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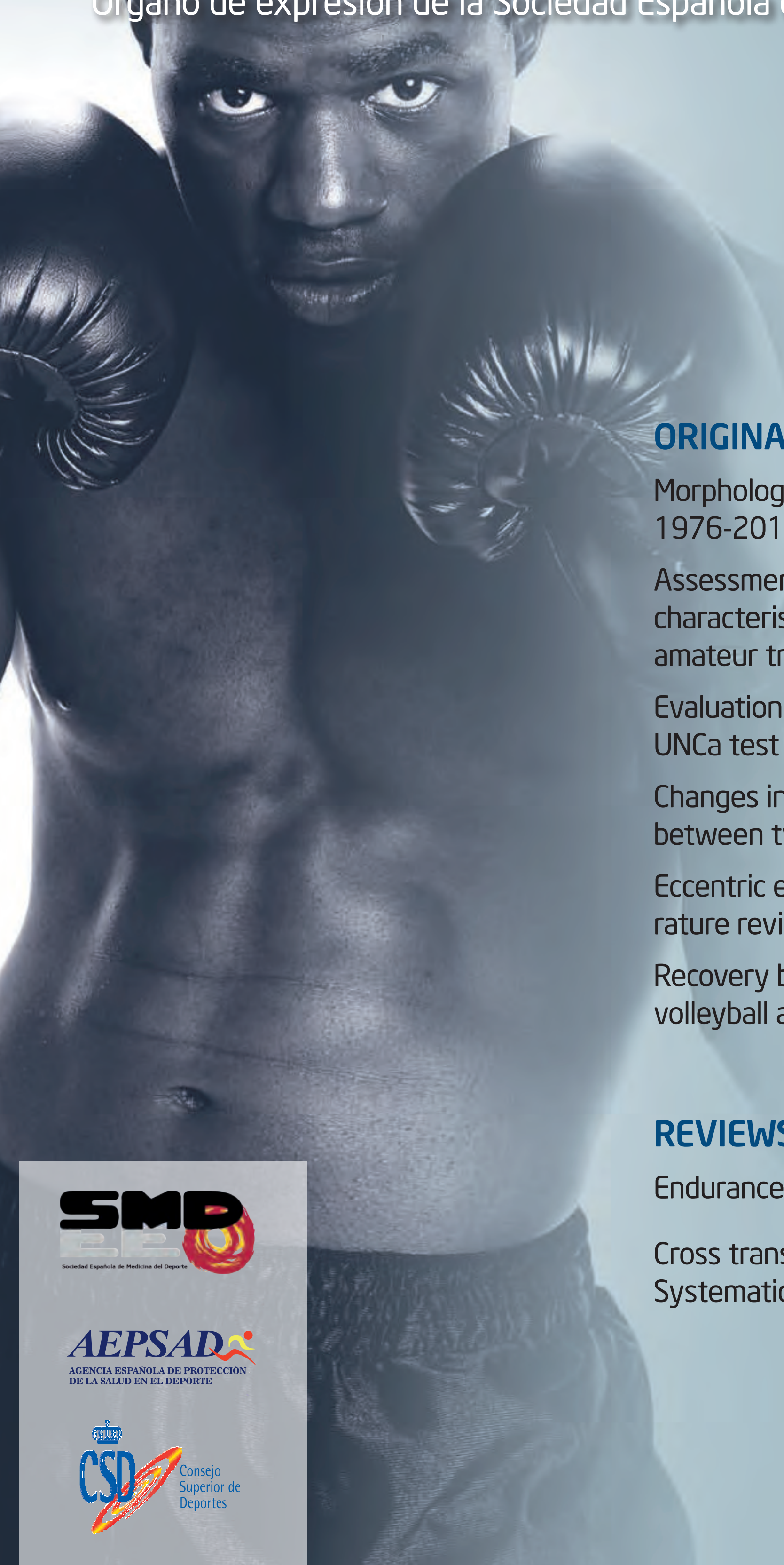

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Summary / Sumario

Understanding the composition of sports recovery drinks, a necessity for adequate prescription

Conocer la composición de las bebidas de reposición para el deporte, una necesidad para una adecuada prescripción

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For more than 30 years, research in the field of rehydration and recovery has been one of the priorities in the area of sports medicine, especially in sports practice. Such research has explored glucose, sodium and other minerals and vitamins, for example, focusing on a rapidly absorbable source of carbohydrates, such as glucose, sucrose or dextrins. It has also looked into sodium salts and other minerals. All of this in order to help achieve an adequate level of physical performance with an optimal supply of water and nutrients that are necessary for energy metabolism and human physiology in sports practice.

In this context, over the past 20 years, scientific consensus has been achieved in the European Union and its member countries, which have come to establish, based on scientific evidence, the necessary composition of recovery drinks. In 2001, the Scientific Committee on Food of the Directorate-General for Health and Consumers of the European Commission established a position *(Composition and specifications for carbohydrate-electrolyte solutions)* in which the composition requirements of a recovery drink were collected based on scientific evidence. According to this report, carbohydrates should be the majority source of energy in such beverages and they should be effective in maintaining and restoring hydration status. To achieve this, beverages should contain not less than 80-kcal/1000 ml and not more than 350 kcal/1000 ml, with at least 75% of the energy being carbohydrates with a high glycemic index such as glucose, dextrins and sucrose. These beverages must contain between 460 – 1,150 mg/1,000 ml of sodium. The composition must cover an osmolality range between 220 and 330 mOsml/kg of water, being considered an isotonic drink when in the range of +/- 10%, i.e. 270 – 330 mOsm/kg of water.

In 2015, a technical report by the *European Food Safety Authority* ratified the 2001 report of the *Scientific Committee on Food*. Particularly as concerns recovery drinks, the former underlined the role of hydration and carbohydrate supplementation in maintaining physical performance during high-intensity physical exercise, as well as the role of electrolytes (specifically sodium) in maintaining adequate hydration during physical exercise and for rehydration afterward. In addition, it reiterated the importance of other related nutrients with other physiological aspects such as thiamine (vit B1), pyridoxine (vit B6), long-chain polyunsaturated fatty acids, caffeine, and creatine as ergogenic aids.

In 2016, Pöchmüller *et al.* performed a systematic review and meta-analysis on the beneficial effects of carbohydrates with performance trials in randomized controlled competitions. They concluded that carbohydrates in a concentration range of 6-8% had a beneficial effect on male cyclists and that more research was needed as regards a wide variety of other exercises of a duration less than 90 minutes.

In line with the scientific evidence and the positioning of Food Safety authorities, the recommendations regarding the usefulness of recovery drinks with carbohydrates in sports and on the composition and guidelines for fluid replacement have been established and approved based on the consensus on sports drinks by Sports Medicine Societies in different countries.

In 2012, Manonelles P. established that athletes' hydration is a fundamental aspect within the different and diverse strategies to improve physical performance and avoid health problems. However, it is fitting to also keep in mind the important role of the temperature and relative humidity of the environment, since hydration guidelines are clearly

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modified as a result of such environmental conditions in certain sports and performance areas.

Sweating, as well as prolonged exertion, causes both losses of fluid and electrolytes that must be compensated through replacement drinks. Additionally, it requires the use of energy substrates that decrease and deplete muscle glycogen reserves. It is, thus, essential to account for both of these factors, ensuring that beverages have a specific composition to produce the desired effect of providing water, carbohydrates and electrolytes to athletes.

To be optimal, they must be used in suitable amounts and proportions in accordance with the type of physical effort, its duration and intensity. The aim being to guarantee an improvement in sports performance and avoid potential physiological problems and even pathologies related to heat.

In 2008, the Spanish Society of Sports Medicine, through its nutrition group, established a consensus on 5 general recommendations for fluid replacement composition and guidelines, in line with what had been established by the *Scientific Committee on Food* of the European Union. However, that consensus diverged from the latter as related to its recommendations for the time for fluid replacement, be it during sports practice or thereafter. The importance of hydration and carbohydrate and electrolyte replacement through beverages was highlighted, the values of which must appear on beverage labels. Their caloric value is recommended to be between 8/kcal/100 ml and 35 kcal/100 ml of which at least 75% must come from high glycemic load carbohydrates. Sodium content is recommended to be within the range of 46 mg/100 ml and 115 mg/100 ml. Osmolality should be between 200-330 mOsm/kg of water and always below a maximum of 400 mOsm/kg, with at least 75% provided by high glycemic load carbohydrates. Sports drinks used for immediate post-effort consumption must also have an amount of sodium ion between 92 mg / 100 ml and 115 mg / 100ml and a potassium intake in the range of 2-6 mmol/l. The conditions of osmolality should be the same as for beverages consumed during sports practice.

Indisputably, it seems that the scientific evidence on the requirements for replacement drink composition is clear, and not only thanks to the opinion of the scientific community. Indeed, in the European Union, the European Food Safety Authority has approved three health claims related to these properties, which the Commission, the Parliament and the Council included in Regulation 432/2012, either at the time of its publication or subsequently via amendments of that Regulation. As a result, health claims of such beverages can only be made if a beverage falls within the composition guidelines established in the applicable legislation, and under the conditions stipulated therein. Table 1 compiles these health claims and the conditions under which they can be considered to be met.

Conclusion

There is scientific evidence related to the ideal composition of replacement drinks both during and after training or competition. This scientific evidence has been approved by the *European Food Safety Authority* and included in Regulation 432/2012. The latter establishes a list of permitted health claims that can be made on foods, other than those referring to the reduction of disease risk and to children's development and health. It is essential to continue researching the composition of replacement drinks according to the physical exercise carried out, both by type of sports activity, duration, and intensity, while also taking into account different environmental conditions. Replacement drinks can be supplemented with other nutritional contributions and bioactive

Table 1. Health claims permitted by Regulation 432/2012.

Carbohydrate-electrolyte solutions	
Carbohydrate-electrolyte solutions contribute to the maintenance of endurance performance during prolonged endurance exercise	In order to bear the claim carbohydrate-electrolyte solutions should contain 80-350 kcal/L from carbohydrates, and at least 75 % of the energy should be derived from carbohydrates which induce a high glycaemic response, such as glucose, glucose polymers and sucrose. In addition, these beverages should contain between 20 mmol/L (460 mg/L) and 50 mmol/L (1,150 mg/L) of sodium, and have an osmolality between 200-330 mOsm/kg water.
Carbohydrate-electrolyte solutions enhance the absorption of water during physical exercise	
Carbohydrate solutions	
Carbohydrate solutions contribute to improved physical performance during high-intensity and prolonged physical exercise in trained adults	The claim may be used only for carbohydrate solutions which, in accordance with the instructions for use, provide between 30 and 90 g of carbohydrates per hour, where the carbohydrates concerned are glucose, sucrose, fructose or maltodextrin, under the following conditions: –Fructose (from fructose or sucrose) should not account for more than one third of all carbohydrates, and –Glucose (from glucose, sucrose or maltodextrin) should not exceed 60 g/h. The consumer shall be informed that only trained adults performing high-intensity (at least 65 % of VO_2max) and long-term (at least 60 min) physical exercise obtain the beneficial effect.

compounds that can provide an ergogenic aid. For all these reasons, it is essential that in all sports activities – and in the acts related to them – the drinks that accompany them must be replacement drinks. This is important both to facilitate adequate nutritional education in athletes and to be able to develop messages consistent with the nutritional recommendations and the physiological activities in which they are involved. There are components that are not recommended, such as carbon dioxide and alcohol and any other one that is not included within the composition guidelines. Moreover, these are also inherent and binding characteristics of a mutually exclusive character. All drinks that contain such properties, in addition to "zero" or "without" drinks, should not be presented as beverages related to hydration, replenishment and sport.

Editorial written based on the statement recently released by the Spanish Society of Sports Medicine on replacement drinks in sport.

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Original article

Morphological evolution of Cuban super heavyweight boxers, 1976-2014

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Summary

Objective: To evaluate the morphological changes of Cuban super heavyweight boxers, more and less successful, through the period 1976-2014.
Material and method: Thirty super heavy boxers, who were members of the Cuban national teams in the period 1976-2014, were compared; The strategy consisted of separating the group in the periods 1976-1989, 1990-1999, 2000-2009 and 2010-2014. Sixteen anthropometric dimensions were recorded (weight, height, sitting height, six skinfold thickness, five girths and two breadths), from which the body composition and the somatotype were obtained. The data were analyzed applying the Analysis of variance (ANOVA). The conglomerate analysis based on the Euclidean distance was used in order to evaluate the correspondence between physical development and sports performance. A discriminant analysis was carried out in order to analyze the contribution of the anthropometrical variables to the variance of different clusters.
Results: Most of the anthropometric dimensions and indicators showed significant differences, having an impact on the increase in adiposity, body fat and endomorphy ($p < 0.05$), as well as the decrease in the indicators dependent on height ($p < 0.05$). The analysis by conglomerates, as well as the study of the Migratory Distances of the somatotype, showed that the Olympic medalist boxers differed in terms of the characteristics of body composition and in terms of the intensity of the somatotype changes in the period 1976-2014.
Conclusions: The Cuban boxer of the super heavyweight category showed a wide range of morphological demands, but these were framed within the international trends of professional boxers. The morphological attributes of the Olympic medalists differed from each other, and from the rest of the boxers investigated over time. These results provide anthropometric data of high scientific value, both for selection and for medical control of training.

Key words:
Anthropometry. Body Composition. Somatotype. Boxing.

Evolución morfológica de boxeadores superpesados cubanos, 1976-2014

Resumen

Objetivo: Evaluar los cambios morfológicos de boxeadores superpesados cubanos, más y menos exitosos, a través del período 1976-2014.
Material y método: Treinta boxeadores superpesados, los cuales fueron miembros de las selecciones nacionales de Cuba en el periodo 1976-2014 fueron comparados; la estrategia consistió en separar el grupo en los periodos 1976-1989,1990-1999, 2000-2009 y 2010-2014. Se registraron 16 dimensiones antropométricas (peso, estatura, estatura sentada, seis paníĉulos adiposos, cinco perímetros y dos diámetros óseos), a partir de las cuales fue obtenida la composición corporal y el somatotipo. Las comparaciones fueron realizadas aplicando un Análisis de varianza (ANOVA). Fue empleado el análisis de conglomerado basado en la distancia euclidiana con el objetivo de evaluar la correspondencia entre el desarrollo físico y el resultado deportivo. Un análisis discriminante fue realizado con el objetivo de analizar la contribución de las variables antropométricas a la varianza de los diferentes clústeres.
Resultados: La mayoría de las dimensiones antropométricas e indicadores mostraron diferencias significativas, repercutiendo en el aumento de la adiposidad, grasa corporal y la endomorfia ($p<0,05$), así como la disminución de los indicadores dependientes de la estatura ($p<0,05$). El análisis por conglomerados, así el estudio de las Distancias Migratorias del somatotipo arrojaron que los boxeadores medallistas olímpicos se diferenciaron en cuanto a las características de la composición corporal y en cuanto a la intensidad de los cambios del somatotipo en el periodo 1976-2014.
Conclusiones: El boxeador cubano de la categoría superpesado mostró un amplio rango de demandas morfológicas, pero estas se enmarcaron dentro de las tendencias internacionales de boxeadores profesionales. Los atributos morfológicos de los medallistas olímpicos se diferenciaron entre sí, y del resto de los boxeadores investigados a través del tiempo. Estos resultados proporcionan datos antropométricos de elevado valor científico, tanto para la selección, como para el control médico del entrenamiento.

Palabras clave:
Antropometría. Composición Corporal. Somatotipo. Boxeo.

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Introduction

In the research carried out in Cuba on boxers, based on databases of more than 1,500 boxers participating in international competitions, their anthropometric profile is situated between the scope of 7.7 and 15.2% body fat, obesity lower than the 4th percentile channel for the most successful boxers, between 84.8% and 92.3% of fat-free mass, a predominantly balanced meso-mectomorphic or mesomorphic somatotype, as well as a relative predominance of limbs over trunk[1-3].

Related to boxing, research on the anthropometric characteristics in super heavyweights is scarce, since most studies usually make groupings out of convenience that include such subjects within very heterogeneous groups of competitive categories that are usually those greater than 81kg[1,4-8].

The morphological profile of Cuban super heavyweight boxers could constitute a characteristic model of the successful boxer in this competitive category. This proposition is reinforced by the international record achieved in the period 1972-2014, during which the country garnered 10 youth world titles, 11 Pan American Games titles, 9 world seniors championships, as well as 5 Olympic golds of the 12 awarded in the Olympics since 1972[9].

Norton *et al.* evaluated data from other authors and concluded that, on average, the modern super heavyweight champion is taller and heavier than predecessors from the beginning of the century. However, related to larger boxers, they suggested that the advantages of greater absolute muscle power in striking are not as great as the disadvantages regarding speed and agility[10].

Achieving morphological optimization is a higher level of sports development that has been defined as: "the achievement of an optimal physical structure, somatotype and body composition that allows greater efficiency in sports performance"[10]. This phenomenon takes place within and through the generations. Indeed, athletes' morphologies are susceptible to improve when they move up to a higher competitive level and simply in accordance with sports development throughout the decades. The result of which is a new conceptual model, via adaptive evolution, for the biomedical monitoring of athlete training[11].

The phenomenon of morphological evolution in super heavyweight boxers has been scarcely documented in the specialized literature. Thus, the objective of this work is to evaluate the morphological evolution of Cuban super heavyweight boxers—the successful and lesser so—during the period 1976-2014.

Material and method

This is a descriptive, longitudinal and retrospective study.

Boxers were evaluated in the pre-competitive stage of preparation.

Sample

A total of 30 boxers of the super heavyweight category between 20 and 29 years old (24.2± 3.2), members of Cuba's national boxing teams. Their sporting age was between 9 and 17 years (13.2 ±4.0). Only those with at least one international participation between the Olympic cycles between 1976 and 2014 were selected. The periods compared were: 1976-1989 (n=6), 1990-1999 (n=7), 2000-2009 (n=7) and 2010-2014 (n=10).

The sample consisted of 16.6% Olympic medalists, 16.7% world champions, 33.3% Pan American champions, 16.7% youth world champions. Of those evaluated, 56.6% (n=17) were average boxers (Pr.), with no relevant record at the Pan American, world or Olympic level.

Experimental design

The ethics committee of Cuba's Sports Medicine Institute approved the use of the data for this study as the research was carried out with respect for the principles established by the Declaration of Helsinki[12].

The technical staff of the Department of Cineanthropometry of Cuba's Sports Medicine Institute, where the national reference laboratory for Advancement in Cineanthropometry is located, performed the evaluations.

The selected anthropometric dimensions were evaluated according to the methodology used in the 1976 Montreal Olympic Games Anthropological Project (MOGAP)[13].

The dimensions evaluated were: (1) body weight (kg), height (cm), sitting height (cm); (2) six adipous panicles (mm): triceps, subscapular, supraspinal, abdominal, thigh and leg; (3) five circumferences (cm): normal chest, waist, flexed arm, mid-thigh and medial calf; (4) two bone diameters (cm): humerus and femur. The equipment used included the balance (Detecto, USA) of 0.1 kg precision for the measurement of body weight; a stadiometer (Holtain, UK) of 0.1 mm precision for height and sitting height; four panicle meters (10g/m^3) of 0.2 mm precision (Holtain, UK); two precision thickness gauges of 1mm precision to determine bone diameters and three tape measures of 1mm precision (Holtain, UK) to measure circumferences.

From the anthropometric dimensions obtained, the body mass index (BMI) of each pugilist was determined using the formula: weight (kg)/height (m)^2. Body composition (BC) was analyzed via the sum of the six panicles (mm) used, as well as a regression equation obtained from the data of Withers et al. from 1987. From this, body density was obtained, from which the percentage of fat, kilograms of fat and kg of active body mass were derived. The Active Body Substance Index was calculated using the formula: active body mass/height (cm/g^3)[14]. The formula used to obtain the percentage of fat from body density (BD) was as follows[13].

$$BD = 1.1026 - 0.00031*(Age) - 0.000036*(S6p)$$

R^2=0.738; EEE=0.00579g/cm^3 and 2.5%;

Application range: 15-39 years

S6p being the sum of the subscapular, triceps, supraspinal, abdominal, mid-thigh and calf skinfolds. R^2: formula coefficient of determination. EEE: Standard Error of the Estimate.

The analysis of the Heath–Carter anthropometric somatotype included determining its components, plotting them in the somatochart, as well as determining the Somatotype Altitudinal Distance (SAD) and the Migratory Distances (DM), which allowed the dispersion of the individual somatotype to be determined with respect to the group and the intensity of related changes through the decades[15].

Statistical analysis

A descriptive analysis of the data was performed to calculate central tendencies and dispersion (mean ± standard deviation). The relative amounts of the somatotype categories were also obtained.

The Somatotype Altitudinal Distance was converted into the Somatotypical Altitudinal Mean (MAS) by estimating its average. Individual estimates of the Somatotype Altitudinal Distance for Olympic medalists of each period were compared to the Somatotypical Altitudinal Mean of their period.

For each variable, an analysis of variance (ANOVA) was performed to verify the assumption of equality of means between the competitive periods 1976-1989, 1990-1999, 2000-2009 and 2010-2014. For each variable analyzed, the assumptions of randomness, normality and homogeneity of variance were verified through the tests of runs, Shapiro-Wilk and Levene, respectively. Welch's robust mean comparison test was used to analyze five variables where the assumption of normality was not met (sitting height, supraspinal skinfold, mid-thigh skinfold, obesity, fat percentage). Multiple Bonferroni and Games-Howell comparisons were used to determine the magnitude of significant differences between competitive periods.

In order to assess the correspondence between physical development and sports outcome, cluster analysis was used employing the Ward agglomeration method and Euclidean distances as a measure. The analysis included the 16 studied dimensions, body composition indicators and somatotype. For this procedure, the athletes were categorized according to their track record: average boxer (Pr.), Pan American champion (CP), Olympic medalist (MO), Olympic champion (CO), junior world champion (CMJ) and junior world medalist (MMJ).

A discriminant analysis, with Ward scores as an independent variable, was used as an exploratory technique to define which variables contributed most to the variability between the clusters obtained. Stepwise regression was used for this analysis.

The statistical processing of the data was carried out with the IBM SPSS statistical package, version 21.0 (Inc, Chicago, Illinois, United States) for Windows. The level of significance set for all contrasts was $p<0.05$.

Results

Table 1 shows the descriptive statistics (mean± standard deviation) for the evaluated anthropometric dimensions, the results of the analysis of variance, and the post hoc multiple comparison test.

Of the 16 anthropometric dimensions, only six showed significant differences when contrasting the studied periods. The boxers studied were significantly different in height, supraspinal, abdominal and mid-thigh skinfolds, waist and mid-thigh circumferences ($p<0.05$).

The multiple post hoc comparison revealed that the boxers of the period 1976-1989 (A) were significantly taller than those of the periods 2000-2009 (C) and 2010-2014 (D); they also had a smaller supraspinal, abdominal, and mid-thigh skinfold, in addition to waist circumference than those of the other competitive periods ($p<0.05$). Regarding the circumference of the thigh, it was only significantly different from the other groups (A, B, D) in the period 2000-2009 (C).

Table 2 shows the characteristics of the BC and the somatotype in each of the evaluated stages, as well as the results of the analysis of variance and the post hoc test.

Table 1. Mean and standard deviation (mean ± standard deviation) of the anthropometric dimensions of super heavyweight boxers by generations.

	1976-1989 (N=6)	1990-1999 (N=7)	2000-2009 N=7	2010-2014 N=10	Sig.	*Post hoc* Test
Weight	100.7±5.2	103.0±7.1	104.4±8.6	104.9±8.5	0.160^{ns}	
Height	193.2±3.9	192.5±5.5	189.5±7.7	189.2±5.1	0.03*	A,B *vs* C,D
Sitting height	95.8±2.6	94.7±2.6	95.5±3.3	94.5±1.4	0.433^{ns}	
Adipous panicles						
Subscapular	13.0±2.2	16.4±6.4	14.6±4.9	17.4±6.6	0.07^{ns}	
Triceps	9.8±2.7	11.6±6.3	13.0±4.5	14.4±5.5	0.144^{ns}	
Supraspinal	9.8±2.6	11.0±5.7	11.6±4.6	12.6±6.0	0.04*	A *vs* B,C,D
Abdominal	13.4±4.3	18.2±9.9	16.6±3.4	25.0±11.7	0.02*	A *vs* B.D
Mid-thigh	9.4±2.0	14.0±6.0	15.8±3.7	16.0±9.3	0.004*	A *vs* C
Medial calf	7.8±3.2	10.1±4.0	12.1±4.1	11.2±2.0	0.07^{ns}	
Perimeters						
Normal thorax	106.8±2.3	108.0±2.9	111.7±1.9	107.2±1.8	0.302^{ns}	
Flexed arm	37.6±1.11	38.2±1.50	39.0±2.6	37.9±1.2	0.421^{ns}	
Waist	86.5±0.8	88.8±4.5	90.1±0.2	89.7±2.7	0.007*	A *vs* C, D
Mid-thigh	58.9±1.7	60.9±2.9	63.9±4.2	56.6±5.6	0.04*	C *vs* A,B,D
Middle leg	40.6±2.8	41.0±3.4	41.9±5.1	41.4±4.3	0.715^{ns}	
Diameters						
Humerus	7.5±0.90	7.7±0.64	7.6±0.63	7.6±0.61	0.976^{ns}	
Femur	10.3±0.22	10.4±0.44	10.5±0.50	10.6±0.48	0.758^{ns}	

*p<0,05; ^{ns}: p>0,05; A:1976-1989; B:1990-1999; C:2010-2009; D:2010-2014

With the exception of body mass index, active body mass and mesomorphy, all indicators showed significant differences between competitive periods after the analysis of variance (p<0.05). In turn, the multiple post hoc comparison tests revealed that the super heavyweight boxers of the period 1976-1989 (A) had a significantly lower sum of skinfolds, percentage, kilograms of fat, active body substance index and endomorphy than those of other competitive periods (p<0.05). The boxers of the period 1976-1989 revealed a significantly higher ectomorphy than those of other competitive periods (p<0.05).

The average somatotype in each of the studied periods was mesoendomorphic; the average super heavyweight became increasingly endomorphic and mesomorphic, while ectomorphy became less represented. From the qualitative point of view, 66.7% of the boxers were mesoendomorphic, 20% balanced mesomorphic, in addition to some mesomorphic-endomorphic (6.6%), mesoectomorphic (3.3%) and endomesomorphic (3.3%) types.

By comparing the Somatotypical Altitudinal Mean to the Somatotype Altitudinal Distance of the Olympic medalists in each period, it was found that while the somatotype was relatively homogeneous in all periods (MAS <2), the somatotype of the medalists differed more and more from the average of the boxers within their period (SAD>SAM). This difference became more marked as time advanced, given that the medalists' estimates were 1.82; 2.24; 2.71 and 2.93 for the periods 1976-1989, 1990-1999, 2000-2009 and 2010-2014, respectively.

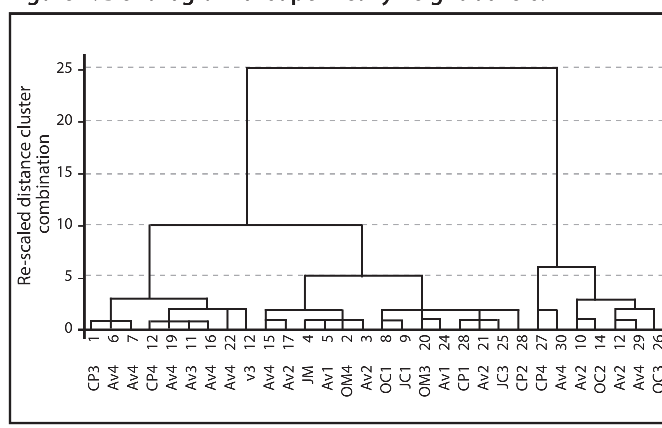
The dendrogram in Figure 1 was obtained through a cluster analysis. Each subject was considered individually in this analysis. All subjects' differences were analyzed with respect to the subjects assigned to the different clusters. Three clusters were derived from this analysis, defined as follows: CP3 to Pr3 (cluster 1), Pr4 to CP2 (cluster 2), and CP4 to CO3 (cluster 3).

To determine the optimal number of clusters, the agglomerations schedule produced by the analysis was observed to show at what stage the first sudden acceleration in cluster formation occurred. The union of case 1 with case 2 was chosen where the inflection was found with a coefficient of 436, 662.

A distinguishing note regarding the different clusters is that all boxers from the period 1976-1989 appeared in cluster 2; those from 2010 to 2014 were distributed in the two extreme clusters (cluster 1 and 3). Another trend found is that 61.5% (n=8) of the medalists were in cluster 2; cluster 1 included only 15.3% (n=2) and cluster 3 included the remaining 23.5% (n=4). Cluster 1 included the most average boxers (Pr.), accounting for 41.2% (n=7); cluster 2 included 35.3% (n=6), and cluster 3 was made up of 23.5% average boxers (n=4).

The discriminant analysis yielded a single significant canonical function that explained 100% of the variance in the clusters based on the sum of the six adipose panicles (λ = 0.088; gl=2; p =0.000; canonical correlation=0.955). Wilks' lambda test for differences in equality between

Figure 1. Dendrogram of super heavyweight boxers.



Av: average boxer; PAC: Pan American champion; OM: Olympic medalist; OC: Olympic champion; JC: Junior world champion; JM: Junior world medalist; 1: 1976-1989; 2: 1990-1999; 3: 2000-2009; 4: 2010-2014.

Table 2. Body composition, somatotype and altitudinal distance from the somatotype.

