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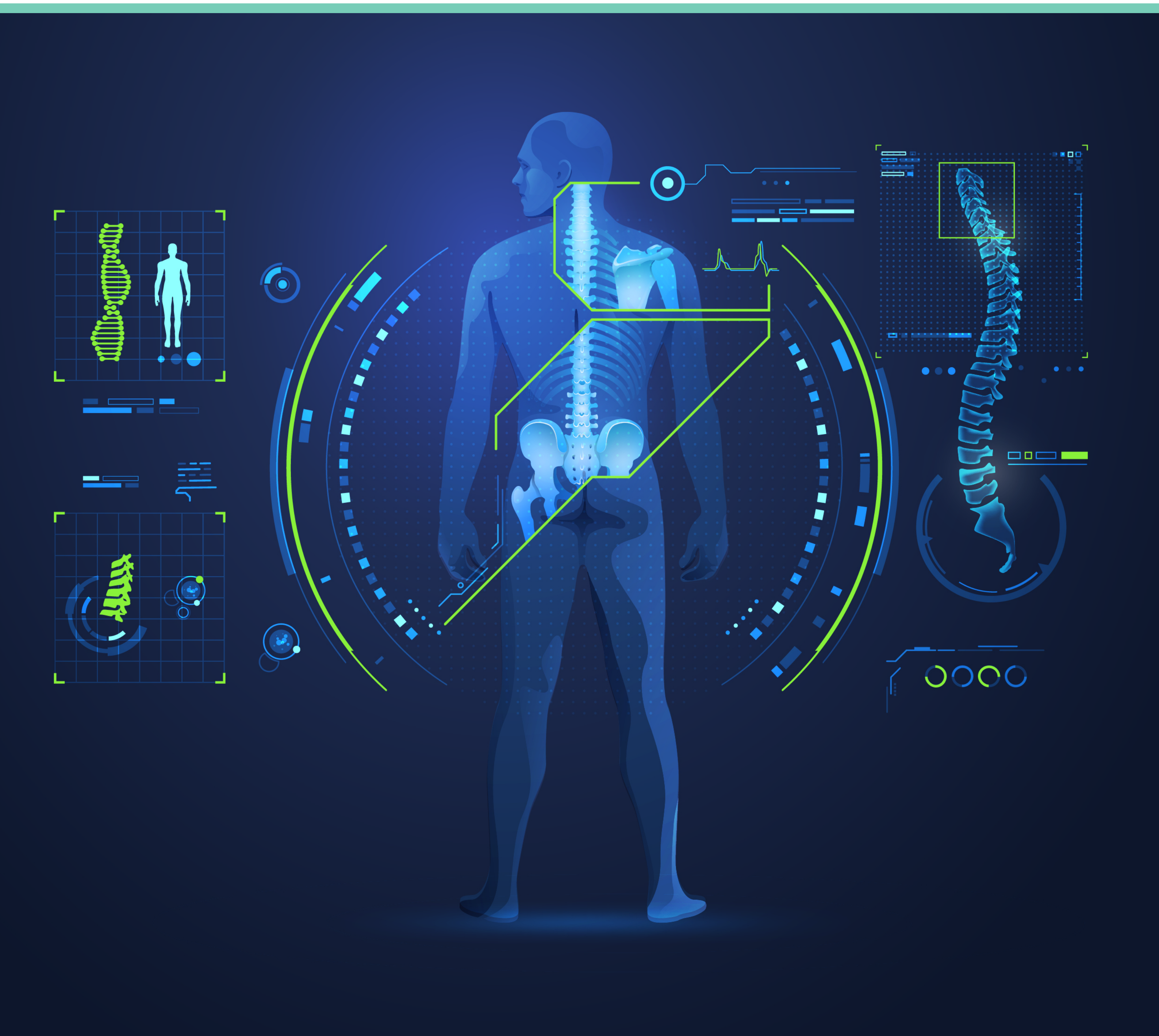

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SUMARIO / SUMMARY / RESUMO

Editorial

The studies published in this issue cover different areas within physical activity and sport. MLS Sport Research aims to publish original research and review articles in basic, applied, and methodological areas that contribute to progress in the field of Physical Activity and Sport Sciences.

Published studies must comply with the different phases of research with methodological rigor. MLS Sport Research will address different areas within physical activity and sport: health, physical education, injury prevention and rehabilitation, first aid, new technologies, physiology, nutrition, psychology, leadership and management, training, and sport performance.

The first article deals with the "Relationship between dissymmetry in lower limbs and pedaling force distribution in non-professional cyclists." The aim of this study was to relate lower limb dissymmetry and pedaling. Twenty-three non-professional cycling subjects participated.

The second study is entitled "Effect of the implementation of a flexibility program on joint range of motion and the speed of straight fist blows in boxing and Muay Thai athletes." The objective of this research was to determine the results of the implementation of a program for the development of Flexibility in Boxing and Muay Thai athletes on the articular range of motion (ROM) and the speed production of straight punches.

The next of the studies addresses "Countermovement jump and T-agility test, possible indicators of accumulated fatigue in youth basketball players?" In this research, the countermovement jump (CMJ) and the T-agility test (TaT) were studied as possible indicators of accumulated fatigue in youth basketball players.

The fourth study addresses the "Association between cardiorespiratory resistance and intellectual maturity in primary school children: educational implications." This study analyzed the relationship between cardiorespiratory endurance in students aged 10 to 12 years and their intellectual maturity as an indicator to improve academic performance. Data were collected from primary schools in Spain. A total of one hundred fifty 5th and 6th graders participated.

The issue of the journal is completed with an article on "Injury incidence in soccer." The objective of this study was to know the injuries produced throughout the 2016/2017 season of the Spanish first and second division according to the type of injury, position of the player, minute in which the injury occurs, and the age of the player.

Dr. Álvaro Velarde Sotres and Dr. Felipe García Pinillos
Editores Jefe / Editors in chief / Editores Chefe

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RELATIONSHIP BETWEEN DISSYMMETRY IN LOWER LIMBS AND PEDALING FORCE DISTRIBUTION WITH NO PROFESSIONAL CYCLISTS

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Abstract. In this work we had the objective to relate the dissymmetry of the lower limbs with the asymmetry index. 23 no professional cycling subjects participated. It was done a dissymmetry test with the direct method, in which we measured from the anterior superior iliac spine to the tibial malleolus and we compared the results with the other leg, so before to do this test we proceed to the Weber-Barstow maneuver, which began in supine position on the litter with the legs in parallel and flexed, it was performed an hip extension, the subject returned to the initial position and the examiner stretched the legs, and for last a test of distribution of power was done on the Wattbike, with a duration of 10 minutes and an intensity of 5 over 10 in the range of perceived exertion. To reach a correct cycling position, we used a goniometer to measure the knee angle and then we continued with previous published guidelines. The statistical analysis was done with JASP, in which we first performed a descriptive study and then a correlation test according to its normality. The asymmetry index was 4,086 %, with a slight bigger force distribution in favor of the right leg versus the left leg (50,56 % - 49,44 %). It had a slight positive tend in the relation of the dissymmetry and the power distribution in pedaling, but without significance data.

Keywords: dissymmetry, cycling, lower limbs, pedaling, dominant leg.

RELACIÓN ENTRE LA DISMETRÍA DE LOS MIEMBROS INFERIORES Y EL ÍNDICE DE ASIMETRÍA EN EL PEDALEO EN CICLISTAS NO PROFESIONALES

Resumen. Este estudio tiene como objetivo relacionar la dismetría de los miembros inferiores y el índice de asimetría en el pedaleo. 23 sujetos no profesionales del ciclismo participaron en el estudio. Se realizó un test de dismetría mediante el método directo, que consiste en la medición desde la espina ilíaca anterosuperior hasta el maléolo tibial y la comparación de los resultados con la otra pierna. Antes de realizar esta prueba se realizó la maniobra Weber Barstow, la cual consiste una extensión de cadera partiendo de decúbito supino en la camilla con las piernas en paralelo y flexionadas, para después volver a la posición inicial. Por último, se realizó un test de efectividad de pedaleo sobre la Wattbike de 10 minutos, a una intensidad de 5 sobre 10 del rango de esfuerzo percibido. Para conseguir una posición correcta de los participantes se usó un goniómetro para medir el ángulo de rodilla y se siguieron las pautas de protocolos preestablecidos. El análisis estadístico fue realizado con JASP. Se realizó un estudio descriptivo y posteriormente un test de correlación acorde a su normalidad. El índice de asimetría fue del 4,086 %, con una ligera mayor distribución de fuerza de la pierna derecha sobre la izquierda (50.56 % - 49.44 %). Se encontró una tendencia positiva en la relación entre mayor magnitud de dismetría y el índice de asimetría, pero sin significancia estadística.

Palabras clave: dismetría, ciclismo, miembros inferiores, pedaleo, pierna dominante

Introduction

Bilateral symmetry in humans is considered a genetic sign of health (Fink et al., 2019) and is considered a basic requirement for efficient movement (Kendall et al., 2005). Many human parts develop with bilateral symmetry. This implies that the right and left parts of the human being can be divided into identical parts. However, because of biological factors related to human development or environmental and environmental factors, bilateral symmetry is rarely found in humans (Lindhauer, 1998). This bilateral symmetry is affected by external factors such as gravity and by internal factors such as the sensory system and the musculoskeletal system (Siegler et al., 2019). In turn, structural and functional asymmetry can cause poor posture and impair motor patterning (Picelli et al., 2016). In contrast, greater bilateral knee symmetry in 8-year-old Jamaican subjects shows improved sprinting ability after 14 years in 100- to 200-meter events, while ankle symmetry also shows a small positive effect on this ability (Trivers et al., 2013). This is because symmetry is more efficient in running, so less energy expenditure is made (Trivers et al., 2014). Therefore, sports science highlights the importance of maintaining a symmetrical body to improve athletic performance and to prevent injuries (Hinton et al., 2017). Meanwhile, human beings have a lateral preference, also called dominance or laterality, in which when performing any voluntary motor action, the dominant laterality is always chosen (Carpes et al., 2010). Since in several sports there are repeated technical actions, asymmetry ends up occurring as in soccer with the throwing leg and the stability leg (DeLang et al., 2017).

In relation to cycling, a cyclic sport and apparently symmetrical in pedaling, it seems that pedaling speed and external load influence bilateral pedaling asymmetry, although there is great variability in the rate of asymmetry among the participating subjects and among the different evaluation protocols of each study (Carpes et al., 2010). On this, many studies have examined bilateral pedaling and demonstrated a certain degree of asymmetry in different variables such as strength, force moment, workload, and power or intensity generated during pedaling (Carpes et al., 2010). Likewise, the asymmetry index in the different studies on asymmetric pedaling shows very varied values. Both a very high asymmetry index and a very low index have been found, as in the case of the relationship between pedaling cadence and asymmetry index, in which no firm evidence has been found on how the influence of cadence on asymmetry index is (Carpes et al., 2010). In contrast, subjects who are more trained or experienced in the discipline present smaller asymmetries than those subjects who are not so trained in the discipline (Carpes et al., 2008). It should be noted that the relationships between asymmetry, injury risk, and performance are only theoretical aspects in cycling, without reaching a clear answer of what actually happens practically (Bini et al., 2017).

On the other hand, there is proven evidence that bilateral lower limb differences in relation to power and workload generated in uninjured cyclists are from 5% to 20% (Carpes et al., 2007a), but in cyclists with an anterior cruciate ligament deficiency or previous injury, it can grow up to 400% (Hunt et al., 2003). In turn, there is much controversy about the relationship between asymmetry and pedaling intensity. On the one hand, it has been shown that asymmetry increases if work intensity increases (Bini and Hume, 2014). On the other hand, it has been indicated that asymmetry is reduced if work intensity is reduced (Carpes et al., 2007b). Other studies have indicated that there is no variation in asymmetry at different work intensities (Bini et al., 2007; Garcia Lopez et al., 2015). With respect to the asymmetry index in peak force moments in pedaling, it was found at low to moderate work intensities (Carpes et al., 2007b), while in other researches they were found at high intensities (Trecroci et al., 2018), so there is no clear evidence of how is the correlation of peak force moments in pedaling and different pedaling intensities. Meanwhile, the scientific literature agrees that feedback training can reduce pedaling asymmetry (Bini et al., 2017). Furthermore, a variation in saddle height has no effect on pedaling asymmetry at the moment of force in the different tests that were performed, which were the Wingate test, a maximal incremental test, and a constant load test (Diefenthaeler et al., 2016). The technical retraining in subjects with asymmetries of more than 20% has a positive effect, so it reduces the asymmetry in the pedaling force and this can reach an index very similar to subjects with a very symmetrical pedaling, so it can be qualified that it is very important the feedback to improve the asymmetry index (Bini et al., 2017).

About the pedaling cadence and its relationship with asymmetry there is no clear conclusion, but it was shown that increasing the cadence from 60 revolutions per minute (rpm) to 120 rpm, at the same work intensity, reduces the asymmetry index from 29% to 10% (Smak et al., 1999). It was also observed that increasing pedaling cadence training presented a reduction in asymmetry (Maloney, 2019). In an evaluation on pedaling asymmetry in which the force produced during the propulsive phase and its relationship to different pedaling cadences was considered, consisting of 60, 80, and 100 pedal strokes per minute and with two different intensity levels, at 100 and 235 watts, no direct relationship was found (Daly and Cavanagh, 1976).

Some of the studies cited differentiate between the dominant leg and the non-dominant leg. Consequently, a study on the degree of functional asymmetry of the lower limbs and the consequence on pedaling effectiveness is of some practical interest. This is because 70% of the world's population suffers from lower limb dysmetria (Valverde Tarazona et al., 2017), which is unknown how it affects pedaling. Therefore, the overall objective of the study was to analyze whether there is any correlation between lower limb dysmetria and pedaling asymmetry index. The proposed hypothesis is that functional dysmetria has no correlation with pedaling effectiveness.

Method

Participants

A total of 23 non-professional cycling subjects were selected as a sample for the study, of which 5 were discarded for not having a dysmetria of more than 0.5cm.18 subjects finally participated, of which 15 are male and 3 are female: (μ age 23.09 ± 6.3 years), (μ weight 69.87 ± 7.5kgs), and (μ height 176.87 ± 9.3cms). All participants gave their consent to participate in the study, which was previously approved by the ethical committee.

