indicative of stress and, consequently, serve to monitor the training load[25]. Therefore, the dynamics of HR_{max} was similar to that of LnRMSSD, but in the opposite direction. As HR_{max} increased, LnRMSSD decreased, thus indicating sympathetic behavior. Also, where there was a greater increase in HR_{max}, there was also a

Figure 3. Internal load analyses for all moments.

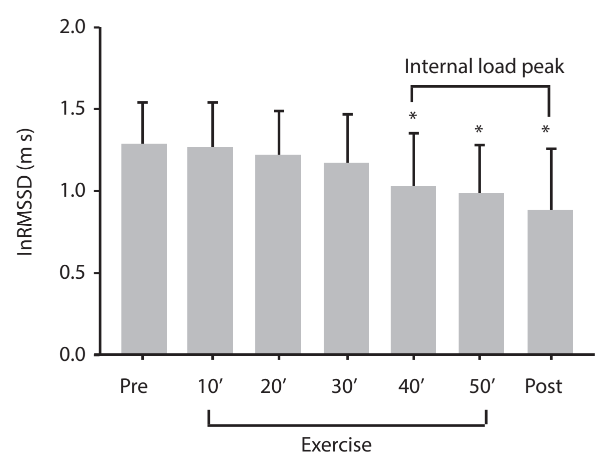
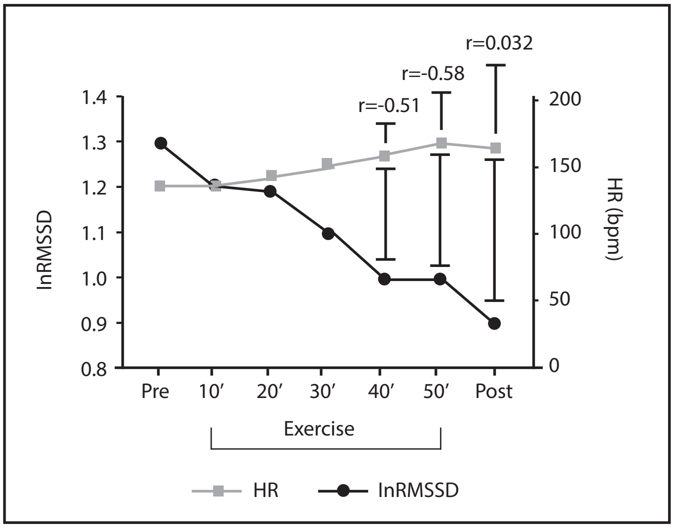


Table 2. Behavior HRV, for all analyses moments.

Index				Moment			
Time Domain	**Pre**	**10’**	**20’**	**30’**	**40’**	**50’**	**Post**
RR (ms)	562.9 ± 104.2	556.3 ± 117.6	531.9 ± 103.3	488.8 ± 126.3[a,b]	463.3 ± 92.5[a,b,c]	430.1 ± 99.7[a,b,c]	437.9 ± 86.6[a,b,c]
SDNN (ms)	30.96 ± 14.9	29.20 ± 14.5	28.27 ± 12.5	26.04 ± 14.3	18.88 ± 12.07[a,b,c]	12.71 ± 8.2[a,b,c,d]	14.05 ± 10.5[a,b,c]
RMSSD (ms)	26.75 ± 15.5	25.22 ± 15.9	24.13 ± 15.0	21.28 ± 14.3	15.40 ± 11.1[a,b,c]	12.12 ± 8.1[a,b,c,d]	13.95 ± 12.2[a,b,c]
PNN50 (%)	4.35 ± 4.8	3.93 ± 6.1	3.55 ± 4.8	2.76 ± 3.4	1.59 ± 2.3	1.45 ± 2.1	1.66 ± 3.8
Frequency Domain	**Pre**	**10’**	**20’**	**30’**	**40’**	**50’**	**Post**
LF (n.u.)	7.63 ± 11.8	78.98 ± 12.0	82.22 ± 11.5	74.85 ± 17.0	75.45 ± 18.0	66.43 ± 23.3[b,c]	67.90 ± 20.6[c]
HF (n.u.)	22.46 ± 11.7	20.94 ± 12.0	17.73 ± 11.5	24.73 ± 16.8	24.26 ± 17.62	33.36 ± 23.2[b,c]	31.47 ± 20.4[c]
LF/HF (ratio)	4.74 ± 2.9	5.10 ± 3.0	6.86 ± 5.0	4.79 ± 3.5	5.27 ± 3.6	4.72 ± 5.0	4.49 ± 4.5

[a]Significant difference compared to the pre- moment (P<0.05). [b]Significant difference compared to 10 minutes (P<0.05). [c]Significant difference compared to the time 20 minutes (P<0.05). [d]Significant difference compared to the 30 minute moment (P<0.05).

Figure 4. Between correlation HR and lnRMSSD in the session.



greater reduction in HRV (LnRMSSD). However, when the correlation was applied, the results did not show a high correlation between the variables. For 40 minutes of exercise, there was an average negative correlation (r=-0.51) and in the same way it was for 50 minutes of exercise (r=-0.58). This indicates that when variable A increases (HR), B decreases (LnRMSSD). These correlations are acceptable and despite being average, we can suggest that, in these individuals, HRmax can be an internal load parameter. However, in the recovery phase, the correlation was positive (variable A increases, B also increases) but insignificant (r=0.032) (Figure 4).

Discussion

The aim of the present study was to evaluate the autonomic responses and the internal load through HRV during a HIFT session. For the analysis of autonomic behavior, HRV indices in the time domain (RR, SDNN, RMSSD, and PNN50%) and frequency (LF, HF and LF/HF) were used[1]. For the evaluation of the internal load, the lnRMSSD was used, and this parameter is suitable for analyzes of the training load[17].

Regarding HRV pre and post intervention, the findings of the present study demonstrate important changes in the time domain via the SDNN and RMSSD indices (*P*<0.001), where a significant vagal (parasympathetic) withdrawal was demonstrated due to the high sympathetic activity. In the time domain, significant differences were observed in the HF index (*P*=0.041), where, even with a high training load, after the effort there was a significant parasympathetic reactivation, with this behavior being important for cardiovascular recovery. However, for LF/HF, no significant differences were observed (*P*=0.483), possibly generated by high sympathetic activity. This index, even though there are limitations and controversies in its interpretation[21], could indicate a possible balance between sympathetic and parasympathetic activities, thus determining better autonomic behavior[23].

Through the analysis of HRV kinetics in the effort, it is possible to identify potential cardiovascular overloads and, in this way promote important adjustments to avoid health damage and/or poor performance. In the present study, a HIFT session was able to generate significant (negative) changes (*P*<0.05) in HRV identified through the indices (time domain), RR (starting at 30 minutes), SDNN (starting at 40 minutes), RMSSD (starting at 40 minutes). Interestingly, it seems that during the HIFT activity, there may be a physiological compensation, through which balance is promoted, even with high intensity and a higher level of fatigue. The frequency domain indices (LF and HF), showed positive results (*P*<0.05) at the end of the session (50 minutes and recovery phase), showing less sympathetic activity (LF) and greater parasympathetic activity (HF).

Additionally, in the evaluation of the internal load, the present study showed a greater peak of stress at the end of the session (starting at 40 minutes), lasting until recovery. Also, HRmax also showed higher values correlating with HRV for the same moments of higher levels of the internal load identified through the LnRMSSD index, and can thus be used as an internal load control parameter[15]. HRV is considered an important tool for the analysis of autonomic behavior[3] and internal load[14]. However, studies that evaluated HRV in HIFT are still few. Tibana *et al.*[20] identified positive results (preparation phase) and negative results (competition phase) of LnRMSSD in a 38-week follow-up, stating that the greater the training load, the greater the repercussion the internal load. Despite being acute, our findings may elucidate this premise, where greater changes in HRV were identified at the moments of greater loads (longer activity time).

HIFT is a modality that is widely used for improving physical fitness and conditioning, and is characterized by a high level of motivation[24]. HIFT is a type of activity with high physiological demand, which can lead to high levels of hormonal, metabolic and inflammatory changes, thus being able to generate both positive and negative responses in physiological adaptations[25]. In order to increase the information on this training method, the present study evaluated HRV responses to health and performance. Our findings replicate those of Kliszczewicz *et al.*[26], who also observed significant changes in HRV that can affect autonomic control (cardiovascular health) and also the training load, enabling greater reduction in performance.

With regard to mechanisms, HIFT is an activity that generates high physiological (acute and chronic) changes[27] interfering in biochemical[19], metabolic[25] and cardiovascular components[26]. These changes are affected by high intensity imposed by the exercises performed in HIFT and, consequently, generate changes in HRV that, in several acute episodes (training session), can affect a sum of stress causing negative changes in a chronic way[20]. Like these metabolic or biochemical factors, changes in cortisol, testosterone, norepinephrine may have a negative impact on cardiac behavior and, consequently, alter HRV. These changes affect the central nervous system, which in turn influences all organic physiology and, as a result, there is a reduction in health and performance[28]. However, through HRV it is possible to observe these changes and thus control possible undesirable events[14,29]. In HIFT, the use of HRV can be a great strategy to monitor the individual's training load in response to the training. Also, it can be applied outside the exercise (f.ex., during rest) for the assessment of the individual's recovery state, helping control the following training sessions even better.

Limitations

The present study has some limitations, and these may have affected the observed results. In order to verify HRV responses specifically for exercise, measurement in resting-state was not applied, only in exercise (warm-up, main training phase, and active recovery). The exercise session time (70 minutes) was somewhat shorter than that normally used in real practice (around 90 minutes on average), which may underestimate or overestimate the HRV reactions in autonomic behavior and internal load. Finally, the experiment was held during only one session, not letting to extrapolate the findings in order to allow for chronic interpretations. Nevertheless, there might be a possible explanation of what could have happened if there were no assertive control of the intensity and a variation of stimuli. Therefore, this study contains important information that could be used by coaches in their HIFT planning and prescription.

Practical applications

This study contains important information that can be used by coaches when planning and prescribing HIFT. Through the findings of this research, it is possible to have a visualization about what can happen in autonomic behavior when performing exercises related to HIFT and so, being able to control the training load more to avoid loss of performance and promote the preservation of health.

Conclusion

The present study observed that high-intensity functional training can alter HRV and thus cause changes in autonomic behavior. In addition, this type of modality can provide significant levels of training loads, affecting physiological responses and, consequently, the individuals' functional efficiency. Training prescriptions for this type of activity should be composed in the way that there are no imbalances capable of generating damage to health and performance.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Task Force of the European Society of Cardiology. Heart rate variability. standards of measurement, physiological interpretation, and clinical use. *Circulation.* 1996;93:1043–65.
2. Laborde S, Mosley E, Thayer JF. Heart rate variability and cardiac vagal tone in psychophysiological research – Recommendations for experiment planning, data analysis, and data reporting. 2017;8:1-18.
3. Young HA and Benton D. Heart-rate variability: a biomarker to study the influence of nutrition on physiological and psychological health? *Behav Phamacology*. 2018;29:140-51.
4. Geus EJC, Gianaros PJ, Brindle RC, Jennings JR, and Berntson GG. Should heart rate variability be "corrected" for heart rate? Biological, quantitative, and interpretive considerations. *Psychophysiology.* 2019;1-26.
5. Salahuddin N, Shafquat A, Marashly Q, Zaza KJ, Sharshir M, Khurshid M, *et al*. Increases in heart rate variability signal improved outcomes in rapid response team consultations: A cohort study. *Cariol Reserarch Pract.* 2018;1-8.
6. Botsva N, Naishtetik I, Khimion L, and Chernetchenko D. Predictors of aging based on the analysis of heart rate variability. *Pacing Clin Electrophysiol.* 2017;1-10.
7. Carter JB, Banister EW, and Blaber AP. The effect of age and gender on heart rate variability after endurance training. *Med Sci Sport. Exerc.* 2033;35:1333-40.
8. Hulegar AA, Nisarga P, Kisan R, Meghana A, Chandran S, Raju T, *et al*. Influence of age and gender on autonomic regulation of heart. *J Clin Monit Comput.* 2013;27:259-64.
9. Sant'Ana LO, Lima MJ, Simoni R, Scudese E, Oliveira CQ, Scartoni FR, *et al.* Heart rate variability in the frequency domain after strength training with citrus aurantium supplementation. *Int Phys Med J.* 2020;5:110-3.
10. Vanzella LM, Dagostinho DBB, Figueiredo MPF, Castrillón CIM, Junior JN, Vanderlei LCM. Periodized aerobic interval training modifies geometric indices of heart rate variability in metabolic syndrome. *Medicina* (B. Aires). 2019;55:1-11.
11. Vanderlei LCM, Pastre CM, Hoshi A, Carvalho TD, Godoy MF. Noções básicas de variabilidade da frequência cardíaca e sua aplicabilidade clínica. 2009;24:205-17.
12. Bara-filho MG, Freitas DS, Moreira D, Matta MO, Lima JRP, Nakamura FY. Heart rate variability and soccer training: a case study. *Motriz Rio Claro.* 2013;19:171-7.
13. Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco MR. Ultra-short-term heart rate variability is sensitive to training effects in team sports players. *J Sport Sci Med*. 2015;14:602-5.
14. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sport Med*. 2013;43:773-81.
15. Schneider C, Hanakam F, Wiewelhove T, Döweling A, Kellmann M, Meyer T, *et al*. Heart rate monitoring in team sports — A conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Front Physiol.* 2019;9:1-19.
16. Vesterinen V, Hakkinen K, Hynynen E, Al E. Heart rate variability in prediction of individual adaptation to endurance training in recreational endurance runners. *Scand J Med Sci Sport.* 2013;23:171-80.
17. Schmitt L, Regnard J, Millet GP. Monitoring fatigue status with HRV measures in elite athletes: An avenue beyond RMSSD? *Front Physiol.* 2015;6:2013-5.
18. Mclaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR and Weston M. The relationships between internal and external measures of training load and intensity in team sports: A Meta-Analysis. *Sport Med.* 2017.
19. Tibana RA, Almeida LM, Nuno MFS, Nascimento DC, Sousa Neto IV, Almeida JA, *et al.* Two consecutive days of crossfit training affects pro and anti-inflammatory cytokines and osteoprotegerin without impairments in muscle power. *Front Physiol.* 2016;7:1-8.
20. Tibana RA, Nuno MFS, Prestes J, Feito Y, Ernesto C, Voltarelli FA. Monitoring training load, well-being, heart rate variability and competitive performance of a functional-fitness female athlete: A case study. *Sports.* 2019;7:1-11.
21. Billman GE. The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. 2013;4:1-5.
22. Plews DJ, Scott B, Altini M, Wood M., Kilding AE, Laursen PB. Comparison of heart-rate-variability recording with smartphone photoplethysmography, Polar H7 chest strap, and electrocardiography. *Int J Sport Physiol Perform*. 2017;12:1324-8.
23. Sant' Ana LO, Machado S, Ribeiro AAS, Reis NR, Campos YAC, Silva JGV, *et al*. Effects of cardiovascular interval training in healthy elderly subjects: A systematic review. *Front Physiol.* 2020;11:1-10.
24. Feito Y, Heinrich KM, Butcher S, Mangine GT. High intensity functional training (HIFT): definition and research implications for improved fitness. *Appl Physiol Nutr Metab.* 2019;44:727-35.
25. Jacob N, Novaes JS, Behm DG, Vieira JG, Dias MR, Vianna JM. Characterization of hormonal, metabolic, and inflammatory responses in crossfit training: A systematic rewiew. *Front. Physiol.* 2020;28:1001.
26. Kliszczewicz B, Williamson C, Bechke E, Mckenzie MJ, Hoffstetter W. Autonomic responses to a short and long bout of high intensity functional training. *J Sport Sci.* 2018;36:1872-9.
27. Kliszczewicz B, Markert CD, Bechke E, Williamson C, Clemons KN, Snarr RL, *et al.* Acute effect of popular high intensity functional training exercise on physiological markers of Growth. *J Strength Cond Res*. 2018;35:1677-84.
28. Kemp AH. and Quintana DS. The relationship between mental and physical health: Insights from the study of heart rate variability. *Int J Psychophysiol.* 2013;89:288-96.
29. Meeusen R, Duclos M, Forster C, Fry A, Glesson M, Nieman D, *et al.* European journal of sport science prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Eur J Sport Sci.* 2013;13:1-2.