	1976-1989 (N=6)	1990-1999 (N=7)	2000-2009 N=7	2010-2014 N=10	Sig.	*Post Hoc* Test
Body composition						
Body mass index	27.0±2.1	27.8±1.4	29.1±2.9	29.3±3.1	0.195^{ns}	
Sum of 6 fatty skinfolds	63.4±11.6	73.8±30.5	80.7±22.9	95.2±34.4	0.03*	A *vs* C,D
Fat percentage (Withers et al.)	11.7±1.7	12.8±4.8	14.1±3.6	16.7±5.7	0.04*	A *vs* C,D
Kg of fat	11.8±2.0	13.2±5.2	14.8±4.7	16.1±7.6	0.04*	A *vs* C,D
Kg Active body mass	88.9±3.8	89.8±6.8	89.5±6.8	88.5±4.0	0.965^{ns}	
Active body substance index	1.23±0.11	1.26±0.05	1.32±0.11	1.31±0.10	0.04*	A *vs* C,D
Somatotipo						
Endomorphy	2.9±0.68	3.1±1.37	3.4±1.30	4.2±1.30	0.007*	A **vs** D
Mesomorphy	5.2±1.37	5.5±0.65	5.7±0.98	6.2±1.21	0.349^{ns}	
Ectomorphy	1.8±0.90	1.5±0.61	1.2±0.77	1.2±0.91	0.01*	A *vs* B,C,D
Homogeneity indices						
Mean altitudinal somatotype	1.81±0.63	1.5±0.57	1.47±0.70	1.87±0.95	0.04*	A *vs* B,C

*p<0,05; ^{ns}: p>0,05; A¨1976-1989; B:1990-1999; C:2010-2009; D:2010-2014 group means showed that the clusters differed significantly in terms of the sum of the six adipose panicles (p<0.05). The stepwise inclusion method discarded the rest of the variables included in the research as independent variables.

Figure 2a shows the general distribution of the studied group. The average trend throughout the studied periods is shown in Figure 2b; it was found that the average somatotype became increasingly endomorphic and mesomorphic over time. Figure 2c only reflects the Olympic medalists of each period; the same evolution as in Figure 2b was not found. This last aspect was quantified based on the estimate of the DM, which evidenced a low-intensity evolution for the average somatotype between the periods (MD = 1.88 units) with respect to 2c; the intensity of change in somatotype for medalists was 4.05 times higher than the group average (MD=7.62 units).

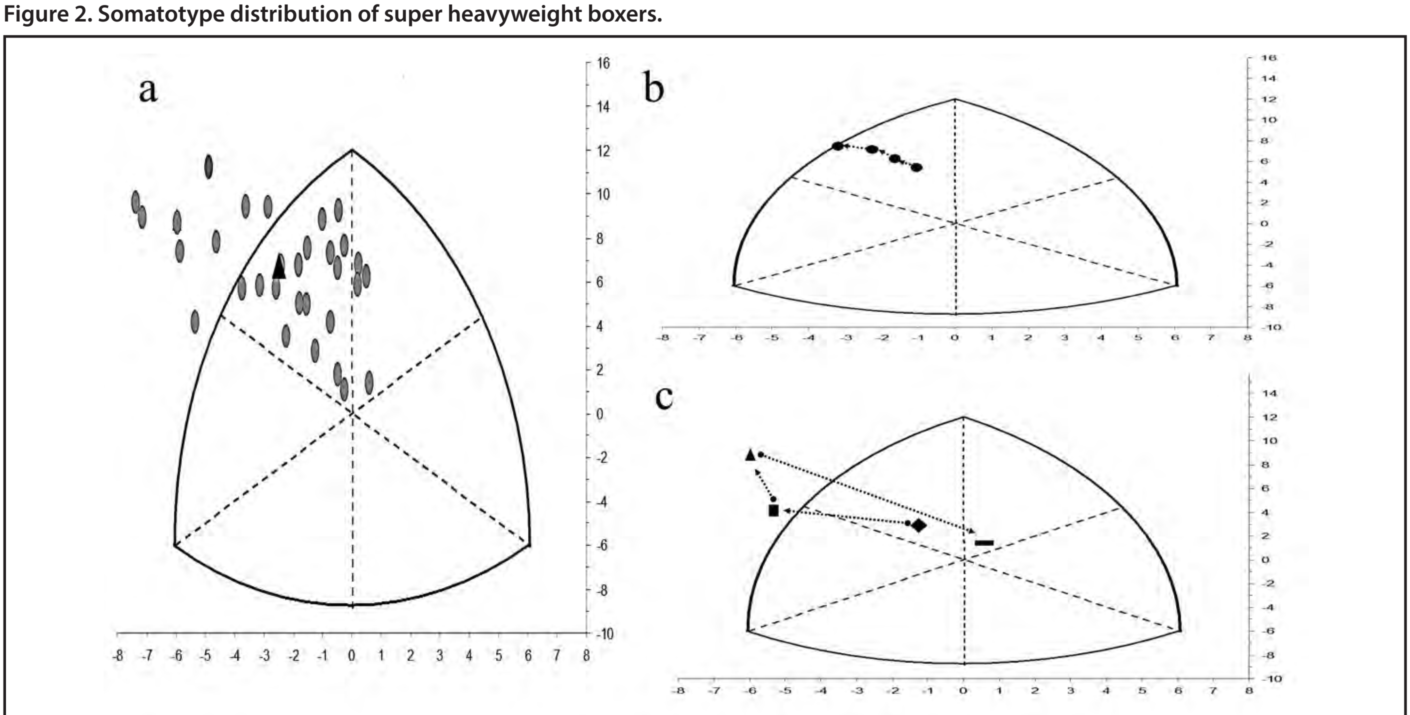
Discussion

Based on the research carried out in the main international databases (PubMed, Scopus, Scielo), only one anthropometric study was found related exclusively to boxers of the super heavyweight category, but it addressed aspects related to the morphological evolution of professional boxers[16]. Therefore, the present work could be the first to address the characteristics of physical development and its evolution in amateur elite boxers of the super-heavyweight category. The result contributes knowledge regarding elite boxers' anthropometric characteristics, especially since the analyzed sample was made up of athletes with broad competitive achievements at an international level.

By analyzing a series of data provided by Norton and Olds on the evolution of athletes in the twentieth century[17], as well as the research carried out by Han *et al.*[16] on the evolution of super heavyweight boxers in the period 1889-2019, the authors of this study consider that the weights and heights of the average Cuban super heavyweight did not differ from those found in the examined professional boxers. One of the causes for this may be that, while at the international level, height and weight increases were obtained over the years, according to the aforementioned authors, the average Cuban pugilist had already achieved optimized values for these variables in the 1970s.

This research demonstrates that the competitive success of the boxers studied was related to a wide range of morphological demands. But when reviewing other research, it was found that these characteristics were within the morphological variability of professional boxers internationally. For instance, in Han *et al.*[16], lower results were obtained for body weight (97.5±11.5 kg) and height (187.3±6.5 cm), but were similar in BMI (27.8±2.4 kg/m^2) for international professional boxers. On the other hand, the results achieved were similar to those obtained by Norton and Olds[16]. By modeling professional boxers' morphological evolution in the period 1970-2000, these authors showed that incremental rates for body weight (1kg/decade) and height (0.6 cm/decade) led super heavyweight boxers to achieve results similar to those of the present research.

Figure 2. Somatotype distribution of super heavyweight boxers.



a: individual somatopoints and centroids (▲); b: average somatotype (•) by periods, where ← = direction following the average somatotype from 1976-1989 to 2010-2014. migration of the individual somatotype, where: ♦ = Olympic medalist from the period 1976-1989; = Olympic medalist from the period 1990-1999; ▲= Olympic medalist from the period 2000-2009; – = Olympic medalist from the period 2010-2014

Han *et al.*[16] obtained significant correlations by relating variables that define obesity (r between 0.248-0.603), muscularity (r between 0.239-0.510) and bone development (r = 0.312) with the year of measurement. These authors attributed the changes found in the body mass index of professional champions to the century-related evolution in their musculoskeletal development. In the examined boxers they found that an increase in body mass index over the century could be due to increased obesity, being accompanied by increases in waist circumference.

In the present research, a significant average increase in the sum of skinfolds, percentage of fat and kilograms of fat was found, with a relatively constant body mass index and active body mass. This finding demonstrates the difference in body composition between boxers who competed in the period 1976-1989 and those who competed after this period.

From the methodological point of view, this research constitutes an advance that allows us to elucidate the true advances in body composition and somatotype during the evolution process, which have been discerned essentially on the basis of the body mass index in other investigations[10,16,18,19]. Only a limited number of studies—in other sports—have shown how the somatotype and some component of body composition vary through the decades[20-23].

In a research study carried out in the Spanish sports population, it was found that a BMI of up to 32.8 kg/m^2 in athletes can be considered overweight due to the development of the lean component and not of obesity[24]. However, when research is aimed at evaluating morphological evolution over the decades, the use of BC and somatotype become relevant owing to the uncertainty of BMI to quantify lean and fatty components in the sports population.

It was shown that the somatotype of the average Cuban super heavyweight boxer was mesoendomorphic during the period under analysis. However, the endomomorphic component gradually increased while the ectomorphic component decreased. The fact that the average somatotype has evolved so much reflects the range of variability in which these athletes could be successful, an aspect that was demonstrated in previous research carried out in samples of Cuban and foreign boxers[2,3,25].

The cluster analysis confirmed that the athletes' sports-related outcomes were not necessarily associated with physical development, as has occurred in other sports[26-28]. Even so, there was a higher proportion of medalists in cluster 2 with all the boxers of the decade between 1976-1989. These boxers were precisely those with lower values in percentage of fat, kilograms of fat and endomorphy. In addition, they had greater stature and linearity, a determining factor for competitive success in boxing, as demonstrated in previous research[29].

A greater number of athletes may be encountered in cluster 2 owing to the fact that, in their search for morphological optimization, headhunters particularly searched for super heavyweight boxers with the physical attributes of the boxers that had developed in the 1970s and 1980s. This is substantiated by the fact that, in this historical period, Cuban researchers managed to characterize the profile of a standard male athlete in this division in the international and national levels[2]. In addition, in this period, Cuban super heavyweight boxers marked their relevance by having the only three-time Olympic champion in this division[3].

The results of the discriminant analysis revealed that the sum of the adipose panicles was the only variable that contributed decisively to the variance associated with the morphological differences between the athletes under investigation. The notable contribution of this variable also demonstrates that it was the determining factor that contributed most to changes in body composition through the studied generations.

Although this statistical analysis is not very frequently used in this type of research, other authors have recommended it to understand how athletes adjust their anthropometric characteristics according to their sports discipline or their performance[26-30]. In the present research, doing so was very useful as it made it possible to describe the group in terms of its morphometric similarities, in addition to observing behavior patterns in the periods under examination.

Conclusions

Cuban boxers of the super heavyweight category proved to have a wide range of morphological demands, which were in keeping with international trends among professional boxers despite their changes over time. Olympic medalists' morphological attributes differed from one another over time and in relation to the other examined boxers. These results provide anthropometric data of high scientific value, both in the interest of this selection and for medical monitoring of training.

Conflict of interest

The authors declare that there is no conflict of interest.

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Original article

Analysis and relationship between the anthropometric and somatotype characteristics and cardiovascular capacity in amateur mountain runners: a pilot study

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Summary

Purpose: The aim of this study was to describe the anthropometrical and cardiovascular characteristics of short course trail runners and analyze the associations, if any, between both anthropometric and cardiovascular features of amateur trail runners.
Material and method: Anthropometrical evaluation and an incremental maximum test with 10% of grade on a treadmill were performed on a group of 10 short distance amateur trail runners.
Results: Significant negative correlations were found between the body max index (BMI) and the speed at VT1 (Vel_{VT1}) ($r = -0,95$, $p < 0,001$), or the time to reach VT1 ($r = -0,91$, $p = 0,002$) and between the body fat percentage and the respiratory exchange ratio at VT2 ($r = -0,80$, $p = 0,016$) or the time to reach VT2 ($r = -0,83$, $p = 0,01$). Calf circumference was also found to be positively associated with oxygen consumption at VT1 ($r = 0,74$, $p = 0,037$), at VT2 ($r = 0,90$, $p = 0,002$) and with the maximal oxygen uptake ($r = 0,85$, $p = 0,007$).
Conclusions: Results indicate that both body fat percentage and calf circumference could be related to the performance on an incremental test protocol with inclination in amateur trail runners.

Key words:
Body composition.
Oxygen consumption.
Physiological thresholds.
Trail running. Kinanthropometry.

Análisis y asociación entre las características antropométricas, somatotipo y capacidad cardiovascular en corredores de montaña de categoría amateur: un estudio piloto

Resumen

Objetivo: Los objetivos del presente estudio fueron describir las características antropométricas y la capacidad cardiovascular de corredores *amateurs* de *trail running* de corta distancia y analizar si existe asociación entre las características antropométricas y la capacidad cardiovascular en los corredores de montaña.
Material y método: A un grupo de 10 corredores de *trail running* de corta distancia de categoría amateur se les realizó un análisis antropométrico y un test incremental máximo con un 10% de inclinación en tapiz rodante.
Resultados: Se encontraron correlaciones significativas y negativas entre el índice de masa corporal (IMC) y la velocidad alcanzada al primer umbral ventilatorio (Vel_{VT1}) ($r = -0,95$, $p < 0,001$), así como con el tiempo en alcanzar el VT1 (t_{VT1}) ($r = -0,91$, $p = 0,002$) y entre porcentaje (%) de grasa corporal y el índice de intercambio respiratorio al segundo umbral ventilatorio (RER_{VT2}) ($r = -0,80$, $p = 0,016$) así como con el tiempo en alcanzar el VT2 (t_{VT2}) ($r = -0,83$, $p < 0,01$). También se encontraron correlaciones significativas y positivas entre el perímetro de pierna y el consumo de oxígeno al VT1 ($VO_{2\,VT1}$) ($r = 0,74$, $p = 0,037$), el consumo de oxígeno al VT2 ($VO_{2\,VT2}$) ($r = 0,90$, $p = 0,002$) y el consumo máximo de oxígeno ($VO_{2\,max}$) ($r = 0,85$, $p = 0,007$).
Conclusiones: Los resultados obtenidos en el presente estudio ponen de manifiesto que tanto el % de grasa corporal como el perímetro de la pierna pueden estar asociados al rendimiento en una prueba incremental con inclinación en los corredores amateur de montaña participantes en el estudio.

Palabras clave:
Composición corporal.
Consumo de oxígeno.
Umbrales fisiológicos. Trail running.
Cineantropometría.

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Introduction

Trail running (mountain running) is a sports discipline that involves races along mountain tracks of varying distances ranging from 1 km to more than 100 km, in which important elevation gains and losses need to be overcome through different types of terrain and in variable weather conditions[1]. Due to the characteristics of the races, this type of sport places high demands on participants at both a neuromuscular[2] and cardiovascular[3] level. Therefore, *trail running* races are highly demanding from a physiological point of view. Possibly due to this high demand and the athletic challenge involved, the practice of *trail running* has become increasingly popular over the last few years, with regard to the number of races, competitions and participants, primarily at an amateur level[4–6]. This considerable boom has led mountain running to be recently recognised by the World Athletics and to have its own world championship[7]. However, despite this boom, in practice the existing scientific literature relating to this sport is still limited and even more so for runners at an amateur level. Consequently, there is a need for more scientific studies to analyse this sports discipline and the characteristics of its participants.

Although with regard to other endurance disciplines, it has been reported that body composition is a determining factor in athletic performance[3,9–12], due to the characteristics of *trail running*, in which athletes must overcome important elevation gains, the anthropometric characteristics of the runners could take on even greater importance in order to achieve sporting success[3]. Prior investigations have studied the body composition of mountain runners, analysing the anthropometric characteristics of long-distance runners (42 km – more than 217 km)[9,14]. However, given that studies made on the anthropometric characteristics of short-distance runners (<42 km) are limited[15,16], it could be of interest to conduct further studies in this regard, in order to obtain scientific evidence on the anthropometric profile of short-distance mountain runners.

On the other hand, as in other endurance disciplines[17–20], an analysis has also been made of the physical performance and physiological characteristics of the runners taking part in *trail running*[3,6,8,15,16,21–24]. It is common to use laboratory tests to measure the cardiovascular capacity of runners[3,8,15,16] analysing maximal and submaximal aerobic performance markers that make it possible to determine the physiological characteristics of the athletes and to subsequently prescribe, monitor and assess training. Most of the in-laboratory protocols used with mountain runners have been conducted with no incline[26–28]. However, given the fact that a considerable part of the *trail running* races takes place on uphill terrain and that it has been reported that the running economy or the energy cost of the runners could be different depending on whether they are running on level terrain or uphill [21], further studies are needed in order to analyse the physiological characteristics of trail runners using protocols with an incline[3,29–31].

Prior studies conducted with endurance athletes analysed the relationship between body composition and physiological performance in a laboratory test[11,32–35]. However, for trail runners, the knowledge available on the influence of the anthropometric characteristics of the runners on physiological performance in a standardised laboratory test is very limited. Despite the fact that some studies have reported that the anthropometric characteristics of mountain runners have a significant correlation with performance in competition9,16,37, we have found no studies that analyse the relationship between body composition and performance in laboratory -based incremental running tests. Knowledge of whether or not anthropometric characteristics are related to the physiological characteristics of the trail runners could be relevant to understanding the extent to which the results obtained in an incremental test, which are generally used to monitor the adaptations induced by the training process, could in some way be influenced by changes in body composition.

Considering the importance of evaluating the anthropometric characteristics and cardiovascular capacity of mountain runners using protocols with an incline, with a view to designing personalised training programs, the objectives of this study were to firstly describe the anthropometric characteristics, somatotype and cardiovascular capacity of short-distance (< 42 km) *trail runners* and, secondly, to analyse whether there is any relationship between the anthropometric characteristics and the cardiovascular capacity of mountain runners at an amateur level.

Material and method

Participants

10 mountain runners took part in this study, who were competing in short-distance races at an amateur level (38.0 ± 9.5 years, 174.0 ± 8.1 cm, 65.21 ± 9.52 kg, 8.58 ± 2.28 % fat, 21.44 ± 1.96 $kg{\cdot}m^{-2}$) with a valid federation membership, of which there were 9 men and 1 woman. In order to take part in the study, participants were required to have at least one year of experience in mountain races, at least 5 years of experience in an endurance sport as a member of a federation, and not to have suffered an injury in the 5 months prior to the study. Before the study started, all participants were informed of the objectives and methodology to be used during the investigation and they had the possibility to freely withdraw and with no penalty at any stage of the investigation. Before taking part in the study, they signed an informed consent form. The investigation followed the guidelines established by the Declaration of Helsinki (2013) and was approved by the Ethics Committee for Research on Human Subjects (CEISH) of the University of the Basque Country (UPV/EHU) (Ceid Ref. No. : M10/2017/200).

Procedure

During the competition season, and always one month before an important race, the participants were evaluated in a single session, in which an analysis was made of their anthropometric profile as well as a laboratory-based maximal incremental running test performed on a treadmill. The runners were familiar with tests of this nature, having performed them previously as part of their training program. They were asked not to alter their daily routine with regard to diet and training in the days prior to the investigation in order to maintain their normal condition. For the tests, the participants were asked to come well-rested and hydrated, to have performed low-intensity exercise (<90 min at <70% of the maximum individual heart rate, FC_{max}) during the days prior to the test, to have spent at least 4 days resting since the last competition (to ensure glycogen replenishment) and not to eat anything in the 2 h prior to the tests. Of the 10 mountain runners taking part, the results of 2 runners in the laboratory-based incremental test were not included in the analysis. This was either due to problems with the measurement of the study variables or to logistics problems when conducting the test.

Measurements

Anthropometric and somatotype characteristics The measurements of the anthropometric characteristics were taken following the guidelines established by the International Society Advancement Kinanthropometry (ISAK)[38]. A scale with measuring rod (Seca, Bonn, Germany) was used to measure the height and body mass with an accuracy of 1 mm and 0.05 kg respectively. The height and body mass measurements were then used to calculate the Body Mass Index (BMI). The skin folds (biceps, triceps, subscapular, abdomen, iliac crest, supraspinale, anterior thigh and medial calf) were measured using a skinfold calliper (Holtain, Crymych, United Kingdom) and the sum of the 8 folds was calculated (Σ folds). The percentage of body fat was calculated using the Yuhasz formula[39]. The circumferences [(relaxed arm, flexed and contracted arm, waist (minimum)], hip (maximum) were measured using a non-flexible tape measure graduated in millimetres (Holtain 110P-98606, Crymych, United Kingdom). The circumferences were used to calculate the ratio between the waist circumference and the hip circumference (waist-hip index). Furthermore, a sliding calliper (HLT-100, Holtain Ltd., Crymych, United Kingdom) was used to measure the biepicondylar (humerus) and bicondylar (femur) widths. Finally, a calculation was made of the somatotype component[40] of each mountain runner taking part.

Laboratory-Based Maximal Incremental Running Testing: The participants performed a continuous Maximal Incremental Running Test on a treadmill (ERGelek™ EG2, Vitoria-Gasteiz, Spain) using the protocol with incline described above for mountain runners[31]. The test started at 6 $km \cdot h^{-1}$, always with an incline of 10%. Every 2.5 min, the speed was increased by 1 $km \cdot h^{-1}$. The aforementioned treadmill, which had been calibrated by the manufacturer prior to the start of the study, was used to continuously record the running speed and the test time. At the end of each stage and on completion of the test, the heart rate (HR) was measured with a heart rate monitor (Polar™ Electro Oy, Kempele, Finland). The following ventilatory variables were analysed: ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2), which were recorded throughout the entire test using a gas analyser (Medisoft™ Ergocard, Medisoft Group, Sorinnes, Belgium). Furthermore, the Respiratory Exchange Rate (RER) was calculated as the ratio between $VCO_2 \cdot VO_2$-1[41,42]. Apart from the HR; the variables were obtained at the ventilatory threshold 1 (VT1), which was considered to be the moment at which the ventilation-volume of oxygen ratio ($VE \cdot VO_2$-1)and the end-tidal oxygen tension (PETO2) started to increase without the corresponding increase in the end-tidal carbon dioxide tension (PETCO2)[44,45] and at ventilatory threshold 2 (VT2), which is considered as the moment when the values of both equivalents ($VCO_2 \cdot VE$-1 and $VO_2 \cdot VE$-1) increased with a drop in PETCO2[46], and the maximum values (Max). The test was considered to be maximum when two of the following three criteria were met: a) the VO_2 ceased to increase despite the increase in the speed demanded, b) 90% of the heart rate was exceeded (HR_{max}) estimated according to age (220-age), c) the RER was greater than 1.15.

Statistical analysis

The results are shown as a mean ± standard deviation of the mean. In order to determine the magnitudes of the relationships between the anthropometric variables and the variables obtained in the laboratory-based incremental running test, the Pearson (r) correlation was used with confidence intervals (CI) at 95%. The interpretation of the correlations was made through the following magnitude scale: trivial (r <0.1), low (r = 0.10-0.30), moderate (r = 0.31-0.50), high (r = 0.51-0.70), very high (r = 0.71-0.90) and almost perfect (r >0.9)[47]. The statistical analysis was made with the Statistical Package for Social Sciences (SPSSTM Inc, version 23.0 for Windows, Chicago, IL, EE.UU.). The statistical significance cut-off was set at p <0.05.

Table 1. Results of the anthropometric and somatotype characteristics of mountain runners (n=10).

	Minimum	Maximum	Mean ± SD
Skin folds			
Triceps (mm)	4.30	16.70	8.58 ± 3.76
Subscapular (mm)	5.80	12.20	8.20 ± 1.95
Biceps (mm)	2.40	5.70	3.48 ± 1.20
Iliac crest (mm)	5.90	15.00	9.12 ± 3.30
Supraspinale (mm)	3.80	12.50	6.44 ± 2.59
Abdomen (mm)	4.50	21.50	11.30 ± 5.72
Thigh (mm)	3.70	23.60	10.78 ± 5.50
Calf (mm)	3.40	10.00	5.74 ± 2.22
Σ of 8 folds (mm)	38.30	109.60	62.65 ± 21.89
Body fat (%)	5.70	12.60	8.58 ± 2.28
Circumferences			
Relaxed arm (cm)	22.80	30.50	27.43 ± 2.43
Contracted and flexed arm (cm)	25.50	33.10	29.83 ± 2.55
Waist (cm)	66.70	84.00	74.44 ± 4.93
Hip (cm)	86.00	99.70	92.82 ± 4.10
Leg (cm)	32.30	40.50	36.60 ± 2.50
Waist-Hip index	0.76	0.85	0.80 ± 0.04
Widths			
Humerus (cm)	5.50	37.90	9.83 ± 9.88
Femur (cm)	8.00	11.20	9.75 ± 0.93
Somatotype			
Endomorph	1.40	3.30	2.20 ± 0.76
Mesomorph	2.80	5.90	4.62 ± 1.16
Ectomorph	1.80	4.50	3.16 ± 0.87

ST = standard deviation; Σ = sum

Table 2. Results obtained in the laboratory-based maximum incremental test by the mountain runners (n=8).

	Minimum	Maximum	Mean ± SD
VT1			
VE_{VT1} ($L·min^{-1}$)	60.52	83.54	71.36 ± 8.63
VO_{2VT1} ($L·min^{-1}$)	2.32	3.22	2.86 ± 0.27
VO_{2VT1} ($mL·kg^{-1}·min^{-1}$)	38.57	51.62	43.98 ± 4.33
VCO_{2VT1} ($L·min^{-1}$)	2.16	2.94	2.67 ± 0.23
RER_{VT1}	0.89	0.96	0.93 ± 0.02
$Vel_{VT}1$ ($km·h^{-1}$)	7.00	8.00	7.44 ± 0.53
t_{VT1} (min:s)	3:15	6:45	5:10 ± 1:19
VT2			
VE_{VT2} ($L·min^{-1}$)	103.37	165.18	134.02 ± 17.65
VO_{2VT2} ($L·min^{-1}$)	3.35	5.14	4.10 ± 0.55
VO_{2VT2} ($mL·kg^{-1}·min^{-1}$)	55.93	71.32	63.02 ± 4.65
VCO_{2VT2} ($L·min^{-1}$)	3.49	5.77	4.48 ± 0.65
RER_{VT2}	1.04	1.23	1.09 ± 0.06
Vel_{VT2} ($km·h^{-1}$)	10.00	13.00	11.56 ± 0.88
t_{VT2} (min:s)	10:45	18:15	15:03 ± 2:13
Max			
VE_{max} ($L·min^{-1}$)	114.15	180.81	147.53 ± 23.14
VO_{2max} ($L·min^{-1}$)	3.42	5.59	4.23 ± 0.70
VO_{2max} ($mL·kg^{-1}·min^{-1}$)	56.48	77.50	64.66 ± 6.41
VCO_{2max} ($L·min^{-1}$)	3.77	6.09	4.73 ± 0.70
RER_{max}	1.09	1.24	1.12 ± 0.05
Vel_{max} ($km·h^{-1}$)	11.00	13.00	12.33 ± 0.71
t_{agot} (min:s)	12:38	18:58	16:42 ± 1:58
HR_{max} ($p·min^{-1}$)	160	202	184.90 ± 11.73

SD = Standard deviation, VT1 = first ventilation threshold, VT2 = second ventilation threshold, Max = max values, VE = lung ventilation, VO_2 = oxygen consumption (absolute and relativized to body mass, VCO_2 = carbon dioxide production, RER = respiration exchange rate, Vel = velocity, t = time, tagot = time to exhaustion, HRmax = maximum heart rate.

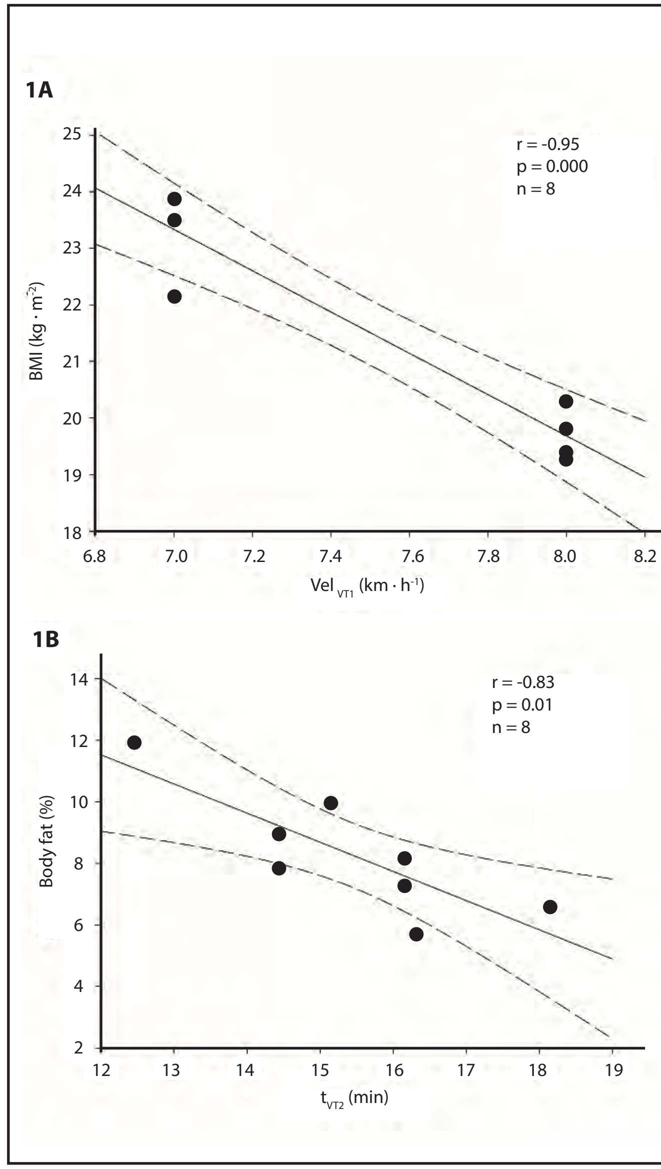
Results

Table 1 shows the results of the anthropometric characteristics (skin folds, circumferences, widths and estimated variables) and of the somatotype of the mountain runners taking part in the study.

Table 2 gives the results obtained by the mountain runners taking part in this study in the laboratory-based maximal incremental running test, for the values obtained at VT1, VT2 and also the maximum values.

With regard to the relationship between the anthropometric characteristics and the results obtained in the laboratory-based incremental test, significant negative correlations were found between the BMI and Vel_{VT1} ($r = -0.95$, $p < 0.001$, *almost perfect*) (Figure 1A), the BMI and t_{VT1} ($r = -0.91$, $p = 0.002$, *almost perfect*), between the percentage of body fat and the RER_{VT2} ($r = -0.80$, $p = 0.016$, *very high*) and between % of fat and t_{VT2} ($r = -0{,}83$, $p = 0{,}01$, *very high*) (Figure 1B). Significant positive correlations were also found between the circumference of the calf and $VO_{2\,VT1}$ ($r = 0.74$, $p = 0.037$, *very high*), the $VO_{2\,VT2}$ ($r = 0.90$, $p = 0.002$, *almost perfect*) (Figure 2A) and VO_{2max} ($r = 0.85$, $p = 0.007$, *very high*) (Figure 2B).