The sample was chosen by convenience and non-probabilistic sampling, with the approach that the sample chosen was greater than 20 subjects. The recruitment of volunteer participants was done through social networks and in different classes of a university, commenting on the details of the inclusion and exclusion criteria and certain details of the test to be performed. The inclusion criterion was to perform physical exercise at least 30 minutes a week and a frequency of 3 days a week. The exclusion criterion was to have any injury, to have undergone an operation that could interfere with the test or their dysmetria measurements, or to have a professional or semi-professional cycling license. It was taken into account that, of the subjects, several of them might not have dysmetria, so these were discarded for the experimental study because they did not meet the requirements of the study.

Material

The instruments used were the Wattbike to perform the asymmetry test. The Wattbike is an exercise bike with included software of power generated by the cyclist and the distribution of forces of each leg to measure the asymmetry. The Wattbike was chosen because it is a validated and reliable tool to measure the variable of the distribution of forces in pedaling (Hopker et al., 2010). For the pedaling test, the weight data were entered and the subject was allowed to pedal 5 minutes at the standardized intensity. After that, a 10-minute Wattbike test was created, following the indications mentioned in the study procedure. Another instrument used was the goniometer to measure the biomechanically correct angles of the participants. The goniometer was chosen because it is a reliable instrument for measuring joint mobility of the knee and ankle (Gil Fernández and Zuli Escobar, 2011). It was used at maximum pedaling extension for both legs to measure that the subjects were in the correct angle ranges to perform the test. The range of perceived exertion (RPE) was used to calculate the exercise intensity of the participants. The scale used was zero to ten (1 is the low value and a very mild form exercise, while 10 is a maximum effort such as a sprint). This tool is validated to calculate exercise intensity in cycling and with high correlation with lactate and heart rate (Zinoubi et al., 2018). As a last tool, Excel was used as a database to perform the subsequent statistical analysis. In the Excel database, the different variables to be analyzed were entered.

Variables

The variables analyzed in the study were the characteristic data of the subjects such as age in years, height in centimeters, weight in kilograms, cycling experience stipulated in years of practice, length of right leg, and left leg in centimeters. With these last measurements, the dysmetria in centimeters was calculated, which is a main variable of this research, resulting from leg of greater length - leg of lesser length. If the result showed 0.5 cm or more, and according to the inclusion criteria, the subject was included as a participant in the study. With these variables, a descriptive study was subsequently carried out. On the other hand, the knee angle at the maximum extension of the pedaling cycle was calculated, which was stipulated at about 145º, and the average watts of the test performed, which were collected at the end of the test from the Wattbike. Finally, the force distribution in percentage of the left leg and right leg was obtained, with which the corresponding asymmetry index formula ((Dominant leg - Non-dominant leg) / (Dominant leg + Non-dominant leg / 2) x 100) could be performed (Bini and Hume, 2014) (Bini and Hume, 2014).

Procedure

The participants were summoned to the biomechanics laboratory of the Universidad Europea del Atlántico to perform the different tests for data collection.

The first test performed was a test to check for dysmetria, in which the subjects had to pass a dysmetria of 0.5 mm (Valverde Tarazona et al., 2017). This test was the direct method that has been proposed as a protocol for the assessment of lower limb length differences (Jamaluddin et al., 2011). The direct method consisted of measuring with a tape measure the lower limb from the anterosuperior iliac spine to the tibial malleolus, and the results were compared with the other leg. Before performing this test, the Weber Barstow maneuver was performed. It starts in the supine position on the couch with the legs parallel and flexed, and a hip extension is performed. After that, the subject returns to the initial position and the examiner stretches the legs. In case the test was positive (+ 0.5 mm of dysmetria), the following test was performed.

The second test consisted of adjusting the rider properly on the Wattbike with the correct knee and ankle angles in the pedal cycle with maximum knee extension. The recommended and biomechanically proven angles were followed (Garcia Lopez et al., 2009). These angles were checked using a goniometer. The participants had to pedal with normal footwear or boots with mountain bike clipless pedals, with the requirement of not being able to wear lifts or wedges in the boots or cleats. After the correct fit, they performed a 5-minute warm-up on the Wattbike at a range of perceived exertion (RPE) of three out of ten. Once the warm-up was completed, they began the pedaling effectiveness test at a medium intensity, a cadence greater than eighty pedal strokes per minute and lasting ten minutes, following a previously described protocol (Kell and Greer, 2017). The intensity chosen was a five out of ten RPE, the subjective intensity was previously explained to the subject. During the force distribution test, having a conversation with the subject was avoided in order to have their concentration on the test. It was also placed in front of the subject so that the subject would not divert his or her attention to one side, and this would allow an asymmetry by modifying the posture of the participant. Because the Wattbike monitor displays different values for the percentage of pedaling force, it was tilted until the subject could not see the monitor and thus not get feedback from it. Finally, the subject was encouraged to pedal in a seated position for the entire ten minutes of the test. Once the pedaling force distribution test was completed, the data were recorded in the database created in Excel in which the average watts of the test, and the force distribution of each leg were recorded as a percentage.

Statistical analysis

Statistical analysis was performed with JASP software. The statistical tests performed were first a descriptive study in which the mean, minimum, maximum, and standard deviation were measured. This was followed by the Shapiro-Wilks test for normality, which was chosen because it is the test to be used if the sample is less than 50 subjects. The result, with a chosen significance level of $p < 0.05$, determined that Spearman's correlation test was necessary.

Results

The descriptive data collected on the characteristics of the subjects show that the participants were almost 25 years old, 1.76 m tall, 71.2 kg in weight, and a length in cm of the right leg of 91.74 cm and 91.8 cm of the left leg.

Table 1
Descriptive data of the participating subjects

	Age	Height	Weight	Right leg	Left leg
Mean	24.8	176.667	71.222	91.744	91.8
Standard deviation	6.902	8.423	10.435	5.462	5.208

Regarding the dysmetria test performed, a dysmetria of 0.87 cm on average was first found in the subjects, assuming this later in an asymmetry index of 4.086 in the force distribution test in the pedaling performed. More force applied with the right leg was also observed. An average of 139.722 W was collected and a slight superiority of the power of the right leg 70.762 W versus 68.961 W of the left leg.

Table 2
Descriptive data of the study variables

	% Asymmetry Index	Dysmetria in cm	% Right l.	% Left l.
Mean	4.086	0.872	50.556	49.444
Standard deviation	2.851	0.455	1.854	1.854
Minimum	0.000	0.500	48.000	46.000
Maximum	10.390	2.000	54.000	52.000

Note: This table shows the asymmetry index obtained in the test, the dysmetria in centimeters of the participating subjects, and the percentage of total forces of each lower extremity, where righ l. = right leg, and left l. = left leg.

Table 3
Force results collected during the test at Wattbike

	Ave. watts	L.L. watts	R.L. watts
Mean	139.722	68.961	70.762
Standard deviation	47.524	23.105	24.754
Minimum	65.000	30.550	34.300
Maximum	209.000	100.000	112.860

Note: This table shows the power data collected during the test, both from the average total and unilaterally according to the force distribution of each leg mentioned in the table above. Ave. watts = average watts, L.L. watts = left leg watts, and R.L. watts = right leg watts.

In the Spearman correlation performed between the dysmetria variables and the asymmetry index, it was observed that there is no correlation between both variables, with a result of $p = 0.182$.

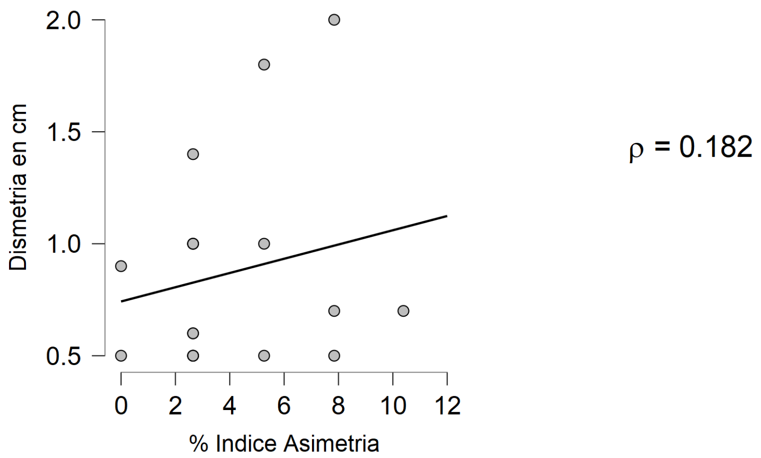

Figure 1. The relationship between dysmetria and asymmetry index.

Discussion and conclusions

It is observed that the asymmetry index obtained in the pedaling force distribution test was 4.086%. This difference is greater than the 2 % of dysmetria in pedaling force found in the study conducted with experienced cyclists, with a protocol of 3 series of 5 minutes at different pedaling intensities (Garcia Lopez et al., 2015). However, it is closer to the asymmetry rate between 3 and 5 % shown in the study conducted with trained cyclists on the Wattbike (Kell and Greer, 2017), although there are certain differences in these asymmetry rates. It also coincides, in part, with the study conducted with a sample of 10 cyclists and/or triathletes with competitive experience in which it was observed that there is from 5 to 11 % of asymmetry in pedaling (Bini, and Hume. 2014). In another study with another 10 cyclists and triathletes with competitive experience, a similar asymmetry rate was also found, consisting of 3 to 10 % in a 4 km time trial (Bini and Carpes, 2013). On the other hand, in another 4 km time trial with 10 experienced cyclists and triathletes, asymmetry results of 8 to 22 % in effective force, 5 to 10 % in resultant force, and 1 to 3 % in pedaling efficiency were obtained (Bini and Hume, 2015). All these studies show that the rate of asymmetry ranges from 2 % to 11 %. It should be noted that it is a wide range, but if the asymmetry index is less than 10 %, this is optimal, while if it is higher, it is usually an injury risk factor and proceeds to lower sports performance due to lower efficiency. In the study that had as objective the effect of cadence on asymmetry maintaining the same intensity, ranges of asymmetry index ranging from 10 to 29 % were found (Smak et al., 1999), so in this case it widely exceeds the asymmetry index that we obtained in the study.

It should be noted that, when studying the magnitude of dysmetria and its relationship with pedaling effectiveness, a slight positive trend was obtained, but it cannot be compared with other studies since the scientific literature has not taken into account the dysmetria of the participants, but rather the predominance of laterality. This small tendency for the asymmetry index to increase as dysmetria increases cannot be answered by the results of this study.

The intensity of the test is another factor to take into account when interpreting the results of previous studies in relation to those obtained in this one. This can lead to increases in the asymmetry index (Bini and Carpes, 2013), which can be from 4 % to 11

% (Bini and Hume, 2014). However, in another study, no differences were found at different intensities, which were 200, 250, and 300 watts (Garcia Lopez et al., 2015). In another study, it was observed that the asymmetry is reduced with lower intensity (Carpes et al., 2007b), and it was also observed that at the lower intensity and higher cadence there is the highest asymmetry index (Sanderson et al., 1991). In this study, participants were asked to pedal at an average intensity of 5 out of 10 of the RPE. Therefore, the test was executed at the same intensity for all subjects, making comparison with previous studies impossible. In any case, this fact, in terms of power generated, may be due to the different level of the participating subjects and to the variability of the subjective intensity of the RPE.

Conclusion

The results of this study indicate that the asymmetry index is 4.086 % in the distribution of forces in pedaling or pedaling effectiveness, being the correlation of this asymmetry index and the magnitudes of dysmetria of p = 0.182. That is, there is no significance or correlation between these variables, although there is a slight positive trend between the asymmetry index in pedaling and the greater magnitude of dysmetria of the lower limbs. This responds positively to the initial hypothesis that there was no correlation between the functional dysmetria of the subjects and the asymmetry index in the distribution of forces in pedaling.

Future studies are recommended to identify if, from more than 1 cm of dysmetria, there is more asymmetry in pedaling, as there were not too many participants who had that magnitude of dysmetria. Another recommendation is to replicate the study with cyclists with their own bike fit and trained with this posture in order to be able to simply adjust the Wattbike; or alternatively to put the bike on a roller to run a pedaling effectiveness test, taking into account only functional dysmetria in trained subjects and a correct and trained posture.

Despite the findings obtained, it is necessary to point out some limitations. There were inexperienced subjects who had no background using the subjective RPE scale, so the perceived exertion of 5 out of 10 could have been different. In addition, the biomechanical fit on the bicycle was performed simply with maximum knee extension in the pedaling cycle, measuring the ankle and knee. This is a basic way of adjusting the most inexperienced subjects to be within an optimal range but not the most correct one according to the characteristics of each subject.

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EFFECT OF THE IMPLEMENTATION OF A FLEXIBILITY PROGRAM ON JOINT RANGE OF MOTION AND THE SPEED OF STRAIGHT FIST BLOWS IN BOXING AND MUAY THAI ATHLETES

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Abstract. The objective of this research was to determine the results of the implementation of a program for the development of Flexibility in Boxing and Muay Thai athletes, on the joint range of motion (ROM) and the production of Speed of straight fist blows. A quantitative methodology was used with a pre-experimental research design. From the evaluation of Flexibility in 10 Boxing and Muay Thai athletes using the Flexitest method, and after evidencing the lowest levels of this capacity in the ankle, shoulder and wrist areas, a 6-week training program was developed using the dynamic, static and FNP methods for the training of these areas. Peak speeds achieved by participants in straight fist blows thrown into the air were also assessed. Statistically significant differences were observed when comparing the joint ranges pre and post program training of Flexibility in the ankle and shoulder joints. With respect to Speed, no statistically significant differences were observed in any of the gestures evaluated. The strength of association was low to zero when correlating the Flexibility and Speed production of the gestures. Although the flexibility of shoulders and ankles was improved, the speed of the striking gestures was not modified and could not be considered an association between both variables.

Keywords: flexibility, range of motion, boxing, muay thai, fist blow.