Original article

Greater trochanteric pain syndrome (GTPS): updated multifactorial approach

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Summary

Introduction: Greater Trochanter Pain Syndrome (GTPS) is an ill-defined clinical pathology. Advances in imaging tests coupled with the interest in sports medicine could lead to a better understanding of predisposing factors and in choosing the most effective treatment.
Objective: Given its etiological variability, this study proposes an updated review of the main etiological factors linked to the development of this multifactorial pathology that occurs with pain in the lateral aspect of the thigh and hip.
Material and method: We conduct an unrestricted electronic search by language and date to the end of September 2022 for studies related to etiological factors in the SDTM. We searched Cochrane Library and databases EMBASE, MEDLINE and PUBMED. We analyze 9 original articles, 1 multicenter study and 1 observational study, 6 reviews (analyzing a total of 648 articles), 3 RCTs and 4 case-control studies.
Results: Of the etiological factors found, 47.8% of articles indicate that the most important is the morphological factor, followed by biomechanical factors in 30.4% and muscular factors in 21.8%.
Conclusion: The need to recognize the possible etiological factors that allow designing an effective individualized treatment according to the etiological factor prevalent in each patient is evident.

Key words:
Greater trochanteric pain syndrome (GTPS). Etiology. Treatment.

Síndrome doloroso del trocánter mayor (SDTM): enfoque multifactorial actualizado

Resumen

Introducción: El Síndrome Doloroso del Trocante Mayor (SDTM) es una patología clínica mal definida. Los avances en pruebas de imagen junto al interés de la medicina deportiva podrían conducir a una mejor comprensión de los factores predisponentes y en la elección del tratamiento más efectivo.
Objetivo: Dada su variabilidad etiológica, este estudio plantea una revisión actualizada de los principales factores etiológicos vinculados al desarrollo de esta patología multifactorial que cursa con dolor en la cara lateral de muslo y cadera.
Material y método: Se realiza búsqueda electrónica sin restricciones por idioma y fecha hasta finales de septiembre de 2022 para estudios relacionados con factores etiológicos en el SDTM. Se realiza búsqueda en Cochrane Library y bases de datos EMBASE, MEDLINE y PUBMED. Se analizan 9 articulo originales, 1 estudio multicéntrico y 1 estudio observacional, 6 revisiones bibliográficas (que analizan un total de 648 artículos), 3 ECA y 4 estudios de caso-control.
Resultados: De los factores etiológicos encontrados, el 47,8% de artículos señalan que el más importante es el factor morfológico, seguido por los factores biomecánicos en el 30,4% y musculares en el 21,8%.
Conclusión: Se evidencia la necesidad de reconocer los posibles factores etiológicos que permitan diseñar un tratamiento eficaz individualizado según factor etiológico prevalente en cada paciente.

Palabras clave:
Síndrome doloroso del trocánter mayor (SDTM). Etiología. Tratamientos.

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Introduction

Greater trochanteric pain syndrome (GTPS) is a multifactorial pathology which is a painful condition on the outer side of the hip and thigh[1,2], with an annual incidence of 1.8 percent[3], and a prevalence of 23.5% among women and 8% among men aged between 50 and 75 years old[2].

This is a complex syndrome, and its symptoms are largely superimposed on other types of pathologies. Until the early 2000s, it was known as greater trochanteric bursitis, although later with the use of imaging studies, it was shown that only 20 percent is due to bursitis, and the remaining 80 percent was due to an alteration in the gluteus tendons[4] (enthesopathy, tendinitis or tears) or without significant anatomic alteration. Stegemamm described it as "the great simulator"[5].

Although GTPS is an eminently clinical and poorly defined pathology, progress in imaging tests (ultrasound and resonance scans) and interest from sports medicine have led to a better understanding of symptoms and care for these patients[6].

Material and method

An electronic search was made with no language or date restrictions to the end of September 2022 for studies related to GTPS aetiological factors.

A search was made in the Cochrane Library and databases such as EMBASE, MEDLINE and PUBMED. The search terms used were greater trochanteric pain syndrome (GTPS), outer side of the hip, gluteus tendinopathy, aetiology, biomechanics, morphology and muscle-tendon strain.

Duplicated articles were eliminated from the searches, leaving a total of 23 articles with an impact factor range between 0.84 and 6.6 according to Journal Citation Indicator (JCI) (Figure 1).

Inclusion criteria

Aged over 16 years old, diagnostic criteria for GTPS, subjects might have co-morbidities with lumbar and/or hip pathology.

Exclusion criteria

Severe traumas, neurological or neoplastic diseases. Recently surgery on spine or hip.

Main aetiological factors involved in the greater trochanteric pain syndrome (GTPS)

There are three main aetiological factors of GTPS, listed below.

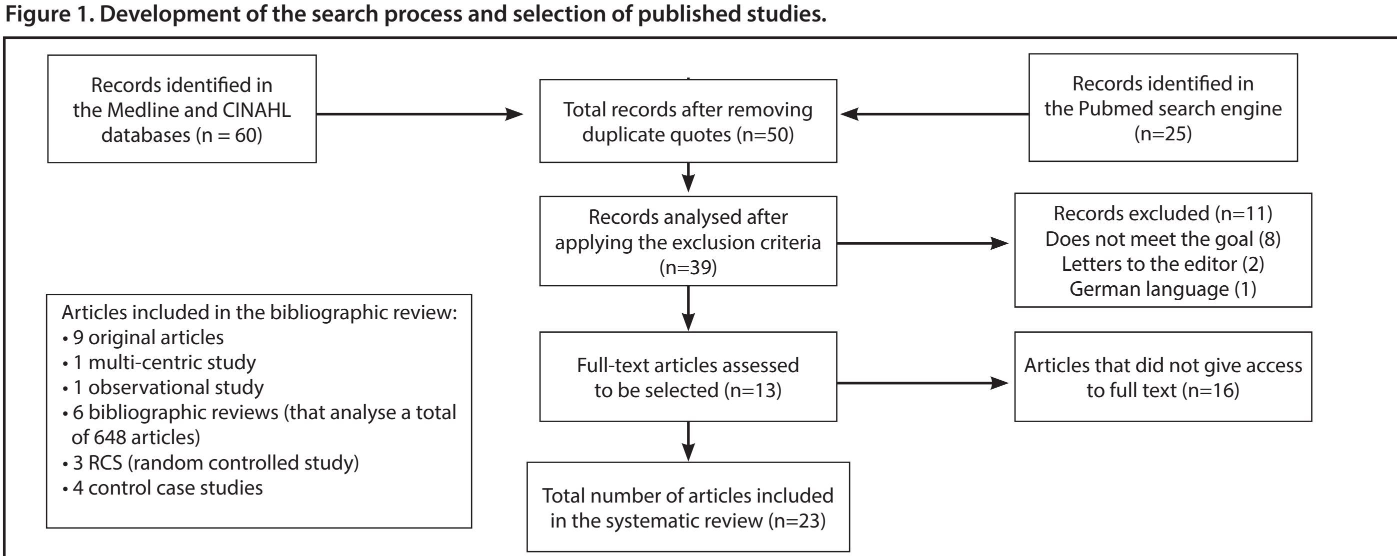
Associated muscular factors

One of the causes involved seems to be a tendinopathy of the gluteus medius and minimus tendons at the point where they are inserted in the greater femur trochanter[2]. At this level, the iliotibial band seems to be involved, as it passes over these tendons and compresses them significantly during the maximum hip adduction[7]. Some authors consider both gluteal tendons as part of the same muscle[8], as they both have the same function and innervation (Table 1).

The gluteus medius is injured by micro and/or macro traumas to the hip and pelvis[9], while the gluteus minimus is injured as the consequence of the loss of function of the gluteus medius. The cause of these injuries is unknown, although it is believed that they are the product of degenerative changes in the muscle-tendon unit and if not treated, this might lead to degenerative tendinopathy, chronic pain on the outer side of the hip and possibly, retraction of the tendon towards the trochanter zone[10].

Other factors involved in GTPS might be failed repair processes at tendon level (fibrosis), increased adiposity in the muscle, sedentary

Figure 1. Development of the search process and selection of published studies.



RCS: random controlled study.

Table 1. Anatomical reminder of the gluteal muscles and fascia tensor.

		Origin	Insertion	Function	Innervation
Gluteus	**Maximus**	Fascia that covers the gluteus medius, the outer surface of the ilium behind the posterior gluteal line, spine erector fascia, dorsal surface of the inner portion of the sacrum, side edge of the coccyx and outer surface of the sacrotuberous ligament.	Outer side of the fascia lata iliotibial band and the gluteal tuberosity of the proximal portion of the femur.	Powerful extension of the thigh with the hip flexed. Side stabiliser of the hip and knee. Abduction and external rotation of the thigh.	Lower gluteal nerve L5,S1,S2
	Medius	Outer surface of the ilium between the anterior and posterior gluteal lines	Extended articular facet over the side surface of the greater trochanter.	It abducts the thigh. It holds the pelvis stable over the limb in support. It stops the counter-lateral pelvis dropping in swing phase and rotates the thigh medially.	Upper gluteal nerve L4,L5,S1
	Minimus	Outer surface of the ilium between the inferior and anterior gluteal lines	Linear articular facet located on the anterolateral side of the greater trochanter.	It abducts the thigh. It holds the pelvis stable over the limb in support. It stops the counter-lateral pelvis dropping in swing phase and rotates the thigh medially.	Upper gluteal nerve L4,L5,S1
Fascia tensor		Lateral side of the iliac crest between ASIS and the crest protuberance.	Iliotibial band of the fascia lata	It flexes, abducts and medially rotates the thigh. It tenses the fascia lata and stabilises the knee	Upper gluteal nerve L4,L5,S1

Taken from: Drake Rl, Vogl AW, Mitchell AWM. Chapter 6: lower limb. Gluteal region Basic Gray's Anatomy, Barcelona: Elsevier; 2013. 2nd edition 281-3.

lifestyle, increase in the Body Mass Index (BMI), scoliosis, dysmetria and in sporting practice, errors in high intensity training[11] (Table 2).

Associated morphological factorss

Being a woman and middle aged are two risk factors related to GTPS.

Several biomechanical and morphological factors can be bound to their prevalence in women. One of them is the increase in the Q angle (Figure 2). Its increase produces a rise in tension and compression in the gluteus tendon during repetitive movements, as seen in many sporting disciplines[12].

This gluteus tendon compression was described by Taylor-Haas *et al.*[13] among young long-distance runners. This author assessed the kinematics of the pelvis and the hip and concluded that the risk of injury is greater among female rather than male runners. Female runners presented greater hip adduction compared to their male counterparts, which caused a possible tendon lesion due to compression in the greater trochanter area. However, Williams and Cohen[14] relate this tendon compression to a morphological difference in the greater trochanter (smaller size), and this compression would be with the iliotibial band and due to pelvic orientation (Table 3).