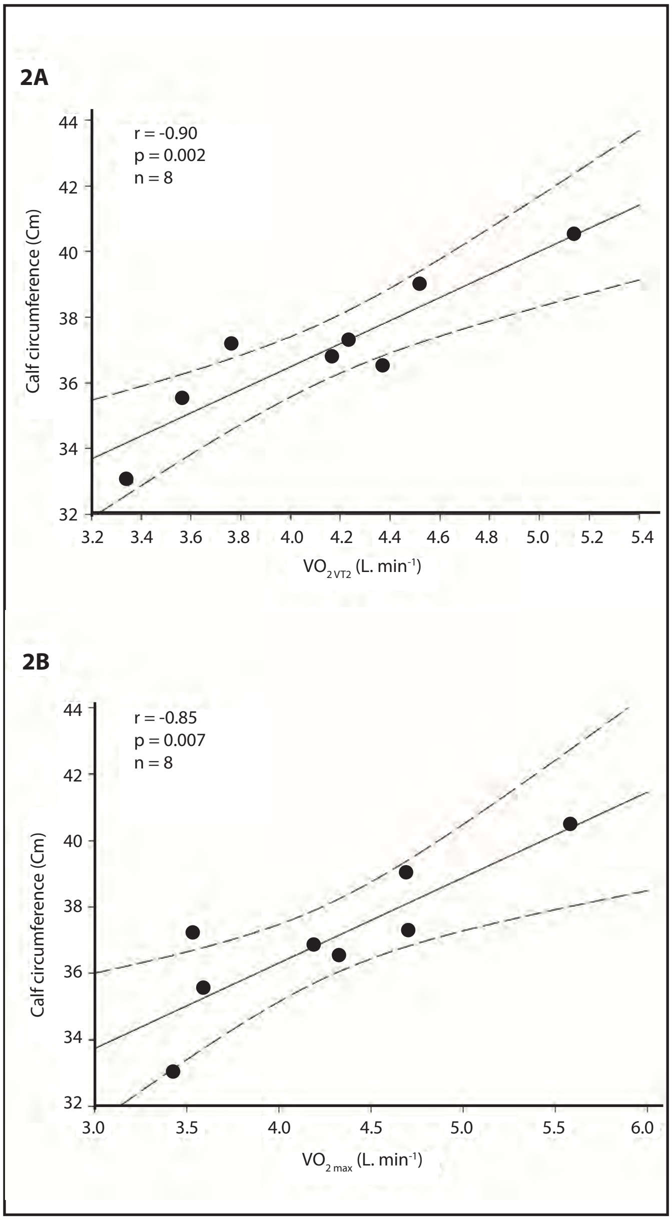
Figure 1. Correlation between the body mass index (BMI) and the velocity achieved at the first ventilation threshold (Vel_{VT1}) (1A) and between the percentage (%) of fat and the time employed to reach the second ventilatory threshold (t_{VT2}) (1B). Solid black lines = linear regression lines. Dashed black lines = confidence intervals of 95%.



Discussion

The study objectives were, on the one hand, to describe the anthropometric characteristics and the performance in a standard laboratory-based maximal incremental running test of mountain runners at an amateur level and, on the other hand, to analyse the relationship between the anthropometric characteristics of these runners and their cardiovascular performance. Based on the scientific literature consulted, this study is the first to analyse the relationship between the anthropo-

Figure 2. Correlation between the calf circumference and oxygen consumption at the second ventilatory threshold (VO_{2VT2}) (2A) and maximal oxygen consumption VO_{2max}) (2B). Solid black lines = linear regression lines. Dashed black lines = confidence intervals of 95%.



metric characteristics and the performance obtained in a laboratory test with an incline, for trail runners in an amateur category who regularly compete in short-distance mountain races (<42 km). considering the increasing popularity of amateur trail running over the last few years, an in-depth knowledge of this relationship could be extremely helpful for sports coaches and for the athletes themselves, in order to optimise the training process.

The anthropometric characteristics of endurance runners has been extensively discussed in scientific literature[29,48–50], possibly due to the close relationship with athletic performance[11,36,50,51]. Specifically, the anthropometric characteristics of trail runners have also been analysed[9,12,14,16,48,52], given that this could be particularly relevant to athletic performance in this discipline due to the fact that body mass may have a significant influence when running on terrain with elevation gains and losses[16]. The runners taking part in this study had a body fat percentage of 8.58 ± 2.28 % and a BMI of 21.44 ± 1.86 $kg{\cdot}m^{-2}$. These results are similar to those obtained in the previous study made with short-distance trail runners (< 42 km) by Alvero-Cruz *et al.*[16] (% body fat = 9.96 ± 1.35 %, BMI = 22.67 ± 1.62 $kg{\cdot}m^{-2}$). However, both the % of body fat and the BMI of the runners taking part in this study and in that of Alvero-Cruz *et al.*[16] were less (45.9 % for % of fat and 10.78 % for BMI) than the values obtained for long-distance runners (> 42 km), for runners taking part in a161 km race (% fat = 16.1± 4.1 %, BMI = 24.8 ± 2.7 $kg{\cdot}m^{-2}$)[12], and also for those taking part in a 217 km race (% fat = 13.2 ± 1.8 %, BMI = 24.8 ± 2.7 $kg{\cdot}m^{-2}$)[9] as well as participants in 24-hour races (% fat = 16.1 ± 4.1%, BMI = 23.1 ± 1.8 $kg{\cdot}m^{-2}$)[52]. Contrary to what might be expected, long-distance runners had a higher % of body fat and a higher BMI than short-distance runners. *A priori*, it would be expected that long-distance runners would have lower fat percentages and BMI due to the fact that, in principle, the training performed to prepare for races of this type and the actual competitions ought to be longer and, consequently, with a greater use of energy substrates through lipid uptake[53], which would lead to a sharper drop in the % of fat and BMI in comparison to short-distance runners. It is possible that these contradictory results are due to the characteristics of the sample. Although amateurs, the runners taking part in this study were at a high competition level, while those runners taking part in the studies by Hoffman *et al.*[12] and Belli *et al.*[9] were from extremely varied levels and included athletes who completed the race and those who did not. Another plausible explanation to account for the marked differences between the studies could be related to the different methodology used to estimate the body fat percentage. All the same, both Hoffman *et al.*[12] and Belli *et al.*[9] found a positive relationship between the body fat percentage and race time. Therefore, in future investigations, it could be of interest to compare the fat % and the BMI of short- and long-distance runners of a similar competition level. Taking account of the fact that for both short-distance races[3,16] and long-distance ones[9,12] a positive relationship was observed between the % of body fat and the competition time, it seems reasonable to think that one of the de trail runners' objectives should be to reduce the body fat % and BMI in order to improve their competition performance. Nevertheless, the possible relationship between the fat % and competition performance may also be related to the fact that, in order to improve performance, more adequate training is required and, therefore, the actual training may lead to a change in the body fat %. However, bearing in mind that Hoffman[37] reported that in very long-distance races (161 km) a higher percentage of body fat measured prior to the race may not be a disadvantage in races with a high energy demand[37], considering that this type of competition may require high lipid demands. In this respect, further studies may be necessary for the different types of trail running.

Despite the fact that numerous studies have used laboratory tests to analyse the physiological characteristics of trail runners and have reported data for the maximal values obtained[3,7,54], few studies have focussed on analysing the submaximal values[16,22,25]. The analysis of these values may help to better understand the characteristics of mountain runners and make it possible to better plan training sessions. Furthermore, taking account of the fact that a large part of the mountain running competitions involve significant elevation gains, the analysis of the physiological characteristics of the runners using protocols with an incline could be relevant[23,25,55]. In this regard, the athletes taking part in our study achieved a relative VO_{2max} of 64.66 ± 6.41 mL·kg^{-1}·min^{-1}. These results are similar to the VO_{2max} figures for high-level short-distance runners (27 km) (61.1 - 69.7 mL·kg^{-1}·min^{-1})[15] obtained by Alvero-Cruz *et al.*[16] with trained runners (67 ± 7 mL·kg^{-1}·min^{-1}) and even to those obtained by Björklund *et al.*[3], for elite runners (68.1 ± 5.8 mL·kg^{-1}·min^{-1} in men). Likewise, the results obtained by Alvero-Cruz *et al.*[16] for VO_2 at VT1 (43 ± 6 mL·kg^{-1}·min^{-1}) are very similar to those obtained in this study (43.98 ± 4.33 mL·kg^{-1}·min^{-1}), although slightly lower (7.97 %) than those observed in $VO_{2\,VT2}$ (58 ± 5 mL·kg^{-1}·min^{-1} *vs* 63.02 ± 4.65 mL·kg-$^{-1}$·min^{-1}). Due to the fact that the studies analysed use different measurement protocols, different sampling characteristics with regard to age and sex and different competition levels, it is difficult to determine the influence of these variables on VO_2 performance. However, the results obtained herein with regard to VO_{2max}. are higher (13.04%) than those obtained by Wüthrich *et al.*[31] (57.2 ± 6.1 mL·kg^{-1}·min^{-1}) for participants who were able to complete an ultra-distance race (110 Km), using the same protocol and also higher (12.65%) than the results obtained by Fornasiero *et al.*[22] for ultra-distance amateur runners (65 km) with a protocol with an incline. These results could suggest that a high VO_{2max} has no determinant influence on very long distance races. As previously described, for a 65 km race, VT1 is not exceeded during approximately 82% of the competition time and the average intensity of the race is approximately 77% of HR_{max}. (approximately 66% of VO_{2max}.)[22]. By contrast, for short-distance races (27 km) the average running intensity was reported to be approximately 89% of HR_{max} [15]. As a result of these different race characteristics, the training of the runners may seek different goals and, therefore, different physiological adaptations.

A number of prior studies conducted with asphalt runners analysed the relationship between the anthropometric characteristics and the laboratory test results[11,29,34,36]. However, there is no evidence for trail runners in this regard. The results obtained in this study show that, despite the fact that no significant relationship was obtained between the anthropometric characteristics of the runners and the maximum values for VO_2, significant negative correlations were observed between the BMI and Vel_{VT1}, the BMI and t_{VT1}, between the body fat % and RER_{VT2} and between the fat % and t_{VT2}. These results indicate that the runners with a greater fat % or BMI had a poorer submaximal performance for the test with a ramp. Despite the fact that there are no similar studies for *trail runners* in order to compare these results, these relationships appear to indicate that the % of fat and BMI can play a very important role when running on a ramp. These results reveal that the BMI and fat % could have a better relationship with the submaximal values obtained in the laboratory test in comparison to the maximal values.

On the other hand, the results obtained in this study show significant positive correlations between the calf circumference and $VO_{2\,VT1}$, $VO_{2\,VT2}$ and VO_{2max}. Although a number of studies conducted with asphalt runners reported greater mass in the lower limbs (generally measuring the calf circumference) is related to poorer running economy[56–58], leading to poorer performance on level or slightly sloping terrain, the results obtained herein show that this trend may be the opposite for races on sloping terrain. Vernillo *et al.*[24] reported that the power required for uphill terrain is greater than for level running given that, with the increase in the elevation profile, runners tend to run with a forefoot strike pattern[24], probably demanding more work from the ankle extensor muscles (gastrocnemius and soleus)[55]. It is possible that these differences between level running and graded running can explain the contradictory results obtained when compared to previous studies. Along these same lines, previous studies have reported that the neuromuscular capacity could be a relevant performance factor in uphill races[2,24], a factor that could explain the relationship found between the calf circumference and the maximal and submaximal VO_2 values. In this regard, it could be of interest to determine whether the calf circumference is also related to performance in mountain races over the different distances.

Conclusions

The results obtained in this study, compared to previously published studies show that the fat % and the BMI of the short-distance trail runners appear to be lower than that of longer distance runners (>100 km). With regard to the physiological characteristics, the results obtained herein for the values for VO_{2max} y $VO_{2\,VT1}$ and $VO_{2\,VT2}$ are similar to those obtained in other studies with short-distance trail runners. However, the VO_{2max} values of the runners taking part in this study, as well as those obtained in similar studies with short-distance runners, appear to be greater than those obtained for long-distance runners.

To the best of our knowledge, this is the first study to analyse the relationships between anthropometric characteristics and performance in a maximal continuous incremental incline test for short-distance amateur trail runners. It was observed that those study participants with a higher fat % and BMI achieved a lower Vel_{VT1}, lower t_{VT1}, lower RER_{VT2} and lower t_{VT2}, indicating that those runners with a higher fat % or BMI had a poorer submaximal performance with regard to the incremental incline test. Furthermore, significant positive correlations were observed between the between the calf circumference and VO_{2VT1}, $VO_{2\,VT2}$ and $VO_{2\,max}$. These results suggest that both fat % and BMI and the calf circumference could be determinant in performance in an incremental running incline test. Future studies, with a greater number of participants, could permit a multiple regression analysis and an in-depth study of the optimal combination of the different anthropometric variables in order to promote cardiovascular performance in standard laboratory-based incline incremental short-distance trail running tests.

Conflict of interest

The authors have no conflict of interest at all.

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Original article

Assessment of professional Argentine football players using the UNCa test

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Summary

Objective: To evaluate the maximum oxygen consumption (VO2max) and the Maximum Aerobic Speed (MAS) with direct and portable measurement in field, in professional soccer players using the UNCa test.
Material and method: 9 professional soccer players (age: 26.8±5.12 years, mass: 78.7±5.8 kg, height: 177.3±5.8 cm), belonging to the first and promotion categories of AFA soccer league, were measured in the field with the UNCa test using direct gas measurement. A subsample of 3 players was also measured on treadmill. On treadmill and in the field, the same Medgraphics® VO_{2000} gas analyzer was used.
Results: In the field, a VO_{2max} of 52.18±5.86 ml/kg/min, and a MAS of 14.8±1.3 km/h were found. Also, a correlation between VO_{2max} and MAS of r = 0.75, and between MAS and the final speed reached (FSR) r=0.91. In the subsample, no differences were found between treadmill and field in VO_{2max}; 46.6±1.4 ml/kg/min and 48.1±2.2 ml/kg/min (p <0.001) respectively. Differences between MAS are shown; 17.0±0.0 km/h for the treadmill and 13.7±1.5 km/h for the field (p <0.001) replicating the protocol.
Conclusion: If professional players of the Argentine Football Association (AFA) were measured directly and in the field, applying the UNCa test for the first time. The VO_{2max} and MAS values were slightly lower than those published in the bibliography.

Key words:
Field test.
Maximal aerobics speed.
Team sports. VO_{2max}.

Evaluación de jugadores argentinos de futbol profesional utilizando el UNCa test

Resumen

Objetivo: Evaluar el consumo máximo de oxígeno (VO_{2max}) y la Velocidad Aeróbica Máxima (VAM) con medición directa y portátil en campo, en futbolistas profesionales utilizando el UNCa test.
Material y método: 9 futbolistas profesionales (edad: 26,8±5,12 años, masa: 78,7±5,8 kg, estatura: 177,3±5,8 cm), pertenecientes a las categorías primera y ascenso de futbol AFA, fueron medidos en campo con el UNCa test utilizando medición directa de gases. Una submuestra de 3 jugadores fue evaluada también en cinta. En cinta y en campo, se utilizó el mismo analizador de gases VO_{2000} de Medgraphics®.
Resultados: En campo se observó un $VO_{2máx}$ de 52,18±5,86 ml/kg/min, y una VAM de 14,8±1,3 km/h. Se halló una correlación entre el VO_{2max} y la VAM de r=0,75, y entre la VAM y la velocidad final alcanzada (VFA) r= 0,91. En la submuestra, no se encontraron diferencias entre cinta y campo en el VO_{2max}; 46,6±1,4 ml/kg/min y 48,1±2,2 ml/kg/min (p<0,001) respectivamente. Se observó diferencias entre las VAM; 17,0±0,0 km/h para la cinta y 13,7±1,5 km/h para el campo (p<0,001) replicando el protocolo.
Conclusión: Se midió de forma directa y en campo a jugadores profesionales de la Asociación del Fútbol Argentino (AFA) aplicando por primera vez el UNCa test. Los valores de VO_{2max} y VAM, fueron levemente menor a los publicado en la bibliografía.

Palabras clave:
Test de campo.
Velocidad aeróbica máxima.
Deportes de conjunto. VO_{2max}.

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Introduction

During a professional football match, players can cover distances between 10,000 and 12,000 metres, and although players are running at different speeds[1], oxygen consumption is clearly an important variable concerning this physiological demand. It is defined as the possibility of doing physical work due to the subject's capacity to transport and metabolise O_2 in a unit of time. An individual's maximum capacity for physical work can be studied through maximum oxygen consumption (VO_{2max}). In professional players, the VO_{2max} varies between 55 and 75 ml/kg/min, depending on the level of play in their league[2-4]. One way that this variable can be implemented and used in players' physical training is through maximum aerobic speed (MAS), which is the minimum speed at which the VO_{2max} is reached in a test of progressive characteristics[5]. This variable can be used to plan running training[6-9]. To identify its value, it is necessary to know the VO_{2max} which requires a portable gas analyser. This technology is not available in many clubs in Argentina. However, it is possible to use the final speed reached (FSR) from an indirect field test to estimate the MAS[10] because both correspond to very similar intensities[11].

As opposed to a direct test, the field tests have the advantage of measuring several subjects at the same time, they are cheaper, they do not require too much time and the athlete is measured where they actually train[12]. There are several tests to estimate MAS, including the Montreal University Test –UMTT[13] with an increment protocol of 1 km · h^{-1} every 2 minutes, the VAM-EVAL Test with a protocol of 0.5 km·h^{-1} every 1 minute[14], the 45-15 Test with a protocol of 0.5 km·h^{-1} every 45 seconds with a break of 15 seconds[15], the 5-minute Test[16], the *Shuttle Squared Test* with a protocol of 0.5 km · h^{-1} every 1 minute[17], and the Catamarca National University Test - UNCa test with a protocol of 1 km · h^{-1} every 1 minute[18].

Among the aforementioned tests, the UNCa test was validated among physical education students comparing the MAS on a treadmill with the FSR on the pitch (r= 0.82) and subsequently among amateur football players (r= 0.81) and amateur rugby players (r= 0.87)[18-20]. Due to its protocol (1.0 km · h^{-1} every 1 minute), it implies using less time compared to other tests[19]. The test route follows a 120-metre hexagon. A hexagon is used for two reasons, a) measuring the athletes where they actually train (training ground or pitch) without having to use an athletics track (as required by the aforementioned tests) and b) not using tests with 'there and back' characteristics (Course Navette, YoYo test, among others) that underestimate the MAS[10,14,17].

While the UNCa test has been validated[18] and used among athletes from different disciplines[19,20], it has not been applied to professional football players. This study proposes to apply the UNCa test to Argentine professional football players to measure VO_{2max} and MAS in the field.

Material and method

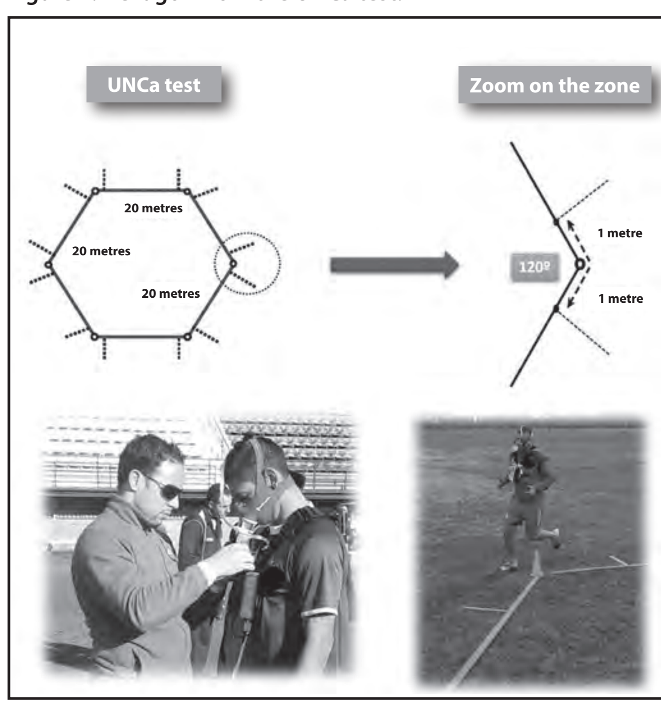
The study had an observational design and a relational analytical analysis level. It used a convenience sample.

Sample and population

9 professional football players were assessed on the pitch using direct measurement. Subsequently, 3 of them were measured again using direct measurement, in the laboratory on a treadmill. The players belonged to clubs from the province of Buenos Aires (conurbation) from the top categories of Argentine football, in the AFA league (Argentine Football Association). All the players were Argentine nationals. The players were measured on the pitch, on the training ground, with the UNCa test using a VO2000 portable gas analyser made by Medgraphics®. A sub-sample, comprising 3 players, was assessed on the same club's laboratory treadmill. The study was organised abiding by Resolution 1480/11 of the Argentine Public Health Ministry, Guide for Research using Human Beings. Participation in this study was voluntary and the players were informed beforehand about each of the tests. Data remained anonymous. A medical support team was constantly present during the assessments.

Field measurement (UNCa test): the subjects run around the perimeter of a 120-metre hexagon. (See Figure 1). The angle between the sides was 120º. The speed is dictated by an audio signal[21]. On each side of the hexagon, there is a 2-metre zone that the participant must have reached when the test beep is heard (see zoom on Figure 1). The test has 2 warm-up stages: 3 minutes at 8.0 km·h^{-1}, and 2 minutes at 10.0 km·h^{-1}. Without stopping, from there on, the speed increases by 1.0 km·h^{-1} every minute, until exhaustion. Exhaustion is understood to be when the subject is late to the arrival zones (vertex of the hexagon) on 2 occasions, or they quit the test because they cannot keep up the audio signal running pace. Incomplete stages are not counted.

Figure 1. Hexagon from the UNCa test.



Laboratory measurement: In the laboratory, the average temperature during the test varies between 22-24°C. Prior to the test, warm up took place at 2 speeds: 2 minutes at 8.0 km/h and 2 minutes at 10.0 km/h. The test began immediately afterwards. The test was incremental, beginning at 10 km/h and increasing by 1 km/h every 2 minutes in the first three stages and then every minute, until exhaustion. Exhaustion is understood to be when the subject can no longer keep up the treadmill speed and quits the test. The gradient of the treadmill is not increased throughout the test. The peak running speed reached at the exhaustion point must be maintained for 1 minute (FSR). The device uses Breezesuite software for processing and data analysis. Body mass and stature were also measured.

On the treadmill and on the pitch, the same VO_{2000} gas analyser by Medgraphics® was used, with the following dimensions: 10.5 x 5 x 14 cm, and a weight of 740 g. It contains a galvanic cell that analyses O_2 with accuracy of ±0.1 %, and a non-dispersed infra-red system, that measures the production of CO_2 with accuracy of ±0.2 %. The data was averaged out in 10 s intervals. The following physiological variables were measured: maximum consumption (VO_{2max}), carbon dioxide production: VCO_2 (ml/kg/min), ventilation (ml/min), heart rate (HR) and the MAS (km/h). The VO_{2max} was accepted when at least 3 of the following criteria were met: a) levelling (plateau) of the VO_{2max}, despite an increase in the treadmill speed, VO2 <150 ml O_2; b) a respiratory gas exchange ratio was reached (VCO_2/VO_2) that was equal to or greater than 1.09; c) the heart rate during the last minute exceeded 95% of the maximum heart rate expected for their age; and d) the subjects could no longer continuing running despite verbal stimulus. The VO_{2max} was expressed in relative values (ml/kg/min).[5] The MAS was located jointly with the VO_{2max}.[22-24]. If the player completed another stage after achieving the VO_{2max}, the speed was considered to be FSR (final speed reached) in the last complete stage,18 to differentiate it from the MAS. The following were also calculated in both measurements: ventilatory threshold 1 (VT1) and ventilatory threshold 2 (VT2) in ml/kg/min and as a % of the VO_{2max}, and the respiratory exchange ratio (RER). The VT1 was determined by using the criteria of an increase both in the ventilatory equivalent for oxygen (VE/VO_2) and the oxygen pressure at the end of exhalation ($P_{ET}O_2$) with no concomitant increase in the ventilatory equivalent for carbon dioxide (VE/VCO_2). VT2 was determined using the criterion of an increase in both the VE/VO_2 and VE/VCO_2 and a drop in $P_{ET}CO_2$.

Statistical analysis

The data was analysed using the SPSS statistics package from IBM® 22.0. The Shapiro-Wilk test was performed beforehand to corroborate the presence of normality. Then descriptive statistics were applied to calculate the median and standard deviation. The ratios between the various variables were calculated using the Pearson correlation coefficient. Descriptive statistics were applied to the sub-sample assessed on the treadmill. In all cases, an alpha $p<0.05$ was accepted.

Results

9 professional football players were assessed, with an average age of 26.8±5.12 years, an average body mass of 78.7±5.8 kg, and a height of 177.3±5.8 cm.

Table 1 presents the cardiorespiratory variables measured on the pitch on players with particular interest in the VO_{2max}, the MAS and the FSR. On the other hand, it was seen that the time of the tests varied between 488 and 739 s with an average of 593 s.

Table 2 highlights the high correlation existing between the FSR and the MAS (0.919 p=0.000).

Table 3 shows the sub-sample (N=3) measured on the treadmill and pitch, with the same protocol. The average VO_{2max} values were 46.6±1.4 ml/kg/min on the treadmill and 48.1±2.2 ml/kg/min on the pitch, thereby presenting a difference of 1.5±1.9 ml/kg/min (3.02%). The MAS values were: 17.0±0.0 km/h on the treadmill and 13.7±1.5 km/h on the pitch, thereby presenting a difference of 3.3±1.1 km/h (24.9%).

Table 1. Variables measured during the UNCa test.

#	VO_{2max} ml/kg/min	VO_{2max} ml/min	MAS Km/h	RER	HR bpm	VE l/min	VT2 %	VT2 ml/kg/min	FSR Km/h	Dist. m	Time s
1	61.1	5190	16	1.04	-	161.3	80	49.0	17	2140	676
2	59.3	4332	17	1.10	204	162.2	84	50.1	18	2440	739
3	56.4	4344	15	1.10	189	130.4	82	46.6	15	1860	613
4	54.8	4000	15	1.12	186	105.1	76	41.5	15	1860	613
5	49.5	4354	13	0.95	202	104.4	83	41.0	14	1360	488
6	49.3	3622	15	1.23	185	144.3	82	40.5	15	1860	613
7	48	3984	14	1.03	190	110.7	88	42.3	15	1600	550
8	45.7	3380	15	1.22	-	132	76	35.1	15	1860	613
9	45.5	3728	13	1.07	199	119.1	85	38.7	14	1360	488
X	52.18	4,103.8	14.8	1.10	193.6	129.9	81.8	42.8	15.3	1,786.7	593
DS	5.86	533.2	1.3	0.1	7.9	22.3	4.0	4.9	1.3	353.8	82.8

VO_{2max}: maximum oxygen consumption, MAS: maximum aerobic speed, HR bpm: heart rate in beats per minutes, RER: respiratory exchange ratio, VE: maximum ventilated volume, VT2: ventilatory threshold, %VT2%: % of the VO_2 in the VT2, FSR; final speed achieved in the last complete stage. Dist: Accumulated distance, Time: accumulated test time.

Table 2. Correlations.

Ratio	Coefficient	Value *p*
VO_{2max} (ml/kg/min) and VT2	0.916	0.001
VO_{2max} (ml/kg/min) and MAS (km/h)	0.755	0.019
MAS (km/h) and VE_{max} (L/min)	0.808	0.008
FSR and VO_{2max} (ml/kg/min)	0.783	0.012
FSR and MAS (km/h)	0.919	0.000

VO_{2max}: consumo de oxígeno máximo, VAM: velocidad aeróbica máxima, VE_{max}: volumen ventilado máximo, VT2: umbral ventilatorio, VFA: Velocidad final alcanzada.

Table 3. Assessment on the treadmill (sub-sample n=3).

#	Test	VO_{2max} (ml/kg/ /min)	MAS (km/h)	RER	HR lpm	VT2 (ml/kg/ /min)	VT2 %	FSR Km/h
5	Pitch	49.5	13	0.95	202	41.5	83	14
	Treadmill	45.9	17	1.07	198	39.8	87	18
6	Pitch	49.3	15	1.10	189	46.6	82	15
	Treadmill	48.2	17	1.13	178	39	81	17
9	Pitch	45.5	13	1.07	199	38.7	85	14
	Treadmill	45.7	17	1.16	187	35.3	78	17

VO_{2max}: Maximum oxygen consumption, MAS: maximum aerobic speed, RER: respiratory exchange ratio, HR bpm: heart rate, VT2: ventilatory threshold 2, VT2%: % of the VO_{2max}, FSR; final speed reached in the last complete stage.

Table 4. Studies published on professional football players that measured on the pitch.

Studies	Sample	VO_{2max} ml/kg/min	MAS Km/h	VT2 %	Test
		Measurement on the pitch			
Dupont *et al.*[6] 2004	n=22	60.1±3.4	15.9±0.8	no	UMTT
Dupont *et al.*[25] 2005	n=11	59.4±4.2	17.2±1.3	no	UMTT
Zouhal *et al.*[26] 2013	n=7	58.0±6.0	17.1±0.6	no	VamEval
Present study	n=9	52.2±5.9	14.8±1.3	81.8±4.0	UNCa

VO_{2max}: maximum oxygen consumption, MAS: maximum aerobic speed, VT2: ventilatory threshold 2.

Discussion

For the first time, professional football players from the Argentine Football Association (AFA) were measured directly and on the pitch using the UNCa test.

The VO_{2max} obtained on the pitch was slightly lower than in other studies[6,25,26]. They are shown in Table 4 and were carried out on the pitch using portable analysers. Dupont *et al* obtained VO_{2max} of 60.1±3.4 on French football players. The same work team obtained similar values in another study: 59.4±4.2. Zouhal *et al*,[25] obtained a VO_{2max} of 58.0±6 among 7 French football players.