EFECTO DE LA IMPLEMENTACIÓN DE UN PROGRAMA DE FLEXIBILIDAD SOBRE LOS RANGOS DE MOVILIDAD ARTICULAR Y LA VELOCIDAD DE LOS GOLPES RECTOS DE PUÑO EN ATLETAS DE BOXEO Y MUAY THAI

Resumen. El objetivo de esta investigación fue determinar los resultados de la implementación de un programa para el desarrollo de la Flexibilidad en atletas de Boxeo y Muay Thai, sobre la rangos de movilidad (ROM) articulares y la producción de Velocidad de los golpes rectos de puño. Se utilizó una metodología cuantitativa con un diseño de investigación preexperimental. A partir de la evaluación de la Flexibilidad en 10 atletas de Boxeo y Muay Thai utilizando el método Flexitest, y tras evidenciar los niveles más bajos de esta capacidad en las zonas de tobillo, hombro y muñeca, se desarrolló un programa de entrenamiento de 6 semanas de duración utilizando los métodos dinámico, estático y FNP para el entrenamiento de estas zonas. También se evaluaron las Velocidades pico alcanzadas por los participantes en golpes de puño rectos lanzados al aire. Se observaron diferencias estadísticamente significativas al comparar los rangos articulares pre y post programa de entrenamiento de la Flexibilidad en las articulaciones de tobillo y hombro. Con respecto a la Velocidad no se observaron diferencias estadísticamente significativas en ninguno de los gestos evaluados. La fuerza de asociación resultó de baja a nula al correlacionar la Flexibilidad y producción de Velocidad de los gestos. Si bien se mejoró la Flexibilidad de hombros y tobillos, la Velocidad de los gestos de golpeo no se vio modificada y no se pudo considerar una asociación entre ambas variables.

Palabras clave: flexibilidad, rango de movimiento, boxeo, muay thai, golpe de puño.

Introduction

Flexibility, along with Strength, Endurance, and Speed, is one of the biomotor capacities that condition sports performance (Hohmann et al., 2005). However, throughout history, its development has been disadvantaged because of studies that generated a poor perception about the effects of its implementation (Chaabene et al., 2019). In this context, it becomes important to reconsider the benefits of the use of stretching work in the preparation of athletes.

In Combat Sports, the development of Flexibility exercises, besides being proposed due to a custom of historical nature (Chaabene et al., 2019), would be considered as a conditioner of performance in most of its modalities (Basar et al., 2014; El-Ashker, 2018; Franchini & Herrera-Valenzuela, 2021; Lima, 2017; Lenka & Shah, 2019; Sánchez-Sánchez et al., 2014; Saraiva et al., 2014; Schwartz et al., 2015; Slimani et al., 2016; Wongputthichai & Ketchatturat, 2017).

Several authors have postulated about the benefits of having adequate levels of this capacity, from its positive impact on the strength-velocity productions during muscle contractions (Del Rio Valdivia et al., 2015; Hunter & Marshall, 2001; Kokkonen et al., 2007 and 2010), which is why it was determined to know the levels of this capacity in a group of Boxing and Muay Thai athletes.

After evaluating the Flexibility from the Flexitest method (Araujo, 2005 and 2008) in a sample composed of 10 competitors of these disciplines, and after the analysis of the results, the lowest levels of range of motion (ROM) in the ankle, wrist and shoulder areas were evidenced.

According to the problems encountered, the implementation of a program for the development of flexibility with the sample of athletes mentioned was determined and the results obtained were analyzed in order to evaluate its effect on ROM and speed of execution of straight fist strikes.

Flexibility and sports performance

In the field of sport, improvements in Flexibility could be related to increases in the ability to apply muscular force and achieve more powerful actions (Kokkonen et al., 2007 and 2010; Shrier, 2004).

Sporting gestures, and particularly those of a ballistic nature, involve muscular chaining actions in which a series of shortening and lengthening reactions of various muscles are combined to varying degrees, which occur in different planes of movement at the same time following a spiral-diagonal activation pattern (McAtee & Charland, 2010). Thus, when the athlete moves by activating his antagonist musculature to accumulate energy to be used later in the agonist action, he can thus achieve a greater ROM and travel for his acceleration, which may allow him to apply a greater amount of Force (Weineck, 2005).

Taking the above into consideration, improvements in the Flexibility of athletes could offer benefits on the production of Strength-Speed, from its incidence on the stretch-shortening cycle (SSC).

The SSC, present in most sports actions, makes it possible to link an eccentric muscle stretching action with a concentric muscle shortening action performed at high intensity, so as to develop a large amount of force in a very short period of time from the use of the potential energy stored in the elastic components (Copoví Lanusse, 2015).

Improved Flexibility could have a positive impact on SSC due to a reduction in passive *stiffness* or resistance of structures to deformation, allowing optimal stretching with a greater reserve of potential kinetic energy by a reflex accumulation of a greater number of muscle fibers in the motor sequence (Gleim & McHugh, 1997; Kim, 2006; Medeiros & Lima, 2017; Rodriguez Casallas & Gracia Diaz, 2015; Weineck, 2005).

The benefits of improved flexibility on SSC performance would be in contrast to the role of active muscle *stiffness* in isolated isometric or concentric actions. This is so since in these cases a higher *stiffness* would have been shown to be positively related to isometric force production, rate of isometric, and concentric force development (See Figure 1), which would be explained by a more efficient contractile force transmission in the muscle-tendon units.

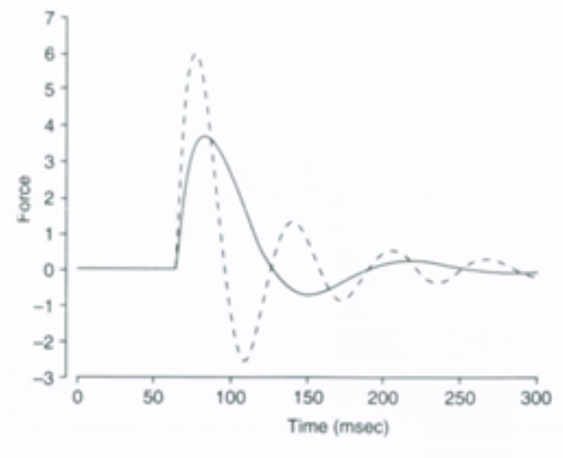

Figure 1. Force-time curve and muscle stiffness.

Note: representation of the oscillations generated by applying forces on two systems. A system with higher stiffness (dotted line) would allow a higher initial force transmission to occur and will oscillate at a higher frequency. Taken from Gleim, G. W. & McHugh, M. P. (1997). Flexibility and Its Effects on Sports Injury and Performance (p. 290). *Sports Medicine*.

Following the research work carried out by Rees et al. (2007), Flexibility training through the PNF (Proprioceptive Neuromuscular Facilitation) method, not only could generate improvements on ROM but also an increase in muscle-tendon *stiffness* with improvements on Strength development.

According to Medeiros & Lima (2017), another viscoelastic property that has an influence on the improvement of muscle performance is the reduction of hysteresis or loss of energy as heat. According to these researchers from a stretching regimen, this parameter can be positively influenced allowing a reduction in energy dissipation in the muscle-tendon unit.

Data acquired on punch kinematics from studies by Cheraghi et al. (2014) indicated that boxers partially flex their upper extremity joints, especially the elbow joint, at the onset of the gesture. Piorkowski et al. (2011) also found from the analysis of video recordings, that during the onset of a fist strike the performers performed knee flexion/extension counter movements. Apparently, these athletes would intuitively be using the SSC to throw punches, allowing to think that the development of Flexibility could be related to improvements in the ability to throw fist punches in a faster and more powerful way.

Method

The methodology used for this research was quantitative since it was based on the collection and analysis of data composed of a score for twenty passive joint movements and the peak velocity in different combinations of straight fist strikes.

Research Design

The research design was pre-experimental and action-research type, considering that it was a problem evidenced in a specific group of athletes and for whom an intervention proposal was carried out, which was included as part of their daily training.

The development presented a longitudinal character since the data were collected in a pre-test and after the conditioning activity (of 6 weeks duration) in a post-test.

Population and Sample

The study was carried out with a non-probabilistic sample composed of 6 boxing athletes (1 woman and 5 men) and 4 Muay Thai athletes (4 men), who carried out their training together at the Integral Fitness training center located in the Autonomous City of Buenos Aires, Argentina. The inclusion criteria consisted of having more than one year of training experience in these activities and having participated in some *amateur* or professional competition. In addition, they should not be recovering from any injury that could compromise the results of the *tests*.

Variables

The dependent variable was composed of the participants' levels of flexibility and the speed achieved in straight fist strikes, while the independent variable was the conditioning activity, that is, the training program for this physical capacity (see Figure 2).

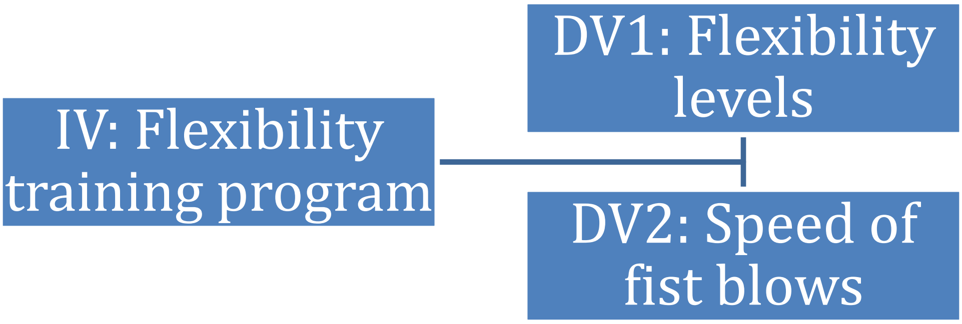

Figure 2. Study variables.

Note: IV - independent variable, DV - dependent variable.

Measuring Instruments and Techniques

The Flexitest method (Araujo, 2005) was used to evaluate the flexibility levels of the participants. This tool allows the measurement of 20 joint movements performed passively and has been used in athletes from different disciplines (Farinatti et al., 2014; Marinho et al., 2011; Montealegre Suárez & Vidarte Claros, 2019; Roa López, 2009). The maximum ROM achieved by each joint was compared with a list of images showing different positions, allowing a score to be assigned for each one according to its amplitude. According to the score given, the following rating scale was established: 0 very poor, 1 poor, 2 average, 3 good, and 4 very good. In addition, the sum of the results of all the movements provided an indicator of the overall Flexibility level of the subject called flexindex. As there were no significant differences between the two sides of the body except for pathological conditions (Braganca de Viana et al., 2008), the measurement of the limbs was carried out only on the right side of the participants. Regarding the reliability of this test, high intra- and inter-observer levels were determined for Flexitest (Araujo, 2005 and 2008).

Hykso Punch Trackers accelerometers were used to determine the speed of execution of isolated straight punches and in combinations. These devices are placed on the wrists of the athletes and allow knowing the peak velocity developed during specific punching gestures (Omcirk et al., 2021). Its design is specifically prepared for this task, allowing data collection from remote synchronization with mobile devices such as *smartphones* or *tablets*. A good level of intra-tool reliability of these sensors was determined by comparing them with the data obtained from the analysis of gestures through the Kinovea software (López et al., 2020).

Procedures

Initial evaluation

First of all, the flexibility levels of the athletes were evaluated through the Flexitest method (Araujo, 2005). For this, a session was organized specifically for this purpose in the morning hours and distanced with a minimum of thirty minutes from any physical exercise, considering that in the early hours of the day flexibility levels are higher (Rodríguez Casallas & Gracia Díaz, 2015), and that the increase in body temperature could modify muscular and joint resistance (Bishop, 2003).

Once all the individual scores were obtained, they were also grouped according to body zones; thus, forming seven averages: ankle, knee, hip, trunk, wrist, elbow, and shoulder.

After analyzing the results, it was concluded that the lowest levels of flexibility were in the ankle, shoulder, and wrist areas.

During the evaluation day, the peak velocities achieved in straight punches thrown in the air with both hands (jab and direct) and in combinations of these movements (jab-direct and jab-direct-jab-direct) were also recorded using *Hykso Punch Trackers*. The objective of this was to obtain a performance indicator of straight punches, and then compare them after the application of the program for the development of Flexibility.

Training periodization

Considering the results of the evaluations, a plan for flexibility training was developed, focusing only on the 3 areas where the lowest ROMs were observed: ankle, wrist, and shoulder.

This periodization was based on the model presented in the work of Lima et al. (2019), where the training load was dosed following an incremental staggering throughout the weeks. The work was programmed with a frequency of three weekly stimuli, located at a time of the day immediately after the strength training was developed (Leite et al., 2017); thus, to ensure greater adherence and achieve completion.

The macrocycle, with a duration of 6 weeks (Franchini & Herrera-Valenzuela, 2021), was divided into two mesocycles of three weeks each (See Tables 1 and 2). During the first mesocycle, exercises under the dynamic and static stretching methods were used. When moving to the second mesocycle, dynamic work was maintained, but with the objective of increasing the intensity of the work, static exercises were developed under the FNP modality in its two variants: agonist tension-relaxation and antagonist tension-relaxation (Franchini & Herrera-Valenzuela, 2021; Hohmann et al., 2005; Kim, 2006; McAtee & Charland, 2010; Peck et al., 2014; Weineck, 2005).

Table 1

1st Mesocycle

No.	Exercise	Method	MICROCYCLE 1		MICROCYCLE 2		MICROCYCLE 3	
			Reps/Seg	Series	Reps/Seg	Series	Reps/Seg	Series
1	Ankle rotations	Dynamic	12c/l	3	12c/l	4	15c/l	4
2	Dorsiflexion of ankles	Static	20"	3	30"	3	30"	4
3	Plantar flexion	Static	20"	3	30"	3	30"	4
4	Shoulder circles with elastic bands	Dynamic	12c/l	3	15c/l	4	15c/l	4
5	Internal rotation of shoulders	Static	20"	3	30"	3	30"	4
6	External shoulder rotation	Static	20"	3	30"	3	30"	4
7	Posterior shoulder abduction	Static	20"	3	30"	3	30"	4
8	Posterior shoulder adduction	Static	20"	3	30"	3	30"	4
9	Wrist rotations	Dynamic	12c/l	3	12c/l	4	15c/l	4
10	Wrist flexion	Static	20"	3	30"	3	30"	4
11	Wrist extension	Static	20"	3	30"	3	30"	4

Note: model of the first mesocycle of the periodization of the Flexibility training.