Woyski *et al.*[15] also consider the trochanter morphology to be relevant and consider that there is a reduction in the insertion area in the greater trochanter in women that generates a shorter power arm, increasing the traction of the gluteus tendons and lower biomechanical efficiency (Figure 3).

Grimaldi and Fearon[1] relate the failure of conservative management in women with a femoral neck angle under 134°, when assessing patients proposed for tendon reconstruction surgery. This finding suggests a greater risk of severity, but not a risk factor for developing injuries. These

Table 2. Selected studies for associated muscular factors

Author(s)	Year	Journal	Quartile (Q)	Conclusions
Reid D.	2016	*Journal of orthopaedics*	Q3	One of its possible causes in sport are errors in high intensity training leading to degenerative tendinopathy of the trochanteric tendons.
Robinson NA, *et al.*	2019	*Gait & posture*	Q4	The iliotibial band compresses the gluteal tendons during maximum hip adduction
Stephens G, *et al.*	2019	*Musculoskeletal care*	Q3	Tendinopathy of the medium and minor gluteal tendons at the point where they are inserted in the greater femur trochanter
Godshaw B, *et al.*	2019	*The Ochsner journal*	Q3	Lack of treatment leads to a degenerative tendinopathy, chronic pain on the outer side of the hip and/or retraction of the tendon towards the trochanter area.
Bajuri MY, *et al.*	2022	*Cureus*	Q3	The gluteus medius is injured by micro and/or macro traumas to the hip and pelvis

Figure 2. Representation of the Q angle. Angle formed between two segments. One from the anterior superior iliac spine (ASIS) to the centre of the ball joint and another from the centre of the ball joint to anterior tuberosity of the tibia (ATT).

Table 3. Summary of the main pelvic differences between sexes.

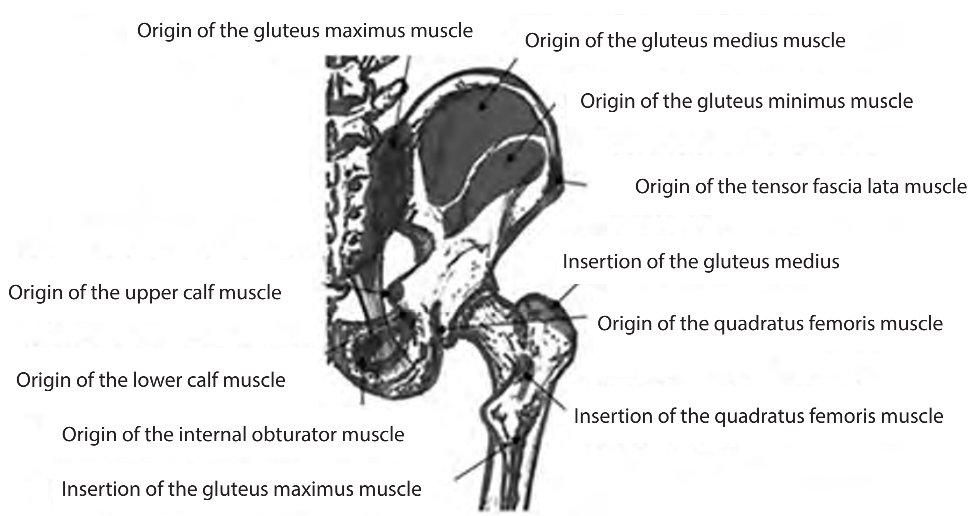
Pelvic characteristics	Women	Men
Size and shape	Wide and slim with separated iliacs	Narrow and thick with iliacs together
Upper opening	Circular	Pyriform (pear-shaped)
Blocking orifices	Oval-shaped	Round
Acetabulum	Small minor cover of femoral head	Large with major co-ver of femoral head
Promontory	Not very prominent and wide wings	Prominent and na-rrow wings
Sub-pubic angle	80º-85º with wide pubis	50º-60º with narrow pubis
Ischial spines	No medial protrusion	Medial protrusion

authors consider that the coxa vara morphology of the female pelvis and its greater trochanter displacement are potential underlying factors for a greater compressive load on the gluteus tendons, via the iliotibial band. However, the study by Santos *et al.*[16] finds no association between this increase and the prevalence of GTPS among women.

The age factor, and possible association with sarcopenia, muscular fat degeneration and associated loss of strength, would lead to a progressive break down of the femoral neck as a compensatory biomechanical alternative for the increase in the abductor lever arm[16].

Pelsser *et al.*[17] have demonstrated that the increase in the acetabulum anteversion is associated with gluteal tendinopathy and trochanteric bursitis compared to the controls (18.8º in cases compared to 15.4° in controls). The increase in this anteversion can alter the biomechanics of the gluteus tendons and become a possible link with GTPS[6].

Figure 3. Representation of origins and insertions of the pelvic musculature.



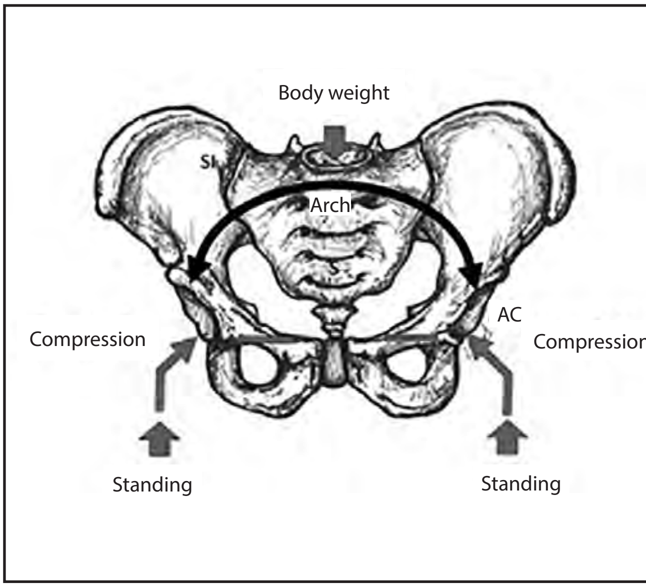
Source: Ruiz ML, Dugnol J. Chapter 13: músculos del miembro inferior. Cuadernos prácticos de anatomía. Aparato Locomotor, Oviedo: Facultad Padre Osso; 2020, p. 76.

Figure 4 shows a black arrow that represents the body weight pressing on the sacrum, distributed through the sacroiliac joints in an arch which then passes to the coxofemoral joints. This is counteracted by the forces exerted from the ground through the femurs during standing. The arrows in the pubis represent neutralisation of loads from the forces exerted on the femurs.

Saltychev *et al.*[18] have proposed that there is a direct relationship between the pelvic tilt in the frontal plane and GTPS. The lumbar alignment and the sacral tilt (horizontalization) would also be related to GTPS[19].

Meanwhile, Canetti *et al.*[20] confirms the association between sacral horizontalization and GTPS and suggests that they cause biomechanical changes in the gluteus tendons due to pelvic retroversion. In turn, if the lumbar spine presents little mobility, the only form of movement is pelvic retroversion[8]. Consequently, pelvic retroversion increases the distance between two points of insertion of the gluteal muscles, which results in an increase in gluteal muscular tension as mentioned above. This increase in tension, particularly in the gluteus medius can trigger insertional tendinopathy and can generate excessive friction with the tensor fascia lata, leading to a bursitis which is secondary to the tendinopathy (Table 4).

Figure 4. Pelvic biomechanics.



Source: Ruiz ML, Dugnol J. Chapter 5: miembro inferior. Cuadernos prácticos de anatomía. Aparato Locomotor, Oviedo: Facultad Padre Osso; 2020, p. 27; and modified from: Caillet, R. Biomecánica. Madrid. Marbán; 2017, p. 248.

Table 4. Selected studies for associated morphological factors.

Author(s)	Year	Journal	Quartile (Q)	Conclusions
Pelsser V, *et al.*	2001	*American journal of roentgenology*	Q1	The increase in the acetabulum anteversion is associated with gluteal tendinopathy and trochanteric bursitis.
Williams BS, Cohen SP	2009	*Anesthesia and analgesia*	Q1	They relate this tendon compression to three conditions: smaller area of the greater trochanter, action of the iliotibial band and pelvic orientation.
Woyski D, *et al.*	2013	*Surgical and radiologic anatomy: SRA*	Q3	The decrease in the insertion area in the greater trochanter among women leads to a shorter power arm and an increase in the traction of the gluteus tendons and lower biomechanical efficiency.
Grimaldi A, Fearon A	2015	*Journal of orthopaedic and sports physical therapy*	Q1	Greater failure of the conservation treatment in women with a femoral neck angle under 134°. These patients are proposed for tendon reconstruction surgery.
Saltychev M, *et al.*	2018	*Acta orthopaedica*	Q1	Direct relationship between the pelvic swing in the frontal plane and GTPS
Canetti R, *et al*.	2020	*Skeletal radiology*	Q3	The association between sacral horizontalization and GTPS causes biomechanical changes in the gluteus tendons due to pelvic retroversion.
Santos L, *et al.*	2021	*Clinics*	Q3	The age factor, possibly associated with sarcopenia, muscular fat degeneration and associated loss of strength, would lead to a progressive break down of the femoral neck compensating for the increase in the abductor lever arm
Sunil K, *et al.*	2021	*Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA*	Q1	The pelvic anteversion can alter the biomechanics of the gluteus tendons.
Miyasaki MR, *et al.*	2021	*International journal of rheumatic diseases*	Q4	Lumbar alignment would be related to GTPS
Taylor-Haas, *et al*.	2022	*Journal of science and medicine in sport*	Q1	A group of female runners presented greater hip adduction compared to their male counterparts, which possible injured the tendon due to compression in the greater trochanter zone
Seidman AJ, Varacallo M	2022	*Clinics*	Q3	The increase in the Q angle in women produces an increase in tension and compression in the gluteus tendon during repetitive movements, as seen in many athletes

Associated biomechanical factors

The treatment approach should not only focus on recovery from the anatomical injury to the gluteus tendon or the pain on the outside of the thigh, but it should also correct the biomechanical alterations. This should consider which changes might be occurring in those tendons when walking and specifically when initiating monopodal support, which patients refer to as painful (Table 5).

The gait cycle is defined as the sequence of components produced between the same foot making two successive contacts with the ground. The gait cycle is divided into two periods: support and swing[21]. When walking, the body moves its centre of gravity with the greatest possible economy of energy. The main determining factors that help to reduce the displacement of the centre of pressure or CoP during walking are, firstly, the obliquity of the frontal plane pelvis, controlled by the abductors and, secondly, the rotation of the pelvis in the side plane, performed by the pelvic-trochanteric muscles[22] (Figure 5).

Molina and Carratalá[23] consider that the pelvis movements are not wide but are influenced by gender. Women present greater swing in the frontal plane, greater transversal width and greater anteversion that influences the CoP path.

The centre of pressure (CoP) path or gait line can provide useful information to assess or detect the function and the pathology of the foot and the hip (Figure 6). The centre of pressure is the area where an immediate force acts on the sole of the foot. This force is a component of the resulting vertical reaction force from the ground that reacts with the sole of the foot[24,25]. The CoP progression is a path formed by a series of coordinates from the centre of pressure that goes from the heel to the forefoot during the support phase[25].

The first phase of monopodal support in gait is called the loading reception or acceptance, also known as rocker[1]. This phase is divided into two moments, initial contact (IC) and loading response (LR). The hip, that participates in the stability, the forward movement and the support for the weight during gait, is in flex in this phase, with the consequent concentric work of the gluteus maximus and the hamstrings (Figure 7). The hip abductors, gluteus medius and minimus, act eccentrically to counteract the adduction moment created by the body mass on this joint, controlling the sideways displacement of the body and the contralateral pelvic drop in the frontal plane.

The second part, LR, is when the gluteal muscles or hamstrings work concentrically to make the body position vertical, predicting the pelvic anteversion and the flexing of the torso. In a frontal plane, the hip is in a neutral position or with slight adduction in the IC, increasing in LR and MS (midstance). This position is favoured by the valgus knee. It will be found in abduction in the PS and IS. The gluteus medius continues to act here, in fact, Perry and Burnfield[26] consider that this muscle is more intensely activated than the tensor and this activation lasts longer than the gluteus maximus.