Regarding the maximum aerobic speed on the pitch (MAS), it was lower compared to other studies[6,25,26]. Dupont *et al*, reported an initial MAS of 15.9±0.8 km/h^{-1}, among 22 football players from the national league in France, using the UMTT, that after physical preparation involving high intensity interval training, was improved to 17.3±0.8 km/h^{-1}. In a second study using footballers, Dupont *et al*,[25] obtained a MAS of 17.2±1.3 km/h^{-1}. Zouhal *et al*[26], measured the MAS using the VAM-EVAL test on 7 national level football players in France to plan high-intensity interval work. The author reported a MAS of 17.1±0.6 km/h^{-1}.

A strong correlation was observed between the FSR and the MAS which gives it a practical value; if the physical trainer does not have a gas analyser, they can use the speed obtained in the last complete stage as a reference to design the aerobic strength training[7,10,17-22]

The difference observed between the MAS on the treadmill and pitch is similar to what was reported by other studies[11,18,23,24]. The speeds are not exchangeable, where the speed on the pitch is less than the treadmill MAS[11,18,23,24]. This confirms that the MAS is protocol-dependent, as opposed to the VO_{2max} that was similar in both environments.

Finally, using a gas analyser made it possible to study sub-maximum parameters such as ventilatory thresholds, that are relevant in football players to assess their physiological profile. It is demonstrated that the VO_{2max} indicator is less sensitive to changes in the status of the professional football players' training compared to the ventilatory thresholds[27]. In the majority of the papers published, the second threshold or the ventilatory threshold 2 (VT2) stands between 80 and 88 % of the VO_{2max}[27-29], which coincides with 81.8 % of the VO_{2max} described in this paper.

It is considered necessary to continue researching the application of the UNCa test in professional football. This paper involved a small sample of players, and it is typical of this type of research which involves top-performing athletes (professional players). However, the results obtained can help plan training[30].

Conclusions

Professional football players from the Argentine Football Association (AFA) were measured directly and on the pitch for the first time applying the UNCa test. The VO_{2max} and MAS values were slightly lower than those published in the bibliography. If no portable equipment is available to analyse ventilated gases, the FSR from the last complete stage of the UNCa test can be used to organise the aerobic strength training loads.

Conflict of interests

The authors do not declare any conflict of interests.

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Changes in muscle coactivation during running: a comparison between two techniques, forefoot vs rearfoot

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Summary

Introduction: Surface electromyography has been a technique used to describe muscle activity during running. However, there is little literature that analyses the behaviour of muscle coactivation in runners, describing the effect between two techniques associated with the initial contact, such as the use of rearfoot (RF) and forefoot (FF).
Material and method: The purpose of this study was to compare muscle coactivation levels developed in the lower limb during two running techniques, FF vs RF. Fourteen amateur runners were evaluated (eight men, six women; age= 23.21 ± 3.58 years, mass= 63.89 ± 8.13 kg, height= 1.68 ± 0.08m). Surface electromyography was used to measure muscle activity during both running techniques evaluated on a treadmill, considering the muscle pairs: Rectus femoris- Biceps femoris (RFe-BF), Lateral Gastrocnemius–Tibialis Anterior (LG-TA), and Medial Gastrocnemius - Tibialis Anterior (MG-TA). These were calculated in three windows considering ten running cycles (0-5%, 80-100%, and 0-100%). To compare FF *vs* RF t-student test for paired data was used.
Results: It was observed significant differences in the MG-TA pair (FF= 18.42 ± 11.84% *vs* RF = 39.05 ± 13.28%, p = 0.0018 during 0-5%, and RFe-BF pair (FF = 42.38 ± 18.11% *vs* RF = 28.37 ± 17.2%, p = 0.0331) during 80-100% of the race.
Conclusion: Our findings show that the behaviour of muscle coactivation is different between FF *vs* RF techniques if we analyze little windows in the running cycle. This could be associated with an increase in the joint stability between these short intervals, represented in the initial and final regions of the running cycle.

Key words:
Lower limb. Muscle pairs. Running cycle. Surface electromyography.

Cambios en la coactivación muscular durante la carrera: una comparación entre dos técnicas (antepié *vs* retropié)

Resumen

Introducción: La electromiografía de superficie ha sido una técnica usada para describir la actividad muscular durante la carrera. Sin embargo, hay poca literatura que analice el comportamiento de la coactivación muscular en corredores, describiendo el efecto entre dos técnicas asociadas al contacto inial, tal como el uso de retropié y antepié.
Material y método: El propósito de este estudio fue comparar los niveles de coactivación desarrollados en la extremidad inferior, utilizando dos técnicas de carrera, antepié (FF) *vs* retropié (RF). Catorce corredores *amateurs* fueron evaluados (8 hombres, 6 mujeres; edad = 23,21 ± 3,58 años, masa = 63,89± 8,13 kg, estatura = 1,68 ± 0,08 m). Se utilizó electromiografía de superficie para medir la actividad muscular al momento de ejecutar ambas técnicas de carrera sobre una trotadora, considerando los siguientes pares musculares: Recto Femoral- Bíceps Femoral (RFe-BF), Gastrocnemio Lateral – Tibial Anterior (LG-TA) y Gastrocnemio Medial - Tibial Anterior (MG-TA). Estos se calcularon en tres ventanas considerando diez ciclos de ejecución (0-5%, 80-100% y 0-100%). Para comparar FF *vs* RF se utilizó la prueba t-student para datos pareados.
Resultados: Se observan diferencias significativas en el par MG-TA (FF = 18,42 ± 11,84% *vs* RF = 39,05 ± 13,28%, p = 0,0018) durante el 0-5%, y el par RFe-BF (FF = 42,38 ± 18,11% *vs* RF = 28,37 ± 17,2%, p = 0,0331) durante el 80-100% de la carrera.
Conclusión: Nuestros hallazgos muestran que el comportamiento de la coactivación muscular es diferente entre las técnicas de FF y RF si analizamos pequeñas ventanas en el ciclo de carrera. Esto podría estar asociado con un aumento de la estabilidad articular entre estos cortos intervalos, representados en la región inicial y final del ciclo de carrera.

Palabras clave:
Extremidad inferior. Pares musculares. Ciclo de carrera. Electromiografía de superficie.

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Introduction

The popularity of running has increased over the years, mainly in young people, men and women. This increase has been accompanied by a rise in the number of injuries[1]. Some epidemiological studies indicate that more than 50% of regular runners report more than one injury annually and that the majority are due to overuse[2]. However, there are a large number of factors associated with an adverse event, including sex, distance travelled, and the type of technique used during initial contact, the latter being a highly associated factor with the rate of injury to lower limbs[3]. One of the first studies linked to the description of running techniques was developed by Laughton *et al.*[4]. Today, among the techniques used at initial contact, the use of forefoot (FF) and rearfoot (RF) stands out, the latter being the most used by amateur runners[5]. These techniques have been extensively studied, especially the kinematic and kinetic variables[1,6,7].

Although both techniques involve energy absorption between impact and medium support, their biomechanics are different. The RF technique is associated with laxity of the plantar fascia and structures surrounding the ankle-foot complex, transferring energy to the proximal bone structures (one of which is the tibia)[8]. Furthermore, the FF technique achieves energy absorption through the plantar fascia and eccentric contraction of the lower limb extensors[8–10]. To achieve this, a rigid ankle-foot complex is required, specifically to maintain tension over the plantar fascia. However, there are no studies that describe the muscle activity produced to maintain joint stability.

A study developed by Lieberman *et al.* (2010), states that the FF technique could reduce the risk of injury due to the low energy absorbed by the knee, generating less acceleration of the tibia and impact on the ground[10].

Landreneau *et al.* reported increased activity of the medial gastrocnemius (MG) with FF technique during impact and mid support without kinematic differences in the frontal plane of the ankle. This suggests that runners using the FF technique develop neuromuscular adaptation mechanisms to stabilize the joints in both the sagittal and frontal planes[11].

A review developed by Latash, affirms that the coactivation of antagonistic muscle pairs could be a neural control mechanism to improve joint stability[12]. However, there is little evidence based on the activity of the lower limb muscles during these running techniques. As stated above, the objective of the research sought to compare the variations in the levels of coactivation in the lower limb when using FF *vs* RF techniques in amateur runners. Based on the above, we hypothesized that there are differences in the coactivation levels when comparing both running techniques.

Material and method

Considering a cross-sectional study, fourteen amateur runners were included, with a running frequency equal to or greater than three times a week (5 kilometres each day). These runners were selected considering participation in 10 km races. Participants with any injury, surgery, or lower limb pain within the six months before the procedure, were excluded. All volunteers signed an informed consent, approved by a local ethics committee in accordance with the Declaration of Helsinki (March 2019; code: CEC201905).

Evaluation protocol

Regarding the evaluation protocol, we requested all participants who attended to bring their regular training shoe (greater than or equal to one month of use). Initially, anthropometric characteristics of each athlete utilised to biomechanics 3D model and the dominant lower limb (leg used to kick a soccer ball) were evaluated. The kinematic behaviour of the foot during the race was described by two reflective markers located at the base of the second metatarsal and apex of the calcaneus, according to the plugin gait model[13]. These markers determined the moments of the initial contact and take-off of the race, using a 3D analysis system with eight infrared cameras (T- Series; Vicon Motion Systems, Oxford, UK) at a capture frequency of 200Hz. Simultaneously, the EMG activity of five muscles was recorded in the dominant lower limb of each runner, according to SENIAM recommendation[14]. The evaluated muscles were: tibialis anterior (TA), medial gastrocnemius (MG), lateral gastrocnemius (LG), rectus femoris (RFe), and biceps femoris (BF). Previously, the areas established for each muscle were shaved and cleaned with 95% denatured alcohol and cotton. EMG signals were recorded using EMG equipment (Bagnoli-16. Delsys®, USA), with a sampling frequency of 1000 Hz. Then, each volunteer developed a five-minute warm-up at a self-selected speed over a treadmill (H/P/Cosmos®, Model LE200 CE, Germany). Subsequently, each athlete ran for approximately three minutes at a previously determined speed (average of three self-selected speeds under the following indication: "we will adjust the speed of the treadmill as close as possible to your running speed, this should be comfortable for you"). Twenty cycles were recorded at the end of each running technique (FF and RF), the order of which was randomized for each participant. Finally, the maximum voluntary contraction (MVC) of each muscle mentioned above (MG, LG, TA, RFe, and BF) was measured. This allowed normalizing the EMG signals acquired during the race and expressing them as a percentage of the MVC.

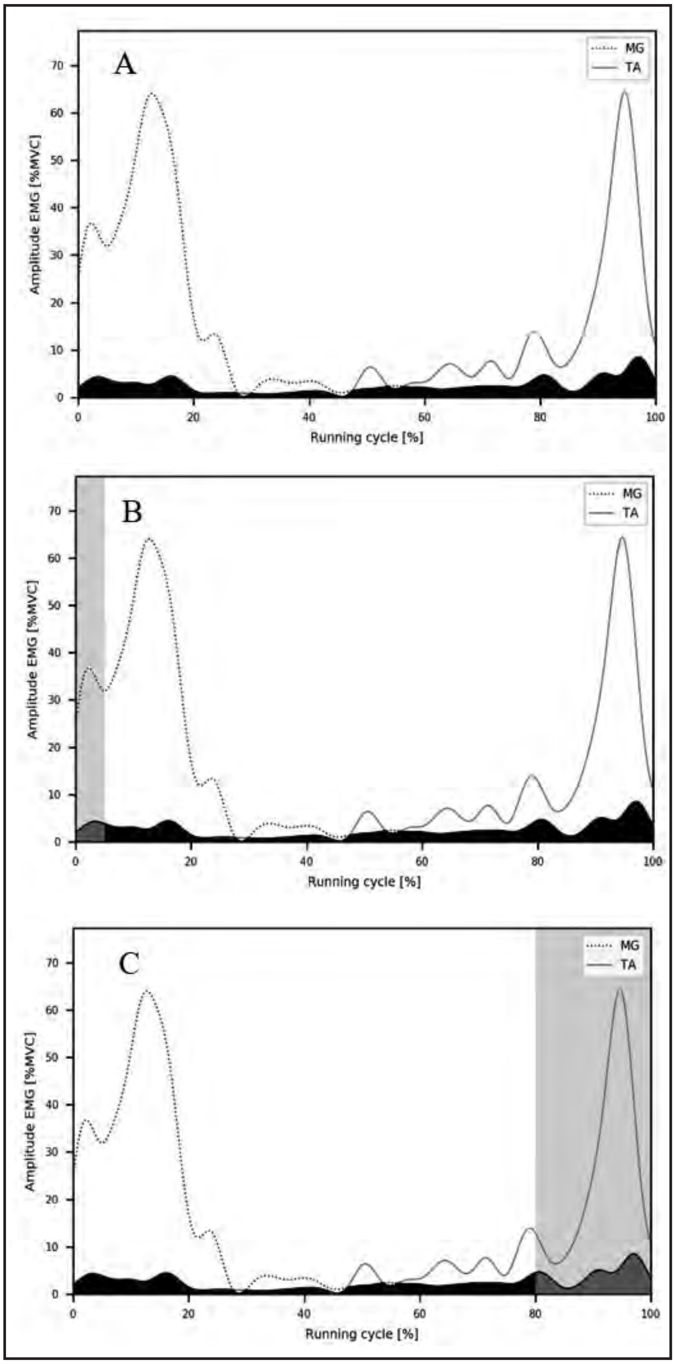
Data processing

The EMG signals were rectified and processed with a fourth-order 20Hz low pass filter (Butterworth type)[15]. The EMG amplitude was calculated considering the average of the rectified signals during ten running cycles. Then each muscle was adjusted to its respective MVC (reported as %MVC). After that, the muscle coactivation was calculated using the formula proposed by Falconer & Winter[16].

$$\frac{\%\ \text{Coactivation} = \ (\text{A\&B common area})}{(\text{A area}+\text{B area})} \times 100$$

Where A (e.g. activity of the TA) and B (e.g. activity of the MG) represent two antagonistic muscles, considering the common area between them (A & B) divided by the sum of their areas (A + B), multiplied by 100. With this, the following muscle pairs were determined: rectus femoris-biceps femoris (RFe-BF), lateral gastrocnemius – tibialis anterior (LG-TA), and medial gastrocnemius - tibialis anterior (MG-TA). These coactivation data were calculated in ten central cycles of the race, considering three windows: i.- between 0-5% running cycle (stance phase), ii.- between 80-100% running cycle (swing phase), iii.- and the complete cycle (0-100%) (Figure 1). All data were processed with Python 3.5 (Van Rossum, 2014).

Figure 1 . Shows three windows where it was calculated the muscle coactivation during the rearfoot technique, using the MG-TA muscle pair. A) 0-100% running cycle; B) 0-5% running cycle (initial grey area); and C) 80-100% running cycle (final grey area). The black area represents the coactivation between both muscles (MG-TA).



Statistical analysis

The demographic data of the volunteers was characterized by a descriptive statistic (average and standard deviation). Previously, the normality of the variables (muscle coactivation and amplitude) was evaluated with the Shapiro-Wilk test, considering the data of three windows analyzed (0-5%, 80-100%, and 0-100% of the running cycle). The coactivation data (RFe-BF, LG-TA, and MG-TA muscles pairs) was represented with the average and its standard deviation. To compare between both running techniques (FF vs RF) the t-student test for paired data was used. Additionally, the effect size was calculated, in order to report the magnitudes of the differences founded, considering the Cohen's *d*[18]: small ~ 0.2, medium ~ 0.5, large ~ 0.8, and very large ~ 1.3. All statistical analyses were carried out at two tails, establishing the differences with a p-value <0.05, using the GraphPad Prism software (version 8.4.1, San Diego, California USA).

Results

Fourteen runners (6 women and 8 men) were evaluated; their average running speed was 8.68 km/h (Table 1). All reported initial contact with rearfoot as their primary technique.

When comparing the coactivation levels reported by the different muscle pairs between the FF vs RF techniques, significant differences were found in the GM-TA pair (FF = 18.42 ± 11.84% *vs* RF = 39.05 ± 13.28%, *p* = 0.0018, *d*=1.63) during 0-5% at the initial stance phase, and in RFe-BF (FF = 42.38 ± 18.11% *vs* RF = 28.37 ± 17.2%, *p* = 0.0331, *d*=0.79) during 80-100% in the swing phase (Table 2). Both muscle pairs describe a large effect, considering Cohen's d. Regarding the LG-TA muscle pair, there were no significant differences between running techniques (Table 2).

Discussion

The objective of the present investigation was to compare the levels of muscle coactivation in the lower limb during two running techniques (FF *vs* RF). For this, three windows of analysis were considered. In relation to the aforementioned, the main differences were found in the most small windows (0-5% and 80-100% of the running cycle) when it was compared FF *vs* RF techniques. The first finding reports a greater magnitude of coactivation for the MG-TA pair with the use of RF between 0-5% of the running cycle. This could be attributed to an increased requirement for ankle stability during the initial impact, offset by an increase in the coactivation of the MG-TA pair during the use of RF. Which could be related to the findings of Kuhman *et al.,* who refers to

Table 1. Demographic characteristics of the evaluated runners (average and standard deviation).

	Men (n=8)	Women (n=6)	Total (n=14)
Age(years)	22.38 (1.60)	24.33 (5.2)	23.21 (3.58)
Height(m)	1.74 (0.05)	1.61 (0.05)	1.68 (0.08)
Mass (kg)	69.68 (3.64)	56.18 (5.36)	63.89 (8.13)
BMI (kg/m^2)	23.15 (1.58)	21.63 (1.04)	22.5 (1.56)
Speed (km/h)	9.46 (1.14)	7.63 (0.53)	8.68 (1.3)

Table 2 . Comparison between muscle coactivations represented by the average and standard deviation in the rearfoot vs forefoot techniques (considering three windows analysed in relation to the running cycle: [0-100%], [80-100%], and [0-5%]). Significant differences are indicated with a *p<0.05. Additionally, the effect size was reported with Cohen's d.

		Rearfoot (n=14)	Forefoot (n=14)	p-value	Cohen's *d*
0-100%	RFe-BF (%)	36.58 (11.97)	37.73 (12.31)	0.4229	0.09 (small)
	MG-TA (%)	24.71 (5.09)	25.11 (8.21)	0.8294	0.05 (small)
	LG-TA (%)	24.76 (4.18)	25.80 (9.52)	0.6624	0.12 (small)
80-100%	RFe-BF (%)	28.37 (17.21)	42.38 (18.11)	**0.0331***	0.79 (large)
	MG-TA (%)	35.55 (13.50)	28.08 (13.50)	0.1976	0.55 (medium)
	LG-TA (%)	35.98 (14.52)	28.68 (17.41)	0.3367	0.45 (medium)
0-5%	RFe-BF (%)	53.96 (22.70)	49.54 (20.44)	0.5134	0.20 (small)
	MG-TA (%)	39.05 (13.28)	18.42 (11.84)	**0.0018***	1.63 (very large)
	LG-TA (%)	30.28 (13.63)	22.89 (17.10)	0.1748	0.47 (Medium)

the need for a higher dorsiflexor torque at impact to control the sudden plantarflexion generated after heel contact[7]. Likewise, another study reflects a greater magnitude of the anterior tibial during the RF technique, this could justify a type of eccentric work of this muscle during the beginning of the support phase, providing greater synchronization with the MG[15], also allowing a controlled descent of the forefoot.

The second finding describes a greater coactivation with the use of FF in the RFe-BF pair during 80-100% of the running cycle. This could be related to the lower excursion of the knee's range of motion with the use of FF compared to the RF[4], which would lead to a greater requirement of stability at the hip and knee level, considering that both rectus and biceps femoris are biarticular muscles, responsible for compensating this requirement[19]. Another justification for the second finding is that the literature reports a lower joint contact force in the hip and knee at the moment of the initial impact during the race with the use of FF technique[19]. This could be translated into an energy dissipation strategy associated with the increased coactivation of the RFe-BF pair found in this study. At the same time, the increase of the coactivation during swing phase could also be a consequence of the increased activation of the hamstrings in order to control the extension of the knee, this occurs since in the FF technique, there is a greater degree of flexion in this joint during initial contact, also associated with a shorter stride length[5].

On the other hand, no significant differences were found in the LG-TA pair. This may be associated with the structure and anatomical disposition of the triceps surae, where the MG represents 30% of the total volume, considered twice the volume of the LG, together with a more lateral disposition of the LG[20]. These characteristics could contribute to a low level of muscle coactivation generated between LG and TA during the race.

Based on the findings of the present study, future research could explore other time windows, such as toe off during the stance phase, because this could show a more specific behaviour of the muscle activation and coactivation, in order to improve our understanding of the lower limb during running. Besides, one attractive alternative could be the analysis of the coactivation of muscular pairs in the frontal plane, considering the frequent kinematics alterations in runners, observed by other studies[19].

Some limitations observed in this study were: a) the use of a treadmill to simulate the run at comfortable speed by the runners, considering that, normally, the space and its characteristics could not agree with training places or competitions; b) all runners routinely performed the RF technique, experimentally requesting the use of FF; c) with our current data it is not possible to determine the most appropriate technique for runners, mainly because the differences found are in function of an acute effect between FF *vs* RF. Therefore, this point could be an interesting topic for a future work.

Conclusion

According to the evaluated sample, the behaviour of muscle coactivation is different between FF *vs* RF techniques, considering the temporal window analysis based on the race cycle. Our results show that the FF technique may require pre-activation between antagonist muscles in order to develop possible anticipatory adjustments at the knee and hip levels, allowing better mechanical energy transfer. Also, less ankle coercion would be an adaptation to achieve a mechanical advantage. On the other hand, the RF technique requires greater ankle control to modulate the abrupt fall of the forefoot at the moment of impact, this would be delivered by coactivation between MG-TA.

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Conflict of interest

The author do not declare a conflict of interest.

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Original article

Eccentric exercise and muscle fiber conduction velocity: a literature review

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Summary

Introduction: According to the literature, eccentric exercise has been considered a precursor of neuromuscular changes generated by post-exercise damage, mainly causing an alteration in the muscle cell membrane. Muscle fiber conduction velocity (MFCV) has been one of the physiological variables that have allowed to quantify this alteration. Some investigations have shown a decrease in the MFCV after eccentric exercise protocols; however, few studies have confirmed these findings. This review aimed to describe the recent scientific evidence that reports changes in the MFCV after eccentric exercise protocols.
Material and method: From 265 articles, 6 articles were selected from EBSCO and MEDLINE platforms with a temporal filter of 10 years (between 2010 and April 2020), using inclusion/exclusion criteria predetermined. Firstly, the information from eccentric exercise effect on MFCV, and exercise protocols were described. Secondly, the techniques used to record electromyographic signals and some criteria to determine the MFCV were reported.
Results: Modifications of MFCV can be observed after eccentric exercise in almost all selected articles. At the same time, a decrease of this variable was observed in four studies, associated with the biceps brachii and two portions of the quadriceps muscles. However, one article describes an increase of the MFCV in the vastus lateralis quadriceps.
Conclusion: The articles suggest that eccentric contractions could modify the MFCV behavior of some muscles. However, evidence is still lacking to describe the real cause of these changes.

Key words:
Muscle conduction velocity. Electromyography. Eccentric exercise. Musculoskeletal.

Ejercicio excéntrico y velocidad de conducción de la fibra muscular: una revisión bibliográfica

Resumen

Introducción: Según la literatura, el ejercicio excéntrico ha sido considerado como un precursor de cambios neuromusculares generado por el daño post-ejercicio, causando principalmente una alteración en la permeabilidad de la membrana celular muscular. Una de las variables fisiológicas que ha permitido cuantificar esta alteración, es la velocidad de conducción de la fibra muscular (VCFM). Algunas investigaciones han mostrado una disminución de esta variable posterior a protocolos de ejercicio excéntrico; sin embargo, existen pocos estudios que confirmen este hallazgo. Este estudio tuvo como objetivo describir la evidencia científica reciente que reporte cambios en la VCFM después de protocolos de ejercicio excéntrico.
Material y método: De 265 artículos, se seleccionaron 6 artículos de las plataformas EBSCO y MEDLINE con un filtro temporal de 10 años (entre 2010 y abril de 2020), usando criterios de inclusión/exclusión predeterminados. En primer lugar, se describió el efecto del ejercicio excéntrico sobre la VCFM y los protocolos de ejercicios. Secundariamente, se reportaron las técnicas utilizadas para registrar la señal electromiográfica, y algunos criterios para determinar la VCFM.
Resultados: Es posible observar modificaciones de la VCFM luego del ejercicio excéntrico en casi todos los artículos seleccionados. Al mismo tiempo, se observa una disminución de esta variable en cuatro estudios, asociado a los músculos bíceps braquial y dos porciones del cuádriceps. Sin embargo, un artículo describe un incremento de la VCFM en el vasto lateral del cuádriceps.
Conclusión: Los artículos sugieren que las contracciones excéntricas podrían modificar el comportamiento de la VCFM de algunos músculos. Sin embargo, aún falta evidencia para describir la real causa de estos cambios.

Palabras clave:
Velocidad de conducción muscular. Electromiografía. Ejercicio excéntrico. Musculoesquelético.

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Introduction

From the perspective of training and physical rehabilitation, muscular strength contractions have been useful in therapy, given the neuromuscular adaptations post-exercise[1]. However, questions are still raised based on the possible causes of these adaptations, considering concentric, isometric and eccentric contractions[2,3]. In daily life and in sporting practice, these muscular contractions tend to work together4-6. However, there are essential characteristics that classify eccentric contradictions as the most demanding, considering characteristics such as variation in muscular fibre length and damage to the relevant tissue post-exercise[3,7].

From the physiological perspective, eccentric exercise protocols have demonstrated great selective mechanical damage to fast contracting muscular fibres (type II) and, at the same time, acute disruptions in the peripheral tissue[8]. Some studies link the aforementioned effects to greater mechanical stress on the fast fibres during this type of contractions[8,9], also reporting chemical imbalances between the intracellular and extracellular medium of the damaged fibres[10–12], and differences in the neural control strategy centrally[12]. One of the electromyographic variables that has made it possible to describe possible effects generated by eccentric exercise in muscles is the muscle fibre conduction velocity (MFCV), defined as the speed at which an action potential is propagated through the sarcolemma of a musculoskeletal fibre[13]. This variable reflects possible peripheral muscle changes, as the product of exhaustion[13], a pathology associated with the musculoskeletal system[14,15], or the effect of eccentric exercise[16,17]. According to this latter point, some research has reported a modification of the MFCV against its baseline levels after applying a protocol of eccentric contractions, considering different muscles and eccentric exercise protocols[9,11,18]. One example might be the results reported by Nasrabadi *et al*. 2018, who demonstrated a drop in the MFCV magnitude immediately after and then 24 hours post-exercise in two portions of the quadriceps (vastus lateralis (VL) and the vastus medialis obliquis (VMO))[19]. However, an additional finding described by the aforementioned research corresponds to the level of MFCV reduction when comparing both muscles, greater for the VMO[19]. According to the authors, these differences might be justified by the morphological variations of both muscles, considering the high percentage of fast fibres for the VMO, which would be more susceptible to damage generated by eccentric contractions[19].

There is little research that evaluates the MFCV before and after eccentric training protocols, and at the same time, there are no studies that compile the MFCV variation produced by this type of contractions. According to what has been proposed, the aim of this research was to describe recent scientific evidence that reports changes in MFCV produced by eccentric exercise. The results presented in this bibliographic review focus on the description of the two main points considered by the researchers: a) the effect of eccentric exercise on the MFCV and b) eccentric exercise protocols used to induce muscle damage. At a secondary level, and working from the studies compiled, an attempt was made to describe the tools used to register the EMG signal and selection of some criteria that determine the MFCV.

Material and method

Design

Bibliographic review of articles published from 2010 to April 2020.

Inclusion and exclusion criteria

Articles were included with the following criteria: English language; assessment of the motor unit action potentials (MUAP) with surface electromyography on the musculoskeletal system; before-after experimental studies in humans (healthy persons and/or athletes) with application of eccentric exercise protocols at muscle level; estimation of the MFCV from the propagation of the MUAPs registered with surface EMG. Regarding the exclusion criteria used, reviews were ruled out, as they were considered nonexperimental studies, which lack methodological application to measure the MFCV. Additionally, articles that used persons with any type of pathology were also excluded.

Search strategy

The EBSCO and MEDLINE platforms were used to search the literature; the search used thesauruses or free terms. In the case of the thesauruses, the MeSH terms "Humans", "Electromyography" and "Muscle Contraction/physiology" were used. In the case of the free terms, "Muscle fiber conduction velocity" and "eccentric" were used. These terms were combined with the Boolean connector AND, applying a time filter of 10 years between 2010 and April 2020.

Selection of articles

The articles were firstly selected by title and abstract. Subsequently, only before-after experimental studies were considered, selecting any which reflected the following aspects in the complete text reading: a) the effect of eccentric exercise on MFCV, b) eccentric exercise protocols used to induce muscle damage, and c) description of techniques used to register the EMG signal and selection of some criteria to determine the MFCV. These points were used by two reviewers, who initially generated the search independently. Then, along with a third reviewer, articles were selected based on the complete text reading.

Results

Working from the aforementioned strategy, the initial search brought up a total of 265 articles. By eliminating duplicates and considering the reading of the title, abstract, classification as before-after experimental, only 8 articles remained. Of these, only two were excluded, considering their complete reading alongside the selection criteria. Finally, 6 scientific articles were selected to develop this bibliographic review (Table 1).

Effect of eccentric exercise on the MFCV

Two studies calculated the post-exercise eccentric MFCV in the biceps brachii during sub-maximum isometric contractions (10, 20, 30, 40, 50 and 75% of the maximum voluntary contraction (MVC)[9,11], both reported significant drops in the MFCV beyond 40% of the MVC, observed two hours post-exercise (2H). However, only one study reported the average values of the MFCV (during 40% MVC: 4.4 ± 0.3 m/s (prior to the exercise (PRE)) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.05$; 50% MVC: 4.5 ± 0.3 m/s (PRE) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.01$; 75% MVC: 4.4 ± 0.3 m/s (PRE) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.01$)[9]. In addition, studies that assess the

Table 1. General characteristic sample from the selected studies, eccentric exercise protocols and results obtained based on the (before-after) behaviour of the muscle fibre conduction velocity (MFCV).