Table 2

2nd Mesocycle

No.	Exercise	Method	MICROCYCLE 1		MICROCYCLE 2		MICROCYCLE 3	
			Reps	Series	Reps	Series	Reps	Series
1	Ankle rotations	Dynamic	15c/l	4	15c/l	4	20c/l	4
2	Dorsiflexion of ankles	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Plantar flexion	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
3	Shoulder circles with elastic bands	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Internal rotation of shoulders	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
4	External shoulder rotation	Dynamic	15c/l	4	15c/l	4	20c/l	4
5	Posterior shoulder abduction	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Posterior shoulder adduction	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
6	Wrist rotations	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Wrist flexion	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
7	Wrist extension	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Ankle rotations	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
8	Dorsiflexion of ankles	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	Plantar flexion	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
9	Shoulder circles with elastic bands	Dynamic	15c/l	4	15c/l	4	20c/l	4
10	Internal rotation of shoulders	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
	External shoulder rotation	FNP antagon	5 "x20"	1	5 "x20"	2	5 "x20"	3
11	Posterior shoulder abduction	FNP agonist	5 "x20"	1	5 "x20"	2	5 "x20"	3
		FNP antagon	5 "x20"	4	5 "x20"	2	5 "x20"	3

Note: model of the second mesocycle of the periodization of the Flexibility training.

Final evaluation

For proper control of exercise intensity, athletes were asked to reach moderate pain levels during their execution (See Figure 3), equivalent to 5-6 points on a perceived exertion scale (Apostopoulos, 2015).

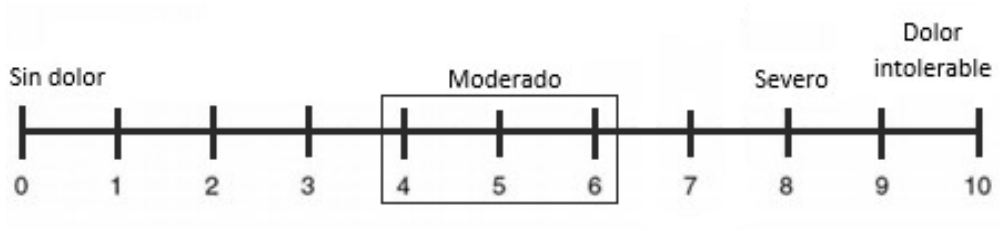

Figure 3. Perceived exertion scale.

Note: pain level that athletes should aim for (4 to 6) when performing the Flexibility exercises.

Once the six weeks of periodization were completed, the athletes were summoned again following the same criteria established for the initial evaluation: morning schedule and prior to the development of their training sessions.

The twenty joint movements corresponding to the Flexitest protocol were evaluated, as well as the speed of execution of straight strokes.

Statistical Analysis

Categorical variables were reported as number of presentation and percentage. Continuous variables that assumed a normal distribution were reported as mean and standard deviation (SD). Otherwise, median and interquartile range (IQR) were used. Statistical tests (Shapiro-Wilk test) and graphical methods (histograms and quantile-quantile) were used to determine the sampling distribution of continuous variables.

Pre- and post-implementation changes in the flexibility program were explored using statistical inference tests. For this purpose, the Student's t-test for paired samples or the Wilcoxon signed-rank test was used.

On the other hand, the strength of association between changes in Flexibility and changes in Velocity production in straight fist strikes was evaluated. For this purpose, Pearson's r correlation coefficient or Spearman's rho correlation coefficient was used, as appropriate. The magnitude of correlation was considered very high (0.9 to 1.0), high (0.7 to 0.89), moderate (0.5 to 0.69), low (0.3 to 0.49), and null (< 0.3) (Mukaka 2012). A p value <0.05 was considered significant. IBM SPSS Macintosh software, version 24.0 (IBM Corp., Armonk, NY, USA) was used for data analysis.

Results

Flexibility

At baseline, the median total score on the flexindex was 46.5 (RIQ 40.75 - 52) points, with a minimum and maximum of 36 and 56 points, respectively (Figure 4). After the training program, the median flexindex score was 54 (RIQ 50.75 - 58.25) points.

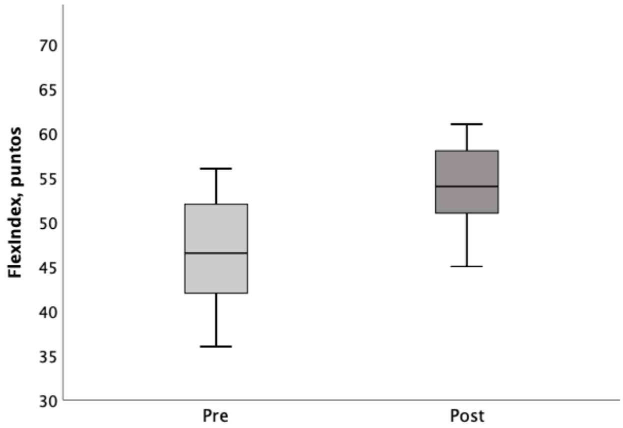

Figure 4. Box plot for the variable flexindex pre- and post-training.

When determining the changes between the beginning and end of the program, a mean difference of 7.9 (SD 5.28) points was observed, with a minimum of 1 and a maximum of 15 points. These differences were statistically significant (p=0.001). Figure 5 shows the individual scores on the flexindex variable pre- and post-program.

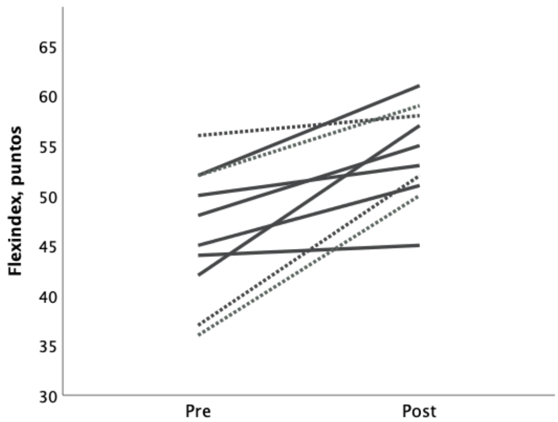

Figure 5. Individual scores in the flexindex variable pre- and post-training.

Note: the sport of the participants is represented by solid (Boxing) and dotted (Muay Thai) lines.

Table 3 presents the pre- and post-program comparisons of the flexibility of the different movements evaluated.

Table 3

Comparison of pre- and post-training flexibility

Variables	Pre	Post	p-value
Ankle dorsiflexion	2 (1.75 - 2)	2 (2 - 3)	0.014
Ankle plantar flexion	2 (1 - 2)	3 (2 - 3)	0.008
Knee flexion	3 (3 - 4)	3 (3 - 4)	0.56
Knee extension	2 (1.75 - 2)	2 (2 - 2)	0.32
Hip flexion	3 (2 - 3)	2.5 (2 - 3)	0.56
Hip extension	3 (2 - 3)	3.5 (2 - 4)	0.014
Hip adduction	3 (3 - 3.25)	4 (3 - 4)	0.18
Hip abduction	3 (2.75 - 3)	3 (3 - 3)	0.32
Trunk flexion	3 (2 - 3)	3 (3 - 3)	0.046
Trunk extension	2.5 (2 - 3.25)	3 (3 - 3.25)	0.034
Lateral trunk flexion	3 (2 - 4)	3 (2.75 - 4)	0.48
Wrist flexion	2 (2 - 2)	2 (2 - 3)	0.083
Wrist extension	2 (2 - 2)	2 (2 - 2.25)	0.32
Elbow flexion	3 (2 - 4)	3 (3 - 3.25)	0.41
Elbow extension	2 (2 - 2)	2 (2 - 2)	0.99
Posterior adduction of the shoulder from abduction to 180º	2.5 (1.75 - 3)	3 (2 - 4)	0.034
Posterior adduction or shoulder extension	1 (1 - 2)	2 (1 - 2.25)	0.059
Posterior shoulder extension	1 (0.75 - 2)	1 (1 - 2)	0.18
Lateral rotation of the shoulder with 90° abduction and 90° elbow flexion	1.5 (1 - 2)	2.5 (1.75 - 3)	0.024
Medial shoulder rotation with 90° abduction and 90° elbow flexion	2.5 (2 - 3.25)	4 (3 - 4)	0.014

Note: n=10, all numerical values are expressed as median and interquartile range (IQR).

Range of Motion

Table 4 presents the pre- and post-flexibility program comparisons for the ROM of the different joint groups evaluated. Statistically significant differences were only observed when comparing the values in the ankle and shoulder joints (p=0.006 and p=0.005, respectively).

Table 4

Comparison of pre- and post-training range of motion.

Variables	Pre	Post	p-value
Ankle	1.75 (1.5 - 2)	2.5 (2.5 - 3)	0.006
Knee	2.5 (2 - 3)	2.5 (2.5 - 3)	0.41
Hip	2.88 (2.31 - 3)	3.13 (2.69 - 3.5)	0.12
Trunk	2.5 (2 - 3.33)	3 (3 - 3.33)	0.06
Wrist	2 (2 - 2.38)	2 (2 - 2.63)	0.32
Elbow	2.5 (2 - 3)	2.5 (2.5 - 2.63)	0.41
Shoulder	1.7 (1.2 - 2.5)	2.4 (1.95 - 2.85)	0.005

Note: n=10, all numerical values are expressed as median and interquartile range (IQR).

Figure 6 shows the medians of each joint group evaluated pre- and post-flexibility training program.

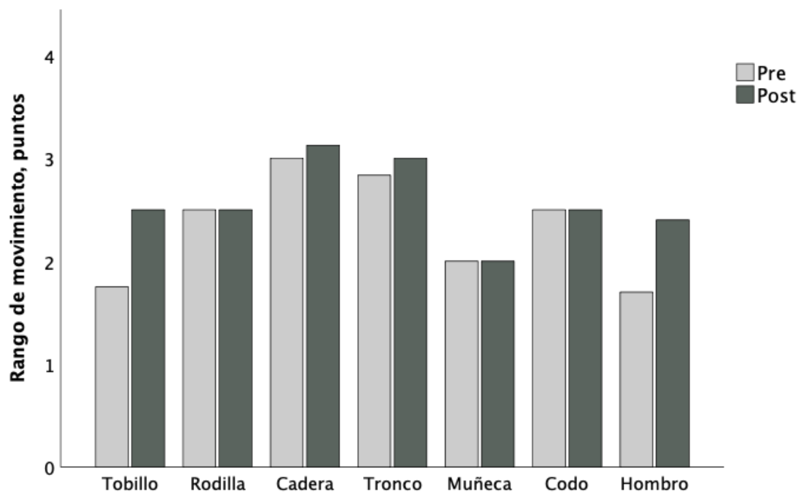

Figure 6. Range of motion pre- and post-training.

Note: bar graph of the range of motion variable for the different joint groups evaluated pre- and post-training program.

Speed Production

Table 5 presents the comparisons in the Speed pre- and post-Flexibility program. No statistically significant differences were observed in any of the evaluated gestures.

Table 5

Comparison of Speed pre- and post-Flexibility program.

Note: all numerical values are expressed as mean and standard deviation (SD).

Variables	Pre	Post	Average of the differences	p-value
Jab (m/s)				
1	4.69 (0.7)	4.54 (0.6)	-0.15 (0.60)	0.45
1.2	4.13 (0.73)	4.32 (0.62)	0.19 (0.89)	0.52
1,2,3,4	5.43 (1.3)	5.88 (1.4)	0.46 (1.01)	0.18
Direct (m/s)				
1	5.41 (0.68)	5.82 (0.85)	0.41 (0.84)	0.16
1.2	4.48 (0.62)	4.67 (0.82)	0.19 (0.80)	0.47
1,2,3,4	5.06 (1.66)	5.12 (1.32)	0.06 (1.08)	0.86

Correlation between changes in Flexibility and Speed

To correlate the change in the Flexibility variable (flexindex) and the changes in the Velocity production of the different straight stroke gestures (Jab and Direct, 1, 1,2 and 1,2,3,4), Spearman's rho correlation coefficient was used (See Table 6). The strength of the association was low when correlating Flexibility and Speed production of Jab 1, Direct 1, and Direct 1,2 gestures. The strength of the association was null when correlating Flexibility and Speed production in *Jab 1*,2, *Jab* 1,2,3,4, and Direct 1,2,3,4 gestures (Table 6).

Table 6

Correlation between changes in flexindex and Speed in Jab and Direct

	Spearman's rho	p-value
Jab (m/s)		
1	-0.426	0.22
1.2	-0.257	0.47
1,2,3,4	-0.120	0.74
Direct (m/s)		
1	-0.363	0.30
1.2	-0.309	0.38
1,2,3,4	-0.171	0.64

Note: all numerical values are expressed as mean and standard deviation (SD).

Discussion and conclusions

Discussion

Several researches have mentioned the benefits in the performance of different gestures after the implementation of programs for the improvement of Flexibility (Del Río Valdivia et al., 2015; Hunter & Marshall, 2001; Kokkonen et al., 2007 and 2010), but in none of the cases specific parameters of punching gestures in combat sports have been evaluated. For this reason, in the present study, we investigated the relationship between improvements in Flexibility and Speed productions of straight punching gestures.

Despite the fact that in the development of the intervention program Flexibility exercises were performed under the FNP method, in contrast to the results evidenced in the research work of Rees et al. (2007), this would not seem to have had a direct impact on the production of Strength of the evaluated gestures. Although it has been considered that the speed of execution of fist strikes influences the Force and Power developed (Mack et al., 2010; Tiwari et al., 2020), the use of a device that specifically measured the latter variables, such as the one employed by Dunn et al. (2019) in their research which had a load cell to measure the applied Force, would have been very useful in order to obtain a greater amount of data on the performance of the specific gestures evaluated.

The analysis of the results of the present research showed a considerable improvement in the flexindex levels. Since this is an indicator of the Flexibility of the subjects at a global level (Araujo, 2008), a positive impact on this capacity can be glimpsed. At the moment that it has not been possible to evidence an improvement in the productions of straight stroke speed, this prevents the possibility of proposing that there is any positive impact on the SSC from the increase in the levels of Flexibility as proposed by some authors (Gleim & McHugh, 1997; Kim, 2006; Medeiros & Lima, 2017; Rodríguez Casallas & Gracia Díaz, 2015; Weineck, 2005).

Taking into account that the 6-week Periodization program for flexibility training applied on Boxing and Muay Thai athletes, showed statistically significant improvements on the ROM of the shoulder and ankle joints of the participants, this could serve as a reference for use in similar populations of athletes with whom we seek to optimize this capacity. In addition, this Periodization is aligned with the proposals of researchers such as Lima et al. (2019), who mentioned the importance of systematization to obtain positive results.