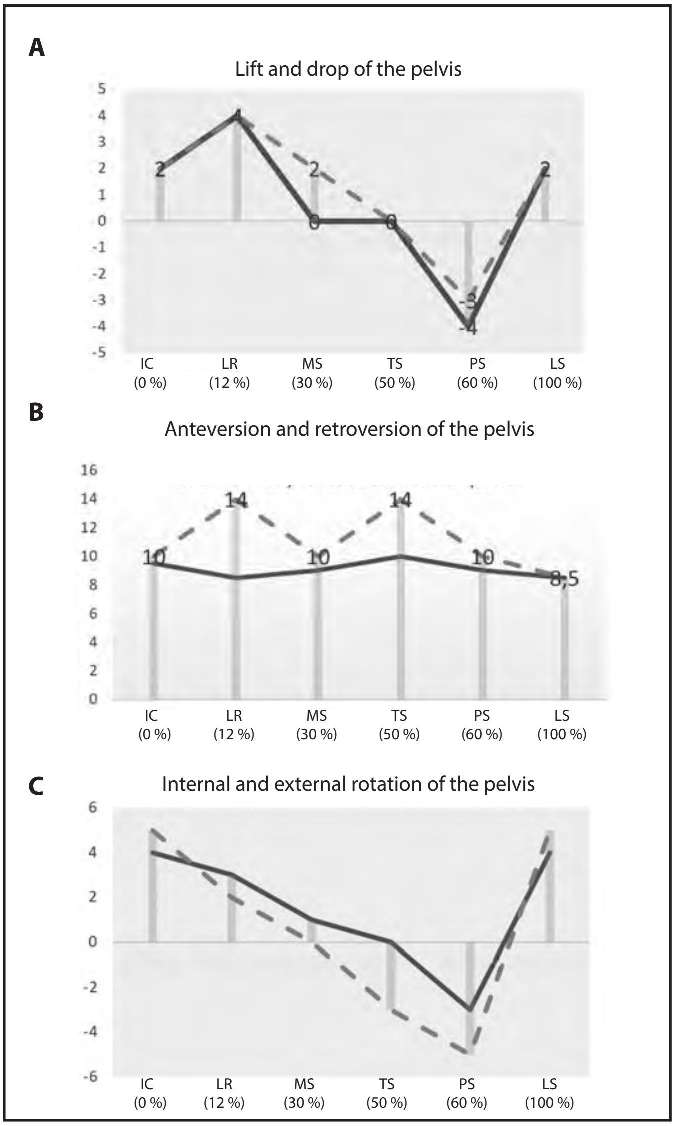
The gluteus medius and minimus participate in the start of the hip abduction and pelvis stabilization during movement and gait. However, they also help to stabilise the femoroacetabular joint. The contraction of the hip abductors not only stabilises the pelvis in relation to the femur in the frontal plane, but also produces compression forces through the femoroacetabular joint, which are 2 or 3 times the body weight. This compression force is inherent to the hip articulation and the deficiency of these abductors is the cause of luxation after total hip arthroplasty. The hip abductors are not only important to initiate movement and pelvic stabilization with the gait, but they can also provide dynamic stabilisation of the femoral head within the acetabulum[27].

In the cases of hip joint laxity, the work increases for the dynamic stabilizing muscles to make sure that the femoral head remains contai-

Table 5. Selected studies for associated biomechanical factors.

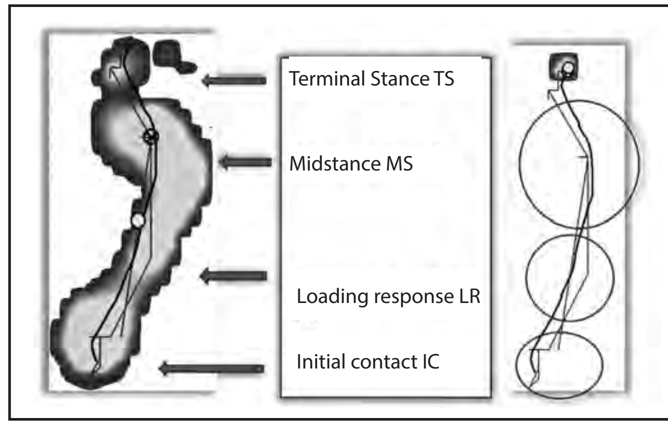
Author(s)	Year	Journal	Quartile (Q)	Conclusions
De Cock, A, *et al.*	2008	*Gait & posture*	Q4	The centre of pressure is the area where an immediate force acts on the sole of the foot. This force is a component of the resulting vertical reaction force of the ground that reacts with the sole of the foot
Chiu MC, *et al.*	2013	*Gait & posture*	Q4	The CoP progression is a path formed by a series of coordinates from the centre of pressure that goes from the heel to the forefoot during the support phase
Giordano BD	2014	*Pediatric clinics of North America*	Q2	In the cases of hip joint laxity, the work increases for the dynamic stabilizing muscles to make sure that the femoral head remains contained in the acetabulum during walking
Grimaldi A, Fearon A	2015	*Journal of orthopaedic and sports physical therapy*	Q1	The iliotibial band provides 30% of the abductor force required to keep the pelvis laterally stable in monopodal support and the remaining 70% is supplied by the trochanter abductors
Reimer L, *et al.*	2019	*Danish medical journal*	Q3	The increase in the muscular work and possible dysfunctional patterns of gait and movement might increase tension in the iliotibial band and lead to a tendinopathy and/or bursitis due to compression
Robinson NA, *et al.*	2019	*Gait & posture*	Q4	In GTPS, there is a drop in the abduction force and an increase in the hip adduction angle, the lateral flexion of the torso and pelvic obliquity during gait
Goldman L, *et al.*	2020	*Orthopaedic journal of sports medicine*	Q2	The hip abductors provide dynamic stabilisation of the femoral head within the acetabulum

Figure 5. Representation of the pelvis movements during gait. A) frontal plane, B) sagittal plane, C) transversal plane. This represents both the support phase (from initial contact (IC) to pre-swing (PS) and late swing (LS)).



IC: initial contact; LR: loading response; MS: midstance; TS: terminal stance; PS: pre-swing; LS: late swing. This represents values from: Molina F, Carratalá M. Ciclo de la marcha: fases y parámetros espaciotemporales. La marcha humana. Biomecánica, evaluación y patología. Madrid: Medica Panamericana; 2020, p. 13-7, as a solid line; and Perry J, Burnfield J. Gait Analysis. Barcelona. Base; 2015, p. 156-81 as a dotted line.

Figure 6. Representation of the right monopodal support phases on the sole of the foot and in the line of the CoP.



ned in the acetabulum during gait[28]. For Reimer *et al.*[29], the increase in muscle work and possible dysfunctional patterns of gait and movement might increase tension in the iliotibial band and lead to a tendinopathy and/or bursitis due to compression.

The next gait phase is complete monopodal support, also called rocker[2]. In this phase, both the gluteus maximus and medius are working, while the fascia lata tensor controls the knee and hip movement. In the final phase of the support, the limb accelerates downwards and forwards from the centre of mass, helped by the forward movement of the contralateral leg, which has exceeded the homolateral limb and is getting ready for initial contact. The femur has external rotation of 5º when starting the monopodal support and inversely, it rotates externally as it enters the swing phase (Figure 6). Remember that both the gluteus medius and minimus are medial rotators. The hip flexes in the swing phase and is almost neutral or slightly extended in the support phase. In the frontal plane, the hip abductor muscles continue to stabilise the pelvis.

For Grimaldi and Fearon[1], the iliotibial band provides 30% of the abductor force required to keep the pelvis laterally stable in monopodal support and the remaining 70% is supplied by the trochanter abductors. Consequently, the iliotibial band is an essential part of this system, as it has been demonstrated that the gluteus medius alone is mechanically insufficient to generate the right force to withstand all the hip adduction on monopodal load. The weakness and atrophy of the trochanter abductors require the iliotibial band to produce greater force, or there will be an increase in the hip adduction, which increases the compression forces. In subjects with a symptomatic pathology of the gluteus tendon, significant fatty atrophy of the gluteus medius and minimus has been demonstrated.

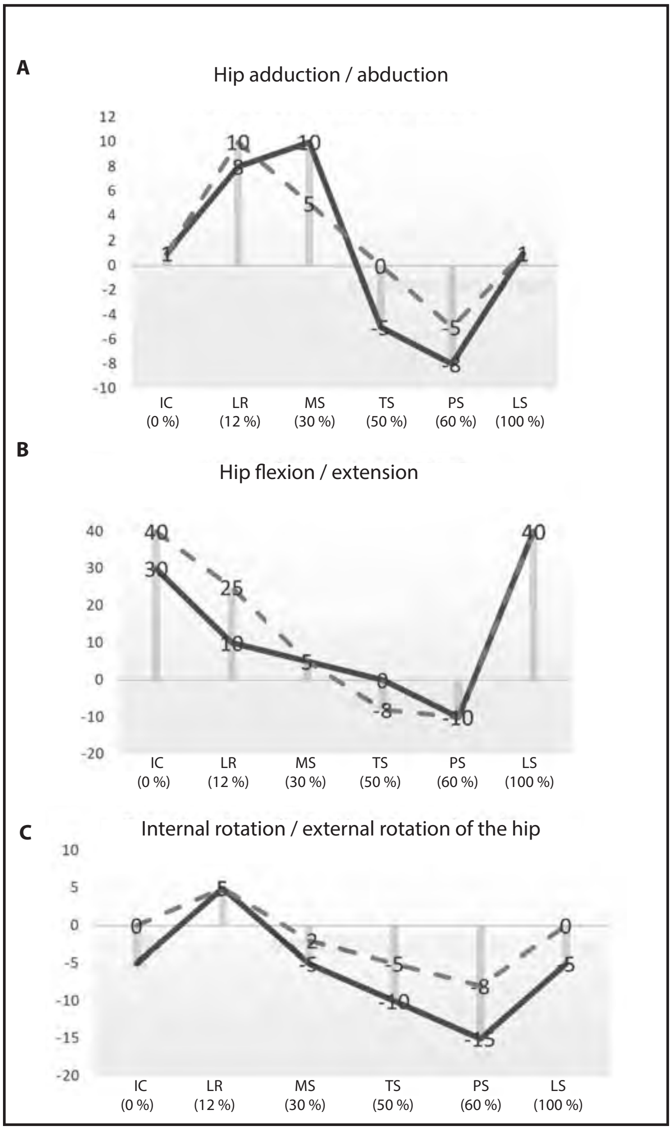
In GTPS, there is a drop in the abduction force and an increase in the hip adduction angle, the lateral flex of the torso and the pelvic obliquity during gait[7] (Figure 8).

Treatments used in the greater trochanteric pain syndrome

All types of anti-inflammatory treatment, including physiotherapy, is the baseline treatment for this syndrome. An international survey on physiotherapy practices in GTPS showed multiple interventions[30]. These interventions are massage (90%), stretching (53%), range of movement (40%), heat therapy (50%), taping (38%) and electrotherapy (25%). Manual therapy focuses on re-educating and strengthening exercises on the gluteal muscles.

There are currently few studies which evaluate the effects of manual therapy, although this treatment is increasingly considered to restore

Figure 7. Representation of the hip movements during walking. A) frontal plane, B) sagittal plane, C) transversal plane. This represents both the support phase (from IC to PS) and swing (LS).



IC: initial contact; LR: loading response; MS: midstance; TS: terminal stance; PS: pre-swing; LS: late swing. This represents values from: Molina F, Carratalá M. Ciclo de la marcha: fases y parámetros espaciotemporales. La marcha humana. Biomecánica, evaluación y patología. Madrid: Medica Panamericana; 2020, p. 13-7, as a solid line; and Perry J, Burnfield J. Gait Analysis. Barcelona. Base; 2015, p. 156-81 as a dotted line.

the three biomechanical alterations as a consequence of the gluteal tendinopathy.

The data provided on applying physical therapy demonstrated that anti-inflammatory treatment is not the most effective. This is because this syndrome (previously called trochanteric bursitis) is multifactorial and it does not seem as though the inflammatory component is its direct cause[3]. Consequently, manipulative therapy must focus on stabilising and normalising the movement while the inflammation is a secondary process (that may or may not be present in patients with

Table 6. Selected studies for treatment performed on the greater trochanteric pain syndrome.

Treatments given				
Authors	**Year**	**Journal**	**Quartile (Q)**	**Conclusion**
French HP, Woodley SJ, Fearon A, O'Connor L, Grimaldi A	2020	*Physiotherapy*	Q1	There are multiple physiotherapy interventions in GTPS: massage, stretching, range of movement, heat therapy, taping and electrotherapy.
Ali SS, Ahmed SI, Khan M, Soomro RR	2014	*Pakistan journal of pharmaceutical sciences*	Q4	The manipulative therapy must focus on stabilising and normalising the movement while the inflammation is a secondary process (that may or may not be present in patients with GTPS) to a tendon injury
Pumarejo Gomez L, Childress JM	2022	*StatPearls*	Book	Application of physical therapy is not the most effective. It does not seem that the inflammatory component is its direct cause.

GTPS) to a tendon injury. This idea is supported by the studies from Ali *et al.*[31] who concluded that manual therapy, specifically treatment using the Maitland method, is clinically more effective to reduce pain, rigidity and improve knee functionality in osteoarthritis as opposed to using physical agents employed in physiotherapy such as anti-inflammatory methods (Table 6).

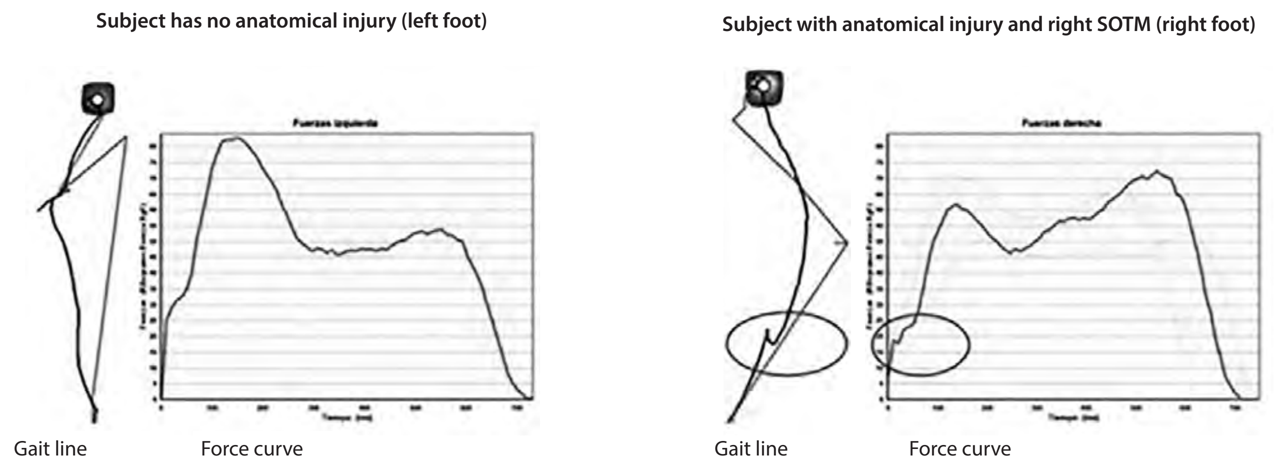
Consequently, if the biomechanical conflict is resolved by applying manipulative techniques, this leads to pelvic stabilisation and normalisation of the movement. Working from restoring these altered biomechanical mechanisms, there should be secondary action on reducing the inflammation and pain on the outer side of the thigh.