Authors	Partici-pants (number/ muscle evaluated)	Eccentric exercise protocol	Measuring times	%MVC when registe-ring the EMG signal	Variation in the post-exercise MFCV	Results/ MFCV variation
Piitulainen, *et al.* 2010.	n=9/ Biceps brachii	Fifty repetitions of maximum eccentric contractions on an isokinetic machine (1 rad/s) divided into 2 phases (F1: 65º-120º/F2: 120º-175º). A 3-second rest was determined between phases, with 20 seconds between each repetition.	Before the protocol (PRE) and two hours (2H), two days and four days after the protocol.	10%, 20%, 30%, 40%, 50%, 75% and 100% of the MVC.	↓	100% MVC: 4.1 ± 0.3 m/s (PRE) *vs* 3.8 ± 0.4m/s (2H), $p < 0.01$.
Piitulainen, *et al.* 2011.	n=24/ Biceps brachii	Three series of twenty repetitions of maximum eccentric contractions on an isokinetic machine (60º/s) in a 110º range of movement (65º-175º) with a break of 15 seconds between repetition and 5 minutes between series.	Before the protocol (PRE), immediately afterwards, 2 hours (2H) and 1 day after the protocol.	100% of the MVC	↓	4.16 ± 0.34m/s (PRE) *vs* 3.43 ± 0.44m/s (2H), $p < 0.01$.
Piitulainen, *et al.* 2012	n=16/ Biceps brachii	Fifty repetitions of maximum eccentric contractions on an isokinetic machine (60º/s) divided into 2 phases (F1: 65º-120º/F2: 120º-175º). A 3-second rest was determined between phases, with 20 seconds between each repetition.	Before the protocol (PRE), two hours (2H), two days and four days after the protocol.	10%, 20%, 30%, 40%, 50% and 75% of the MVC.	↓	40% MVC: 4.4 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.05$. 50% MVC: 4.5 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.01$. 75% MVC: 4.4 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.01$.
Cadore *et al.* 2014.	n=22/ Vastus lateralis	Six-week training programme, applying eccentric contractions (cases) and concentric contractions (controls). The training included progressions of eight, ten and twelve repetitions from two to five series, with five-minute breaks between each series. For the contractions, an isokinetic machine (60º/s) was used with a 90º range of movement in the knee joint. (90º-180º).	Before the training (PRE) and after six weeks of training (POST).	100% MVC	↑	4.17 ± 1.62m/s (PRE) *vs* 4.44 ± 1.19m/s (POST), $p < 0.05$.
González *et al.* 2014.	n=16/ Vastus lateralis	Two sessions of 2 MVC were carried out and four series of twenty dynamic contractions (concentric and eccentric) 1 week apart. There was a two-minute break between each series. An isokinetic machine (60º/s) was used with a range of movement of 90º in the knee joint. (90º-180º).	Before the protocol, immediately after (ID) the protocol and 5 minutes (5M) after the protocol.	100% of the MVC	ND	2.1 ± 0.1m/s (PRE); 2.2 ± 0.1m/s (ID); 2.1 ± 0.1m/s (5M); $p>0.05$.
Nasrabadi, *et al.* 2018	n=15/ Vastus lateralis and vastus medialis obliquis	Two sessions of 2 MVC were carried out and four series of twenty dynamic contractions (concentric and eccentric) 1 week apart. There was a two-minute break between each series. An isokinetic machine (60º/s) was used with a range of movement of 90º in the knee joint. (90º-180º).	Prior to the exercise protocol, two hours and twenty-four hours after the protocol.		↓	100% MVC vastus lateralis: 4.9 ± 0.59 m/s (PRE) *vs* 4.5 ± 0.46 m/s (2H), $p < 0.05$, and 4.5 ± 0.44 m/s (24H post-exercise), $p<0.05$ 100% MVC vastus medialis obliquis: 5.3 ± 0.61 m/s (PRE) vs 4.8 ± 0.54 m/s (2H), $p < 0.05$, and 4.9 ± 0.57 m/s (24H), $p<0.05$. 50% MVC: 24H: -26.1% (VMO) *vs* -20.1% (VL), $p<0.05$.

ND: There are no differences; MVC: maximum voluntary contraction.

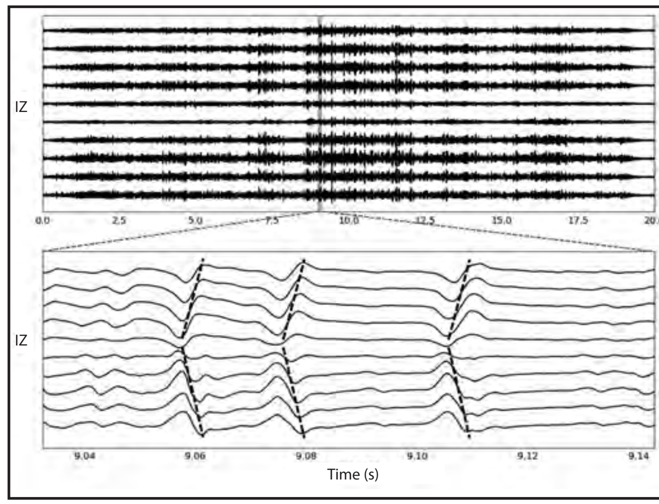
post-exercise eccentric MFCV in the biceps brachii, during maximum isometric or dynamic contractions reported: (a) significant reductions of the MFCV 2H post-exercise in the group exposed to the eccentric contractions (100% MVC: 4.16 ± 0.34 m/s (PRE) *vs* 3.43 ± 0.44 m/s (2H), $p < 0.0118$; and 100% MVC: 4.1 ± 0.3 m/s (PRE) *vs* 3.8 ± 0.4 m/s (2H), $p < 0.01$)[11]. Regarding studies that evaluated the effect of eccentric exercise on the MFCV in the quadriceps, they reported: (a) significant drops in the MFCV during maximum isometric contractions in the vastus lateralis (VL: 4.9 ± 0.59 m/s (PRE) *vs* 4.5 ± 0.46 m/s (2H), $p < 0.05$, and 4.5 ± 0.44 m/s (twenty four hours post-exercise (24H), $p < 0.05$), and vastus medialis obliquis (VMO: 5.3 ± 0.61 m/s (PRE) *vs* 4.8 ± 0.54 m/s (2H), $p < 0.05$, and 4.9 ± 0.57 m/s (24H), $p < 0.05$)[19]; (b) based on the same study, a greater percentage of decay of the MFCV was seen in the vastus medialis obliquis *vs* vastus lateralis during sustained sub-maximum contractions (50% MVC) (24H: - 26.1% (VMO) *vs* – 20.1% (VL), $p < 0.05$)(19); and (c) a significant increase in the MFCV during maximum isometric contractions in the group submitted to eccentric training (4.17 ± 1.62 m/s (PRE) *vs* 4.44 ± 1.19 m/s (six weeks post-exercise), $p < 0.05$)[16].

Protocols for eccentric exercise used to induce muscle damage

Five studies used isokinetic machines to develop eccentric exercise protocols, considering the biceps brachii[9,11,18] and vastus lateralis[16,20] muscles. On the other hand, only one study used the "leg press" machine to induce eccentric muscle damage in the vastus lateralis and vastus medialis obliquis[19]. In relation to the characteristic of the eccentric exercise protocols for biceps brachii, three studies applied different loads to induce muscle damage[9,11,18]. In relation to the applied loads, some research used a series of fifty repetitions with twenty-second rests[9,11], while another study applied three series of twenty repetitions with five-minute breaks between series[18]. Another relevant point is related to the speed of the isokinetic machines used in each study, which were used at 1 rad/s[11] and 60º/s[9,18]. Finally, regarding the characteristics of the developed movement, two studies divided the range of movements into 2 phases (Phase 1: 65º-120º and Phase 2: 120º-175º) three seconds apar[t9,11], while the remaining research maintained the maximum eccentric contraction throughout the entire range of movement (ROM). Regarding the magnitude of the ROM used over the elbow joint, the contractions were made between 65°-175º[9,11,18]. As for the eccentric exercise protocols for the quadriceps (vastus lateralis and medialis), two studies applied different loads to induce muscle damage[16,19] and only one study developed eccentric contractions up to exhaustion[20]. Out of these three studies, one of them applied an eccentric contractions intervention[19], another generated randomised exposures of exhausting dynamic contractions[20], and the last one carried out a training programme with eccentric contractions for six weeks[16]. Two research projects associated with the eccentric exercise of quadriceps used four series, considering twenty[20] and twenty-five contractions[19], with rests of two[20] and three[19] minutes between each series. In the case of the six-week training run by Cadore *et al.,* the progressions included eight, ten and twelve repetitions from two to five series, with five-minute breaks between each series[16]. Studies that applied the eccentric exercise protocol with an isokinetic machine in quadriceps used angular speeds of 60º/s in a range of knee movement between 180º-90º.[16,20] On the other hand, the study that implemented the "leg press" used an external load equal to 150% MVC in a range of knee movements between 180º-60º[19].

Figure 1. Illustrates two types of surface electrode. A) linear arrangement of 16 electrodes (dry array SA16-5 ied 5 mm, OT Bioelettronica, Turin, Italy), and B) grid of 64 electrodes (ELSCH064NM3 ied 10 mm, OT Bioelettronica, Turin, Italy).

Figure 2. Shows the registry of the motor unit action potentials acquired with high density surface electromyography for 20 seconds from a sub-maximum isometric contraction (60%) of the gastrocnemios medial (top picture). The screen shot was obtained with a linear arrangement of 16 channels (*dry array* SA16-5 ied 5 mm, OT Bioelettronica, Turin, Italy). This shows the registry of 10 channels in a window of 0.1 s (between 9.04 s and 9.14 s, lower picture). The vertical dotted lines describe the orientation of the propagation of the potentials (lower picture). IZ: location of the innervation zone.



Techniques used to record the EMG signal and estimate the MFCV

According to the compiled literature, the electromyographic signals were captured using grids of sixty-four electrodes[9,11], or linear arrangements of eight electrodes[16,18–20]. Considering an inter-electrode distance of eight[9,11] and five[16,18–20] millimetres (Figure 1B). In all cases, the innervation zone was located before placing the electrodes on the skin. This was developed with linear arrangements of sixteen[9,11,16,18,20] or eight[19] surface electrodes (Figure 1A). Additionally, different studies report acquiring EMG signals by amplifying a bandwidth between 10–750 Hz[9,11,18], and 10 - 500 Hz[16,19,20], also considering a band filter between 20–450 Hz[11], 10 - 500 Hz[16], or 10 - 750 Hz[9,18]. All the research projects used a sampling frequency of 2048 Hz, which were digitalised with a 12-bit analogue-digital converter. Relating to the estimation of the MFCV and the selection of the EMG channels, the studies mention different methodologies, highlighting the following points: (a) consider two or three[9,11,18] adjacent channels in the lengthways direction of the muscle; (b) use the maximum number of channels according to the propagation of action potentials with minimum changes in shape without the presence of the innervation zone[19]; and (c) considering the arbitrary selection of some EMG channels[16,20] (see Figure 2). It is important to mention that some studies declare that they exclude channels with the presence of noise, close to the innervation zone and more categorically, rule out MFCV values outside a physiological range (2-6 m/s)[9,11,18].

Discussion

Eccentric contractions in the musculoskeletal system have been a useful tool in physical therapy and sport, given the multiple neuromuscular adaptations that can be induced[21,22]. In the same context, one of the variables used to describe these adaptations was MFCV, which has made it possible to determine possible changes in the permeability of the membrane after muscle damage caused by the exercise[16,21,23]. In relation to sports training and therapeutic exercise, eccentric contractions have taken centre stage, demonstrating a greater adaptive effect compared to other types of muscle contractions[8]. However, it is important to consider that this adaptation might be the result of the selective mechanical damage on a set of muscle fibres, especially type II fibres (fast)[3]. In the same context, high-density EMGs have made it possible to investigate possible neuromuscular changes from recording MUAPs located in surface regions of the muscle being assessed, which would modify their activity after eccentric contractions[24]. Although the quantity of studies is limited, the results based on MFCV behaviour could be determined, to some extent, by the architecture of each muscle, and hypothetically, by their resistance to fatigue. One example of this is demonstrated in the results reported by Nasrabadi *et al.* 2018, who describe a significantly greater percentage drop in the MFCV in the vastus medialis obliquis than in the vastus lateralis, 24 hours after applying an eccentric exercise protocol[19], attributing this finding to the morphological differences of each muscle portion[19]. On the contrary, Piitulainen *et al.* 2013 evaluated the MFCV of both portions of the biceps brachii during maximum eccentric contractions, reporting a significant increase in the MFCV, without finding differences between the two portions[10]. These results might support the hypothesis linked to the muscular architecture and its possible relationship with how the MUAPs work and behave in the light of eccentric exercise. Additionally, histological studies have shown that the magnitude of the muscle damage induced by eccentric exercise might depend on the musculoskeletal architecture[25].

One interesting finding observed in the compiled articles is related to muscle damage and the expected effect on the MFCV. Consequently, despite the inflammatory indicators of the muscle damage reaching a maximum value 24H post-exercise, the MFCV describes its maximum decline in 2H post-exercise, and then it returns to baseline levels after 24H[9,11,18]. However, this research proposes that MFCV behaviour is not associated directly with muscle damage 2H post-exercise, but a chemical imbalance induced by the high eccentric loads[16,19,26]. According to the literature, the above was explained by an ionic imbalance of sodium [Na^+] and potassium [K^+], which would affect the membrane permeability[26]. This generated a hypothesis based on the presence of sodium [Na^+] and calcium [Ca^{+2}] channels which are sensitive to stretching of damaged muscle fibres[3], which would alter both the sarcolemma and the T-tubule complex of the affected region and, as a consequence, would delay the action potential in the membrane[26]. These changes might be more visible at high muscular concentrations, mainly affecting fast contraction fibres[9,11,18]. However, there is not enough evidence to determine whether the proposal described above might affect the whole musculoskeletal system in a similar way[18,19], or if the muscle architecture might play an essential role in MFCV behaviour. Another effect developed by external agents on MFCV was discussed by Bazzucchi *et al.*, who suggested that the use of ergogenic elements, such as oral administration of Quercetin might also modulate the effect of eccentric exercise on the MFCV of the biceps brachii[27].

On the other hand, eccentric exercise protocols varied according to the muscle being evaluated, and the most-studied were the biceps brachii[9,11,18] and portions of the quadriceps[16,19,20]. Additionally, use of isokinetic machines was observed in most of the investigations[9,11,16,18,20], highlighting movement control in the different segments of the body and characterisation of the volume of eccentric exercise used, Regarding the eccentric exercise, the findings reported by Cadore *et al.* suggest that MFCV behaviour does not differ between trainings with eccentric and concentric contractions[16]. However, future research might have to prospectively investigate MFCV behaviour considering different muscle groups, after eccentric and concentric contractions.

According to the articles compiled, high-density EMGs might represent the common denominator to register the different MUAPs, associated with subsequent processing of the MFCV. However, the variation in acquisition of the electromyographic signal is represented by the use of multiple electrodes, highlighting the configuration of linear arrangements[16,19] and grids[11,18]. Furthermore, criteria considered to estimate the MFCV are varied, although essential points can be highlighted such as the location of the innervation zone (prior to calculating the MFCV), selection of the number of adjacent channels, exclusion of channels with noise, and ruling out values outside a physiological range (2-6m/s)[9,11,18].

Within the limitations of this research, it is possible to mention some aspects: i) selection by convenience in all studies, ii) selection of articles only in the English language, iii) the very limitations of a bibliographic review[28].

Conclusion

To sum up, the results suggest that the MFCV behaviour in relation to eccentric exercise could be modulated by a series of intrinsic factors that have been modified. However, there is not enough evidence to prove the variation of the MFCV produced by the eccentric exercise, considering that the most evaluated muscles were the biceps brachii and portions of the quadriceps. This could be a challenge for using high density EMG, a frequently-used technique according to the selected articles.

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Conflict of interests

The authors do not declare any conflict of interests.

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Original article

Recovery behavior after matches for returning to training in volleyball athletes

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Summary

The aim of this research was to evaluate the behavior of vertical jumps performance in professional volleyball athletes during matches and training and their relationships with fatigue and recovery through heart rate variability (HRV), ratings of perceived exertion (RPE) and perceived recovery status (PRS). Nine male professional volleyball athletes participated in the study, with mean age: 25.66 ± 5.7 years, mean body mass: 97.81 ± 8.65 Kg and mean height: 200.94 ± 5.19 cm, with experience in national and international competitions. HRV and PRS were evaluated in the morning of matches and in the presentation for the first day of training after matches. RPE was collected immediately after matches and at the end of training days. Jumps performance was monitored during the matches and during the first days of training. The data was grouped by matches and training sessions. Significance level adopted was $\alpha \leq 0.05$. There were no alterations in HRV and PRS evaluated after matches and before training sessions, as well as in RPE after training. Jumps height was greater during the matches ($p< 0.013$) and there were no differences in the number of jumps. There was a positive correlation between the number of jumps during matches and PRS before matches ($r= 0.336$, $p= 0.015$) and a negative correlation between the number of jumps during training and pre-training PRS ($r= -0.318$, $p= 0.002$). We conclude that the recovery period proposed by the team proved to be sufficient for the athletes to maintain the same condition for returning to training. This information can assist physical trainers to prescribe training loads for the return to training.

Key words:
Heart rate. Physical exertion. Recovery of function. Sports.

Comportamiento de la recuperación de atletas de voleibol para el regreso al entrenamiento tras los juegos

Resumen

El objetivo de este estudio fue evaluar el comportamiento del desempeño de salto vertical en atletas de voleibol profesional durante juegos y entrenamientos y su relación con fatiga y recuperación por medio de la variabilidad de la frecuencia cardíaca (VFC), calificaciones de esfuerzo percibido (RPE) y estado de recuperación percibido (PRS). Nueve atletas de voleibol profesionales participaron del estudio, con media de edad: 25,66 + 5,7 años, media de masa corporal: 97,81 + 8,65 kg y media de altura: 200,94 + 5,19 cm, con experiencia en competiciones nacionales e internacionales. La VFC y PRS fueran evaluadas en la mañana de los juegos y en la presentación para el primer día de entrenamiento tras los partidos. La RPE fue evaluada luego después del fin de los juegos y al fin de los días de entreno. Saltos fueron monitoreados durante los partidos y durante el primer día de entreno tras los juegos. Los dados fueron agrupados en juegos y sesiones de entreno. El nivel de significancia adoptado fue $\alpha < 0,05$. No hubo alteraciones en la VFC y PRS evaluados pre juegos y pre entrenos y en la RPE pos entrenamientos. La altura de los saltos fue mayor en los juegos ($p < 0,013$) y no hubo diferencias para el número de saltos. Hubo correlación positiva del número de saltos de juegos con la PRS antes de los juegos ($r= 0,336$, $p= 0,015$) y correlación negativa del número de saltos de entreno con la PRS pre entreno ($r= -0,318$, $p= 0,002$). Concluimos que el período de recuperación propuesto por el equipo se ha mostrado suficiente para los atletas mantenerme la misma condición para el regreso a los entrenos. Y esta información ayuda preparadores físicos a planear las cargas de entrenamiento para el regreso a los entrenos.

Palabras clave:
Frecuencia cardíaca. Esfuerzo físico. Recuperación de función. Deportes.

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Introduction

Competitive periods require balance between training loads and appropriate recovery[1,2] in order to avoid an impairment in performance[3,4]. For monitoring athletes, the choice of simple and easy application methods that combine physical, psychological and physiological indicators seem to provide relevant information on training-load adaptation and recovery for teams[1]. Heart rate variability (HRV) and ratings of perceived exertion (RPE) and perceived recovery status (PRS) consist in assessment parameters of practical applicability and good accuracy.

HRV has been proving to be an important physiological marker for recovery patterns[5,6], able to provide important information on fatigue, adaptation and recovery[5,7–9], and also on pre-competitive anxiety and stress effects[10–12]. High HRV indicates signals of good adaptation, showing healthy and efficient autonomic mechanisms, and inversely, low HRV is an indicator of abnormal and insufficient adaptation of autonomic nervous system (ANS) and may indicate the presence of physiological malfunction[13,14]. HRV alterations allow clinical comparisons able to distinguish between parasympathetic and sympathetic chronic fatigue symptoms. Parasympathetic type is more frequently observed and is characterized by persistent rates of high fatigue, apathy, mood changes, intolerance for prolonged exercise, and sympathetic type seems to be more related with psychoemotional aspects of stress[15].

Specifically in volleyball, studies have not finding significant differences in HRV in evaluations performed before and after training periods[16–19]. On the other hand, after matches there were significant reductions in HRV indexes, due to increased physical demand in relation to the assessment conducted on the morning of match days[19]. Regarding the effects of pre-competitive anxiety and stress, D'Ascenzi *et al.*[20] showed that there were no significant differences in pre-competitive situations evaluated in the morning of matches and baseline values of training days. However, there is still no response on the recovery behavior of athletes after matches when returning to training.

The index, root mean square of the successive differences successive differences between adjacent RR intervals (RMSSD) is the most used of HRV indexes for monitoring athletes of different modalities and showing to be sensitive to alterations in training loads and physical requirements, being representative of parasympathetic system alterations[5,7–9]. The standard deviation of the NN interval (SDNN) index presents similar responses than RMSSD and represents overall variability, without differentiating between changes arising from sympathetic and parasympathetic systems[21–23].

Vertical jumps, for volleyball, appear as the biggest performance criterion, whose monitoring is of fundamental importance[24,25]. The performance of jumps, in a continuous and intermittent way, produces reduction of peak power, increased perceived muscle soreness, increased lactate concentration in the bloodstream, increased HR and decreased performance[26–28].

Among psychological parameters, RPE and PRS have been widely used for monitoring athletes[29–32]. RPE is useful for the assessment of physical stress, intensities prescription, monitoring of training loads and prediction of maximal capacity[31,33]. On the other hand, PRS was created to allow access to the individual recovery state, which is important for identifying decreases in performance associated with the athlete's feeling of not being recovered[34]. Both perceptions scales serve as complement to traditional physical assessments.

However we could not find studies that evaluated the recovery behavior of volleyball athletes for the return to training. Thus, in order to understand the alterations in fatigue levels that high-level competitions could trigger in volleyball athletes and how is the return to training behavior over competitive periods, this study aimed to evaluate the behavior of vertical jumps performance in professional volleyball athletes during matches and training sessions and their relationships with fatigue and recovery through HRV, RPE and PRS. Our hypothesis was that the physical demands of the matches would reduce HRV indexes and PSR, and increase the RPE in first training day after matches.

Material and method

Experimental approach

The purpose of this research was to evaluate the behavior of vertical jumps performance in professional volleyball athletes during matches and training days and their relationships with fatigue and recovery through heart rate variability (HRV), ratings of perceived exertion (RPE) and perceived recovery status (PRS). HRV and PRS were assessed in the morning of matches and in the presentation of the first training day after matches. RPE was collected immediately after matches and at the end of training days. Jumps performance was monitored during the matches and during the first training days (Table 1).

Table 1. Experimental design and procedures.

Matches (n 11)			First training after matches (n 11)		
Pre Matches	Matches	Post Matches	Pre Training	Training	Post Training
HRV (SDNN) (RMSSD) Perceptions of recovery (PR)	Height and number vertical jump	Perceptions of effort (PE)	HRV (SDNN) (RMSSD) Perceptions of recovery (PR)	Height and number vertical jump	Perceptions of effort (PE)

Heart rate variability (HRV), standard deviation of all normal-to-normal RR intervals (SDNN), square root of the mean of the squared differences between adjacent normal R-R intervals (RMSSD), number (n).

Subjects

Nine male professional athletes participated in the study, with mean age: 25.66 ± 5.7 years, mean body mass: 97.81 ± 8.65 Kg and mean height: 200.94 ± 5.19 cm. As inclusion criteria, the athletes should belong to a Brazilian high-performance volleyball team, they should have at least two years of experience in national and international competitions, to present a training volume of at least four hours per day, and should not present previous cardiac surgeries. Those athletes, who were not able to perform the tests proposed (by guidance of the team's medical department) and to participate in the competitions, had their data excluded.

The athletes read and signed the free and informed consent form that contained all pertinent information about the study. The study was approved by the Ethics Committee in Research of Federal University of Rio Grande do Sul (number: 2.622.441).

Procedures

Assessments were performed during the second phase of the Brazilian Volleyball Superliga, the country's most important competition of the modality. It included 11 matches and 11 training sessions in an 11-week period, with matches performed once to twice one to two times a week, recovery periods between matches and training days of 24h and 36 h. All matches occurred during the afternoon. Training sessions were composed by physical skills and techniques during the morning, and tactical and blocking trainings in the afternoon, with a total daily duration between 5 and 8 hours.

HRV and PRS collections were performed before matches, in the morning, at the moment of the athletes' presentation to the training. Performance variables, represented by mean jumps height and mean total jumps number, were collected during all matches and in the first technical, tactical and blocking training sessions that succeeded the matches. RPE was collected after matches and after the first training day subsequent to the matches.

Acquisition and analysis of HRV. All HRV assessments were performed following the same protocol. The subjects remained lying in a supine position for 5 minutes before the HRV collections started. R-R intervals were obtained using a heart rate strap (Polar H7, Kempele, Finland) during 5 minutes in supine position. Each athlete used a heart rate strap for the data collection and all athletes were assessed at the same moment. Assessments were performed in an environment without noise and external interference. Polar H7 Strap collects R-R intervals and does not require additional data processing[35]. R-R intervals values were analyzed in the time domain using the software Kubius HRV (Kubios HRV, Kuopio, Finland). The variables analyzed were: standard deviation of all normal-to-normal RR intervals (SDNN), root mean square of the successive differences between adjacent normal R-R intervals (RMSSD) and the logarithm of RMSSD index (LogRMSSD). SDNN and RMSSD indexes are represented in miliseconds (ms).

Vertical jumps. In the present study, the number of vertical jumps and the mean height of vertical jumps obtained during the matches and training sessions were considered as performance outcomes.

For data acquisition, an inertial measurement unit tool (VERT, Florida, EUA) was used, inserted in an elastic band at the waist height of athletes. This tool captures the average height of vertical jumps and the number of vertical jumps performed[36]. The data collected were immediately transferred to a smartphone via Bluetooth. The capture methodology of these variables was performed according to the study of MacDonald *et al*.[37]. All vertical jumps patterns that comprised matches and training sessions were captured for data analysis of performance.

PRS and RPE. Through the PRS scale used by Laurent *et al*.[34], the athletes' perceived recovery was evaluated. The athletes were asked to answer the following question: What is your perception of recovery at the moment? They should point their response on the scale, before matches and training starts. The scale has scores ranging from 0 to 10, in which 0 is equivalent to no recovery and 10 is equivalent to total recovery.

RPE assessment was collected using the CR-10 scale[38,39]. The athletes were asked to answer the following question: What is your perception of effort for today's match or training? They should point their response on the scale, after the end of matches and training. The scale indexes vary from 0 to 10, in which 0 is equivalent to no effort and 10 is equivalent to maximal effort.

Mean values presented by athletes in RPE and PRS scales were calculated for matches and training days. The athletes were previously familiarized with the scales, with at least two years of experience.

Statistical analysis

All data are presented as means and standard deviations. Normality of the data was confirmed with the Shapiro-Wilk test. The data were grouped in matches and training days. For the comparison between means of the games and training for the HRV indices, PRS and RPE paired t-test was used for the normally distributed data and Wilcoxon test was used for the non-normally distributed data.

In order to verify possible associations between variables, Pearson product-moment test was used for the normally distributed data and the Spearman's rho correlation test was used for the non-normally distributed data. Qualitative assessment of correlation coefficients considers from 0 to 0.30 small correlation, 0.31 to 0.49 moderate correlation, 0.5 to 0.69 strong correlation, 0.7 to 0.89 very strong correlation and from 0.9 to 1 perfect correlation[40,41]. Statistical tests were performed in the SPSS software version 22.0 (IBM, Chicago, USA).

Moreover, effect sizes (ES) were calculated to compare means of matches and training sessions by Cohen's d calculation[42,43]. Qualitative assessment considers <0.19 insignificant effect, from 0.20 to 0.49 small effect, 0.50 to 0.79 medium effect and from 0.80 to 1.29 large effect.

Results

Of the athletes evaluated, two were excluded from the study, one due to cardiac surgery and another due to injury. The data were grouped in matches and training days. The collected HRV, PRS and RPE data of athletes were used in the analysis when their data were also evaluated in the performance analysis. Thus, 48 subjects were analyzed for HRV data, 51 subjects were analyzed for PRS data and 61 subjects were analyzed for RPE data of matches and training sessions. For the performance data, all evaluations of athletes who had their data collected in the matches and training were considered, resulting in 70 subjects.

No differences were observed between HRV indexes before matches and pre-training moments (Table 2).

In the performance variables, the number of vertical jumps performed in matches and training sessions did not show differences. On the other hand, vertical jumps height was higher during matches when compared to training (Table 3).

There was no difference between the PR evaluated before matches and the PR evaluated pre-training. PE also showed no difference between post-matches and post-training (Table 4).

The correlation analyses showed that the number of jumps during matches presented moderate positive correlation with PR in pre-matches moment (r= 0.336, p= 0.015) (Figure 1 A). And the number of jumps during training presented moderate negative correlation with PR in pre-training moment (r= -0.318, p= 0.002) (Figure 1 B).

Table 2. Data evaluated in matches and training with mean ± standard deviation, p value and ES (CI) for HRV through SDNN index (ms), RMSSD index (ms) and LogRMSSD (natural logarithm of RMSSD index) evaluated in the morning of match days and in the moment of re-presentation of athletes for the first day of training after matches.

	n	Match	Training	p	Power	ES (IC)
SDNN (ms)	48	81.95±73.74	144.52±503.95	0.791[b]	0.203	0.17 (-0.23; 0.57)
RMSSD (ms)	48	76.53±69.14	98.81±172.99	0.359[b]	0.203	0.17 (-0.25; 0.55)
LogRMSSD	48	1.88±0.39	1.99±0.39	0.346[a]	0.314	0.17 (-0.25; 0.55)

[a]Student's t test. [b] Wilcoxon test. Heart rate variability (HRV), standard deviation of all normal-to-normal RR intervals (SDNN), square root of the mean of the squared differences between adjacent normal R-R intervals (RMSSD), logarithm of RMSSD (LogRMSSD), effect size (ES), confidence interval (CI) and number of subjects (n).