It should be noted that although the periodization of the flexibility training only contemplated the work on the shoulder, wrist and ankle areas, the comparison of the passive ROM pre- and post-training also showed improvements on the trunk and hip areas, and this could be attributed to the effect of the interconnection of the muscles through the kinetic chains of movement (McAtee & Charland, 2010). This could promote a more efficient functioning of the different body segments during the performance of sporting gestures, so it would be appropriate to consider the analysis of its relationship with the incidence of injuries.

Although it has not been possible to establish a relationship between improvements in the levels of flexibility and speed in specific gestures, the findings of research that have positively related these two variables make it necessary to further investigate this possible association in hitting athletes. This requires abandoning the stereotypes unfounded by the traditionality generated after thousands of years of history in these sports (Balmaseda, 2009; Trial & Wu, 2013), and openness on the part of coaches to encourage this type of research work.

Conclusions

In light of the results of the present research, it has been possible to investigate the effect of the implementation of a flexibility program on joint ROM and speed of execution of straight punches in a sample of ten Boxing and Muay Thai athletes.

After the evaluation of the Flexibility from the Flexitest method in 20 passive joint movements, and having evidenced the lowest levels of this capacity in shoulders, wrists, and ankles, a 6-week periodization program was carried out for its improvement.

When determining the changes between the beginning and end of the program, a statistically significant difference was observed in the levels of global flexibility (flexindex) of the participants.

With respect to the joint groups in which changes in ROM were determined, statistically significant differences were only observed when comparing the values in the ankle and shoulder joints, demonstrating that the wrists did not follow the same trajectory.

Finally, no statistically significant differences were observed in Speed productions in any of the evaluated gestures. The strength of the association between the changes in the levels of Flexibility and the Speed productions of the striking gestures was low when correlating the isolated Jab (1) and Direct (2) strikes, and the Direct throwing 1,2. The strength of the association was null when correlating Flexibility and Speed production in the Jab throwing 1,2 and 1,2,3,4 gestures and the Direct hit by throwing

1,2,3,4. These results prevent the generation of any association between the improvements obtained in Flexibility and Speed production of straight fist strikes.

Because the sample of participants was small, this has generated two limitations to the study: the impossibility of having a control group and its respective randomization.

On the other hand, working with athletes who are in the competitive calendar generates a difficulty for the longitudinal projection of a research, because in many cases the training loads must be modified when a competition is approaching, interfering with the development of the work.

Future research should consider the evaluation of other performance variables in these athletes, such as the application of punching strength, agility, and endurance, as well as other strikes (*cross*, *uppercut,* and kicks in the case of Muay Thai). In addition, working with a control group and a randomized sample would allow a more robust conclusion on the evidence of the results obtained in the research.

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COUNTERMOVEMENT JUMP AND T-AGILITY TEST, POSSIBLE INDICATORS OF ACCUMULATED FATIGUE IN YOUTH BASKETBALL PLAYERS?

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Abstract. Introduction: there is a growing interest in monitoring cumulative fatigue in sport. In this study we aimed to determine whether the Countermovement Jump test (CMJ) and the T-agility test (TaT) are possible indicators of cumulative fatigue in youth basketball players. Methods: 16 male players were divided into experimental (EXP) and control (CONT) groups. All of them performed physical and technical-tactical training with a frequency of 5 times a week, during four microcycles (MiC). During the 1st MiC, all participants trained with a low intensity load. Subsequently, the EXP group trained with progressively higher loads, ending with very high intensities; the CONT group maintained a low training intensity throughout the entire mesocycle. Before the intervention, and at the end of each MiC, all subjects were tested by CMJ and TaT. Results: in EXP, a decrease in performance was observed in both tests ($p \leq 0.05$), when comparing each evaluation with the previous one. In CONT, no loss of performance was observed in CMJ; as for TaT, only a reduction in performance ($p \leq 0.05$) was observed when comparing the evaluation at the end of the 4th MiC with the corresponding one at the end of the 3rd MiC. Additionally, a moderate ($r = -0.589$) and high ($r = 0.683$) correlation was established, respectively, between CMJ and TaT performance in relation to training intensity. Conclusions: these findings would indicate that both tests could be useful as a tool for monitoring accumulated fatigue during a training mesocycle in young basketball players.

Keywords: cumulative fatigue; youth basketball; CMJ; agility test T

SALTO CON CONTRAMOVIMIENTO Y TEST DE AGILIDAD T, ¿POSIBLES INDICADORES DE FATIGA ACUMULADA EN BALONCESTO JUVENIL?

Resumen. Introducción: existe creciente interés en controlar la fatiga acumulada en el deporte. En este trabajo se estudió el salto con contramovimiento (CMJ) y el Test de agilidad T (TaT), como posibles indicadores de fatiga acumulada en jugadores juveniles de baloncesto. Métodos: 16 jugadores masculinos fueron divididos en grupos: experimental (EXP) y control (CONT). Todos realizaron entrenamiento físico y técnico-táctico con una frecuencia de 5 veces semanales, durante cuatro microciclos (MiC). Durante el 1er MiC, todos los participantes entrenaron con una carga de poca intensidad. Subsecuentemente, el grupo EXP entrenó con cargas progresivamente más altas, finalizando con intensidades muy elevadas; el grupo CONT mantuvo una intensidad baja de entrenamiento durante todo el mesociclo. Antes de la intervención, y al finalizar cada MiC, todos los sujetos fueron testeados mediante CMJ y TaT. Resultados: en EXP se observó una pérdida de rendimiento en ambos test ($p < 0.05$), al comparar cada evaluación con la precedente. En CONT, no se observaron pérdidas de rendimiento en CMJ; en cuanto al TaT, únicamente se verificó una reducción en el rendimiento ($p < 0.05$) al comparar la evaluación al finalizar el 4º MiC con la correspondiente al finalizar el 3er MiC. Adicionalmente, se estableció una correlación moderada ($r = -0.589$) y alta ($r = 0.683$) respectivamente, entre el rendimiento en CMJ y TaT, con relación a la intensidad de entrenamiento. Conclusiones: estos hallazgos indicarían que ambos test podrían ser útiles como una herramienta de control de la fatiga acumulada, durante un mesociclo de entrenamiento en baloncesto juvenil.

Palabras clave: fatiga acumulada; baloncesto juvenil; CMJ; test de agilidad T

Introduction

The demands of competition in team sports, increased in recent years, have generated much interest in coaches, physical trainers, and athletes regarding fatigue control; this is due to its relationship with performance and increased risk of injury (Thorpe et al., 2017). In youth categories, it is also necessary to consider the prospective development of players, which makes the control of loads, and the fatigue caused by it, even more relevant in this population (Balyi et al., 2013).

In this context, it is of particular interest to have evaluation strategies that allow estimating the internal load to which athletes are subjected, as well as the degree of fatigue (acute or accumulated) that they are experiencing. Such strategies, in addition to being valid, should ideally be practical, non-invasive, and economical, particularly for their application in sports institutions with limited human and financial resources.

One of the tools that meets these conditions is the modified Borg (1982) rating of perceived exertion scale (RPE). Based on this scale, Foster et al. (1996, 2001) proposed a method for quantifying session load as an alternative to methods based on heart rate. This method is called *session rating of perceived exertion* (sRPE) and consists of multiplying the volume of the session (in minutes) by the RPE indicated by the athlete for the whole session (according to the aforementioned scale). In this way, components of the internal and external load experienced by the player are represented in a single value, which is expressed in arbitrary units (AU).

Considering the challenges in measuring the various types of stress to which subjects are exposed during training, such a method largely represents a legitimate strategy, validating its use in different team sports, including basketball (Moreira et al., 2012; Singh et al., 2007; Wallace et al., 2014).

A strong correlation has also been observed between sRPE values with physiological variables associated with load intensity, such as heart rate, the latter being a representative measure of intensity (Manzi et al., 2010; Montgomery et al., 2010). Given the complex interplay of factors that contribute to individual perception of physical exertion, a multidimensional perspective is necessary to address this process (Tenenbaum and Hutchinson, 2007).

The sRPE strategy further represents a useful and practical strategy for estimating and monitoring cumulative fatigue throughout a microcycle (MiC), mesocycle, or even macrocycle of training (Haddad et al., 2017). In agreement with Clarke et al. (2013), this method could help optimize physical development while minimizing the risk of overtraining, injury, and illness; in part by allowing greater insight into individual response to training loads.

Regarding fatigue estimation, one of the widely used tools is the determination of Countermovement Jump (CMJ). This test has been considered one of the most valid for monitoring neuromuscular fatigue in different sports disciplines (Miras, 2020), in addition to having a high reliability (Gathercole et al., 2015b). In cyclic sports, *almost perfect* correlations were verified between altitude loss and blood lactate and ammonium concentration (r = 0.95 and r = 0.94 respectively) after 40m sprint efforts (Jiménez-Reyes et al., 2016).

In team sports, a progressive loss of performance has been observed in youth basketball players during and one to seven minutes after the competition, with losses of up to 19.8% in maximum height (San Román et al., 2010). An immediate post-competition performance loss of 7.4% in maximum height was also verified in elite handball players (Póvoas et al., 2014). It has been established that the sensitivity of CMJ to detect alterations in neuromuscular function (and concomitantly, neuromuscular fatigue) remains prolonged in time, with performance losses being detected even 72h after intense effort (Gathercole et al., 2015b). For this reason, variations in the performance achieved in CMJ can be used as a control tool, for the adjustment of training loads, and the eventual increase of sports performance (Loturco et al., 2017). Additionally, in the case of basketball, this test presents a high specificity due to the importance of vertical jump as a sporting gesture for this particular discipline. On the other hand, regarding the use of the CMJ for monitoring accumulated fatigue after several microcycles of training, the studies that have been conducted are scarce, and the discrepancies in their results do not allow us to clearly establish the possible usefulness of this test for this purpose (Freitas et al., 2014; Gathercole et al., 2015a). Additionally, to the best of our knowledge, this analysis has not been performed in a population of youth basketball players.

Another quality that contributes to success in collective sports in general, and in basketball in particular, is agility; understood as the ability to quickly change direction and speed (Sekulic et al., 2017; Spiteri et al., 2014). This skill has been recognized as one of the most important for this sport in which players make sudden changes of direction and speed every few seconds, and in a relatively small area of play (Abdelkrim et al., 2010; Boone and Bourgois, 2013; Scanlan et al., 2014). The T-agility test (TaT) is considered one of the most appropriate tests to estimate this skill in basketball because it uses many of the basic movements performed during a game, particularly in defensive maneuvers (Chaouachi et al., 2009; Stojanovic et al., 2018). Despite the potential usefulness of the use of this test as an indirect indicator of fatigue (acute or accumulated) in youth basketball, given the high neuromuscular component involved in its execution, to the best of our knowledge, its use for this purpose has not been analyzed.

In the present work, we try to determine the possible relationship between the accumulated fatigue in a training mesocycle and the performance in the CMJ and TaT tests. The purpose is to provide coaches of collective sports, and particularly youth basketball, with additional practical tools for the control of such fatigue, facilitating the consequent and necessary adjustment of training loads.

Method

Subjects

By means of convenience sampling, 18 players were selected from a youth federated team of the city of Montevideo, belonging to the Uruguayan Basketball Federation (FUBB). The subjects resumed their usual training coinciding with the beginning of the experimental intervention, after 2 months of inactivity due to the restrictions imposed by the COVID-19 pandemic. Prior to the intervention, all participants were orally informed of the characteristics and objectives of the study, after which they read and signed an informed consent form.

The following inclusion criteria were taken into account: i) have a current medical record; ii) have at least two years of experience as a federated basketball player; iii) not present any type of injury or pathology that could affect the results of the study; iv) not be consuming drugs that could affect sports performance; v) not be a smoker; vi) not engage in any other type of training or sport outside the one established in the experimental intervention.

Using convenience sampling, subjects were ~~non-randomly~~ divided into two groups: experimental (EXP) (n = 8; age = 17.8 ± 0.9 years; BMI =23.9 kg/m^2) and control (CONT) (n = 8; age = 17.8 ± 0.9 years; BMI = 24.3 kg/m^2). Both groups competed at a similar level but trained at different times. This allowed, from an organizational point of view, to adequately separate and control the different loads applied. Considering a significance level of p=0.05, there are no differences between the two groups in terms of age (p=0.87) and BMI (p=0.59).

Procedures

The evaluations and experimental intervention were carried out in the month of June 2021; during this mesocycle, the players were in a preseason period and did not participate in any competition or friendly match with other teams. All players attended at least 85% of the training sessions planned during the intervention mesocycle.

Evaluations

On the Saturday prior to the beginning of the experimental intervention, the following variables were measured in all athletes: i) Height and mass, for BMI determination. Height was measured using a SECA 213 stadiometer (SECA, Germany), with a precision of 1mm; mass was determined using a SAGAS scale (TPR - 200, Peru) with a precision of 100g. In both cases the technique described by the International *Society for the Advancement of Kinanthropometry* (ISAK) was used; ii) Maximum height in CMJ. A DMJUMP®2.5 jumping platform (DMJump, Chile) was used for this purpose. Without previous warm-up exercises, the subjects performed three jumps, with a two-minute passive pause between them. From an upright position and without taking their hands off the waist, the players performed a rapid downward movement until reaching a 90º knee flexion, followed immediately by a maximum upward effort to reach the maximum height, according to the protocol described by Bosco et al. (1983). For the purposes of this work, the best attempt of the three was taken as valid; iii) TaT performance. A version of the protocol described by Semenick (1990) was used, modifying the units of measurement from yards to meters, similar to that described by Raya et al. (2013). From the starting position (A), subjects moved at maximum speed to the central cone (B); then by lateral displacement to the cone located 5m to the right (C); then with lateral displacement to the cone (D), located 10m to the left; they returned with lateral displacement to the central cone (B); finally running backwards until crossing the starting line (A) (Figure 1). This test was carried out on the players' regular training field, *after* the CMJ tests had been performed. The players also wore their usual training shoes. A CASIO manual stopwatch, model IP2810, was used to determine the time. Prior to the execution, the players performed a standardized warm-up of 20 minutes, which included joint mobility, dynamic stretching, jumps, jogging, and accelerations. Only one attempt was made per athlete.