Conclusions

The morphological factors of the female pelvis, the smaller insertion area in the greater trochanter, the femoral angle under 134º, greater trochanteric displacement towards coxa vara and an increase in the Q angle are related to greater compression of the gluteus tendons on the greater trochanter in middle aged women. Age itself, associated with pathologies such as sarcopenia and muscular weakness, will lead to a progressive varus as a compensatory biomechanical adaptation to improve the function of the gluteus medius and minimus.

Regarding the biomechanical and muscular factors, the gluteus medius and minimus not only participate in the start of hip abduction

Figure 8. Evolution of the gait line and the force curves in a subject with dissymmetry and right GTPS. This marks the alteration in the development of CoP in monopodal support phase.



and stabilisation of the pelvis, but they also provide dynamic stability to the femoral head within the acetabulum during movement and gait. The increased muscular work of the gluteus medius and minimus and possible alterations to gait patterns and dysfunctional movements might increase tension in the iliotibial band and lead to a tendinopathy and/or bursitis due to compression. Consequently, the alterations seen in GTPS might be the consequence of insufficiency in the hip abductor muscles or an altered motor control strategy. The combination of trochanteric abductor insufficiency, increased contribution of the iliotibial band tensors and excessive use of functional adduction might represent a biomechanical factor for the gluteus tendons which are exposed to the combined load of compression and traction in these patients.

From all the above, there is a clear need to recognise the possible risk factors for GTPS to plan effective treatment to restore lost functionality and reduce pain, the quintessential clinical symptom of GTPS.

Conflicts of interest

The authors declare that there is no conflict of interest.

Bibliography

1. Grimaldi A, Fearon A. Gluteal Tendinopathy: Integrating Pathomechanics and Clinical Features in Its Management. *J Orthop Sports Phys Ther.* 2015;45:910-22.
2. Stephens G, O'Neill S, Clifford C, Cuff A, Forte F, Hawthorn C, *et al.* Greater trochanteric pain syndrome in the UK National Health Service: A multicentre service evaluation. *Musculoskeletal care.* 2019;17:390-8.
3. Pumarejo Gomez L, Childress JM. *Greater Trochanteric Syndrome.* In StatPearls. StatPearls Publishing. 2022.
4. Rho M, Camacho-Soto A, Cheng A, Havran M, Morone NE, Rodríguez E, *et al.* Deconstructing Chronic Low Back Pain in the Older Adult-Step by Step Evidence and Expert-Based Recommendations for Evaluation and Treatment. Part VIII: Lateral Hip and Thigh Pain. *Pain Med.* 2016;17:1249-60.
5. Pozzi G, Lanza E, Parra CG, Merli I, Sconfienza LM, Zerbi A. Incidence of greater trochanteric pain syndrome in patients suspected for femoroacetabular impingement evaluated using magnetic resonance arthrography of the hip. *Radiol Med.* 2017;122:208-14.
6. Sunil Kumar KH, Rawal J, Nakano N, Sarmento A, Khanduja V. Pathogenesis and contemporary diagnoses for lateral hip pain: a scoping review. *Knee Surg Sports Traumatol Arthrosc.* 2021;29:2408-16.
7. Robinson NA, Spratford W, Welvaert M, Gaida J, Fearon AM. Does Dynamic Tape change the walking biomechanics of women with greater trochanteric pain syndrome? A blinded randomised controlled crossover trial. *Gait posture.* 2019;70:275-83.
8. Cailliet, R. *Biomecánica*. Madrid. Marbán; 2017:253.
9. Bajuri MY, Sivasamy P, Simanjuntak G, Azemi AF, Azman MI. Posttraumatic Isolated Right Gluteus Minimus Tear: A Case Report. *Cureus.* 2022;14:e23056.
10. Godshaw B, Wong M, Ojard C, Williams G, Suri M, Jones D. Acute Traumatic Tear of the Gluteus Medius and Gluteus Minimus in a Marathon Runner. *Ochsner J.* 2019;19:405-9.
11. Reid D. The management of greater trochanteric pain syndrome: A systematic literature review. *J Orthop.* 2016;13:15-28.
12. Seidman AJ, Varacallo M. Trochanteric Bursitis. In *StatPearls*. 2022.
13. Taylor-Haas JA, Long JT, Garcia MC, Rauh MJ, Paterno MV, Brindle RA, *et al.* The influence of maturation and sex on pelvis and hip kinematics in youth distance runners. *J Sci Med Sport.* 2022;25:272-8.
14. Williams BS, Cohen SP. Greater trochanteric pain syndrome: a review of anatomy, diagnosis and treatment. *Anesth Analg*. 2019;108:1662-70.
15. Woyski D, Olinger A,Wright B. Smaller insertion area and inefficient mechanics of the gluteus medius in females. *Surg Radiol Anat*. 2013;35:713-9.
16. Santos L, Navarro TP, Machado CJ, Cabrita H, Pires RE, Figueiredo LB, *et al.* Relationship of the Pelvic-Trochanteric Index with greater trochanteric pain syndrome. *Clinics* (Sao Paulo). 2021;76:e3312.
17. Pelsser V, Cardinal E, Hobden R, Aubin B, Lafortune M. Extraarticular snapping hip: sonographic findings. *AJR Am J Roentgenol.* 2001;176:67-73.
18. Saltychev M, Pernaa K, Seppänen M, Mäkelä K, Laimi K. Pelvic incidence and hip disorders. *Acta Orthop.* 2018;89:66-70.
19. Miyasaki MR, Marcioli M, Cunha A, Polesello GC, Marini MG, Fernandes K, *et al.* Greater trochanteric pain syndrome in women: Analysis of magnetic resonance, sagittal alignment, muscular strength and endurance of the hip and trunk. *Int J Rheum Dis.* 2021;24:941-7.
20. Canetti R, de Saint Vincent B, Vieira TD, Fière V, Thaunat M. Spinopelvic parameters in greater trochanteric pain syndrome: a retrospective case-control study. *Skeletal Radiol.* 2020;49:773-8.

21. Molina F, Carratalá M. Ciclo de la marcha: fases y parámetros espaciotemporales. *La marcha humana. Biomecánica, evaluación y patología*. Madrid: Medica Panamericana; 2020:13-7.
22. Molina F, Carratalá M. Patrón cinemático de cadera, rodilla y el tobillo durante la marcha. *La marcha humana. Biomecánica, evaluación y patología*. Madrid: Medica Panamericana; 2020:19-23.
23. Molina F, Carratalá M. Patrón cinemático de la pelvis, del tórax y de los miembros superiores durante la marcha. *La marcha humana. Biomecánica, evaluación y patología*. Madrid: Medica Panamericana; 2020:25-9.
24. De Cock A, Vanrenterghem J, Willems T, Witvrouw E, De Clercq D. The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. *Gait posture.* 2008;27:669-75.
25. Chiu MC, Wu HC, Chang LY. Gait speed and gender effects on center of pressure progression during normal walking. *Gait posture.* 2013;37:43-8.
26. Perry J, Burnfield J. *Análisis de la Marcha.* Barcelona. Base; 2015:156.
27. Goldman L, Land EV, Adsit MH, Balazs C. Hip Stability May Influence the Development of Greater Trochanteric Pain Syndrome: A Case-Control Study of Consecutive Patients. *Orthop J Sports Med.* 2020;8:2325967120958699.
28. Giordano BD. Assessment and treatment of hip pain in the adolescent athlete. *Pediatr Clin North Am.* 2014;61:1137-54.
29. Reimer L, Jacobsen JS, Mechlenburg I. Hypermobility among patients with greater trochanteric pain syndrome. *Dan Med J*. 2019;66:A5539.
30. French HP, Woodley SJ, Fearon A, O'Connor L, Grimaldi A. Physiotherapy management of greater trochanteric pain syndrome (GTPS): an international survey of current physiotherapy practice. *Physiotherapy.* 2020;109:111-20.
31. Ali SS, Ahmed SI, Khan M, Soomro RR. Comparing the effects of manual therapy versus electrophysical agents in the management of knee osteoarthritis. *Pak J Pharm Sci*. 2014;27:1103-6.

Review

Effects of a maximum strength training programme on competitive swimmers: a systematic review

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Summary

Introduction: Maximal strength training programs have been traditionally used in swimming planning, mainly as a complementary dry-land workout. Although there is evidence of the utility of this type of physical preparation, it is still unclear how a maximal strength training program affects different performance variables in swimmers.
Objective: The objective of this systematic review was to conduct a literature review on the effects of a maximal strength training program on the variables associated with swimming performance (swimming speed, stroke frequency, stroke length, turns and reaction time) in competitive swimmers.
Material and method: The primary search was performed until February 2022 in different databases (Web of Science, Pubmed and Scopus). Inclusion criteria: 1) studies analyzing swimming performance parameters; 2) interventions with maximal strength training programs (≥85% RM) of at least four weeks duration; 3) subjects with national competitive level or higher; 4) subjects with at least four years of competitive swimming experience and ten hours of training per week; and 5) investigations comparing the effects of maximal strength training on swimming performance.
Results: A total of eight studies met the inclusion criteria. Eight of the studies examined effects on swim speed, five effects on stroke frequency, five on stroke length, three on start reaction, and two on turns.
Conclusion: A maximal strength training program has a positive effect on swimming speed. Likewise, they significantly increase kinematic variables such as stroke length. However, no evidences of significant stroke frequency modification have been identified.

Key words:
Swimming. Resistance training. Strength training.

Efectos de un programa de entrenamiento de fuerza máxima en nadadores de competición: una revisión sistemática

Resumen

Introducción: Los programas de entrenamiento de fuerza máxima han sido utilizados tradicionalmente en la planificación en natación, principalmente como un trabajo complementario. Aunque existen pruebas de la utilidad que puede evidenciar este tipo de preparación física, aún no queda claro cómo un programa de entrenamiento de fuerza máxima afecta a las diferentes variables del rendimiento en nadadores.
Objetivo: El objetivo de esta revisión sistemática fue realizar una revisión de la literatura sobre los efectos de un programa entrenamiento de fuerza máxima sobre las variables asociadas al rendimiento en natación (velocidad de nado, frecuencia de brazada, longitud de brazada, virajes y tiempo de reacción) en nadadores de competición.
Material y método: La búsqueda fue realizada hasta febrero de 2022 en distintas bases de datos (Web of Science, Pubmed y Scopus). Criterios de inclusión: 1) Estudios que analizaran parámetros de rendimiento en natación; 2) intervenciones con programas de entrenamiento de fuerza máxima (≥85% RM) de al menos cuatro semanas de duración; 3) sujetos con nivel competitivo nacional o superior; 4) sujetos cuatro años de experiencia competitiva en natación y diez horas de entrenamiento semanales; y 5) artículos en los que se comparan los efectos del entrenamiento de fuerza máxima en el rendimiento en natación.
Resultados: Un total de 8 estudios cumplieron los criterios de inclusión. Ocho de los estudios analizaron efectos en la velocidad de nado, cinco efectos en la frecuencia de brazada, cinco en la longitud de brazada, tres en la reacción de salida y dos en los virajes.
Conclusión: Un programa de entrenamiento de fuerza máxima tiene un efecto positivo sobre la velocidad de nado. De igual manera puede afectar variables cinemáticas como la longitud de brazada, por otro lado, no se observan en la frecuencia de brazada.

Palabras clave:
Natación. Entrenamiento de fuerza. Entrenamiento de potencia.

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Introduction

Swimming is clearly different from other sports as movements are mainly made in a horizontal position[1] suspended in a liquid and the propelling actions are made using alternative or simultaneous arm and leg movements. In addition, water presents less resistance to the propelling actions compared to forces against the ground produced in other sports on land[2]. Swimming performance is also defined by physiological, psychological and anatomical components[3,4]. In the same way, a study published in 2013 by Barbosa *et al*.[5] showed that swimming performance depended on kinematic and kinetic energy, where the former is the relationship between the swimming speed, the stroke length and the stroke frequency and the latter is the work energy that is generated when being propelled through the water[5].

The displacement speed in any sport can be defined as a set of functional characteristics that allow motor performance in the least possible time[6]. In swimming, the movement patterns to generate the body's displacement mainly take place when the swimmers exercise propelling resistance forces against the direction of the body's movement. Increasing the stroke and kick frequency makes the force applied greater in a shorter time range, increasing the displacement speed[2]. Consequently, the components of a swimmer's physical condition play a determining role in the propelling actions when swimming. This is the case of strength, which must be developed to generate faster movements against the load represented by the water and thereby maintain the speed when moving for a longer time[7]. Increasing mechanical strength and muscular strength is a key factor in a swimmer's performance[8], the force generated by the body's upper limbs is vitally important for propulsion and speed in swimming[4]. The capacity to apply force in the water is therefore fundamental when competing[9]. Muscular strength is the capacity of a muscle or muscle group to perform reiterated contractions against a resistance which is less than the maximum for a determined period of time[10]. In swimming, it is essential to maintain or increase swimming speed during the effort required in each competitive race[11]. In addition, flexibility in swimming makes it possible to save and distribute strength better with better technical potential[12]. Wide-ranging mobility among swimmers can allow a greater period of action time for the propelling forces, a greater joint mobility arch to make sure that the movement to recover the arm and kick effort does not alter the body's alignment[2].