Table 3. Data evaluated in matches and training with mean ± standard deviation, p value and ES (CI), for the number of jumps performed in matches and technical and tactical training sessions and jumps height (cm) performed in matches and technical and tactical training sessions.

	n	Match	Training	P	Power	ES (CI)
Number of jumps	70	73.08±36.13	78.76±34.57	0.411[a]	0.374	0.16 (-0.19; 0.48)
Jumps height (cm)	70	56.39±10.30	54.53±9.04	0.013*[b]	0.334	0.19 (-0.14; 0.52)

*significant when p value ≤0.05. [a]Student's t test. [b] Wilcoxon test. Effect size (ES), confidence interval (CI) and number of subjects (n).

Table 4. Data evaluated in matches and training with mean ± standard deviation, p value and ES (CI), PR evaluated on the morning of match days and at the moment of re-presentation of athletes for the first day of training after matches, PE evaluated after matches and after the first day of training after matches.

	n	Match	Training	P	Power	ES (CI)
PR	51	7.47±0.58	7.71±1.04	0.461	0.481	0.28 (-0.16; 0.62)
PE	61	5.57±1.84	5.47±1.38	0.930	0.073	0.06 (-0.34; 0.37)

Perceived recovery (PR), perceived effort (PE), effect size (ES), confidence interval (CI), number of subjects (n).

Figure 1. A. Correlation of mean number of jumps during matches with mean PR previous to matches. B. Correlation of mean number of jumps during training with mean PR previous to training.

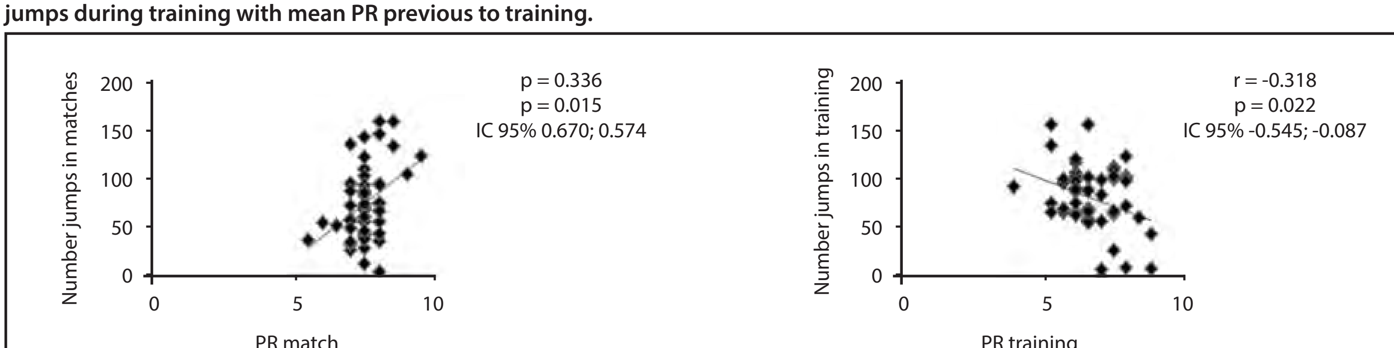

Table 5. Correlations data of mean number of jumps performed in matches and training and mean jumps height performed in matches and training with mean PR of matches and training and mean PE of matches and training.

	PR Matches	PR Training	PE Matches	PE Training
Number of jumps in matches	ρ =0.336 95%CI 0.670; 0.574 Power 0.837 p=0.015	r=0.099 95%CI -0.238;0.429 Power 0.130 p=0.484	r=0.038 95%CI -0.236; 0.294 Power 0.061 p=0.770	ρ =-0.035 95%CI -0.382; 0.223 Power 0.059 p=0.787
Number of jumps in training	ρ =0.077 95%CI -0,222;0.360 Power 0.097 p=0.585	r=-0.318 95%CI -0.545;-0.087 Power 0.790 p=0.022	r=0.047 95%CI -0.269;0.255 Power 0.067 p=0.717	ρ =-0.013 95%CI -0.334;0.213 Power 0.051 p=0.918
Jumps height in matches (cm)	ρ =-0.241 95%CI -0.464;0.022 Power 0.535 p=0.085	ρ =-0.160 95%CI -0.411;0.117 Power 0.267 p=0.258	ρ =-0.191 95%CI -0.445;0.158 Power 0.361 p=0.140	ρ =0.036 95%CI -0.264;0.283 Power 0.060 p=0.782
Jumps height in training (cm)	ρ =-0.036 95%CI -0.291;0.242 Power 0.060 p=0.800	r=-0.066 95%CI -0.386;0.246 Power 0.084 p=0.642	r=-0.249 95%CI -0.434;0.025 Power 0.563 p=0.053	ρ =0.073 95%CI -0.220;0.364 Power 0.092 p=0.575

r: from Pearson product-moment correlation test; ρ: from Spearman's rho correlation test.

Table 6. Correlations data of mean number of jumps performed in matches and training and mean jumps height performed in matches and training with mean SDNN index of matches and training, mean RMSSD of matches and training and mean LogRMSSD of matches and training.

	SDNN Matches	SDNN Training	RMSSD Matches	RMSSD Training	LogRMSSD Matches	LogRMSSD Training
Number of jumps in matches	ρ=-0.128 IC95% -0.409;0.152 Power 0.186 p=0.391	ρ=0.108 IC95% -0.222;0.416 Power 0.145 p=0.471	ρ=0.225 IC95% -0.046;0.509 Power 0.478 p=0.124	ρ=0.239 IC95%-0.062;0.477 Power 0.528 p=0.102	r=0.172 IC95% -0.054;0.388 Power 0.301 p=0.241	r=0.183 IC95%0.039;0.392 Power 0.335 p=0.212
Number of jumps in training	ρ=-0.108 IC95% -0.412;0.189 Power 0.186 p=0.468	ρ=0.142 IC95% -0.161;0.421 Power 0.145 p=0.339	ρ=-0.046 IC95%-0.319;0.239 Power 0.478 p=0.756	ρ=0.166 IC95% -0.138;0.424 Power 0.528 p=0.260	r=-0.028 IC95% -0.281;0.231 Power 0.301 p=0.852	r=0.-187 IC95% -0.067;0.419 Power 0.335 p=0.203
Jumps height in matches (cm)	ρ=-0.252 IC95% -0.020;0.505 Power 0.574 p=0.087	ρ=0.121 IC95% -0.182;0.409 Power 0.171 p=0.418	ρ=-0.049 IC95% -0.329;0.228 Power 0.068 p=0.741	ρ=-0.024 IC95% -0.298;0.256 Power 0.054 p=0.873	ρ=-0.054 IC95% -0.329;0.226 Power 0.073 p=0.717	ρ=-0.024 IC95% -0.298;0.256 Power 0.054 p=0.873
Jumps height in training (cm)	ρ=-0.130 IC95% -0.405;0.181 Power 0.191 p=0.383	ρ=-0.080 IC95% 0.431;0.241 Power 0.101 p=0.591	ρ=-0.182 IC95% 0.449;0.099 Power 0.332 p=0.214	ρ=-0.108 IC95% -0.439;0.207 Power 0.145 p=0.465	r=-0.131 IC95% -0.382;0.117 Power 0.193 p=0.373	r=-0.017 IC95% -0.338;0.303 Power 0.052 p=0.910

r: from Pearson product-moment correlation test; ρ: from Spearman's rho correlation test.

The other performance variables during matches and training presented small correlations with mean PR of matches and training and with mean PE of matches and training (Table 5).

The correlations of the performance variables were small with matches and training SDNN indexes, with matches and training RMSSD indexes and with matches and training LogRMSSD (Table 6).

Discussion

HRV and psychometric outcomes showing to be sensitive to the physical demands imposed to athletes during matches and training sessions[21–23]. In order to evaluate the recovery pattern of athletes when returning to training after matches, our findings demonstrate that there were no HRV alterations evaluated by SDNN, RMSSD and LogRMSSD indexes between the evaluations performed in the morning of the match days and in the morning of the first training days performed after matches, contradicting our hypothesis. Despite the higher jump heights during the matches in comparison to training sessions, but without difference in the number of jumps performed.

The literature shows that high-intensity exercises generate ANS alterations as acute response, generating reductions in HRV indexes. These reductions occur linearly to the intensity, and also alter post-exercise recovery responses[21–23]. studies show that in volleybal athletes, no HRV changes were found before and after training periods[16–18]. But after volleyball matches, reductions in HRV indexes were found when compared to baseline values, due to the physical demands imposed during matches[19].

Our study shows that after the proposed recovery period for the team to return to training, the possible changes in HRV indexes resulting from matches did not remain until the moment of the subsequent training session, despite the physical demands imposed to the athletes during matches are greater in comparison to training, evidenced by the greater means of vertical jumps height in matches.

Besides that the values found for SDNN and RMSSD indexes were very similar to the values showed for aerobically trained athletes[14]. According to the literature, low values of HRV indexes in athletes may represent fatigue conditions and incomplete recovery[9,17,19], which was not found in the athletes evaluated in our study.

Vertical jump is considered an extremely important element in volleyball[24,25,44,45]. In our study, the number of jumps did not show significant difference between matches and training, and the jumps height was greater in matches when compared to that performed in the first training day after matches.

The number of jumps performed was very similar to other study[2]. In addition, jumps height was greater than the values found after weeks of training, evaluated in maximal tests[46,47]. It is noteworthy that in maximal tests, jumps are performed in a controlled manner, and with a pattern defined by the objective of the study. In our study, all patterns were collected in the analysis of matches and training sessions.

The according to our hypothesis greater jumps height performed during matches may result in higher RPE after matches and may lead to reduced HRV indexes and PRS for presentation to training, according to our hypothesis. But these differences between matches and training sessions were not found. Such increase in jumps height during matches may be explained by motivational reasons, because matches are different from training due to the presence of opponents and the pursuit of victory[48].

The findings of RPE and PRS variables support the HRV findings, as significant differences were not found in these outcomes between matches and training. The athletes showed scores that represent a "strong" intensity for RPE of matches and training. The mean RPE found in our study was similar to the values found in the study of Horta *et al.*[2] which also evaluated the competitive phase. The study of Rodrigues-Marroyo *et al.*[49] shows mean RPE as "somewhat strong" score, but the volleybal athletes were evaluated during pre-competitive phase. In our study, mean RPE was higher and may be such difference is due to the phase evaluated, because in competitive phases the training is added to the volume of competitions.

Mean PRS presented scores that represent "very, very good recovery" for matches and training. We did not find other articles that have evaluated PRS in volleyball players. The authors who created the PRS that the importance of the this perceptions scale is to identify decreases in performance in low recovery situations[34]. The use of perception scales for high performance sports must be used along with other assessments, such as performance or physiological ones[1].

In order to verify the existence of associations between the performance variables with other outcomes, our study found moderate positive correlation between the number of jumps performed in the matches and the PRS evaluated on the morning of matches. It shows that in the morning of matches, when the athletes presented higher PRS scores, the number of vertical jumps performed in matches was greater. These findings corroborate Laurent *et al.*[34], creators of the PRS. The authors state that greater recovery levels lead to better performance rates[34].

Instead the number of jumps performed in training days presented moderate negative correlation with mean PRS evaluated in the morning of training days. It shows that higher PRS scores in the morning of training sessions resulted in fewer number of jumps performed during training. This finding contradicts the objectives of the PRS scale. It was expected that higher PRS scores would result in greater mean number of jumps. Motivational factors that differ training from matches may partially explain these findings[48]. Moreover, coaches' requirements may be lower in the first day of training after matches when compared to match days, although the recovery pattern of athletes remains very similar between matches and training.

In this way, the volleyball athletes evaluated did not present significant alterations between the evaluations performed on the morning of matches and on the day of re-presentation of these athletes to training, which demonstrates that the recovery period proposed by the team is enough to maintain the recovery rates for the return to training. The lack of differences between the two moments evaluated may be due to the athletes' high conditioning level, which leads them to present a high physical and psychological tolerance to matches and training loads.

Our biggest limitation was not having evaluated HRV after matches, in order to understand possible ANS alterations. In addition, the fact that we did not collect all variables in all athletes at the same moment, which resulted in different number of subjects, a situation caused by the conduction of collections with minimal interference in the team routine. Strengths of our study are to have evaluated 11 matches and 11 training sessions in an 11-week period with high levels of volleyball performance.

Practical applications

Monitoring recovery patterns help coaches and physical trainers to better prescribe training. And if necessary, to alter recovery periods or training loads to improve the physical conditioning of athletes and to avoid chronic fatigue and possible overtraining.

Compliance with Ethical Standards

The study was approved by the Ethics Committee in Research of Federal University of Rio Grande do Sul (number: 2.622.441).

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Conflict of interest

The author do not declare a conflict of interest.

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Review

Endurance exercise: a model of physiological integration

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Summary

Endurance exercise is a model of physiological integration. There is no other animal activity in which cardiovascular, respiratory, metabolic-endocrine and neuromuscular functions are activated at the same time. Even apparently, silent functions are essential during exercise (digestive, renal). During long-term exercise, the absorption of water and carbohydrates is a determining factor in performance. Kidney function plays a fundamental role in trying to preserve the hydro-electrolyte balance during exercise. In this work we present an integrative physiological perspective during dynamic exercise (mobilization of a large muscle mass with a low to moderate degree of strength development), both from the point of view of health and performance. The response of the heart rate in the first moments of exercise is a good example of the feedforward mechanism. Overall, the nervous system has two control mechanisms: feedforward and feedback. These depend on the central command, a more functional than anatomical entity. The feedforward system allows to immediately start the cardiovascular and respiratory systems. This mechanism is important because it activates the organism to overcome resting state. The feedback system is equally important because it allows the central command to receive the necessary information to "order" the appropriate response according to the intensity of the exercise. The information for retrocontrol comes from various receptors located in: the muscles, the respiratory system and the cardiovascular system. It is complex information that the central nervous system processes with exquisite precision, as can be seen in in endurance exercise.

Key words:
Endurance. Exercise. Feedforward. Feedback. Integration.

El ejercicio de resistencia: un modelo de integración fisiológica

Resumen

El ejercicio dinámico constituye el paradigma de la integración fisiológica. No hay ninguna otra actividad animal en la que se pongan en marcha al mismo tiempo las funciones cardiovasculares, respiratoria, metabolo-endocrina y neuromuscular. Incluso funciones, aparentemente silentes, son esenciales durante el ejercicio (digestiva, renal). Durante ejercicios de larga duración la absorción de agua y carbohidratos es determinante de rendimiento. Así mismo, la función renal juega un papel fundamental en intentar preservar el equilibrio hidro-electrolítico durante el ejercicio. En este trabajo presentamos una perspectiva fisiológica integradora durante el ejercicio dinámico (movilización de una gran masa muscular con bajo a moderado grado de desarrollo de fuerza), tanto desde el punto de vista de la salud como del rendimiento. De forma global y simplificada el sistema nervioso dispone de dos mecanismos de control: el *feedforward* y el *feedback*, dependientes de una entidad más funcional que anatómica, el comando central. El sistema *feedforward* permite poner en marcha de forma inmediata fundamentalmente al sistema cardiovascular y respiratorio. La respuesta de la frecuencia cardiaca en los primeros instantes del ejercicio es un buen ejemplo de la puesta en marcha del mecanismo de *feedforward*. Este mecanismo es transcendental para poner en funcionamiento al organismo a partir de un estado de reposo. El sistema *feedback* es igualmente importante pues permite al comando central recibir la múltiple información necesaria para "ordenar" la respuesta adecuada a la intensidad del ejercicio. La información para el retrocontrol parte de diversos receptores localizados en: la musculatura, el aparato respiratorio y el sistema cardiovascular. Realmente, es una información compleja que el sistema nervioso central procesa con exquisita precisión, como se puede poner de manifiesto en el ejercicio de resistencia.

Palabras clave:
Resistencia. Ejercicio. Retroalimentación. Control neuronal. Integración.

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Introduction

Aerobic exercise is the preferred option to maintain or improve physical fitness in the western world according to the number of practitioners. In the US alone the number of practitioners of sports considered as dynamic by the Mitchell classification[1], sports in which endurance is considered the determinant capacity involved, was estimated at over 66.2 million in 2017. Even if this calculation has considered as practitioners those who use any modality of endurance exercise for fitness, therefore including jogging, running, cycling, and even walking, considered as sport, this high number suggests the importance of endurance and its training for both public health and sports.

From the perspective of Physiology as a science, endurance exercise is a learning opportunity. As a situation where the sheer stress created by the effort virtually compromises most physiological functions in the body, it has become the paradigm to describe the integration of every physiological system in an attempt to cope with increasing demands. The cardiovascular, metabolic and neuroendocrine adjustments must be precise in their tuning to fit the needs of different exercises. It is generally understood that even Nordic walking would already show this physiological integration[2].

At the same time, it may be easily overlooked that the so-called "silent" physiological functions, such as the renal or digestive systems, may also be compromised during very long efforts. In types of exercises considered extreme, such as an ultra-endurance event, the need to restitute substrates[3-5], together with the need to maintain hydroelectric homeostasis[6,7], make the digestive function of capital importance in this context. The absorption and delivery of nutrients has to be assured although blood flow to those organs will be extremely reduced[8]. Also filtering the blood becomes fundamental in endurance events[9]. Even though the blood flow to the kidneys will be minimal, these organs must perform at a high rate in order to ensure that a large proportion of cardiac output is destined to the exercising muscle[10].

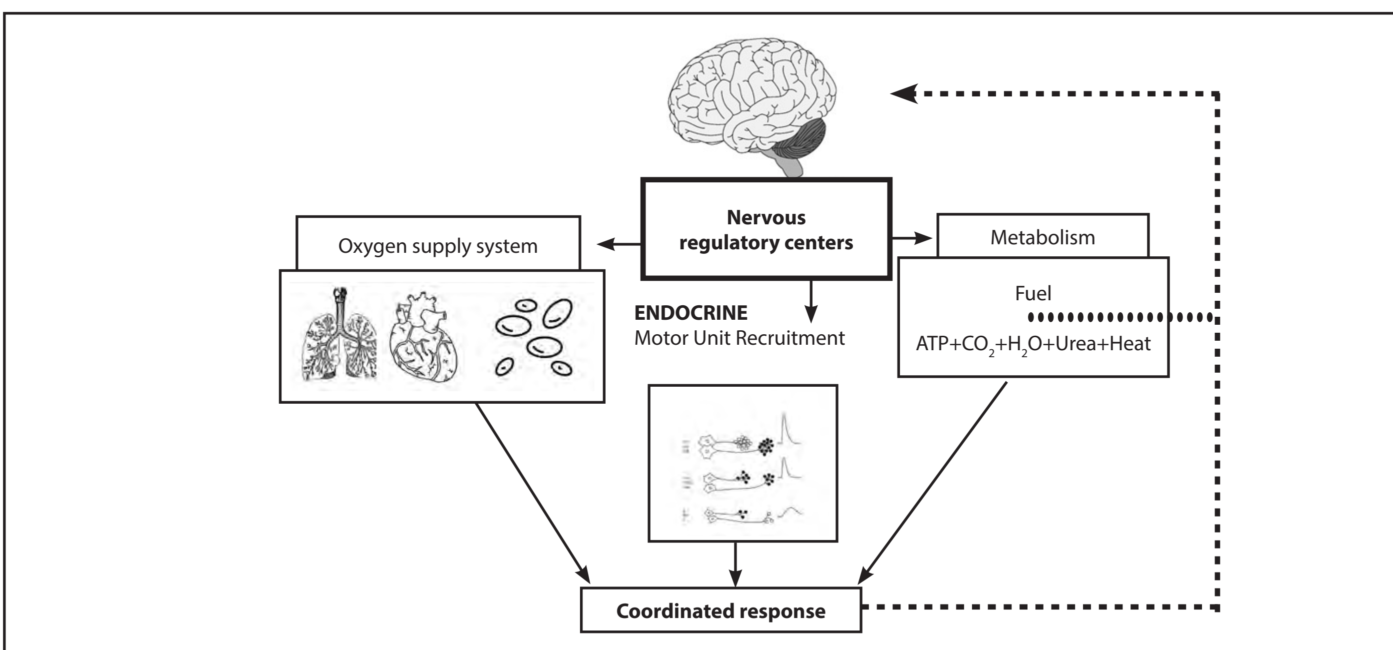
From the perspective of an integrated response, we may see the central nervous system as the main element responsible for the coordination of such a complex response involving all the adjustments required by a moving human body during endurance exercise. Although it is only real if used as a simple level of analysis, Figure 1 illustrates its importance. This simplified model suggests:

The Somatic Nervous System (SNS) must activate the necessary motor units, in the proper order, depending on the intensity of the effort. It does so as follows: activation will descend through the motor pathways[11] and will synapse to motor neurons responsible for the activation of the chosen motor units of the necessary muscles.

The Vegetative Nervous System (VSN) must not only activate the neurons located in the intermediate horn of the spinal cord to activate the thoracic-lumbar system (sympathetic system)[12] but also, at the same time, modulate the activity of neurons located in different encephalic structures in order to attenuate the activity of the cranial-caudal system (parasympathetic system)[13].

The aim of this paper is to summarize and review, from an academic perspective, existing knowledge on the physiological integration of all organs and tissues produced during the most natural stress suffered by an animal, exercise. We will mainly use other reviews and specific textbooks on the topic of sport physiology.

Figure 1. Schematic representation of the integrated response of the body to exercise. The nervous system adjusts the oxygen supply system and metabolism while it selects motor units depending on the intensity of the contraction. As with any other regulation mechanism it requires feedback control suggested here by a discontinuous line.



Physiological parameters resulting from integration during endurance exercise

The integrated response to endurance exercise can be determined through a number of physiological parameters as a result of the coordination of every compromised organ and tissue.

Oxygen consumption ($\dot{V}O_2$) is the parameter that integrates the respiratory, cardiovascular, endocrine and metabolic functions. The higher use of oxygen mostly by muscular tissue is necessary in order to obtain energy. It is also fundamental to increase the availability of different energy substrates. Although metabolism has many and very powerful enzymatic control mechanisms, they are not fast enough to provide the necessary energy ratio. Endocrine control acts precisely on key enzymes to achieve and maintain the use of substrates. At the same time, temperature is another main variable to be controlled during endurance exercise.

Oxygen consumption ($\dot{V}O_2$) during endurance exercise

Figure 2 shows stability of oxygen consumption during an exercise test in our laboratory.

To understand the importance of this integrative parameter we can use the following analysis: An elemental understanding of $\dot{V}O_2$ through gas analysis leads to the following equation:

$$\dot{V}O_2 = (\dot{V}_I \cdot F_I O_2) - (\dot{V}_E \cdot F_E O_2);\ if\ \dot{V}_1 = \dot{V},\ \text{then}$$
$$\dot{V}O_2 = \dot{V}_E\ (F_I O_2 - F_E O_2)\quad \text{(equation 1)}$$

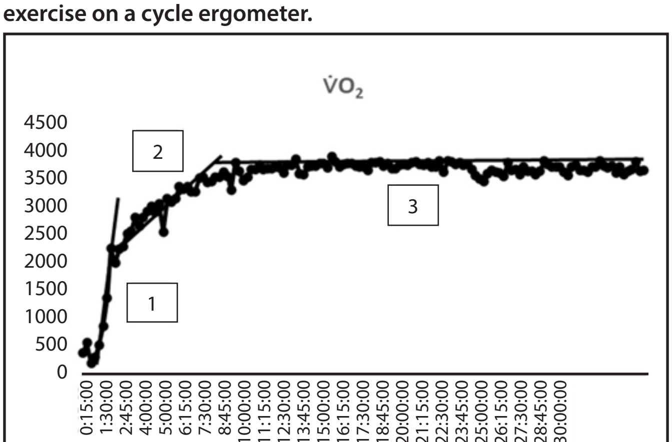
But this equation is only valid whenever the respiratory quotient is below one ($\dot{V}_I = \dot{V}_E$).

To assess $\dot{V}O_2$ over unity it is necessary to use the Geppert and Zunt transformation[14] usually attributed to Haldane.

On the other hand, if in the Fick equation for cardiac output determination $\dot{V}O_2$ is expressed as a variable dependent on $\dot{Q}$ and the arterial-venous oxygen difference, we obtain equation 2.

$$\dot{Q} = (\dot{V}O_2)/(Dif\ a - v\ O_2)\ ;\ \dot{V}O_2 = \dot{Q} \cdot Dif\ a\text{-}v\ O_2\ \text{(equation 2)}$$

Figure 2. Oxygen consumption during a 30´ constant intensity exercise on a cycle ergometer.



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Using equation 1 and 2 we can obtain a good conceptual idea of oxygen consumption as shown in Figure 3. The consumption of oxygen is determined by respiratory, cardiac and cellular functions. All of them, on the one hand, are giving the necessary push to make oxygen available and on the other hand, are consuming it to continue functioning. Excellent coordination of all these systems is necessary for a good performance in an endurance exercise, as they work like a chain, where every link may be the weakest part and therefore the limitation.

An increase in the metabolic needs of a muscular territory can be represented by the increase in local $\dot{V}O_2$. This increase can be obtained by an elevation of alveolar ventilation $\dot{V}_A$ together with a rise in cardiac output ($\dot{Q}$) and an increase in the extraction of oxygen from the blood which expands the arterial-venous oxygen content difference ($Dif_{a\text{-}v}O_2$). The magnitude of these changes will be directly dependent on the intensity of performance during the endurance exercise.

To make it simple the increases in Q, $\dot{V}_A$, $Dif_{a\text{-}v}O_2$ necessary to obtain a stable $\dot{V}O_2$ such as the one shown in Figure 2, may fit in a linear relationship according to the aerobic fitness status and the aim of the exercise.

1º) Q increases linearly, according to Ekelund and Holgrem[15]

$$Q = Q \cdot ([O_2]_{venous}/[O_2]_{arterial}) + (1/[O_2]_{arterial}) \cdot \dot{V}O_2\quad \text{(equation 3)}$$

The slope of the relationship corresponds to $1/[O_2]_{arterial}$.

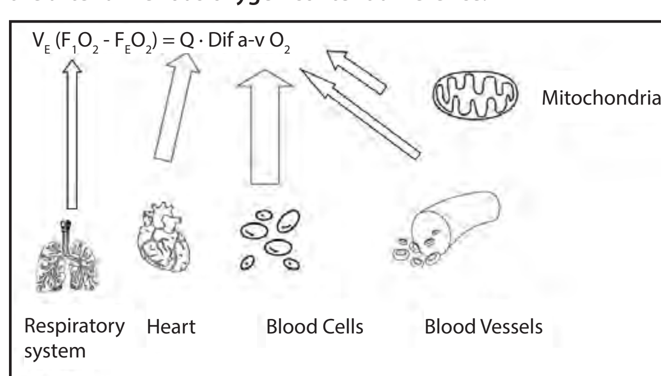
At the same time Q · ($[O_2]_{venous}/[O_2]_{arterial}$). This way to express cardiac output shows the physiological importance of the cardiac pump function during endurance exercise. We can see how low aerobic fitness will show a steeper slope in the $\dot{V}O_2$/Q relationship than that of an elite trained endurance performer.

2º) Increases in $Dif_{a\text{-}v}O_2$ shows a Hyperbolic function again according to the previous authors[16].

$$Dif\ a\text{-}v\ O_2 = 1/(a + b/\dot{V}O_2)\quad \text{(equation 4)}$$

Therefore the horizontal branch ($a = 1/[O_2]_{arterial}$) is asymptotic to the arterial content of oxygen when $\dot{V}O_2$ tends towards infinity. This hyperbolic relationship between dif a-v $O_2/\dot{V}O_2$ has significance for endurance testing and competition. The maximum arterial-venous oxygen

Figure 3. Organs and living tissues are determinants of $\dot{V}O_2$. In black the respiratory system is a $\dot{V}O_2$ determinant as it allows the entrance of a given amount of oxygen. In red the heart is the organ responsible for pumping the blood containing the oxygen to make it available everywhere in the body. In green the local factors (mitochondria, vessels and blood cells) are responsible for the arterial-venous oxygen content difference.



difference value is never reached, because it must necessarily be lower than the arterial blood oxygen concentration. Moreover, taking into account the effects of temperature, CO_2 concentration at the muscular level and oxygen concentration on the hemoglobin dissociation curve, minimum oxygen pressure cannot be reached during a maximum test (approximately 20 mm Hg), because it would mean exceeding or surpassing capillary pressure at which the capillaries would collapse.

The increase in ventilation also presents a lineal correlation during a wide range of intensities

It is well known that the correlation between ventilation and intensity of effort shows two breakpoints[16]. These two points have received several names and we will refer to them as Ventilatory Threshold 1 and 2 (VT_1, VT_2)[17]. There is still discussion concerning the amount of ventilation necessary to maintain a stable amount of lactate during a long-lasting endurance exercise, both in concept[18] and concerning the methods[19].

In summary, the representative parameters of cardiovascular, respiratory, erythrocytary, and mitochondrial functions indicated in Figure 3, all adjust in order to maintain Total $\dot{V}O_2$ stable during endurance exercise. In fact, the erythrocytary role during the adjustment of cardiovascular function, is basically to increase the capacity of the hemoglobin to liberate oxygen (Bohr effect), transport carbon dioxide (Haldane effect)[20], and both combined[21]. Furthermore, the mitochondrial function adjustment is critical to increase the diffusion of oxygen into the muscle, possibly becoming a limitation for the extension of endurance exercise at high intensities[22].

Use of metabolic substrates during endurance exercise

Table 1 shows the use of energy resources during an exercise at an intensity to elicit 50% of $\dot{V}O_{2max}$ lasting four hours[23-25].

A simple analysis of Table 1 suggests:

- As effort continues, the relative amount of lipids increases while the relative amount of carbohydrates decreases as is well known. There is discussion about the processes involved[23-25], but it is generally accepted that lipoprotein lipase in the muscle fiber has a low activity. Therefore, the use of lipid acids depends on the contribution from the liver and the adipose tissue, both subject to high metabolic activity in order to supply fuel to the muscle tissue.
- After the first hour, the supply of glucose from the liver remains constant at an average of 1.8 mmol/L (±0.2).
- The connection between both types of tissues and the liver will prevent the possibility of reaching a point where an athlete could find the muscle empty of fuel during exercise (discussed further in "regulation and control during endurance exercise").

Table 1. Substrate use during 4 hours of constant load exercise.