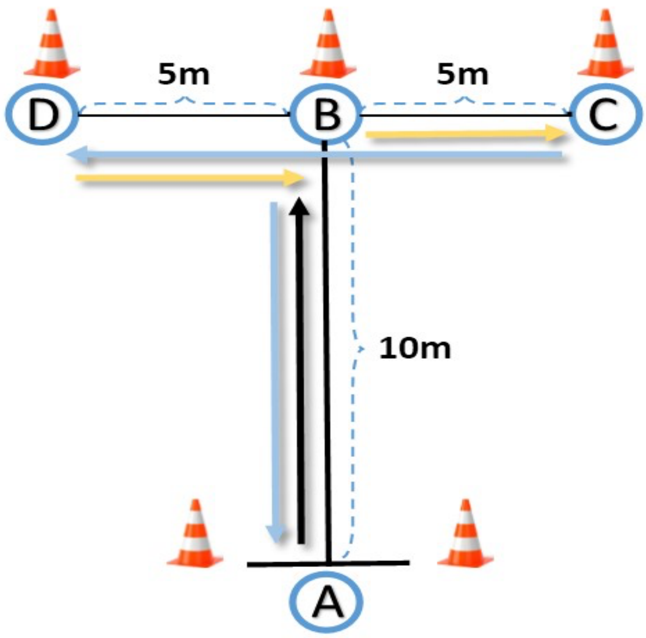

Figure 1. Schematic representation of the T-agility test.

All tests were conducted during the players' regular training schedule. They were carried out at the facilities of the corresponding club, which has a closed court.

On Saturdays, after each of the four MiCs during the intervention, the CMJ and TaT tests were repeated under exactly the same conditions described above. The players were insisted on the importance of adequate rest, the night before each of the evaluation instances. Additionally, and although it was not controlled, they were asked not to modify their eating habits during the time the study lasted. The research was carried out respecting the ethical principles established in the Declaration of Helsinki (Rev.2008).

Experimental intervention

During the intervention mesocycle, both EXP and CONT subjects performed 5 sessions per week. All training sessions began with a standardized 15-minute warm-up based on: jogging, technical skills (dribbling the ball and layups), full-court offensive drills (e.g., 3-on-0; 3-on-2; and 3-on-3 drills), and dynamic stretching exercises.

On Monday, Tuesday, Thursday, and Friday, each of the sessions included, in addition to the warm-up and cool-down, physical preparation exercises (approximately 60 minutes) and then technical-tactical training (approximately 60 minutes). On Wednesdays, the players only undertook technical-tactical training, lasting approximately 120 minutes. All training sessions were directed and/or supervised by two of the authors of this study (A.M and B.C.).

Both in the case of technical-tactical training and physical training, the activities performed were similar in both groups, but the training loads were differentiated considering their sRPE. In the EXP group, the components of the load (particularly in terms of intensity and density) were planned, and then adjusted during the course of the intervention, so as to achieve an increase in the average weekly intensity (in terms of AU) that was increasing by about 20 to 25%, compared to the immediately preceding MiC.

In agreement with Aoki et al. (2017), the increase in the intensity of the training session is mainly due to the increase in actions that require changes of direction, accelerations and decelerations, sprints and other specific actions related to the specificity of the sport. Based on this, the training sessions of the EXP group were planned with a higher volume of work, particularly of exercises involving these types of high-intensity actions.

The technical-tactical training consisted primarily of unopposed drills (2 vs 0 to 5 vs 0) focused on offensive aspects; tactical drills with opposition (1 vs 1 to 4 vs 4) focused on defensive aspects; and technical drills (e.g., shooting, passing). In the EXP group, intensity and volume were constantly manipulated using responses and daily monitoring using the sRPE. Such manipulation included changes in the relationship between work and recovery within and between drills, varying the number of players performing full-court scrimmage drills, as well as strategic change in rules (among others, varying the size of the playing field, number of players, play with or without free throws, and/or inclusion of repeated sprinting after a given game situation).

In addition, an increase in the load and intensity of the overload training sessions was planned. In this way, we sought to enhance the fatigue processes in the players of this group throughout the training mesocycle.

On the other hand, the training loads in the CONT group sessions were adjusted in such a way that the average weekly intensity (in terms of AU) was similar, during the entire mesocycle, to the intensity applied to the EXP group during the first MiC, and remained constant throughout the intervention. In this way, it was ensured that the low average intensity applied to the athletes in the CONT group did not generate cumulative fatigue effects throughout the entire training mesocycle.

The planning of the physical training loads throughout the intervention mesocycle, and the load control used during the intervention for the EXP and CONT groups, can be seen in Table 1.

All sessions were conducted in the same training center, with an ambient temperature ranging from 11° to 20° and humidity between 78% and 82% for the duration of the intervention. Regular verbal encouragement from the head trainer and staff members was allowed during the sessions.

Table 1
Planning of physical training loads during the intervention mesocycle

	EXP	CONT
	Microcycle 1	
Monday	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Tuesday	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Thursday	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Friday	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70mts	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
	Microcycle 2	
Monday	Push MMII 4 x 8-10 x 60-70% 1RM; Pull MMSS 4 x 8 x 60-70% 1RM Sprint 15" X 15" passive pause Run 2 x 7min x 70m	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Tuesday	Push MMSS 4 x 8-10 x 60-70% 1RM; Pull MMII 4 x 8 x 60-70% 1RM Sprint 10" x 20" passive pause Run 3x 6min x 70m	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8reps x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Thursday	Push MMII 4 x 8-10 x 60-70% 1RM; Pull MMSS 4 x 8 x 60-70% 1RM Sprint 15" X 15" passive pause Run 2 x 7min x 70m	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Friday	Push MMSS 4 x 8-10 x 60-70% 1RM; Pull MMII 4 x 8 x 60-70% 1RM Sprint 10" x 20" passive pause Run 3x 6min x 70m	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
	Microcycle 3	
Monday	Push MMII 5x 8-10 x 60-70% 1RM; Pull MMSS 5 x 8 x 60-70% 1RM Sprint 15 "X15 "X15 "passive pause Race 2 x 8 min - 35m round trip	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Tuesday	Push MMSS 5 x 8-10 x 60-70% 1RM; Pull MMII 5 x 8 x 60-70% 1RM Sprint 10" x 10" passive pause Run 4 x 4 min 60m	Push MMSS 3 x 8-10 x 60-70% 1RM; Pull MMII 3 x 8 x 60-70% 1RM Sprint 15" x 30" passive pause Run 2 x 6min x 70m
Thursday	Push MMII 5x 8-10 x 60-70% 1RM; Pull MMSS 5 x 8 x 60-70% 1RM	Push MMII 3 x 8-10 x 60-70% 1RM; Pull MMSS 3 x 8 x 60-70% 1RM

	Sprint 15 "X15 "X15 "passive pause	Sprint 15" x 30" passive pause
	Race 2 x 8 min- 35 mts round trip	Run 2 x 6min x 70m
Friday	Push MMSS 5 x 8-10 x 60-70% 1RM;	Push MMSS 3 x 8-10 x 60-70% 1RM;
	Pull MMII 5 x 8 x 60-70% 1RM	Pull MMII 3 x 8 x 60-70% 1RM
	Sprint 10" x 10" passive pause	Sprint 15" x 30" passive pause
	Run 4 x 4 min x 60m	Run 2 x 6min x 70m
	Microcycle 4	
Monday	Push MMII 6 x 8-10 x 60-70% 1RM;	Push MMII 3 x 8-10 x 60-70% 1RM;
	Pull MMSS 3 x 8 x 60-70% 1RM	Pull MMSS 3 x 8 x 60-70% 1RM
	Sprint 10 "x10" passive pause	Sprint 15" x 30" passive pause
	Run 4 x 6 min x 55m	Run 2 x 6min x 70m
Tuesday	Push MMSS 6 x 8-10 x 60-70% 1RM;	Push MMSS 3 x 8-10 x 60-70% 1RM;
	Pull MMII 3 x 8 x 60-70% 1RM	Pull MMII 3 x 8 x 60-70% 1RM
	Sprint 5" x 5" passive pause	Sprint 15" x 30" passive pause
	Run 4 x 4 min 40m	Run 2 x 6min x 70m
Thursday	Push MMII 6 x 8-10reps x 60-70% 1RM;	Push MMII 3 x 8-10reps x 60-70% 1RM;
	Pull MMSS 3 x 8reps x 60-70% 1RM	Pull MMSS 3 x 8reps x 60-70% 1RM
	Sprint 10 "X10" passive pause	Sprint 15" x 30" passive pause
	Run 4 x 6 min x 55m	Run 2 x 6min x 70m
Friday	Push MMSS 6 x 8-10 x 60-70% 1RM;	Push MMSS 3 x 8-10 x 60-70% 1RM;
	Pull MMII 3 x 8 x 60-70% 1RM	Pull MMII 3 x 8 x 60-70% 1RM
	Sprint 5" x 5" passive pause	Sprint 15" x 30" passive pause
	Run 4 x 4 min x 40m	Run 2 x 6min x 70m

Note: training loads are expressed as sets - repetitions - intensity. Abbreviations: EXP = experimental group; CONT = control group; RM = repetition maximum; MMII = lower limbs; MMSS = upper limbs.

Quantification of session AUs

After the end of the session, each player was asked to mention the perceived intensity of effort for the entire session, using Borg's (1982) modified RPE scale. Following the procedures used by Lupo et al. (2017), who worked with a population similar to that of the present study, this value was collected approximately 30 minutes after the end of each session. This period of time is considered necessary to prevent the subjects from being influenced by the intensity of the training loads applied during the last minutes of the session. In this way, the player can rate the entire session with a greater "perspective," thus, decreasing the bias.

The value obtained was multiplied by the duration of the session (in minutes) to obtain a value in AU. With this data, the average training load of the microcycle was obtained for each participant.

The duration of each session was recorded individually, including intra- and inter-exercise rest periods but excluding the duration of pre-conditioning or cool-down exercises. All players were familiar with the use of the modified RPE because they had used it in previous training sessions; although this is the first time, they used it to estimate whole-session intensity (sRPE).

Statistical analysis of data

A basic descriptive analysis was made of the data obtained, expressed as mean ± standard deviation. The data from the evaluations prior to the experimental intervention for each group (EXP and CONT) were subjected to Student's t-test for independent data, after checking the assumptions of homogeneity of variance (using

Levene's test) and normality (using the Shapiro-Wilk test). If these assumptions were not verified, the Mann-Whitney-Wilcoxon u test was used.

The data obtained for both groups, in the successive CMJ and TaT evaluations, were analyzed by means of a one-factor repeated measures ANOVA test to establish possible differences between the observed means. If a statistically significant difference was found, a post-hoc test was performed to determine at which level or levels this difference was verified.

To determine the correlation between the training load, the CMJ jump height and the time required in the TaT, the Pearson's r test was used, after determining normality by means of the Shapiro-Wilk test.

For all cases, a significance level $\alpha = 0.05$ was established. For statistical analysis, the free software JASP 0.16.1 (University of Amsterdam) was used.

Results

Characteristics of the pre-intervention sample

Table 2 shows the characteristics of the sample studied. Prior to the start of the intervention, there were no significant differences ($p > 0.05$) in the age, height, and mass of the participants.

Table 2
Characteristics of the pre-intervention sample

	EXP	CONT	p- value
Age (years)	17.8 ± 0.9	17.8 ± 0.9	-
Height (cm)	181,8 ± 8,9	182,8 ± 12,3	0.483^{+}
Mass (kg)	78,9 ± 12,7	81,3 ± 8,6	0.105*

Note: In all cases, a significance level of $\alpha = 0.05$ was established; $^{+}$ = Student's t for independent data; * = Mann-Whitney's u. Abbreviations: EXP = experimental group; CONT = control group.

Table 3 shows the results of the TaT and CMJ for the EXP and CONT groups, prior to the experimental intervention. There was no significant difference ($p > 0.05$) between the two groups in terms of performance in the first test mentioned. However, there was a significant difference ($p \leq 0.05$) between both groups in the CMJ performance in favor of the EXP group (39.7cm EXP vs 32.8cm CONT).

Table 1

Performance on the pre-intervention T-agility and CMJ tests.

	EXP	CONT	p- value
TaT (s)	8.2 ± 0.7	8.3 ± 1.2	0.629^{+}
CMJ (cm)	39.7 ± 6.5	32.8 ± 3.7	0.021^{+}

Note: In all cases a significance level of α = 0.05 was established;$^{+}$ = Student's t for independent data; * = Mann-Whitney test. Abbreviations: EXP = experimental; CONT = control; CMJ = *Countermovement Jump* test; TaT = T-agility test.

Training loads used

Table 4 shows the volume, sRPE, and average AU records for each session, individualized by MiC of training, for both groups. In the EXP group, from MiC 1, an increase in the average session load for that week (measured in AU) of 19.6% (micro 1 to 2), 26.6% (micro 2 to 3), and 12% (micro 3 to 4) is verified. In the CONT group, the differences in the loads applied week to week were -1.6% (micro 1 to 2), 0% (micro 2 to 3), and 0.5% (micro 3 to 4). In this last group, and in accordance with what was planned, there were no significant differences between the four training MiC ($p > 0.05$).

Table 4

Record volume, sRPE, and average AU per session for each training microcycle.

	EXP	CONT
	Microcycle 1	
Volume (min)	120 ± 0.0	
sRPE	4.9 ± 0.2	4.7 ± 0.3
AU	**594 ± 20.1**	**564 ± 34.5**
	Microcycle 2	
Volume (min)	120 ± 0.0	120 ± 0.0
sRPE	5,9 ± 0.2	4,6 ± 0.4
AU	**711 ± 25.1**	**555 ± 42.5**
	Microcycle 3	
Volume (min)	120 ± 0.0	120 ± 0.0
sRPE	7,5 ± 0.9	4,6 ± 0.4
AU	**900** ± 37.9	**555** ± 42.5
	Microcycle 4	
Volume (min)	120 ± 0.0	120 ± 0.0
sRPE	8,4 ± 0.4	4,6 ± 0.3
AU	**1008 ± 49.2**	**552 ± 39.1**

Note: Abbreviations: EXP = experimental group; CONT = control group; sRPE = subjective feeling of session effort; AU = arbitrary units.

CMJ test performance

Table 5 and Figure 2 present the results of the CMJ performance for the EXP and CONT groups, pre- and intra-intervention. In EXP, a systematic decrease in values is observed as the MiCs elapse. A significant difference in these results is also verified ($p \leq 0.05$) in the ANOVA test. Comparing the final value (at the end of MiC 4) with the pre-intervention value, a 16% decrease in jump height is verified. As for the CONT group, although a tendency to a decrease in performance is observed, it is less marked than for the EXP group, without showing a statistically significant difference ($p > 0.05$) between the results.