Consequently, several studies have shown the usefulness of strength programmes in competitive sporting disciplines[1,13,14], due to the growth of phosphagens, contractile proteins, development of anaerobic potential, muscular architecture, fibre feathering, protein synthesis and hypertrophy of fast-contracting muscular fibres[15,16], increase in the maximum strength and therefore developing strength at a greater rate[17]. As a consequence, trainers and fitness coaches run strength and physical conditioning programmes to develop swimmers' strength and improve their performance[5,18]. This is the case of kayaking where strength is a fundamental skill for optimum performance because the speed of the craft is due to the continuous application of force in the water using the paddle. Still-water kayaking comprises several competitions ranging from 40 seconds to several hours so the force applied will be different for a 200 m, 1,000 m or marathon race[19].

Some studies have analysed the effects of strength training and conditioning on swimming performance, although there is a lack of scientific evidence to explain the performance improvement parameters[9,13,18]. Some studies demonstrate a correlation between arm strength and swimming performance[9,20], and a link between the leg muscle strength and performance when leaving the starting blocks and turning in swimming[21]. In addition, weak and moderate correlation is found between strength and swimming speed[8,22]. It has been suggested that the possible reasons for a weak relationship between strength training outside the pool and performance in swimming might lie in transferring this strength gain to the pool because it is not as specific[5]. The review by Wirth *et al.*[23], concluded that maximum strength work is vitally important for swimmers, with intensities between 85 and 100% of the MR, allowing central and morphological adaptations that help muscular activation in a short time[23]. On the other hand, one study found that its traditional strength training group and its specific strength training group using strength bands got similar swimming performance results[24].

Although there have been prior systematic reviews to investigate various strength interventions on swimming performance[1,13,15,25], none of them has focused on the effects of a maximum strength training programme on swimmers' performance. These systematic reviews compiled information on the role of muscular strength in swimming and they found a wide variety of training protocols such as the concurrent[14], the plyometric[21] or focused on the lumbar-abdominal belt[25] among others. Therefore, the aim of this study was to analyse the effects of a maximum strength training programme on the variables associated with swimming performance (swimming speed, stroke frequency, stroke length, turns and reaction time) among competitive swimmers.

Material and method

Search strategy

This systematic review was carried out according to recommendations from the PRISMA standard (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[26].

The studies were obtained from the following databases:

PubMed, Web of Science (WOS), and Scopus up to February 2022, using the PICO strategy method (Patient, Intervention, Control and Outcomes)[27], which requires the research question to be devised properly and a literature review using the following keywords: "swimming", "resistance training", "strength training", "weight training", "Power training" and "force". The references from relevant studies were also examined to find other potentially eligible studies.

The following Boolean search operators were used: (swim*[Title]) AND ("resistance training"[Title/Abstract] OR "Strength Training"[Title/

Abstract] OR "weight training" [Title/Abstract] OR "Power training" [Title/Abstract]) NOT ("water polo"[Title/Abstract]).

Due to the low number of articles found with the former strategy, a further search strategy was used to increase the chances of finding other studies: (swim*[Title]) AND ("performance"[Title/Abstract]) AND ("resistance training"[Title/Abstract] OR "Strength Training"[Title/Abstract] OR "weight training" [Title/Abstract] OR "Power training" [Title/Abstract] OR force [Title/Abstract]. Nevertheless, an intensive review of the outcomes of this search did not increase the number of articles that met the inclusion criteria.

Study selection

Studies were included if they met the following criteria:

1) Studies that analyse swimming performance parameters;
2) interventions with maximum strength training programmes (≥85% of the MR) lasting at least four weeks;
3) subjects at national competition level or higher;
4) subjects with at least four years' experience of swimming competitively and ten hours of weekly training;
5) articles which compare the effects of maximum strength training on swimming performance.

Regarding the exclusion criteria, studies were rejected if: 1) Studies were not in English; 2) case reports, communications or congress and conference posters or systematic, literary or narrative reviews; 3) articles that correlate maximum force and swimming performance without strength training; and 4) swimmers with pathologies or some type of injury during the study.

Quality assessment

The PEDro[28] scale was used to assess the quality of the articles, mainly based on agreement of experts and not on empirical data. This instrument makes it possible to quickly recognise which of the random tests might have enough internal validity and statistical information for its results to be interpretable. The scale comprises 11 criteria, and one point is awarded for each criterion that is met. According to the scale, after using the inclusion and exclusion criteria, all selected studies achieved a score of 5 or more and were admitted in this review (Table 1).

Data extraction and synthesis

Once the studies had been read, the study objectives were consulted for data referring to the participants (number, age, gender). Type of intervention, duration of the intervention (weeks), variables analysed, procedure (series, repetitions, intensities), analysis method and results. To score each study, the degree of significance of the p value appeared in the results section to be checked, and also the size of the effect was facilitated to calculate from the average and the standard deviation.

Summary of the search

The PRISMA methodology was used, consisting of a list of 27 items (Figure 1) and a four-phase flow chart. At first, 348 studies were recognised using the database and an additional record was found in other sources (Google Scholar). Excluding duplicate articles left 191 articles. After reading the summaries carefully, 32 articles were chosen to read the complete text. 24 were excluded according to the inclusion and exclusion criteria. Finally, 8 studies were included in this systematic review.

Results

Characteristics of the included studies

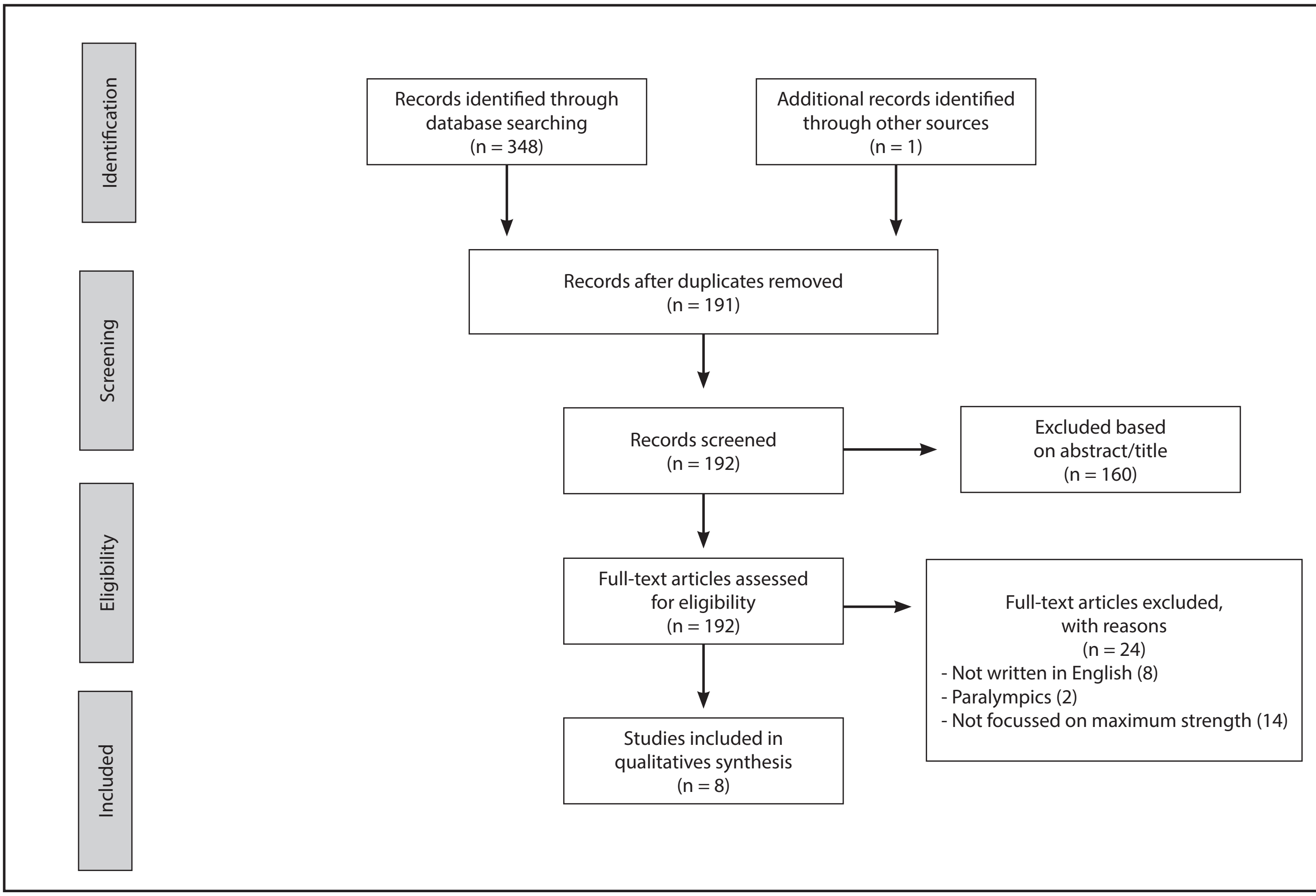
The classification of all the studies included a total of 166 athletes (109 men and 57 women), with ages ranging between 14 and 23 years

Table 1. PEDro scale to classify studies.

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Born *et al*., 2020	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Aspenes *et al.,* 2009	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Jones *et al.*, 2017	N	Y	N	Y	N	N	N	Y	Y	Y	Y	5
Girold, *et al.*, 2012	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Girold *et al.,* 2007	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Strass, 1988	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5
Schumann *et al.*, 2019	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Amara *et al.*, 2021	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6

1. The selection criteria were listed; 2. The subjects were assigned to the groups at random (one cross-study, the subjects were distributed at random as the treatment was received); 3. Assigning was hidden; 4. The groups were similar at the beginning concerning the most important prognostic indicators; 5. The subjects were blinded; 6. The therapists who gave the treatment were blinded; 7. The evaluators that measured at least one key result were blinded; 8. The results were obtained from at least one key result. The measurements for at least one of the key results were obtained from more than 85% of the subjects; 9. They were initially assigned to the groups; the results were shown for all subjects who received the treatment or who were assigned to the control group, or when this could not happen, the data was analysed for at least one key result by "intention to treat"; 10. The results were informed from the statistical comparisons between groups at least for one key result; 11. The study provides specific measures and variability at least for one key outcome.

Figure 1. PRISMA flow chart.



old, admitted according to the review inclusion criteria. Due to the methodological variety of each study, a descriptive chart was provided featuring the general characteristics of the studies where maximum strength training was used in swimmers. Table 2 shows the general characteristics of the studies included in this systematic review. It includes a brief description of the subjects specifying the number of persons involved in each study, their respective gender, age, intervention time, competitive levels, the maximum strength programme carried out and the performance measure.

Type of study

Depending on the type of study, there were five Random Controlled Tests[9,24,29-31], one pilot study[32], one design with repeated measurements between groups[33], and one comparative study[34]. The size of the sample was also analysed, differentiating between the control group, experimental group, gender and average age of the subjects. Seven studies used a sample equal to or greater than 16 subjects[9,24,29-33]. Regarding measurement of the effects of maximum strength training on swimming performance variants, Tables 3 to 7 were devised to show the results from each of the respective variables measured.

The following studies presented in Table 3 show the results for swimming speed. Aspenes *et al.*[9] found a significant improvement in performance in the 400 metres freestyle (P <0.05) with a decrease in swimming time from 290.43 to 286.43 seconds in the experimental group and no change in the control group. Concerning performance in the 50 and 100 metres freestyle, no significant improvements were found in the experimental group, or in the control group (P = 0.11 and P = 0.12), respectively.

In another study by Girold *et al.*[24], the swimming speed performance in 50 metres freestyle improved significantly (P <0.05) both in week 6 and in week 12 (2.8 ± 2.5%) after a period of maximum strength training. No changes were observed in the control group's performance (P >0.05). Furthermore, Girold *et al.*[34] obtained significant changes in the average swimming speed over 50 metres freestyle (P <0.05) after a four-week period of strength training (+2 ± 1.3%); no changes were observed in the control group's performance throughout the study.

Table 2. General characteristics of the studies selected for the systematic review.

Studies	No. of participants	Gender	Age	Weeks	Competitive level	Strength training programme	Average performance
Born *et al.,* 2020	21	F = 12 M = 9	17.1 ± 2.6	6	National and international	Squat and dead weight 3x (6-8) rep - 4x y (2-4) rep +2.5 kg per finished series	5 m 10 m 15 m 25 m Starting reaction Stroke pace Stroke length
Aspenes *et al.,* 2009	20	F = 12 M = 8	16.5 ± 1.5	11	National	Cable cross over 3x5 rep + 1.5 kg per finished series 5 MR	50 m 100 m 400 m Stroke length Stroke pace
Jones *et al.*, 2017	12	F = 2 M = 10	19.4 ± 1.1	6	International	Bench Press, press, bench pull, shoulder press, chin-ups, and squat 4-5x (5-8) rep at 85-90% of MR	Turns 5 m
Girold *et al., 2012*	24	F = 12 M = 12	21.8 ± 3.9	4	National	Chin-ups and draws with pulleys 3x3 rep at 80-90% of the MR	50 m Stroke length Stroke pace
Girold *et al.*, 2007	21	F = 11 M = 10	16.5 ± 3.5	12	National	Bench press, chin-up, draw with barbells, squat and jumps 6 rep at 80-90% of MR	50 m Stroke length Stroke pace
Strass,1988	19	F = 2 M = 17	16.6 ± 1.2	6	National	Arm extensor muscles using weights 3x (3/90%MR-2/95% MR-1/100%MR)	25 m 50 m Stroke length Stroke pace
Schumann *et al.,* 2020	16	F = 6 M = 10	15.1 ± 1.1	7	International	Squat, dead weight, bench press and chin-ups 4x (3-4) rep at 85-90% of MR	5 m 10 m 15 m 400 m Starting reaction
Amara *et al.*, 2021	33	F = 0 M = 33	16.1 ± 1.2	9	National	Bench press and press 3-4-5 x (3-4-5) rep at 85-90% of the MR	25 m 50 m Time Starting reaction

F: female; Kg: kilogram; M: male; m: metres; Rep: repetitions; MR: maximum repetition.