Substrate	Rest	1 h	2 h	3 h	4 h
Carbohydrates (%)	54	27	20	17	13
Lipids (%)	46	73	80	83	87
Carbohydrates (mm/min)	7.2	3.6	2.6	2.3	1.7
Lipids (mm/L)	0.45	0.71	0.78	0.81	0.87
Glycemia (mmol/L)	4	2	1.5	1.8	2

Taking into account the total availability of glucose in the liver (around 90 g of glycogen), an athlete running a marathon could sustain his or her running intensity for around 20 min if it depended solely on glucose (consuming around 5g/min)[26]. Besides, there is a gradual decrease in muscular glycogen although there is a need to use it in order to maintain mechanical performance[26]. According to this, the coordination between muscle, liver and adipose tissue is essential.

The role of the Liver. The liver, via complex mechanisms of internal regulation (through enzymes) together with external regulation (through hormones), maintains glycemia during endurance exercise as can be seen in Table 1. Once the availability of glycogen in the liver is finished some other tissues can contribute to glycemia providing substrates (amino acids, glycerol or lactate) in order to maintain the availability of glucose[27,28]. But this is a slow process. In fact, as athletes will be ingesting glucose, it will cause an increase in the alanine and Cori cycles which would be hard to detect during long duration endurance exercise. An increase in the Cori cycle during recovery, even in fasting conditions has appeared in the literature[29]. Although the main destination for glucose will be the nervous system, as it is significantly dependent on it, during endurance exercise there is a high consumption of this substrate in muscle too.

The process of the interaction between glucose and fatty acids[30] allows the use of the latter in certain situations to save glucose, being therefore of importance during endurance exercise[30-32]. The increase in the concentration of fatty acids in the blood together with an increase in their absorption by the muscle fibers causes an increase in oxidation while at the same time producing a decrease in the oxidation of glucose. This adjustment is achieved thanks to the control of key enzymes; for example, a change in the activity of glycogen-phosphorylase compared to glycogen-synthase. Control of the former is complex but there are at least three known mechanisms involved in the change from the inactive to the active form of the enzyme[24]. The most powerful of these mechanisms is the action of hormones that activate the protein kinase and, in turn, the enzyme[33]. At the same time there is an increase in the muscular destruction of glycogen and there is also an increase in the release of fatty acids by adipose tissue due to the activation of the triacylglycerol lipase and the deactivation of the lipoprotein lipase[34]. Again, these changes are caused by the action of hormones through their effect on the protein kinase[24]. Clearly, the coordination of the process of interaction between glucose and lipids is indispensable for endurance exercise, in order to allow the simultaneous consumption of both fatty acids and carbohydrates[35].

Hormonal control. As has been previously noted, the liver is a target organ for most hormones during exercise. We traditionally divide these hormones into anabolic and catabolic[31] and according to this basic division it has been suggested that the relative concentration of anabolic hormones should decrease while the relative concentration of catabolic hormones should increase during exercise. During long duration endurance exercise, somehow the hypothesis fails to prove true in the analysis of the concentration of hormones in the blood. For example, the growth hormone increases during long duration endurance exercise[36]. Since this hormone is clearly anabolic, the possible explanations for this "paradoxical response" have been based on the stress caused by exercise increasing the concentration of GH-RH while decreasing somatostatin (SS), respectively activator and inhibitor of GH liberation. The two hypothalamic neurohormones are subject to modulation by a host of neurotransmitters, especially the noradrenergic and cholinergic ones and other hypothalamic neuropeptides, and are the final mediators of metabolic, endocrine, neural, and immune influences for the secretion of GH[36]. We may consider the response of GH liberation coherent with both acute stress and endurance exercise, in itself an acute stress. But it has to be considered that the lipolytic effect and the increase in plasma glucose caused by GH are both desirable in this type of exercise, while it also eases the entrance of amino acids into the fiber cells and stimulates protein synthesis.

Moreover, the hormones considered regulators of glycemia[31] have a determinant role during endurance exercise to control the use of carbohydrates. The importance of maintaining glycemia can hardly be exaggerated, since nervous system function strongly relies on it. On the one hand, the increase of glucagon enhances glucose availability for muscle tissue and the nervous system. On the other hand, insulin is an anabolic hormone and so decreases[31], but only to the point where it still increases the transport of glucose to tissues, as the entrance of glucose to the muscle is not only an effect of muscular contraction during exercise[37,38] but insulin remains fundamental in glucose consumption[39]. Some other glucose regulator hormones (epinephrine and cortisol) may be of importance during endurance exercise[31].

Thermoregulation in endurance exercise

Regulation of body temperature is under the control of a complex feedback system. There are receptors, integration centers and active responders[40]. During exercise the transformation of chemical energy from the fuel into heat approximates 70% and 1L of oxygen consumption equals 4.8 Kcal. The object of thermoregulation is to control the core temperature in a range where homeostasis is possible, even while we are exercising. There are several mechanisms available to dissipate the excess of heat[41]. Evaporation is the principal measure to dissipate heat, reaching 40% of energy produced under normal temperature and humidity.

Sweat production and evaporation are related to exercise intensity up to the level at which sweat production reaches its maximum. There is a cost to be paid for this efficient control mechanism[41]: water and electrolytes loss, both of them determinant ingredients of endurance performance. The amount of water lost in sweat can increase to 4L/h in some subjects, leading to a situation termed dehydration if not corrected. Again, there are important mechanisms previously mentioned, such as substrate metabolic processes and hormones (the renin-angiotensin-aldosterone axis, or the antidiuretic hormone relationship to thirst), that will play a determinant role in the attempt to maintain the internal hydro and electrolytic balance.

There is another additional cost to be considered for thermal regulation. During endurance exercise there is also a competition between muscle and skin vascular territories for the cardiac output[42,43] and a limitation for performance due to blood flow redistributed to the skin.

Integrated physiological response during endurance exercise

It has been already mentioned in the introduction that the control of physiological responses during endurance exercise belongs to the nervous system. and the involved mechanisms can be basically divided into: feedforward and feedback mechanisms. Feedforward mechanisms are those that are activated previously to any reflex mechanism that can be elicited by the effort. Feedback mechanisms are those that will respond to signals from different receptors. Feedforward mechanisms allow an immediate activation of different processes, although they have a drawback in that they are not being controlled. It is the interaction between these two types of mechanisms that allows precise control of the variables to attain a state of homeostasis during endurance exercise.

As shown in Figure 2, $\dot{V}O_2$ stability implies nervous regulation of respiratory and cardiovascular systems while the active tissues must use the increased oxygen supply for energy extraction. Nevertheless, pointing to the specific structures in the nervous system responsible for this regulation is harder. The intervention of descending pathways on the regulation of the cardiorespiratory apparatus has been proposed for over a century. Zunt suggested the term "cortical irradiation" for these locomotor and cardiorespiratory descending pathways but recently they have been grouped under the term Central Command (CC), which is currently accepted. The study of the interaction between CC with the nociceptors and metaboreceptors during exercise is still a challenge for science.

In the next few lines there will be a brief mention of the nervous mechanisms implied in maintaining homeostasis during endurance exercise in an extreme ultra-resistance event[3-7] considering the main mechanisms signaled previously: feedforward, feedback and the integration of feedforward-feedback.

Feedforward control of endurance exercise

An important portion of the fast increase in $\dot{V}O_2$ at the onset of exercise, shown in Figure 2 is caused by CC activity, roughly a ninefold increase in $\dot{V}O_2$ (from 213 ml/min to 1990 ml/min) in 1.5min. To achieve this, the cardiovascular and respiratory functions logically must increase correspondingly (see Figure 3). The feedforward mechanism suggests an increase in $\dot{V}O_2$ far in excess of demand. That is to say, at the beginning of an exercise of constant intensity more oxygen is offered and consumed through the feedforward mechanism. This excess $\dot{V}O_2$ is known as the oxygen deficit. The initial increase in $\dot{V}O_2$ requires an increase in cardiac output (Q) and alveolar ventilation ($\dot{V}A$). The increase in Q is mainly due to vagal inhibition together with activation of the sympathetic vegetative nervous system[44].

The feedback mechanism during endurance exercise

The mean value of $\dot{V}O_2$ in Figure 2 is 3684 ml/min (± 83 ml/min). To maintain this value, the cardio-respiratory control centers adjust the efferent signal to the cardiovascular and respiratory systems for peripheral feedback. The participation of the different signals for the cardio-respiratory adjustment is complex to assess, as it comes from baroreceptors, peripheral and central chemo-receptors, mechanoreceptors of the respiratory musculature and the pulmonary parenchyma. All this information reaches the medulla, the fundamental center of cardio-respiratory control, where the respiratory nuclei (dorsal and ventral) and cardiovascular nuclei (nucleus of the solitary tract, dorsal nucleus of the vagus and vascular center) are located. The result is:

- An adjustment of the "central" parameters (cardiac output and alveolar ventilation) to maintain a ventilation/perfusion ratio ($\dot{V}A/Q$) close to the unit, which facilitates the exchange of gases.
- An adjustment of the "peripheral" parameters: redistribution of blood flow, increasing in the active territories (muscular, cerebral and coronary), decreasing in the less active ones (digestive and renal). Brain flow is basically maintained by self-regulating mechanisms, mainly by the effect of carbon dioxide. Brain circulation is very sensitive to variations in the partial pressure of carbon dioxide, so that its increase (hypercapnia) causes vasodilatation and decrease (hypocapnia) the opposite effects. Coronary blood flow during exercise is mainly maintained by self-regulating mechanisms, mediated by molecules released as a result of myocardial metabolic controls and by the action of the vegetative nervous system. The importance of the activity of the myocardial metabolism is evidenced by the arteriovenous difference, which increases slightly during exercise.
- An adjustment of the receivers for movement control in relation to cardio-respiratory variations. For example, the sensitive terminations III and IV of the muscles are sensitive to metabolic conditions[45]. Control of muscle blood flow is mediated by the release of lactic acid, CO_2 partial pressure, concentration of H^+ and other molecules (bradykinin and prostaglandins). These variables trigger reflex reactions (known as chemoreflex or metaboloreflex), mediated by the sympathetic nervous system that adjust cardiac output and systemic blood pressure to maintain the metabolic conditions in the muscle territory. However, the mechanisms of cardio-respiratory regulation may be misadjusted when central temperature control is a priority, especially in hot and humid environments. The cutaneous vasoconstriction produced during exercise comes into conflict with the greater demand for blood flow in the skin that is necessary to promote sweating. This discrepancy between heat dissipation and cardio-respiratory control can affect ventricular performance. This contrast explains in part the phenomena known as cardiovascular drift and respiratory drift.
- Finally, it is important to remember that metabolism is also under peripheral feedback control too. Previous points have mentioned that different metabolic pathways do have intrinsic regulation mechanisms, but the activation of the sympathetic nervous system increases the response of said mechanisms (the transformation of glycogen-phosphorylase from inactive to active will be increased as an example).

Integration of feedforward and feedback mechanisms during endurance exercise

Figure 1 represents in a diagram both previously presented physiological regulation mechanisms interacting during an endurance exercise. Solid lines represent feedforward mechanisms while the dotted lines represent feedback mechanism. Representing a continuous situation where the feedforward mechanism is acting as a launching team and "starts the engine" while progressively receiving the addition of the "maintenance team" represented here by the feedback mechanism.

Sequential activation of motor units is produced following Henneman's size principle[46]. Therefore, the motoneurons are activated due to neuron cell size and distribution of the cells in the anterior horn of the spinal cord[47]. According to this principle the motoneurons would be recruited always in the following order of motor units: Slow Twitch (ST) →Fast Slow twitch → Fast Twitch (FT). An increase in respiratory and cardiovascular activity can be perceived by the increase in cardiac output (Q) and alveolar ventilation (VA) allowing an adequate distribution of oxygen to the active tissues during effort.

As a result of the increased needs produced by the effort simultaneous to the increased availability of oxygen, the muscles increase absorption and consume the necessary amount of oxygen to perform the mechanical work demanded while also being capable of sustaining a certain intensity during an extended period of time. In order to maintain oxygen consumption (VO) the nervous system exerts control over hormones capable in turn of either speeding up or slowing down the internal control mechanisms of each metabolic pathway.

According to this distribution of tasks, the feedback mechanisms represent the activity of centers located hierarchically below the encephalic level while the feedforward mechanism is located in higher encephalic structures. There is however a significant amount of interaction between both mechanisms. Thus, the CC acts on physiological functions, such as cardiac output, the regulation of which is preferentially but not exclusively in the spinal bulb. Peripheral feedback also provides information on the situation of the body as a whole. The importance of central command and peripheral feedback in controlling physiological variables during endurance exercise is yet to be determined. The discussion lies in knowing:

- What nervous structures manage somatic-neurovegetative coordination?
- Is there a single central command or are there different central commands? The question is whether there is a CC to control movement and another for cardiovascular or cardiorespiratory control, all capable of distinct independent functioning, while being perfectly matched and coordinated during exercise?
- Is recruitment completely explained simply by the electrophysiological profile of motor units or is the activity of descendent pathways on the anterior horn of the medulla capable of selecting a different order?[11].
- In turn, are descendent pathways the origin of other collateral descendent pathways this time directed to the cardiorespiratory control centers, deeming therefore unnecessary the existence of a specific CC for cardiorespiratory regulation?

Even if the doubts already expressed have to be all taken into account, in the end the nervous system exerts a perfect regulation over motor control, as well as over all the functions involved in movement. The rest of control mechanisms (feedforward and feedback) are essentially meant to accomplish and maintain the state of the different physiological variables during an endurance exercise, in such a way as to be capable of performing at high intensities for a long period. Obviously, these mechanisms behave in a significantly different manner according to the different intensities achieved and depending on the purpose of the effort. Usually when the aim of the exercise being executed is to improve or maintain the health status, the activation of both mechanisms will only be minimal, i.e. a routine of 6 km of footing per day, especially if we compare it with the maximal activation found in someone training to improve running performance with the intention of running a complete marathon race at 3 min/km. In both cases, the difference for the nervous system will only be one of targets and therefore it will adjust to the separate situations perfectly, showing that endurance exercise is a unique physiological integration paradigm.

Conflict of interest

The authors do not declare a conflict of interest.

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Review

Cross-transfer of motor control in visuomotor tasks. Systematic review

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Summary

Introduction: The term "cross-education" describes the perfomance improvement, both in motor control and strength, of a limb after training the opposite. Despite its current interest, there is no consensus on many concepts of the transfer of a visuomotor skill. The aim of the present research was to review the current literature on the phenomenon of cross-education in visuomotor skills in order to determine the magnitude of transference and its relationships with the context of the intervention.
Results: A literature search was conducted during December 2019 in the databases Pubmed, CINAHL, MEDLINE, Web of Science, SPORTdiscus and Scopus. The descriptors "Motor ability" and "Motor skill" were used, in addition to the keywords "Motor control", "skill", "Task", "cross over effect", "cross exercise", "contralateral learning", "inter limb transfer "," cross transfer "", cross education ". After applying the inclusion and exclusion criteria, a total of 19 articles were obtained for analysis. Of these articles, 12 are RCTs, 4 crossover clinical trial, 2 are non-randomized trials and only 1 lacks a control group. Most of the articles consist of a short-term intervention. Only 5 studies are of a duration of between 4 and 6 weeks.
Conclusion: the cross-education phenomenon occurs in visuomotor skills. However, the magnitude of transference and its relation to the amount of learning of the trained member seems to be very variable depending on the context of the intervention. Likewise, the scarce consensus and the methodological differences in the studies make it difficult to draw firm conclusions about the effects of the context on the transference.

Key words:
Cross-transfer. Cross-education. Interlimb-transfer. Crossover effect. Motor control. Ability. Visuomotor.

Transferencia cruzada en el control motor en tareas visuomotoras. Revisión sistemática

Resumen

Introducción: El término *cross-education* describe la mejora de rendimiento, tanto en control motor como en fuerza, de un miembro tras el entrenamiento del contrario. A pesar de su actual interés, no existe consenso en muchos conceptos de la transferencia de una habilidad visuomotora.
Objetivo: El objetivo del presente estudio fue revisar la literatura actual sobre el fenómeno *cross-education* en habilidades visuomotoras para determinar la magnitud de transferencia y sus relaciones con el contexto de la intervención.
Resultados: Se realizó una búsqueda bibliográfica durante diciembre de 2019 en las bases de datos Pubmed, CINAHL, MEDLINE, Web of Science, SPORTdiscus y Scopus. Se emplearon los descriptores "Motor ability" y "Motor skill", además de las palabras clave "Motor control", "skill", "Task", "cross over effect", "cross exercise", "contralateral learning", "inter limb transfer", "cross transfer", "cross education". Tras la aplicación de los criterios de inclusión y de exclusión, se obtuvo un total de 19 artículos para realizar el análisis. De estos artículos, 12 son ECA, 4 ensayos clínicos cruzados, 2 son ensayos no aleatorizados y solo 1 carece de grupo control. La mayoría de artículos constan de una intervención a corto plazo. Tan solo 5 estudios son de una duración de entre 4 y 6 semanas.
Conclusión: El fenómeno *cross-education* ocurre en habilidades de tipo visuomotor. Sin embargo, la magnitud de transferencia y su relación con la cantidad de aprendizaje del miembro entrenado parecen muy variables dependiendo del contexto de la intervención. Asimismo, el escaso consenso y las diferencias metodológicas de los estudios dificultan extraer conclusiones contundentes acerca de los efectos del contexto sobre la transferencia.

Palabras clave:
Cross-transfer. Cross-education. Interlimb-transfer. Crossover effect. Control Motor. Habilidad. Visuomotor.

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Introduction

The term *cross-education*, referred to in this review as transfer and cross-transfer, was coined by Edward Wheeler Scripture[1] in 1894. It defines the improvement in the performance (strength and motor control) of a limb after training the opposite counterpart, even though currently these tend to be considered two separate entities[2,3].

There are two main theoretical models which justify the phenomenon: cross activation and bilateral access[2]. Cross activation maintains that adaptations in both cerebral hemispheres are driven by bilateral cortical activity generated during unilateral training (cross facilitation), relating the transfer of a task to the neuronal load it generates[2]. Bilateral access holds that motor engrams developed during unilateral training are not specific to the trained side and are accessible for both limbs[2].

Aspects of cross-education are still being studied. Originally it was thought that transfer does not occur symmetrically, determining that there would only be transfer from the dominant hemisphere[4,5], associating this asymmetry with hemispheric specialisation[6]. Another focus of attention regarding which consensus does not exist is the influence of neuronal degenerative changes. While some studies conclude that transfer is minimal in older subjects[7,8], others, based on the reduction in hemispheric laterality outlined in the HAROLD model (*Hemispheric Asymmetry Reduction in Older Adults*)[9], point to transfer similar to that found in younger people[10,11]. Although many reviews analyse the scale of strength transfer and its relationship with the learning percentage of the trained limb, there are no recent reviews which reflect the magnitude of this relationship in motor control.

In recent years, the attention which the phenomenon of cross-transfer has received has increased, as has the number of trials focussing on it[12]. This is due to its clinical potential and possible application in the rehabilitation of multiple conditions which involve the inability or difficulty to move a limb, be it for musculoskeletal or neurological reasons.

Given the potential of this tool and the limited consensus on it, the objective of this study is to review the current literature on cross-transfer in visuomotor skills to determine the scale of transfer and its relationships with the context of the task and the patient.

Materials and methods

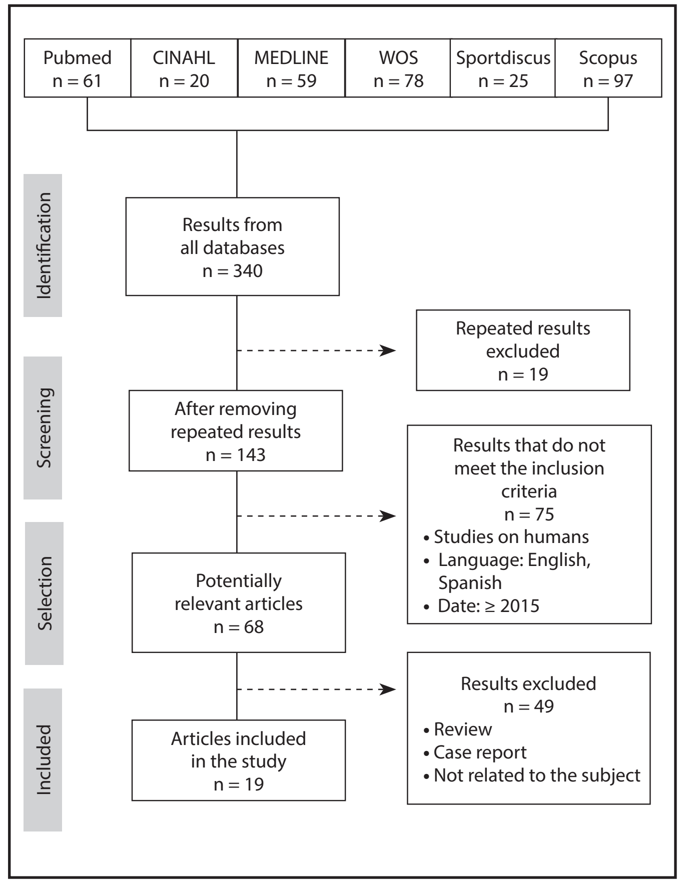
Search strategy

A bibliographic search was carried out in the Pubmed, CINAHL, MEDLINE, Web of Science, SPORTdiscus and Scopus databases between 20 May and 4 June 2021, including all the studies published from 2015 to the present. The search formulas and terms were as follows:

Medline, Cinahl, Pubmed, Sportdiscus: (THESAURUS* *OR "Motor skill" OR "Motor control" OR "skill" OR "Task"*) AND (*"cross over effect" OR "cross exercise" OR "contralateral learning" OR "inter limb transfer" OR "cross transfer" OR "cross education"*).

- *Pubmed: "Motor Skills"(Mesh).*

Figure 1. Study selection flow diagram.



- Medline, Cinahl: *MH "Motor Skills".*
- Sportdiscus: *DE "MOTOR ability".*
- Scopus and Web of Science: *TITLE-ABS-KEY (("Motor skill" OR "Motor control" OR "skill" OR "Task") AND ("cross over effect" OR "cross exercise" OR "contralateral learning" OR "inter limb transfer" OR "cross transfer" OR "cross education")).*

To establish which results were valid for review, a set of criteria was applied following the selection process shown in Figure 1.

Results

Table 1 shows the characteristics of the papers in terms of sample, design and duration of the studies, together with an analysis of their methodological quality.

The mean of the samples is 35 individuals. Most of the studies involve young patients (22-26 years old).

All the interventions bar 8 [14,18,19,21,27-30] are based on tracking trajectories, points or positions. Only 5 of the studies are long-term (4-10 weeks)[3,19,27,29,30]. Only 4 papers focus purely on the lower limbs (LL)[22-24,26]. Only 5 of the studies include a washout period (1-2 weeks)[3,20,21,25].

Table 1. Summary of the methodology of the studies analysed.

	Design	Jadad	Sample	Duration	Washout period
Leung *et al.*[13]	RCT	1/5	N=44 (24♂ and 20♀) A=26.1± 6.8 years old	2 days	2 weeks
Dickins *et al.*[14]	CCT	1/5	N=40 (20♂ and 20♀) A = EG1: 24.25 years old EG2: 70.00 years old	2 days	
Graziado *et al.*[15]	NRCT	0/5	N=24 A = EG1: 28 ± 2 years old EG2: 67 ± 9 years old	1 day	
Pan *et al.*[16]	RCT	1/5	N=40 (17♂ and 23♀) A= EG1: 71.9 ±9.6 years old EG2: 70.4 ±6.8 years old	1 day	
Sainburg *et al.*[17]	NRCT	1/5	N=11 (3♂ and 8♀) A=20-25 years old	2 days	
Steinberg *et al.*[18]	RCT	3/5	N=80 (39♂ and 41♀) A=24.87 ±4.14 years old	4 days	
Christiansen *et al.*[19]	RCT	2/5	N=24 (24♂) A=24±4 years old	6 weeks 3 sessions/week	
Bo *et al.*[20]	NCT	0/5	N=27 (10♂ and 17♀) A=18-34 years old	2 days	10 days
Kidgell *et al.*[21]	CCT	2/5	N=14 (8♂ and 6♀) A=22.6± 6.6 years old	3 days	1 week for different tasks
Krishnan *et al.*[22]	RCT	1/5	N= 20 A=22.8± 5.8 years old	1 day	
Krishnan *et al.*[23]	RCT	1/5	N= 44 (18♂ and 26♀) A= EG1: 67.2 ± 4.1 years old EG2: 24.8 ± 6.9 years old	2 days	
Yen *et al.*[24]	RCT	1/5	N= 20 (7♂ and 13♀) A= EG1: 24 ± 4.4 years old EG2 22.2 ± 0.4 years old	1 day	
Leung *et al.*[3]	RCT	1/5	N= 43 (21♂ and 22♀) A=26.4 ± 6.9 years old	4 weeks 3 sessions/week	2 weeks
Neva *et al.*[25]	CCT	1/5	N=17 A=24 ± 3 years old	4 days	2 weeks
Krishnan[26]	RCT	1/5	N=45 (25♂ and 20♀) A=22.3 ± 5.7 years old	1-2 days (according to EG)	
Witkowski *et al.*[27]	RCT	1/5	N=32 (16♂ and 16♀) A=14-20 years old	10 weeks	
Wang *et al.*[28]	RCT	1/5	N=24 (16♂ and 8♀) EG1: 27.3 ± 4.4 years old EG2: 20.7 ± 3.8 years old	1 day	
Beg *et al.*[29]	RCT	3/5	N=50 (20♂ and 30♀) A=23.4 ± 2.5 years old	4 weeks 2 sessions/week	
Brocken *et al.*[30]	CCT	2/5	N=68 (68♀) A=9.5-12.5 years old	7 weeks 14 sessions	

♂: male; ♀: female; A: age; RCT: randomised clinical trial; CCT: crossover clinical trial; NRCT: non-randomised clinical trial; NCT: non-controlled trial; N: sample.

Table 2. Intervention and main results.

	Intervention	Variables analysed	Main results
Leung *et al.*[13]	4 EG: CT vs STM vs STwM vs Control CT: match the position of the elbow with that shown on the screen.	1-RM and MVC CSE, SLII	CSE and SLII transfer (p<0.001) SLII differences between EG: STM, CT > STwM, control
Dickins *et al.*[14]	2 EG: old vs young 2 types of CT: Ballistic thumb abduction Finger-to-thumb opposition sequences	CSE Peak velocity correct sequences	Young: better overall performance Transfer in the 2 tasks (p <0.001) Increase in CSE only in the simple task (p = 0.001) with no differences between groups (p> 0.1). No relationship between CSE and transfer (p> 0.1).
Graziado *et al.*[15]	2 EG: old vs young CT: tracking points by electromyographic activity of the abductor pollicis brevis, 3rd dorsal interosseous.	Euclidean cursor-centre distance: - 120 ms after start (distance) - For 1s on reaching the objective (score)	Young: better overall performance Significant transfer (p <0.001) Differences between ages in the distance variable, (significant only in the elderly: p <0.001) Score transfer significant relationship with learning (p = 0.016).
Pan *et al.*[16]	2 EG: healthy and with PN. CT: Point tracking on screen with digital pen.	Initial direction error	Significant transfer (p <0.001), greater in RL than LR (p = 0.003). Less transfer in healthy (p = 0.01). Non-symmetrical transfer in healthy; but symmetrical with PN, RL Group greater after-effects (p=0,045).
Sainburg *et al.*[17]	2 EG: RL vs LR CT: Point tracking using the index.	V_{max} Peak acceleration Acceleration duration	Non-symmetrical Vmax transfer (p = 0.855) Asymmetrical transfer of Peak acceleration (lower in LR, p = 0.0059) and of Acceleration duration (higher in LR, p = 0.0059) No differences after contralateral practice
Steinberg *et al.*[18]	2 EG: mirror vs control 2 subgroups per EG: novices vs experts 2 types of CT with basketball: Stationary dribbling Slalom dribbling	Correct sequences Dribbling error	Significant transfer (p <0.001) with differences according to EG and experience (p <0.05) Only experts differences according to EG: (p <0.01), better with mirror Differences in control groups, greater transfer in novices (p <0.05) No differences between groups with mirror (p> 0.05) Dribbling error transfer without differences (p> 0.05) Transfer in slalom: experts greater with mirror (p <0.05); novices no transfer with mirror (p> 0.05)
Christiansen *et al.*[19]	2 EG: progressive difficulty vs no progression CT: a game called "BreakOut" contro-lled by abduction and adduction of the 5th digit.	CSE "BreakOut" score	Transfer only in progressive EG (p <0.001) Increase in initial CSE without differences (p <0.05) Increase in final CSE only in progressive EG No relationship between CSE and transfer (p> 0.05).
Bo *et al.*[20]	1 EG: with and without motor disability CT: Point tracking with handheld joystick.	DE MT Root mean square error	Transfer not related to ADC score (p> 0.05) DE transfer (p <0.05) in normal feedback and MT transfer (p <0.05) in enhanced feedback. Transfer regardless of feedback (p> 0.05) Relationship between learning and transfer: DE (p <0.02) in normal feedback, MT (p <0.04) in enhanced feedback.
Kidgell *et al.*[21]	3 EG divided into 3 CT: "O'Connor dexterity" "Purdue pegboard" "Mirror Purdue pegboard"	Time to perform the task	Greater transfer in Mirror Purdue (p <0.05). Relationship between learning and transfer in Mirror Purdue (p=0.03)
Krishnan *et al.*[22]	2 EG: RL vs LR CT: Adjust gait pattern to the one indicated in real time on the screen.	Tracking error	Significant transfer (p <0.003) No significant differences between sides (p = 0.247) Relationship between learning and transfer: 84% (p<0.001)
Krishnan *et al.*[23]	2 EG: old vs young CT: Adjust gait pattern to the one indicated in real time on the screen.	Tracking error	Young: better performance Less transfer in the elderly (p <0.05) but without differences in test without visual feedback (p> 0.1) Relationship between learning and transfer (p> 0.001): 79% young; 56% elderly

(continue)

Table 2. Intervention and main results *(continuation).*

	Intervention	Variables analysed	Main results
Yen *et al.*[24]	2 EG: RL vs LR CT: Point tracking using isometric force of the ankle	MT Accuracy	Significant transfer (p <0.01) No differences between sides (p = 0.05)
Leung *et al.*[3]	4 EG: CT vs STM vs STwM vs Control CT: match the position of the elbow with that shown on the screen.	1-RM and MVC CSE, SLII MT	Greater skill transfer in the CT group (GROUP x TIME: p = 0.005) but non-significant relationship between learning and transfer (p> 0.05). Specific transfer similar between EG (p> 0.05). Greater CSE and SLII improvements in CT and STM No relationship SLII or CSE and transfer (p> 0.05).
Neva *et al.*[25]	2 EG: Previous aerobic warm-up* vs Control CT: Point tracking with handheld joystick.	Maximum side shift Angle at peak velocity Response time and MT	Differences between groups during the intervention which were no longer significant by the end (p> 0.05). Significant transfer (p <0.05) Differences between groups in reaction time (p = 0.045) which disappear in retention (p> 0.05).
Krishnan[26]	2 EG: massed practice vs distributed practice CT: Adjust gait pattern to the one indicated in real time on the screen.	Tracking error	Greater transfer in distributed practice (p <0.044). Significant relationship (p <0.001) between learning and transfer (76%).
Witkowski *et al.*[27]	2 EG: CT vs Control Intervention in 3 phases: Whole-body, eye-to-hand and eye-to-foot, specific to fencing	Hand-grip strength Accuracy of hits in 3 different tests	No significant differences in strength (p = 0.05) Significant improvement in 3/3 (p <0.001) Significant transfer in 2/3 (p<0.001 and p<0.01)
Wang *et al.*[28]	2 EG: Left-handed vs Right-handed 2 subgroups: LR vs RL CT: "pegboard task"	Time to perform the task	Significant improvement and transfer (p <0.05) except right hand of the right-handed, no improvement or transfer (p> 0.1) No relationship between learning and transfer (p> 0.1
Beg *et al.*[29]	2 EG: CT vs Control CT: "pegboard task"	Time to perform the task JTT test	Significant improvement and transfer in the task (p <0.05) and in JTT (p <0.05) except in the writing and simulated feeding subtests
Brocken *et al.*[30]	2 EG: EG A: CT, Control EG B: Control, CT CT: training with hockey stick (adapted) with hands switched over	Time to perform the test	Significant improvement and transfer (p <0.016) EG B faster in pre-test (p <0.001); but EG A greater general improvement (p = 0.043). Longer times in pre-test related to greater improvement p= 0.04

RL: cross-transfer from the dominant side; MD: motor difficulties; CT: coordination training; CSE: corticospinal excitability; DE: direction error; STM: strength training with metronome; STwM: strength training without metronome; EG; experimental group; SLII: short latency intracortical inhibition; LR: cross-transfer from the non-dominant side; min: minutes; MVC, maximum voluntary contraction; N: sample; RM: repetition maximum; MT: movement time. V_{max}: peak velocity.