Table 2

Pre- and intra-intervention CMJ test results

	Initial	**Micro 1**	**Micro 2**	**Micro 3**	**Micro 4**	**p-value**
EXP	39.7 ± 6.5	37.9 ± 6.4	36.1 ± 6.0	34.8 ± 6.3	33.3 ± 6.3	< 0.001
CONT	32.8 ± 3.7	31.6 ± 3.8	32.2 ± 3.8	31.8 ± 3.7	30.3 ± 4.1	0.058*

Note: A one-factor repeated measures ANOVA test was used; in all cases a significance level of $\alpha = 0.05$ was established. * Greenhouse-Geisser correction was used since the data did not meet the assumption of sphericity. Initial = value prior to the intervention; Micro = value taken at the end of the corresponding microcycle. Abbreviations: CMJ = *Countermovement Jump* test.

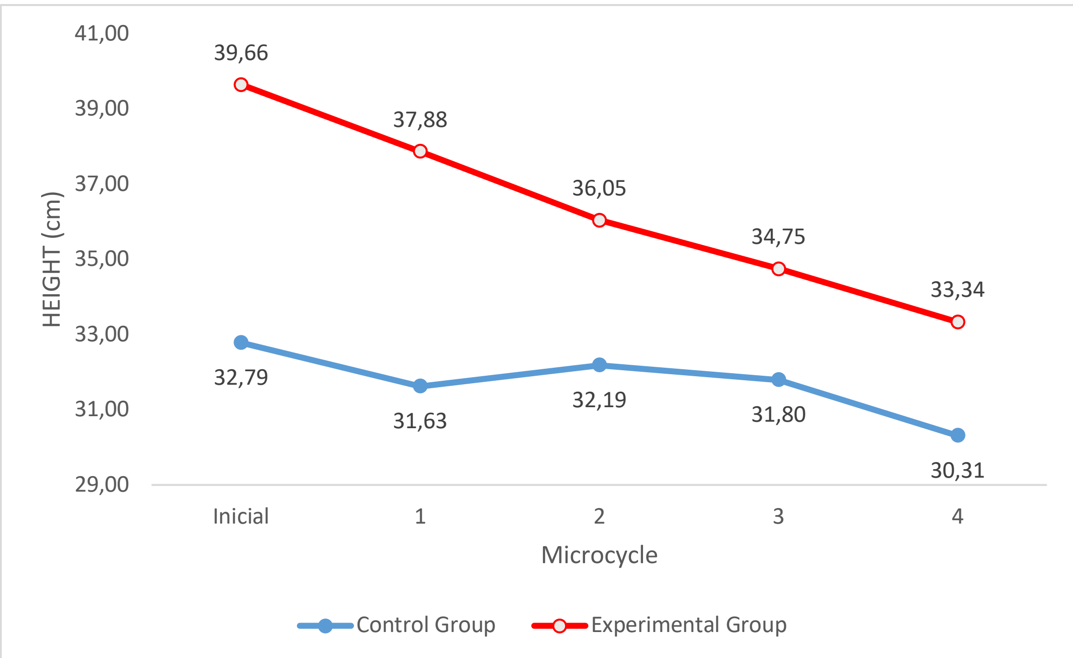

Figure 2. Performance in the CMJ test for the Experimental and Control groups.

Table 6 shows the Post hoc test performed on the EXP group. It shows that there is a statistically significant difference ($p \leq 0.05$) when comparing each of the MiCs considered.

Figure 3 shows the correlation between the average height reached in the CMJ and the average training load (AU) applied in the corresponding MiC session. A significant correlation ($p < 0.001$) of $r = -0.589$ was verified. The same following the classification of Goss-Sampson (2019) is interpreted as moderate ($0.4 < r \leq 0.6$).

Table 3
Post hoc comparison of CMJ test performance for the Experimental Group.

		Average difference (cm)	p-value
Initial	Micro 1	1.8 ± 0.4	< 0.001
	Micro 2	3.7 ± 0.4	< 0.001
	Micro 3	4.9 ± 0.4	< 0.001
	Micro 4	6.4 ± 0.4	< 0.001
Micro 1	Micro 2	1.8 ± 0.4	< 0.001
	Micro 3	3.1 ± 0.4	< 0.001
	Micro 4	4.5 ± 0.4	< 0.001
Micro 2	Micro 3	1.3 ± 0.4	0.005
	Micro 4	2.7 ± 0.4	< 0.001
Micro 3	Micro 4	1.4 ± 0.4	0.005

Note: The Holm-Bonferroni test was used. In all cases a significance level of $\alpha = 0.05$ was established. Initial = value prior to the experimental intervention; Micro = value taken at the end of the corresponding microcycle.

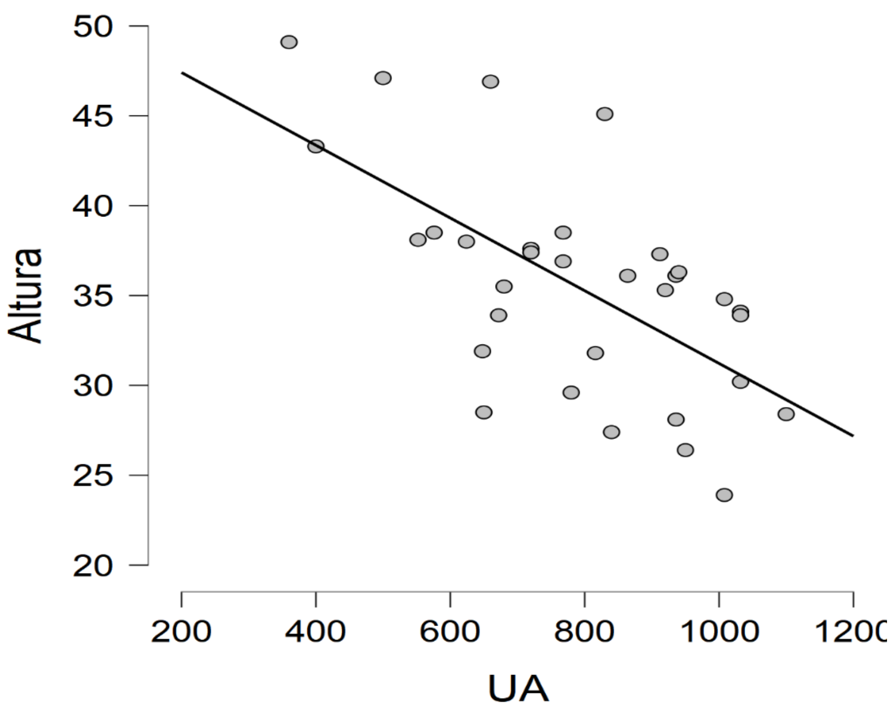

Figure 3. CMJ performance as a function of applied load.
Note: Only data from the EXP group were considered. AU = average training load of the session during a given microcycle.

Agility test performance T

Table 7 and Figure 4 show the results of TaT performance for the EXP and CONT groups. In both, a trend towards an increase in the time demanded for the completion of the test (i.e., a reduction in performance) is observed, more marked in the EXP group than in CONT. In both cases, a statistically significant difference ($p \leq 0.05$) was verified when comparing the results of the different evaluation instances by means of ANOVA test.

Table 4
Pre- and intra-intervention T-agility test results

	Initial	**Micro 1**	**Micro 2**	**Micro 3**	**Micro 4**	**p-value**
EXP	8.2 ± 0.7	8.4 ± 0.7	8.9 ± 0.8	10.1 ± 1.3	11.2 ± 1.5	< 0.001*
CONT	8.4 ± 1.3	8.3 ± 1.2	8.6 ± 1.1	8.7 ± 0.9	9.3 ± 0.9	0.003*

Note: A one-factor repeated measures ANOVA test was used; in all cases a significance level of $\alpha = 0.05$ was established. * Greenhouse-Geisser correction was used since the data did not meet the assumption of sphericity. Initial = value prior to the intervention; Micro = value taken at the end of the corresponding microcycle. Abbreviations: EXP = experimental group; CONT = control group.

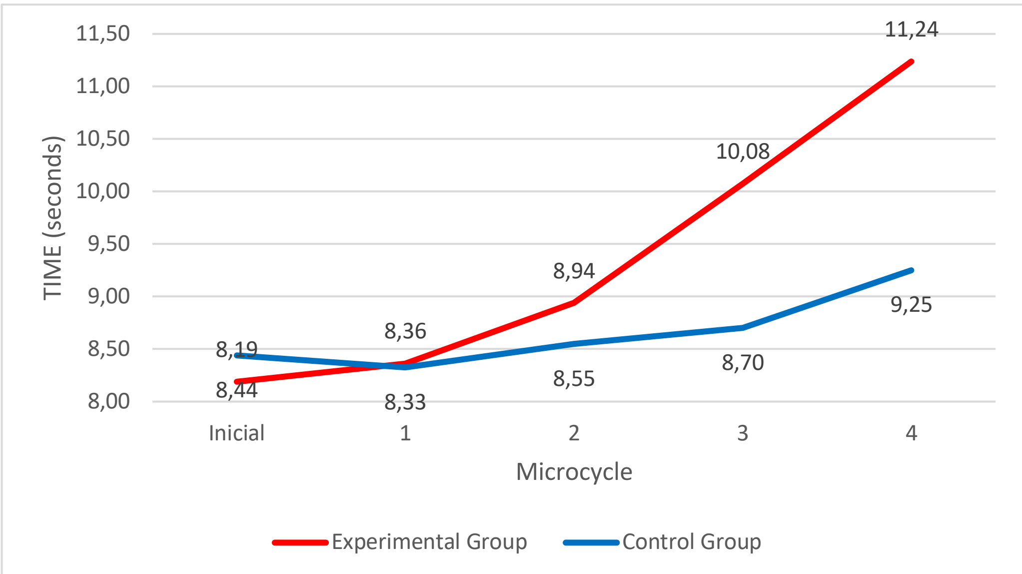

Figure 4. Performance in the *T*-agility test.

The Post hoc test for both groups can be seen in Table 8 (EXP group) and Table 9 (CONT group). In the first case, it is observed that, with the exception of MiC 1, when compared to the initial value, there is a statistically significant reduction in performance in the successive evaluations considered, with respect to the results of the immediately preceding MiC. In the CONT group, on the other hand, there is only a significant reduction in performance in the test performed in MiC 4 compared to the result obtained in MiC 3.

Table 5
Post hoc test on T-agility test performance for the experimental group.

		Average difference (s)	p-value
Initial Value	Micro 1	-0.18 ± 0.3	0.498
	Micro 2	-0.8 ± 0.3	0.020
	Micro 3	-1.9 ± 0.3	< 0.001
	Micro 4	-3.1 ± 0.3	< 0.001
Micro 1	Micro 2	-0.575 ± 0.3	0.064
	Micro 3	-1.7 ± 0.3	< 0.001
	Micro 4	-2.9 ± 0.3	< 0.001
Micro 2	Micro 3	-1.1 ± 0.3	< 0.001
	Micro 4	-2.3c± 0.3	< 0.001
Micro 3	Micro 4	-1.2 ± 0.3	< 0.001

Note: Holm's test was used. In all cases a significance level of α = 0.05 was established. Initial value = value prior to the experimental intervention; Micro = value taken at the end of the corresponding microcycle.

Table 9
Post hoc comparison of T-agility test performance for the control group.

		Average difference (s)	p-value
Initial Value	Micro 1	0.1 ± 0.2	0.989
	Micro 2	-0.1 ± 0.2	0.989
	Micro 3	-0.3 ± 0.2	0.468
	Micro 4	-0.8 ± 0.2	< 0.001
Micro 1	Micro 2	-0.2 ± 0.2	0.592
	Micro 3	-0.4 ± 0.2	0.117
	Micro 4	-0.9 ± 0.2	< 0.001
Micro 2	Micro 3	-0.2 ± 0.2	0.989
	Micro 4	-0.7 ± 0.2	< 0.001
Micro 3	Micro 4	-0.6 ± 0.2	0.008

Note: Holm's test was used. In all cases a significance level of α = 0.05 was established. Initial value = value prior to the experimental intervention; Micro = value taken at the end of the corresponding microcycle.

Figure 5 shows the correlation between TaT performance and the average session training load applied during each MiC. A positive correlation of $r = 0.683$ was verified, statistically significant ($p < 0.001$), which is interpreted following the Goss-Sampson classification (2019) as high ($0.6 < r \leq 0.8$).

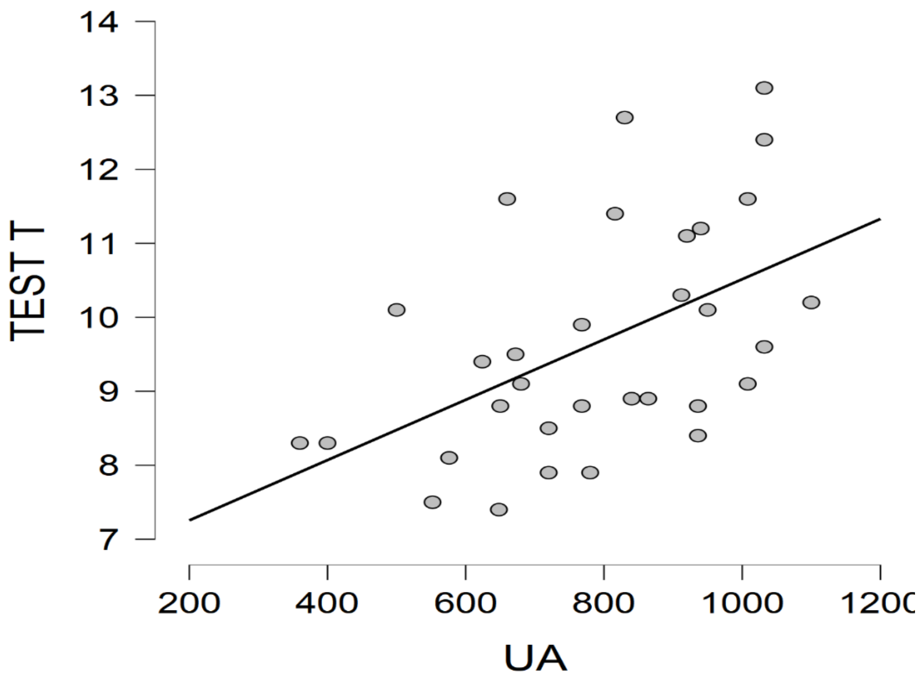

Figure 5. TaT performance as a function of applied load.
Note: Only the results of the experimental group were considered. AU = average session load for the corresponding microcycle, expressed as arbitrary units.