The research carried out by Schumann *et al.*[35] did not demonstrate significant changes in the time over 400 metres freestyle during the intervention in either group. Regarding the speed over 5 metres and 15 metres, there were no significant changes in the experimental group, although the control group tended towards statistical significance ($P = 0.054$). Over 10 metres, performance improved (3.6%) in the experimental group ($P = 0.039$) but not in the control group. Similarly, after a maximum strength training intervention, Amara *et al.*[36] identified positive and significant effects on the 25 metres freestyle ($P < 0.001$) with a decrease in time from 13.52 ± 0.56 to 12.76 ± 0.54 seconds and in the 50 metres freestyle ($P < 0.001$) with a significant time improvement (Pretest 26.91 ± 1.29 and Post-test 25.20 ± 1.26 seconds) while no significant differences were found in the control group. Strass[37] also found positive effects of a maximum strength intervention using the arm extensor muscles, in average speed over 25 metres freestyle ($P < 0.001$) and at a distance of 50 metres freestyle ($P < 0.001$) with an average speed from 1.77 ± 0.08 to 1.81 ± 0.08 m/s. The control group did not demonstrate significant changes in the parameters for the swimming disciplines between pre and post measurements.

On the other hand, the study by Born *et al.*[38], did not find any significant differences between the pre and post split times over 5, 10, 15 and 25 metres ($P = 0.65$, 0.64, 0.53, and 0.74, respectively), but the peer comparison indicated an improvement over 5 metres ($P = 0.02$), 15 metres ($P = 0.03$) and 25 metres ($P = 0.01$). Similarly, Jones *et al.*[39], did not observe any effects in the time measured over the first 5 metres.

The studies related to stroke frequency in maximum strength training feature in Table 4. In the research by Aspenes *et al.*[14], there were no changes in the stroke frequency in the experimental group (0.953 vs 0.930 Hertz), or in the control group (0.885 vs 0.872 Hertz). Furthermore, in the study by Girold *et al.*[24], no significant differences were found in the stroke frequency in the experimental group for maximum strength, although they were found in the control group

Table 3. Effects of a maximum strength training programme on swimming speed.

Study	Measurement	Results
Aspenes, 2009	50 metres (s)	*P* = 0.11
Aspenes, 2009	100 metres (s)	*P* = 0.12
Aspenes, 2009	400 metres (s)	*P* <0.05*
Girold, 2007	50 metres (s)	*P* <0.05*
Girold, 2012	50 metres (s)	*P* <0.05*
Schumann, 2020	5 metres (s)	*P* = 0.054
Schumann, 2020	10 metres (s)	*P* = 0.039*
Schumann, 2020	15 metres (s)	*P* = 0.054
Schumann, 2020	400 metres (s)	*P* >0.05
Amara, 2021	25 metres (s)	*P* <0.001*
Amara, 2021	50 metres (s)	*P* <0.001*
Strass, 1988	25 metres (s)	*P* <0.001*
Strass, 1988	50 metres (s)	*P* <0.001*
Born, 2020	5 metres (s)	*P* = 0.65
Born, 2020	10 metres (s)	*P* = 0.64
Born, 2020	15 metres (s)	*P* = 0.53
Born, 2020	25 metres (s)	*P* = 0.74
Jones, 2017	5 metres (s)	*P* >0.05

p <0.05: significant; *:significant; s: seconds.

Table 4. Effects of a maximum strength training programme on stroke frequency in swimming.

Study	Measurement	Results
Aspenes *et al.,* 2009	Stroke frequency (Hz)	*P* >0.05
Girold *et al.,* 2007	Stroke frequency (c*m)	*P* >0.05
Girold *et al.,* 2012	Stroke frequency (c*m)	*P* >0.05
Strass, 1988	Stroke frequency (c*m)	*P* <0.05*↓
Born *et al.*, 2020	Stroke frequency (c*m)	*P* >0.05

p <0,05: significativo; *:significativo; ↓: Disminución; c*m: ciclo*min; Hz: Hertz.

(*P* <0.05) from week 0 (47.8±3.7 cycle*min) to week 12 (48.7±3.7 cycle*min). The same authors[29] did not find a significant result in the increase of stroke frequency after eight weeks of maximum strength training in the experimental group[30]. A significant result was demonstrated in the study by Strass[32], as the stroke frequency dropped from 55.0 ± 4.0 to 53.5 ± 3.4 cycle*min both in the 25 metres freestyle (*P* <0.05) and in 50 metres freestyle (*P* <0.05) in the experimental group (56.7 ± 3.2 to 54.7 ± 3.6 cycle*min). However, in the study by Born *et al.*[33], there were no significant changes in the stroke frequency in the experimental group.

Table 5 summarizes the studies related to the effects of maximum strength training on stroke length. In the study by Aspenes *et al.*[9], no significant changes were seen in the stroke length for the experimental group in men (pretest 1.68 and post-test 1.73 metres), although it was seen in women (1.61 vs 1.78 m in pretest and post-test, respectively).

Girold *et al.*[24] did not demonstrate significant effects on swimmers' stroke length after 6 weeks, nor after 12 weeks of maximum strength training. A subsequent paper by Girold *et al.*[29] found significant results (*P* <0.05) in the stroke length, which increased in the experimental group from 2.05 ± 0.01 to 2.11 ± 0.08 metres[25].

On the other hand, the study by Strass[32], identified increases in the average values for stroke length (*P* <0.01) both in the 25-metre distance (2.01 ± 0.24 to 2.16 ± 0.26 metres) and over 50 metres (1.88 ± 0.10 to 2.01 ± 0.24 metres). These values correspond to an average increase of 3.9% over 25 metres and 4.1% over 50 metres. Furthermore, the results from Born *et al.*[33] demonstrated a drop in stroke length, although not significant, from 2.04 ± 0.12 to 2.02 ± 0.14 metres after maximum strength training.

The studies related to the effects of maximum strength training on the turn time and the starting reaction are shown in Table 6. Schumann *et al.*[30] found that there were no significant changes in the reaction time on the starting blocks in both groups (*P* >0.05), either experimental or control, while Amara *et al.*[31] revealed significant changes in the starting reaction (*P* <0.001) of the experimental group after 9 weeks of maximum strength training. On the contrary, Born *et al.*[33], did not find significant changes in the reaction time in the experimental group after 6 weeks of intervention. Table 7 shows studies related to the effects of maximum strength training on swimmers' turns.

According to Amara *et al.*[31], the swimmers' turn time dropped significantly (*P* <0.001) after the subjects followed a strength programme,

Table 5. Effects of a maximum strength training programme on stroke length in swimming.

Studies	Measurement	Results
Aspenes *et al.,* 2009	Stroke length (m)	*P* >0.05
Girold *et al.,* 2007	Stroke length (m)	*P* >0.05
Girold *et al.,* 2012	Stroke length (m)	*P* <0.05*↑
Strass, 1988	Stroke length (m)	*P* <0.01*↑
Born *et al.*, 2020	Stroke length (m)	*P* >0.05

P <0.05: significant; *:significant; ↑: Increase; m: metres.

Table 6. Effects of a maximum strength training programme on starting reaction and turning in swimming.

Studies	Measurement	Results
Schumann, 2020	Starting reaction (s)	*P* >0.05
Amara, 2021	Starting reaction (s)	*P* <0.001* ↓
Born, 2020	Starting reaction (s)	*P* >0.05
Amara, 2021	Turning time (s)	*P* <0.001*↓
Jones, 2017	Turning time (s)	*P* >0.05

P <0.05: significant; *:significant ↓: Decrease; s: seconds.

Table 7. Effects of a maximum strength training programme on turning in swimming.

Studies	Measurement	Results
Amara, 2021	Turning time (s)	P <0.001*↓
Jones, 2017	Turning time (s)	P >0.05

P <0.05: significant; *:significant; ↓: Decrease; s: seconds.

while the study by Jones *et al.*[34] found no significant changes in the turn time six weeks after the maximum strength training programme.

Discussion

This systematic review exhaustively examines the effects of a maximum strength training programme on variables associated with swimmers' performance such as average swimming speed, stroke frequency, stroke length, starting reaction and turn time. The results of this review revealed that maximum strength training has a significant effect on swimming performance, particularly on the average speed in short disciplines, such as 25 and 50 metres freestyle. Great variability was observed between the exercises and intensities proposed in the various study protocols, and their methodology. The results of this systematic review are considered important because many trainers use this strength training method in their planning to attain better performance in the water.

Swimming speed

Swimming speed is the product of stroke frequency and stroke length5. This variable was studied after a training programme to improve maximum strength by several authors over short distances from 5 metres to 100 metres[9,24,29-34] and also over middle distances of 400 metres[9,30]. The speed over these distances is related to an improvement in strength as shown by Amaro *et al.*[35], and Marques *et al.*[36], who also assessed short swimming distances on completion of their high intensity physical conditioning interventions. Similar findings can be seen in works by Lopes *et al.*[37] and Amara *et al.*[38], where they analyse the effects of concurrent training among swimmers and the distances used to measure swimming speed ranged from 25 to 100 metres. In the same way, freestyle was the stroke most used by these studies when measuring swimming performance.

The performance or increase in swimming speed is measured by a drop in the time taken to swim the different distances. This review provides different results depending on the distance and the author. Significant improvements were seen in the times over 50 m freestyle in four[24,29,31,32] out of the five studies compiled. Regarding the 25-metre freestyle distance, two studies demonstrated an improvement in performance[31,32], and one showed no change[33], while over short distances from 5 to 15 metres only Schumann *et al.*[30] identified significant improvements in swimming speeds over 10 m. The effects of this type of training in longer races, such as 400 m, have been researched to a lesser extent with inconclusive results[9]. These results are reflected in the systematic review by Muniz *et al.*[39], where they analysed the power and strength training, finding that strength training on the body's limbs and upper torso, as part of the swimmer's training programme, seems crucial to improve propelling forces used in the water.

Consequently, these results might indicate that a general increase in strength, in this case with maximum strength exercises, leads to improvements in swimming performance, particularly over the short distances of 25 and 50 metres freestyle. However, over much shorter distances no improvements were identified, perhaps because in shorter spaces, actions with a more neuromuscular and coordinative component, such as starting speed from the blocks or subaquatic waves play a more important role[40]. Distances over 50 metres have not been studied as much, so more articles are required to analyse the effects of maximum strength over these distances. In practical terms, it might therefore be necessary for the trainers to include weeks of mainly maximum strength training in their schedules for swimmers specialising in short distances.

Stroke frequency

We can understand stroke frequency as the number of stroke cycles that the swimmer makes every minute (cycles/min) or the time that they require to complete one stroke cycle (time/cycle)[2]. In freestyle and backstroke, a stroke cycle is composed of two strokes. This variable is very important in speed competitions in swimming as a higher stroke frequency is related to better performance when competing[13], as the swimming speed is the result of the stroke frequency and the stroke length[5]. Four studies compiled in this review show that stroke frequency is not affected[9,24,29,33] and only one shows[32] a drop. This variable seems not to be affected by maximum strength training, maybe because these are regularly unspecific traditional movements in swimming, or perhaps because stroke frequency is a variable that changes very little during growth and does not vary much between amateur and professional swimmers[41].

Stroke length

The stroke length is the distance covered during each stroke cycle. It is calculated as the swimmer's displacement (in metres) during a stroke cycle[5]. Some prior studies observed significant increases in the stroke length[29,32] while other investigations did not find any changes in this variable[9,24,33]. In a similar way, the review carried out by Crowley *et al.*[14] identified improvements in performance related to increased stroke length on the one hand and improvements in swimming speed with no changes to the stroke length, on the other. In the same way, significant differences have been seen between amateur and professional swimmers' stroke length, where the latter cover a greater distance per stroke cycle[41]. In light of the results, it is not really clear if a maximum strength training programme affects the stroke length, but it does seem as though it might because some studies do not achieve significance, despite improvements, so more articles are required to analyse the effects of maximum strength on this variable.

Reaction time

The reaction time is the time between the starting signal and the swimmer's first movement on the blocks. Only three studies analysed this variable after a maximum strength intervention[30,31,33], and only one of them found an improvement in the starting reaction[31]. Thng *et al*.[40] stated that it is difficult to determine whether traditional or combined training might be more useful to improve the starting reaction. Therefore, the effects of a maximum strength training programme on the starting reaction are not clear, but it is possible that other more specific factors such as explosiveness and reaction have a more important role to play than maximum strength.

Turns

This systematic review only found two studies[31,34] which related maximum strength training to performance in turns and only one revealed significant outcomes showing an improvement in turning performance[31]. Hermosilla *et al*.[42] performed a review where they analysed the effects of various strength programmes on turns. They discovered that high intensities between 85-100% of the MR have a positive effect on the power and force generated during the contact phase with the wall. They thereby concluded that training with maximum and sub-maximum loads might be more efficient to improve the performance on the propulsion. This leads us to consider that maximum strength exercises might help to improve turn performance. However, because very few studies which only measure contact time with the wall and not the distance covered after the propulsion were found and analysed in this review, the real impact of maximum strength on turns remains unknown.