Regarding the heterogeneity of objectives, we find that 3 papers compare transfer in young and old individuals[14,15,23, 5] analyse transfer according to the dominance of the trained limb, 2 studies analyse samples with pathology[16,20], several studies compare interventions of varying difficulty or novelty[14,18,19,21, 2] compare transfer in visuomotor (VT) and strength (ST) training[3,13], only 1 study centres on the influence of previous aerobic warm-up[25], and another focuses on different distributions of practice[26].

All the papers except Leung *et al.*[13] analyse performance. Electrophysiological measurements were taken in 4 studies[3,13,14,19]. While all the studies analysed corticospinal excitability (CSE), only 2 analysed short latency intracortical inhibition (SLII)[3,13].

Discussion

Influence of context on cross-transfer

Difficulty and novelty of the task and transfer

Those papers which analyse the influence of difficulty show improved transfer when the task is challenging for the individual[19,21]. These results support the theoretical proposal whereby the type, novelty and complexity of the task condition transfer[2]. Greater demands for coordination and neuromuscular activation involve greater oxygenation[31] and cortical activation, favouring greater adaptations than simple tasks do[32].

Only Steinberg *et al.*[18] analyse the influence of the novelty of the task on transfer, observing greater effects when the individual is a novice. The greater overall improvement of the novice group with direct feedback could be because the expert group is already at the most advanced stage of learning. At this stage, the sensorimotor map of the task is internalised, and sensory feedback and paying attention to execution are not necessary[33], thereby decreasing the neuronal load and impairing transfer[2]. On the other hand, the benefit gained by the expert group when using the mirror could be because the tasks with normal feedback are considered simple and those viewed in reflection are considered complex. This consideration is described in Kidgell *et al.*[21], where the task considered more complex is the one carried out through reflection in a mirror. This greater complexity forces the subject to focus their attention on both the reflection and execution of the task previously considered simple[2].

Transfer differences according to age

All the studies which include an elderly population find significant transfer[14-16, 23] despite showing lower performance than the younger group during the learning stage[14,15,23]. However, there is no consensus regarding the differences between age groups.

When learning a new gait pattern, older subjects experience less transfer than younger subjects[23]. This is in line with studies which show decreased transfer in the elderly[7,8] due to the mechanisms of neuronal degeneration associated with aging, such as the decrease in CSE[34] and the increase of intracortical inhibition[35], which are both important in the consolidation of motor memory[36]. However, Dickins *et al.*[14] and Graziado *et al.*[15], with interventions focussing on upper limbs (UL), describe transfer as the same[14] or even higher in the elderly[15], which supports the HAROLD model; the aforementioned deficits are compensated by greater bilateral hemispheric recruitment[9].

The greater transfer in the elderly for the variable measuring the feedforward component described by Graziado *et al.*[15] could be due to several factors. While healthy elderly individuals conserve effective predictive adaptability, it remains unclear how this is affected by age[37]. However, findings suggest that the cognitive decline which occurs with age is responsible for the deterioration of predictive control[38]. So, cognitively healthy older individuals could improve and transfer this ability in a similar way to other age groups. On the other hand, the young people may not improve because the part of the task which evaluates anticipation does not pose a sufficient challenge, thereby decreasing transfer and generating a difference between groups. Finally, the lack of consensus on transfer in this population could be partly explained by methodological differences, which modify learning in the elderly population, and by individual characteristics, to which little attention is paid. Personal variables, such as lifestyle, could be protective factors against cognitive and memory decline.

Transfer asymmetry

The findings of the studies on this variable are relatively heterogeneous. While the 2 studies which analyse transfer in LL find that transfer occurs regardless of the trained side[22,24], this factor does condition transfer in UL[16,17,28].

In UL, it is observed that transfer from the dominant limb is greater and adapts better to different tests in the study by Pan *et al.*[16]. This concurs with the ideas advanced by the proficiency model (the dominant side is more effective when adapting to new tasks, transferring more and higher quality information) and hemispheric specialisation (the ability of each hemisphere to produce internal models of different skills)[32]. Specifically, the dominant side benefits from spatial skills[39], as occurs in the paper by Pan *et al.*[16], where a spatial control measurement is analysed. On the other hand, Sainburg *et al.*[17] describe symmetrical transfer but with different adaptations according to the specific function of each hemisphere. This coincides with another study in which the transfer of ball shooting accuracy is symmetrical, but the motor strategies to reach this adaptation differ between sides[40].

Finally, Wang *et al.*[28] obtain an asymmetrical result in right-handers; their right hands do not improve or receive significant transfer, supporting the proficiency model. Left-handers, meanwhile, improve and receive transfer in both hands. This could be due to greater use by the left-handed of the non-dominant arm in their routines, favouring greater interhemispheric connectivity and dexterity with the non-dominant hand than in the right-handed[41].

In the LL studies, symmetrical transfers of spatial control are observed in the gait study[22] and in isometric control of the ankle[24]. The greater symmetry in LL could be explained by less lateralisation of these limbs compared to UL due to the different tasks and motor strategies that distinguish them[42]. Although certain studies concur in confirming LL symmetry[6,43], the evidence which backs this idea is scarce, and there is little consensus on the matter, findings of asymmetry in certain variables also existing[40,42].

Witkowski *et al.*[27] and Brocken *et al.*[30] describe interventions in sports activities which involve equipment designed for use with the non-dominant limb (fencing foil) and with hands switched over (hockey stick), respectively. Both studies observe significant transfer to the dominant side, demonstrating the ability to effectively transfer visuomotor skills from the non-dominant side in asymmetrical sports.

Finally, considering that contextual variables, such as the complexity and novelty of a task, influence the direction of transfer[28], the heterogeneity of the intervention protocols hinders prediction of the symmetry pattern in transfer. This can be seen in Stöckel *et al.*[6], where changing the instructions for the same task leads to variations in transfer from each limb depending on whether the subjects perceive the task as more spatial or more dynamic in nature.

Transfer differences in participants with pathology

The two papers which analyse this variable differ in terms of the pathology involved and, consequently, are not comparable. Nevertheless, they both find significant transfer comparable to that of the healthy group[16,20].

In Pan *et al.*[16], transfer is symmetrical in people with peripheral neuropathy. As this pathology involves degeneration of the somatosensory area [44], the results explained previously could be due to compensatory neural mechanisms in a line similar to that proposed in the HAROLD model and cognitive decline[16].

In Bo *et al*.[20], transfer is similar between people with different motor abilities, suggesting that it is more related to the establishment of motor engrams than motor abilities. Finally, the difference in skill transferred according to feedback could be explained by the observations made in a contemporary study in which the movement time during the task increases as the feedback increases[45]. On this basis, the results of Bo *et al.*[20] could be due to learning about the new condition, movement time improving after adaptation.

Warm-up and practice distribution

In the current literature, it has been observed that spacing out the intervention favours the learning of skills in UL in adults[46]. Despite the paucity of trials in this area with LL, the effect would appear to be the same[47]. In line with these studies, the transfer of a new gait pattern improves with distributed practice[26].

Meanwhile, the temporary improvements in performance after warming up observed by Neva *et al.*[25] differ from the findings of another study in which performance decreases after high intensity exercise[48]. This could be explained by a lower intensity of the warm-up, reducing fatigue when performing the test. On the other hand, temporary changes in reaction times may be due to acute increases in attention after exercise[49], increases in attentional levels facilitating faster reaction times[50].

Scale of performance cross-transfer

All the studies find significant performance improvements in both the trained and the contralateral limb in some of the variables studied[3,14-30]. However, not all the papers indicate the percentage of contralateral improvement. Furthermore, the percentages described vary considerably across the different studies. This could be explained by the different variables analysed and interventions and protocols used in the different studies, leading to greater or lesser transfer and producing data which are not homogeneous.

Scale of long-term transfer

The only 5 studies which analyse long-term cross-transfer find significant transfer at the end of the intervention[3,19,27,29,30]. However, only 2 of them specify the transfer percentages[3,19].

In Leung *et al.*[3], learning and transfer are greater in the group which specifically trains for the task. Although the specific transfer percentage is similar between ST groups (14.4±3.8% to 11.9±4.5% in strength) and VT groups (12.4±2.3% in motor control), the electrophysiological measurements depend on the type of intervention. So, although it is incorrect to say that ST and VT share the same corticospinal responses, they are somewhat similar. On comparing the magnitudes described by Leung *et al.*[3] with similar intervention protocols, these are slightly higher than those described for strength transfer in UL (9.4%)[12]. However, Christiansen *et al.*[19] describe much higher improvement percentages in their progressive training group (76±14%). This could be due to the methodological differences between the two studies. On the one hand, Leung *et al*[3] use a very different task to that of Christiansen *et al.*[19] involving non-progressive difficulty adjustment and compare the results with the control group as Carrol *et al.*[51] suggest in order to reduce the influence of familiarisation with the test. Meanwhile, Christiansen *et al.*[19] do not describe a washout period, their protocol is 2 weeks longer, the sample is smaller, there is no control group, and the variables which measure performance differ greatly between studies.

Relationship between amount of learning and amount of transfer

Most of the studies which analyse this variable, described as a percentage of contralateral improvement with respect to the amount of ipsilateral improvement, obtain significance. However, it is difficult to establish a consensus on this relationship because its magnitude is relatively variable according to the context, as observed in the other sections.

This relationship is significant in the 3 LL studies. The percentages range from 84%[22] to 76%[26] and the result is lower in elderly individuals: 56%[23]. However, all three studies are conducted by the same investigator, with very similar interventions and protocols. Furthermore, two of the studies analyse transfer by comparing the base measurement of the trained limb with the final measurement of the opposite limb, crossing data between limbs and biasing the result. In the UL studies by Bo *et al.*[20] and Graziado *et al.*[15], this relationship is only found in the variables with significant transfer and without differences between groups (homogeneous results). Finally, Kidgell *et al.*[21] only find a correlation with learning in the most difficult task, while Leung *et al.*[3] and Wang *et al.*[28] find no relationship for VT. As occurs in Kidgell *et al.*[21] with the easier tasks, the intervention used in Leung *et al.*[3] may not be difficult enough to produce sufficient improvements to detect significance in the relationship. Similarly, the short duration of the study by Wang *et al.*[28], 4 blocks of practice, may not permit detection of the relationship due to an insufficient amount of improvement.

Electrophysiological measurements

The 2 studies which compare VT and ST transfer find different cortical adaptations between groups. In Leung *et al.*[13], there are only differences between groups for changes in SLII, but none for changes in CSE. However, in a later study, they report greater changes in CSE and SLII in VT and ST with metronome compared to the other groups[3]. This could be explained by the findings of Christiansen *et al.*[19], where both groups initially have equal increases in CSE. However, these changes only last in the group in which the difficulty increases progressively. Thus, in the shorter study, VT and ST may generate the same excitatory changes because when a strength task is new to an individual, there is substantial motor control adaptation regardless of its complexity[32].

In Dickins *et al.*[14], the CSE changes in the simple task but not the complex one could be because neural adaptation is not detected due to it occurring outside the primary motor cortex (M1). This can be explained based on the multiple cortical areas activated in the control of different parameters of the hand grip[52] and on the fact that it is not possible to assume that the interactions between M1 are the origin of cross-facilitation just because the interaction of the two cortices is expressed through M1[2].

Finally, no significant relationship has been found between changes in CSE[3,14,19] or SLII[3] and improved task performance. This is consistent with Ruddy *et al.*[2] when they affirm that cross-facilitation not only occurs in the homologues of the muscles involved in the task but also in the homologues of those which are not. Moreover, this activation lasts over time and is called "post-activation potentiation". Therefore it is wrong to assume that changes in excitability only represent significant adaptive changes.

Conclusions

The studies covered in this review show the presence of motor control transfer in visuomotor tasks in the short and long term. The magnitude and direction of this effect appears to be highly variable, depending on multiple contextual factors, such as state of the nervous system, hemispheric lateralisation and type of task. Similarly, the amount of learning appears to be related to the amount of transfer (albeit variably) but changes in CSE and SLII do not. On another note, the differences between UL and LL are inconclusive due to the limited number of studies reviewed. Finally, the low quality of the studies and general methodological heterogeneity make it difficult to draw firm conclusions from these findings.

It is necessary to conduct more studies of higher methodological quality and with more standardised measurement protocols, recording in more detail individual variables and aspects of the task which could influence transfer. Future trials should also study which factors modify the relationship between amount of learning and transfer to optimise the use of this tool.

Conflict of interest

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

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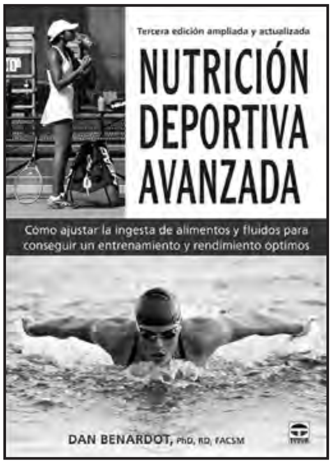

NUTRICIÓN DEPORTIVA AVANZADA

Cómo ajustar la ingesta de alimentos y fluidos para conseguir un entrenamiento y rendimiento óptimos

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Obra con la más completa información sobre nutrición deportiva que le ayudará a alcanzar sus objetivos de rendimiento deportivo. En esta tercera edición ampliada y actualizada, el Dr. Benardot, nutricionista deportivo reconocido a nivel mundial, combina las últimas investigaciones, estrategias e información sobre nutrición deportiva con su experiencia académica y trabajo con deportistas de élite.

Este libro le ayudará a aprender acerca de: las implicaciones del déficit energético relativo en deporte (RED-S) y el equilibrio energético durante el día, de modo que pueda mantenerlo durante el entrenamiento y la competición; las proporciones y cantidades óptimas de nutrientes, vitaminas y minerales para obtener la potencia, la fuerza y el rendimiento máximos; los suplementos más populares y sus efectos sobre su rendimiento deportivo; estrategias para equilibrar los fluidos y electrolitos para evitar la deshidratación y la hiperhidratación; las cuestiones sobre la pérdida de peso y la composición corporal, para aplicar estrategias propias con las que conseguir la proporción fuerza/peso óptima para su deporte. Para extraer lo esencial de la ciencia y llevarlo a la práctica, dispondrá de 13 guías prácticas de nutrición. Estas tablas de referencia de consulta rápida le ayudarán a aplicar fácilmente los principios a su propio plan de nutrición.

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Guía práctica para profesionales del acondicionamiento físico y el deporte

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Tus éxitos como profesional del *fitness* dependen de tu capacidad para proporcionar resultados consistentes a tus clientes. En este libro, el famoso experto en *fitness* y en diseño de programas Alwyn Cosgrove y su director de programación, Craig Rasmussen, comparten el sistema de eficacia probada creado por Alwyn para diseñar programas con los que mejorar el rendimiento de los clientes. Aprenderás a evaluar apropiadamente a cada individuo y a diseñar el programa más eficaz en función de su objetivo; ya sea perder grasa, aumentar la musculatura o la fuerza, o mejorar el acondicionamiento físico general.

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SESIONES PLENARIAS Y PONENCIAS OFICIALES

– Síndrome compartimental en el deporte.
– Síndrome compartimental en el deporte.
– Aplicación de la variabilidad de la frecuencia cardiaca al entrenamiento deportivo.
– Sistemas complejos y deportes de equipo.
– Respuestas fisiológicas y patológicas de la frecuencia cardiaca y de la tensión arterial en la ergometría.
– Sistemas de esponsorización deportiva
– Medicina biológica. Células madre.
– Entrenamiento en deportistas de superélite.

Idioma oficial
El lenguaje oficial del Congreso es el español.
Traducción simultánea de sesiones plenarias y ponencias.

Cursos *on-line* SEMED-FEMEDE

Curso "ANTROPOMETRÍA PARA TITULADOS EN CIENCIAS DEL DEPORTE. ASPECTOS TEÓRICOS"
Curso dirigido a los titulados en Ciencias del Deporte destinado a facilitar a los alumnos del curso los conocimientos necesarios para conocer los fundamentos de la antropometría (puntos anatómicos de referencia, material antropométrico, protocolo de medición, error de medición, composición corporal, somatotipo, proporcionalidad) y la relación entre la antropometría, la salud y el rendimiento deportivo.

Curso "ANTROPOMETRÍA PARA SANITARIOS. ASPECTOS TEÓRICOS"
Curso dirigido a sanitarios destinado a facilitar los conocimientos necesarios para conocer los fundamentos de la antropometría (puntos anatómicos de referencia, material antropométrico, protocolo de medición, error de medición, composición corporal, somatotipo, proporcionalidad) y la relación entre la antropometría y la salud.

Curso "PREVENCIÓN DEL DOPAJE PARA MÉDICOS"
Curso dirigido a médicos destinado a proporcionar os conocimientos específicos sobre el dopaje, sobre las sustancias y métodos de dopaje, sus efectos, sus consecuencias, saber el riesgo que corren los deportistas en caso de que se les detecten esas sustancias, cómo pueden utilizar la medicación que está prohibida y conocer las estrategias de prevención del dopaje.

Curso "PRESCRIPCIÓN DE EJERCICIO FÍSICO PARA PACIENTES CRÓNICOS"
Curso dirigido a médicos destinado a proporcionar los conocimientos específicos sobre los riesgos ligados al sedentarismo y las patologías crónicas que se benefician del ejercicio físico, los conceptos básicos sobre el ejercicio físico relacionado con la salud, el diagnóstico y evaluación como base para la prescripción del ejercicio físico, los principios de la prescripción del ejercicio físico, además de describir las evidencias científicas sobre los efectos beneficiosos y útiles del ejercicio físico.

Curso "ENTRENAMIENTO, RENDIMIENTO, PREVENCIÓN Y PATOLOGÍA DEL CICLISMO"
Curso dirigido a los titulados de las diferentes profesiones sanitarias y a los titulados en ciencias de la actividad física y el deporte, destinado al conocimiento de las prestaciones y rendimiento del deportista, para que cumpla con sus expectativas competitivas y de prolongación de su práctica deportiva, y para que la práctica deportiva minimice las consecuencias que puede tener para su salud, tanto desde el punto de vista médico como lesional.

Curso "FISIOLOGÍA Y VALORACIÓN FUNCIONAL EN EL CICLISMO"
Curso dirigido a los titulados de las diferentes profesiones sanitarias y a los titulados en ciencias de la actividad física y el deporte, destinado al conocimiento profundo de los aspectos fisiológicos y de valoración funcional del ciclismo.

Curso "CARDIOLOGÍA DEL DEPORTE"
Curso dirigido a médicos destinado a proporcionar los conocimientos específicos para el estudio del sistema cardiocirculatorio desde el punto de vista de la actividad física y deportiva, para diagnosticar los problemas cardiovasculares que pueden afectar al deportista, conocer la aptitud cardiológica para la práctica deportiva, realizar la prescripción de ejercicio y conocer y diagnosticar las enfermedades cardiovasculares susceptibles de provocar la muerte súbita del deportista y prevenir su aparición.

Curso "ELECTROCARDIOGRAFÍA PARA MEDICINA DEL DEPORTE"
Curso dirigido a médicos destinado a proporcionar los conocimientos específicos para el estudio del sistema cardiocirculatorio desde el punto de vista del electrocardiograma (ECG).

Curso "AYUDAS ERGOGÉNICAS"
Curso abierto a todos los interesados en el tema que quieren conocer las ayudas ergogénicas y su utilización en el deporte.

Curso "ALIMENTACIÓN, NUTRICIÓN E HIDRATACIÓN EN EL DEPORTE"
Curso dirigido a médicos destinado a facilitar al médico relacionado con la actividad física y el deporte la formación precisa para conocer los elementos necesarios para la obtención de los elementos energéticos necesarios para el esfuerzo físico y para prescribir una adecuada alimentación del deportista.

Curso "ALIMENTACIÓN Y NUTRICIÓN EN EL DEPORTE"
Curso dirigido a los titulados de las diferentes profesiones sanitarias (existe un curso específico para médicos) y para los titulados en ciencias de la actividad física y el deporte, dirigido a facilitar a los profesionales relacionados con la actividad física y el deporte la formación precisa para conocer los elementos necesarios para la obtención de los elementos energéticos necesarios para el esfuerzo físico y para conocer la adecuada alimentación del deportista.

Curso "ALIMENTACIÓN Y NUTRICIÓN EN EL DEPORTE" Para Diplomados y Graduados en Enfermería
Curso dirigido a facilitar a los Diplomados y Graduados en Enfermería la formación precisa para conocer los elementos necesarios para la obtención de los elementos energéticos necesarios para el esfuerzo físico y para conocer la adecuada alimentación del deportista.

Más información:
www.femede.es

Guidelines of publication Archives of Sports Medicine

The ARCHIVES OF SPORTS MEDICINE Journal (Arch Med Deporte) with ISSN 0212-8799 is the official publication of the Spanish Federation of Sports Medicine. This journal publishes original works about all the features related to Medicine and Sports Sciences from 1984. This title has been working uninterruptedly with a frequency of three months until 1995 and two months after this date. Arch Med Deporte works fundamentally with the system of external review carried out by two experts (peer review). It includes regularly articles about clinical or basic research, reviews, articles or publishing commentaries, brief communications and letters to the publisher. The articles may be published in both SPANISH and ENGLISH. The submission of papers in English writing will be particularly valued.

Occasionally oral communications accepted for presentation in the Federation's Congresses will be published.

The Editorial papers will only be published after an Editor requirement.

The manuscripts accepted for publication will become FEMEDE property and their reproduction, total or partial, must be properly authorized. All the authors will have to send a written letter conceding these rights as soon as the article is accepted for publication.

Submit of manuscripts

1. The papers must be submitted at the Editor in Chief's attention, written in double space in a DIN A4 sheet and numbered in the top right corner. It is recommended to use Word format, Times New Roman and font size 12. They must be sent by e-mail to FEMEDE's e-mail address: femede@femede.es.
2. On the first page exclusively it should include: title (Spanish and English), authors' first name, initial of the second name (if applicable), surname and optionally the second one; Main official and academic qualifications, workplace, full address and corresponding author e-mail. Supports received in order to accomplish the study – such as grants, equipments, medicaments, etc- have to be included.
   A letter in which the first author on behalf of all signatories of the study, the assignment of the rights for total or partial reproduction of the article, once accepted for publication shall be attached.
   Furthermore, the main author will propose up to four reviewers to the editor. According to the reviewers, at least one must be from a different nationality than the main author. Reviewers from the same institutions as the authors, will not be accepted.
3. On the second page the abstract of the work will appear both in Spanish and English, and will have an extension of 250-300 words. It will include the intention of the work (aims of the research), methodology, the most out-standing results and the main conclusions. It must be written in such a way to allow the understanding of the essence of the article without reading it completely or partially. After the abstract, from three to ten key words will be specified in Spanish and English, derived from the Medical Subject Headings (MeSH) of the National Library of Medicine (available in: http://www.nlm.nih. gov/mesh/MBrowser.html).
4. The extension of the text will change according to the section applicable:
   a. Original research: maximum 5.000 words, 6 figures and 6 tables.
   b. Review articles: maximum 5.000 words, 5 figures and 4 tables. In case of needing a wider extension it is recommended to contact the journal Editor.
   c. Editorials: they will be written by Editorial Board request.
   d. Letters to the Editor: maximum 1.000 words.
5. Structure of the text: it will change according to the section applicable:
   a. **ORIGINALS RESEARCH**: It will contain an introduction, which must be brief and will contain the aim of the work, written in such a way that the reader can understand the following text.
   Material and method: the material used in the work will be exposed, as well as its characte¬ristics, selection criteria and used techniques, facilitating the necessary data in order to allow the reader to repeat the experience shown. The statistical methods will be detailed described.
   Results: Results must report and not describe the observations made with the material and method used. This information can be published in detail in the text or using tables and figures. Information given in the tables or figures must not be repeated in the text.
   Discussion: The authors will expose their opinions about the results, their possible interpretation, relating the observations to the results obtained by other authors in similar publications, suggestions for future works on the topic, etc. Connect the conclusions with the aims of the study, avoiding free affirmations and conclusions not supported by the information of the work.
   The acknowledgments will appear at the end of the text.

b. **REVIEWS ARTICLES:** The text will be divided in as much paragraphs as the author considers necessary for a perfect compre-hension of the topic treated.

c. **LETTERS TO THE EDITOR:** Discussion about published papers in the last two issues, with the contribution of opinions and experiences briefed in 3 pages, will have preference in this Section.

d. **OTHERS:** Specific sections commissioned by the Journal's Editorial Board.

6. **Bibliography:** it will be presented on pages apart and will be ordered following their appearance in the text, with a correlative numeration. In the text the quote's number will be presented between parentheses, followed or not by the authors' name; if they are mentioned, in case the work was made by two authors both of them will figure, and if there are more than two authors only the first will figure, followed by "et al".

   There will not be personal communication, manuscripts or any unpublished information included in the bibliographical appointments.

   The official citation for the journal Archives of Sports Medicine is Arch Med Sport.

   References will be exposed in the following way:

   - **Journal: order number;** surnames and name's initial of the article authors with no punctuation and separated with a comma (if the number of authors is higher than six, only the six first will figure, followed by "et al"); work's title in its original language; abbreviated journal name, according to the World Medical Periodical; year of publication; volume number; first and last page of the quoted extract. Example: Calbet JA, Radegran G, Boushel R and Saltin B. On the mechanisms that limit oxygen uptake during exercise in acute and chronic hypoxia: role of muscle mass. *J Physiol.* 2009;587:477-90.
   - **Book chapter**: Authors, chapter title, editors, book title, city, publishing house, year and number of pages. Example: Iselin E. Maladie de Kienbock et Syndrome du canal carpien. En : Simon L, Alieu Y. Poignet et Medecine de Reeducation. Londres : Collection de Pathologie Locomotrice Masson; 1981. p162-6.
   - **Book**. Authors, title, city, publishing house, year of publication, page of the quote. Example: Balius R. Ecografía muscular de la extremidad inferior. Sistemática de exploración y lesiones en el deporte. Barcelona. Editorial Masson; 2005. p 34.
   - **World Wide Web**, online journal. Example: Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis (revista electrónica) 1995 JanMar (consultado 0501/2004). Available in: http://www.cdc.gov/ncidod/EID/ eid.htm

7. **Tables and figures.** Tables and figures will be sent on separate files in JPEG format. Tables must be sent in word format.

   Tables shall be numbered according to the order of appearance in the text, with the title on the top and the abbreviations described on the bottom. All nonstandard abbreviations which may be used in the tables shall be explained in footnotes.

   Any kind of graphics, pictures and photographies will be denominated figures. They must be numbered correlatively by order of appearance in the text and will be sent in black and white (except in those works in which colour is justified). Color printing is an economic cost that has to be consulted with the editor.

   All tables as well as figures will be numbered with Arabic numbers following the order of appearance in the text.

   At the end of the text document the tables and figures captions will be included on individual pages.

8. The Journal's Editorial Staff will communicate the reception of submitted articles and will inform about its acceptance and possible date of publication.

9. After hearing the reviewers' suggestions (journal uses peer correction system), may reject the works which are not suitable, or indicate the author the modifications which are thought to be necessary for its acceptance.

10. The Editorial Board is not responsible for the concepts, opinions or affirmations supported by the authors.

11. Submissions of the papers: Archives of Sports Medicine. By e-mail to FEMEDE'S e-mail address: femede@femede.es. The submission will come with a cover letter on which the work's examination for its publication in the Journal will be requested, article type will be specified, and it will be certified by all authors that the work is original and has not been partially or totally published before.

Conflicts of interests

If there should be any relation between the work's authors and any public or private entity, from which a conflict of interests could appear, it must be communicated to the Editor. Authors must fulfil a specific document.

Ethics

All authors that sign the articles accept the responsibility defined by the World Association of Medical Editors.

The papers sent to the journal for evaluation must have been elaborated respecting the international recommendations about clinical and laboratory animals' researches, ratified in Helsinki and updated in 2008 by the American Physiology.

For the performance of controlled clinic essays the CONSORT normative shall be followed, available at http://www.consort-statement.org/

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.