Limitations

Some limitations can be identified within this study. Firstly, the methodological differences between some studies[32-34] and the low methodological quality of others[32] might affect the results. Secondly, the proposed maximum strength programmes use different intensities, volumes and exercises, which leads to a different magnitude of training load[14,24,29-33]. On the other hand, gender differences were not considered either and might affect the results. Furthermore, some studies use elite swimmers[31,33,34] who were experienced in strength training and might be doing concurrent training, which would possibly affect the physical response to these maximum strength stimuli.

Practical applications

Knowing how maximum strength training affects the various performance variables among swimmers makes it possible for trainers to produce more accurate schedules during the season and so better control adaptations to physical training and thereby improve performance in the water. In the same way, depending on the swimmer's profile (sprinter - semi endurance - endurance), the trainers might develop more specific sessions for these swimmers' goals and so improve their performance in competition.

Conclusions

The maximum strength training reveals positive effects on swimming speed over short distances as several studies show improvements in the performance of these disciplines. This type of strength programme could be beneficial for swimmers focused on speed, particularly over 50 m. On the other hand, as far as other kinematic variables are concerned, it seems that improving maximum strength might modify the stroke length, increasing its values without interfering with the stroke frequency. Finally, there is not enough evidence to state that performance in acyclic actions, such as turns and starts, improve significantly after a maximum strength training programme.

Conflicts of interest

The authors declare that there is no conflict of interest.

Bibliography

1. Aspenes ST, Karlsen T. Exercise-training intervention studies in competitive swimming. *Sports Med*. 2012;42:527-43.
2. Maglischo EW. *Natación. Técnica, entrenamiento y competición*. Badalona: Editorial Paidotribo. 2009.
3. Toussaint HM, Hollander AP. Energetics of Competitive Swimming: Implications for Training Programmes. *Sports Med*. 1994;18:384-405.
4. Lavoie JM, Montpetit RR. Applied physiology of swimming. *Sports Med*. 1986;3:165-89.
5. Barbosa TM, Costa MJ, Marinho DA. Proposal of a deterministic model to explain swimming performance. 2013.
6. Grosser M, Brüggemann P, Zintl F. *Alto rendimiento deportivo*. Ediciones Martínez Roca, S. A. 1989.
7. Tudor B, Carlo B. *Periodización del entrenamiento deportivo*. Badalona: Paidotribo. 2016.
8. Trappe SW, Pearson DR. Effects of weight assisted dry-land strength training on swimming performance. *J Strength Cond Res*. 1994;8:209-13.
9. Aspenes S, Kjendlie P-L, Hoff J, Helgerud J. Combined strength and endurance training in competitive swimmers. *J Sports Sci Med*. 2009;8:357-65.
10. Maunder E, Seiler S, Mildenhall MJ, Kilding AE, Plews DJ. The importance of "durability" in the physiological profiling of endurance athletes. *Sports Med*. 2021;51:1619-28.
11. Cancela Carral JM, Camiña Fernández F, Pariente Baglietto S. *Tratado de natación: de la iniciación al perfeccionamiento*. Badalona, Paidotribo. 2011.
12. Vasile L. Endurance training in performance swimming. *Procedia Soc Behav Sci*. 2014;117:232-7.
13. Fone L, van den Tillaar R. Effect of different types of strength training on swimming performance in competitive swimmers: A systematic review. *Sports Med Open*. 2022;8:19.
14. Crowley E, Harrison AJ, Lyons M. The impact of resistance training on swimming performance: A systematic review. *Sports Med*. 2017;47:2285-307.
15. Haff GG, Nimphius S. Training principles for power. *Strength Cond J*. 2012;34:2-12.
16. Saltin B, Gollnick PD. Skeletal muscle adaptability: Significance for metabolism and performance. *Comprehensive Physiology*. 1983:555-631.
17. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. *Sports Med*. 2016;46:1419-49.
18. Batalha N, Raimundo A, Tomas-Carus P, Paulo J, Simão R, Silva AJ. Does a land-based compensatory strength-training programme influences the rotator cuff balance of young competitive swimmers? *Eur J Sport Sci*. 2015;15:764-72.

19. Folgar M, Cárceles F, Román. J. *Entrenamiento en piragüismo de aguas tranquilas.* 2.0 Editora. 2014.

20. Tanaka H, Swensen T. Impact of resistance training on endurance performance: A new form of cross-training? *Sports Med.* 1998;25:191-200.

21. Vantorre J, Chollet D, Seifert L. Biomechanical analysis of the swim-start: a review. *J Sports Sci Med.* 2014;13(2):223-31.

22. Garrido N, Marinho DA, Reis VM, van den Tillaar R, Costa AM, Silva AJ, *et al.* Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? *J Sports Sci Med*. 2010;9:300-10.

23. Wirth K, Keiner M, Fuhrmann S, Nimmerichter A, Haff GG. Strength training in swimming. *Int J Environ Res Public Health.* 2022;19:5369.

24. Girold S, Maurin D, Dugué B, Chatard J-C, Millet G. Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *J Strength Cond Res.* 2007;21:599-605.

25. Muniz-Pardos B, Gomez-Bruton A, Matute-Llorente A, Gonzalez-Aguero A, Gomez-Cabello A, Gonzalo-Skok O, *et al.* Swim-specific resistance training: A systematic review. *J Strength Cond Res.* 2019;33:2875-81.

26. Urrútia G, Bonfill X. Declaración PRISMA: una propuesta para mejorar la publicación de revisiones sistemáticas y metaanálisis. *Med Clin (Barc)*. 2010;135:507-11.

27. da Costa Santos CM, de Mattos Pimenta CA, Nobre MRC. The PICO strategy for the research question construction and evidence search. *Rev Lat Am Enfermagem.* 2007;15:508-11.

28. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther.* 2003;83:713-21.

29. Girold S, Jalab C, Bernard O, Carette P, Kemoun G, Dugué B. Dry-land strength training vs. electrical stimulation in sprint swimming performance. *J Strength Cond Res*. 2012;26:497-505.

30. Schumann M, Notbohm H, Bäcker S, Klocke J, Fuhrmann S, Clephas C. Strength-training periodization: No effect on swimming performance in well-trained adolescent swimmers. *Int J Sports Physiol Perform*. 2020;15:1-9.

31. Amara S, Crowley E, Sammoud S, Negra Y, Hammami R, Chortane OG, *et al.* What is the optimal strength training load to improve swimming performance? A randomized trial of male competitive swimmers. *Int J Environ Res Public Health*. 2021;18:11770.

32. Strass D. Effects of maximal strength training on sprint performance of competitive swimmers. *Swimming science V.* 1988;149-156.

33. Born D-P, Stöggl T, Petrov A, Burkhardt D, Lüthy F, Romann M. Analysis of freestyle swimming sprint start performance after maximal strength or vertical jump training in competitive female and male junior swimmers. *J Strength Cond Res*. 2020;34:323-31.

34. Jones JV, Pyne DB, Haff GG, Newton RU. Comparison of ballistic and strength training on swimming turn and dry-land leg extensor characteristics in elite swimmers. *Int J Sports Sci Coach.* 2018;13:262-9.

35. Amaro NM, Marinho DA, Marques MC, Batalha NP, Morouço PG. Effects of dry-land strength and conditioning programs in age group swimmers. *J Strength Cond Res.* 2017;31:2447-54.

36. Marques MC, Yáñez-García JM, Marinho DA, González-Badillo JJ, Rodríguez-Rosell D. In-season strength training in elite junior swimmers: The role of the low-volume, high-velocity training on swimming performance. *J Hum Kinet.* 2020;74:71-84.

37. Lopes TJ, Neiva HP, Gonçalves CA, Nunes C, Marinho DA. The effects of dry-land strength training on competitive sprinter swimmers. *J Exerc Sci Fit.* 2021;19:32-9.

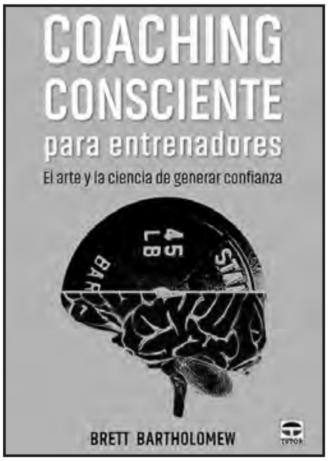
38. Amara S, Barbosa TM, Negra Y, Hammami R, Khalifa R, Chortane SG. The effect of concurrent resistance training on upper body strength, sprint swimming performance and kinematics in competitive adolescent swimmers. A randomized controlled trial. *Int J Environ Res Public Health.* 2021;18:10261.

39. Muniz-Pardos B, Gomez-Bruton A, Matute-Llorente A, Gonzalez-Aguero A, Gomez-Cabello A, Gonzalo-Skok O, *et al.* Nonspecific resistance training and swimming performance: Strength or power? A systematic review: Strength or power? A systematic review. *J Strength Cond Res.* 2022;36:1162-70.

40. Thng S, Pearson S, Keogh JWL. Relationships between dry-land resistance training and swim start performance and effects of such training on the swim start: A systematic review. *Sports Med.* 2019;49:1957-73.

41. Kjendlie P-L, Stallman RK, Stray-Gundersen J. Adults have lower stroke rate during submaximal front crawl swimming than children. *Eur J Appl Physiol.* 2004;91:649-55.

42. Hermosilla F, Sanders R, González-Mohíno F, Yustres I, González-Rave JM. Effects of dry-land training programs on swimming turn performance: A systematic review. Int *J Environ Res Public Health*. 2021;18:9340.



COACHING CONSCIENTE PARA ENTRENADORES

Por: Brett Bartholomew
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En el mundo de la fuerza y el acondicionamiento físico, aprender a cómo guiar a otros -no solo físicamente, sino también psíquica y emocionalmente- es prioritario para que estos obtengan los mejores resultados. En el rendimiento, las personas son la variable esencial, y comprender cómo combinar el conocimiento del propio entrenamiento con los matices de la conducta humana ayuda a los deportistas a conseguir sus metas definitivas. Lamentablemente, mientras que a la ciencia del entrenamiento físico se le ha prestado mucha atención, a la de la comunicación se le ha concedido muy poca. Este libro cubre esa brecha.

Los lectores aprenderán los principios fundamentales para mejorar las interrelaciones con los deportistas, incrementar su compromiso y ganar confianza mediante una comunicación dirigida. Y, lo que es más importante, quienes lean este libro adquirirán también estrategias para aplicar dichos principios en las diferentes situaciones de entrenamiento del día a día que, inevitablemente, van a producirse. El éxito de este libro innovador es que establece un escenario para que el entrenador cree una cultura de éxito, no solo dentro del mundo del deporte sino también fuera de él. Coaching Consciente es un movimiento al que le ha llegado su momento.

EL NEGOCIO DEL MOVIMIENTO

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Esta es la incómoda verdad: la cultura física de gran parte del mundo ha empeorado considerablemente, mientras que los campos de la salud y el *fitness* han aumentado sus beneficios para acabar brindando una ilusión de rehabilitación, preparación física y rendimiento deportivo.

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Campaña de aptitud física, deporte y salud

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.

EJERCICIO EN HIPOXIA PARA LA MEJORA DEL RENDIMIENTO

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20 kilos

Válido para realizar Ejercicio en Hipoxia

Datos Técnicos - Bioaltitude® V100

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MÉTODO: Separación del aire por método físico

AIRE HIPERÓXICO: Sí. hasta 15 L/min

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NIVEL SONORO: <50 dB

BOLSA DE EXPANSIÓN: Incluida. 60 litros de capacidad. Opcional hasta 240 litros.

TUBOS: 2 x 3 m

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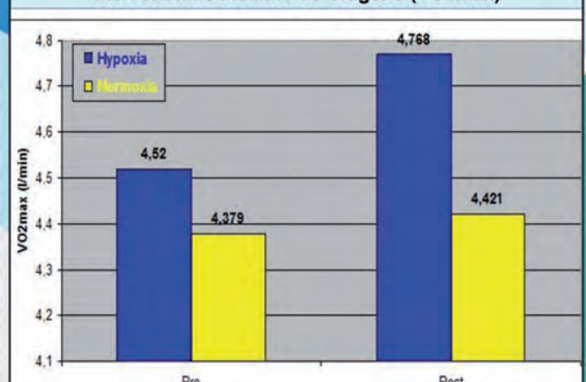

Basado en el estudio de **Dufour y col**: Exercise training in normobaric hypoxia in endurance runners. I. Improvement in aerobic performance capacity. Publicado en el ***Journal of Applied Physiology***

Influencia del Entrenamiento en Hipoxia
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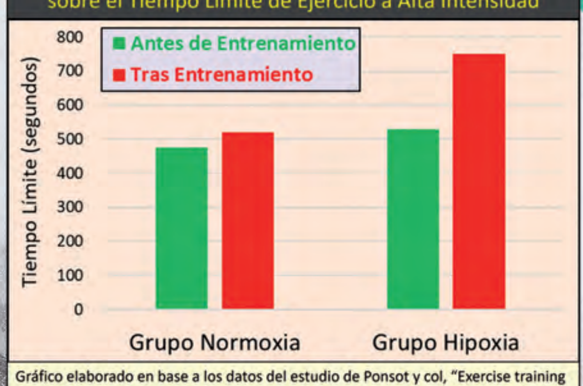

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