Discussion

The present study investigated the possible usefulness of the CMJ and TaT tests as indirect indicators of accumulated fatigue during a training mesocycle in male youth basketball players. To the best of our knowledge, this is the first study with these characteristics. An important limitation of training intervention works is the lack of a control group (Loturco et al., 2017); for this reason, we consider it relevant to our work to have had such a group.

Prior to the start of the intervention, a significant difference was determined between groups in terms of CMJ performance: the EXP group showed a significantly higher mean performance in this test ($p \leq 0.05$) than the mean observed for CONT (EXP = 39.7 cm vs CONT = 32.8 cm). Considering the purpose of this work; however, we understand that this difference does not affect the conclusions derived from it.

After the intervention, the results obtained in EXP showed a significant decrease in performance for both the CMJ and TaT tests, as the MiCs of training elapsed. In the case of CONT, no such loss of performance was observed in CMJ; while in TaT, the loss of performance was only significant in the test performed at the end of the fourth MiC. Given that both groups trained under the same conditions, it can be assumed that this behavior in the performance variables has as a causal phenomenon the difference in the loads applied. In this regard, we believe that the significant loss of performance in the EXP group would be associated with a process of accumulated fatigue throughout the training mesocycle.

In the study by Delextrax et al. (2012), significant decreases in CMJ performance were observed from 12.6% to 19.6% pre- vs. immediate post-session, during a competitive week. In comparison, in our work the results indicated a percentage loss in

CMJ performance of 16.1%, comparing performance at the end of MiC 4 with pre-intervention values. Given that the loss of performance in both works was similar, it leads us to suggest that the CMJ could present a similar sensitivity to detect both acute (post-session) and chronic (post-mesocycle) fatigue processes.

Other works have analyzed the relationship between training load applied over several training MiCs and CMJ performance, although with inconclusive results. In the work of de Freitas et al. (2018), it was observed that when high training loads were accumulated, CMJ performance showed a decrease, compared to what was observed in periods of application of less stressful loads. These results are in agreement with what was found in the present work. On the other hand, and in the opposite direction, in the work of Freitas et al. (2014), after a precompetitive period in which progressive increases in loads were applied to volleyball players, it was concluded that CMJ performance is not a sensitive variable for the determination of cumulative fatigue. With respect to the TaT, although to our knowledge it has not been used as an indirect indicator of fatigue, it has been observed that other agility tests with similar characteristics (e.g., *arrowhead agility test*) are sensitive to post-competition fatigue (Rago et al., 2020); although we do not know their sensitivity for detecting cumulative fatigue. More studies in this area are needed.

Performance loss in CMJ has been accounted for with accumulation of metabolic products in plasma, including CK (Hagstrom et al., 2018), lactate, and ammonium (Jiménez-Reyes et al., 2011). However, given that in this study each test was performed after an extended period of rest, presumably these products are not affecting performance; as their values would be expected to have dropped to normal by the time the test was run. This suggests that the physiological phenomenon expressed by Jiménez-Reyes et al. (2011) would not be adequate to explain at the physiological level what happened in this study.

In this work, the low loads applied to the CONT group (which averaged 557 AU per session, throughout the entire training mesocycle) were intended to avoid the accumulation of fatigue. Consequently, the significant loss of performance experienced by this group for TaT in MiC 4 compared to MiC 3 raises a question. It could be hypothesized that this is related to a process of loss of athletic form, secondary to the low loads applied after four weeks of low intensity training.

However, we understand that this would not be a convincing justification for this observed phenomenon, given that due to the restrictions imposed by the pandemic caused by COVID-19, the players started the intervention after a prolonged period of inactivity. We can speculate; therefore, that their level of athletic fitness was far from optimal, so that even low training loads should represent a positive adaptation.

We believe it is more pertinent to think that this phenomenon could be due, despite the low loads, to an eventual process of accumulated fatigue at the end of the mesocycle, perhaps caused by a possible incorrect planning in the periodization or rests in the applied program. In any case, given the small number of participants in each group (n = 8), caution is required when drawing conclusions.

The detection of fatigue processes in sport in general, and in basketball in particular, is crucial since fatigue is not only associated with a loss of performance (physical and mental) of players but also with an increase in the occurrence of injuries (Walters et al., 2017). The early detection of potentially deleterious fatigue accumulation processes constitutes a practical tool of undoubted usefulness for coaches, allowing them to adjust and optimize training planning. In this sense, we understand that the findings of the present work represent a contribution, particularly for youth basketball coaches.

Conclusions

The results observed in the present study seem to indicate that both the CMJ and TaT tests are sensitive, and concomitantly useful, for the detection of accumulated fatigue in youth federated basketball players. These findings are encouraging since both tests have a number of advantages, among them: they are inexpensive (in terms of cost and human resources) and do not require a significant logistical organization to carry them out. However, we consider it desirable to combine them with other objective indicators, for example: HR variability, post-exertion HR recovery, movement indicators, among others.

Given the limitations of the present work, we consider that these conclusions should be interpreted with caution. In addition, we believe that more studies similar to the present one are needed.

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ASSOCIATION BETWEEN CARDIORESPIRATORY RESISTANCE AND INTELLECTUAL MATURITY IN PRIMARY SCHOOL CHILDREN: EDUCATIONAL IMPLICATIONS

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Abstract. Objective. This study analysed the relation between 10-12-year-old student´s cardiorespiratory resistance and their intellectual maturity as indicator to improve the academic performance. Method. Data were collected from primary education schools in Spain. A total of 150 children in 5th and 6th grades (age = 10.72 ± 1.25 years of age) participated. The Leger test measured cardiorespiratory fitness, the Goodenough-Harris Drawing test assessed intellectual maturity and the school grades the academic performance. Results. Significant differences were found between the genders; boys showed greater cardiorespiratory endurance. However, there were no significant genders differences in mental age. Children with better aerobic endurance physical scores scored better on the Goodenough-Harris Drawing test. In turn, intellectual maturity turned out to be a solid indicator of academic performance. Conclusions. There is a relationship between intellectual maturity and cardiorespiratory endurance in children in the third cycle of primary education, which is relevant to health and academic performance.

Key words: Cognitive development, academic performance, educational achievement physical conditioning, health education, primary education

ASOCIACIÓN ENTRE RESISTENCIA CARDIORRESPIRATORIA Y MADUREZ INTELECTUAL EN NIÑOS DE ESCUELA PRIMARIA: IMPLICACIONES EDUCATIVAS

Resumen. Objetivo. Este estudio analizó la relación entre la resistencia cardiorrespiratoria de estudiantes de 10 a 12 años y su madurez intelectual como indicador para mejorar el rendimiento académico. Método. Los datos se recogieron de centros de Educación Primaria de España. Participaron un total de 150 niños de 5° y 6° grado (edad = 10,72 ± 1,25 años). La prueba de Leger midió la aptitud cardiorrespiratoria, la prueba de dibujo de Goodenough-Harris evaluó la madurez intelectual y las calificaciones escolares el rendimiento académico. Resultados. Se encontraron diferencias significativas entre los géneros; los chicos mostraron mayor resistencia cardiorrespiratoria. Sin embargo, no hubo diferencias significativas de género en la edad mental. Los niños con mejores puntuaciones físicas de resistencia aeróbica obtuvieron mejores resultados en la prueba de dibujo de Goodenough-Harris. A su vez, la madurez intelectual resultó ser un indicador sólido del rendimiento académico. Conclusiones. Existe una relación entre la madurez intelectual y la resistencia cardiorrespiratoria en niños del tercer ciclo de Educación Primaria, lo cual es relevante para la salud y el rendimiento académico.

Palabras clave: Desarrollo cognitivo, rendimiento académico, logro educativo, acondicionamiento físico, educación para la salud, educación primaria.

Introduction

Several investigations have investigated the importance of physical activity in children's health (Boreham & Riddoch, 2001; Janssen et al., 2010). There are numerous biomarkers that determine people's health from a very young age, being physical condition one of them (Ortega, Ruiz, Castillo & Sjöström, 2008). In turn, it is possible to find a connection between body growth, physical condition (Ortega et al., 2011) and cognition (Heinonen et al., 2008). Similarly, there is a close association between motor and cognitive development, which takes place in the cerebellum and prefrontal cortex.

Children who are in good physical shape have greater cortical activation which in turn is reflected in better cognitive performance (Tomporowski, Davis, Miller & Naglieri, 2008). Haapala et al. (2015) and Aberg et al. (2009) showed that motor skills and cardiorespiratory resistance play an important role in cognitive development during childhood and young adulthood. Therefore, increasing physical fitness levels is beneficial for cognition during preadolescent development (Latorre Román, García Pinillos, Pantoja Vallejo, & Berrios Aguayo, 2017; Berrios Aguayo, Pantoja Vallejo, Latorre Román, 2019).

The analysis of children's drawings can be an important indicator of some cognitive aspects such as intellectual maturity (Pérez Testor & Pérez Testor, 2000; Loxton, Mostert, & Moffatt, 2006; Soto, Mendoza y Ramírez, 2009) or even as intelligence indicator (Mamani Ortiz, Choque Ontiveros, & Rojas Salazar, 2014). Furthermore, studying the progression of the drawings that children make over a period of time can show the level of intellectual development (Thomas & Jolley, 1998). In several investigations, children's drawings have been used to analyse cognitive and motor skills (Hasab Allah, El Adawy, Moustafa & Ali, 2012; Imuta et al., 2013; Latorre-Román, Mora-López & García-Pinillos, 2016; Soto et al., 2009). Although the association between physical fitness and cognitive functions has been investigated in various studies (Ellemberg & St-Louis-Deschênes, 2010; Gallotta et al., 2015; Janssen et al., 2014), the relationship between physical condition, mainly cardiorespiratory resistance, and intellectual maturity is unclear.

The chronological age and its relationship with the academic performance has been widely studied (Ardoy et al., 2014; Abel et al., 2016; Vergel-Ortega, Martínez-Lozano, Zafra-Tristancho, & Zafra-Tristancho, 2016). Nevertheless, the association between intellectual maturity and school performance has not got the enough attention, being it really relevant for educational implication.

Taking into account the above information, we propose the following hypothesis: children with greater cardiorespiratory resistance have an older mental age as well as a better academic performance. Therefore, the purpose of this study is to analyse the relationship between mental age and cardiorespiratory resistance in children 10-12 years old which knowledge could be useful to improve the academic performance.

Method

Participants

A total of 150 children 10-12 years old (age = 10.72 ± 1.25 years of age) participated. Demographic characteristics revealed that 81 children were male and 69 were female, and they were selected from two primary schools in southern Spain, one public and one private. Every students of those courses participated in this study except a total of five students with intellectual or physical disabilities such as a wheelchair user or an autistic person. The parents were given an explicit verbal description of the nature and purpose of the research to be carried out and consequently their informed consent was obtained. The study was conducted in compliance with the standards of the Declaration of Helsinki (2013). The study was approved by the Bioethics Committee of the University of Jaen.

Materials and testing

Anthropometric variables

Height (cm) was measured with a stadiometer (Seca 222, Hamburg, Germany) and weight with a weighing scale (Seca 899, Hamburg, Germany). Body mass index (BMI) was calculated by dividing weight (in kilograms) by height^2 (in metres).

Physical variables

Cardiorespiratory endurance was assessed using the Leger test (Leger, Mercier, Gadouryl and Lambert, 1988). In this test, the students start walking and finish running, moving from one point to another located 20 metres away and making a change in direction to the rhythm indicated by a sound signal that is accelerated progressively. The test is stopped when the participant cannot maintain the race pace, registering the last period of the test in which the individual was.

The maximum oxygen consumption (VO_2 max.) was calculated taking into account the speed that the participant reached using the following equation: VO_2 max. = (31,025) + (3,238 * X) - (3,248 * A) + (0,1536 * A * X), X = speed, A = age (Leger et al., 1988). It is another appropriate indicator of cardiorespiratory endurance (Kabiri, Mitchell, Brewer, & Ortiz, 2017).

The reliability and validity of Leger test for determining the VO2 max in children has been widely demonstrated (Liu, Plowman, & Looney, 1992; Ruiz et al., 2009).

Intellectual maturity

For the evaluation of intellectual maturity, the Goodenough-Harris Drawing Test (GHDT), developed by Goodenough (1926) and revised by Harris (1963), was used. The GHDT test indicates the cognitive ability of the student, which in turn is represented in the intellectual maturity of the child or the metal age (MA) and a final score interpreted as intellectual quotient (IQ) (Table 1).

Table 1

Conversion of crude score GHDT to MA

Ages		3	4	5	6	7	8	9	10	11	12	13	14	15	
Months	0	-	4	8	12	16	20	24	28	32	36	40	44	48	Scores
	3	-	5	9	13	17	21	25	29	33	37	41	45	49	
	6	2	6	10	14	18	22	26	30	34	38	42	46	50	
	9	3	7	11	15	19	23	27	31	35	39	43	47	-	

Note: Source: Harris (1963)

The present study used the most recent edition in which the child is asked to make two drawings, one of a man and one of a woman of a whole body (Soto, Mendoza, & Ramírez, 2009). The evaluation focuses on the details and the proportion of the general body of the figure drawn from a man (73 details) and a woman (71 details). We used the average crude score of the two drawings which was the total details performed. The GHDT test was designed to evaluate both children and adolescents up to 15 years of age.

The GHDT test has several editions, all validated. The GHDT showed good reliability and validity compared to other tests of intelligence in children aged 3 to 15 (Abell, Horkheimer, & Nguyen, 1998; Plbrukarn & Theeramanoparp, 2003). The GHDT had not yet been examined from a modern test theory perspective in full. However, Campbell & Bond (2017) revealed that the GHDT and mainly the children's human figure drawings are proper according to Rasch analysis and deem to be generally psychometrically sound.

In addition, a Cohen's Kappa coefficient was calculated to determine the effect of chance. According to Sim & Wright (2005) the concordance between the measurements of two researchers in the GHDT is proper given that the Kappa value is 0.621 (Table 2) being between 0.6 and 0.8 (good concordance).

Table 2
Cohen´s Kappa coefficient

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	,621	,063	27,049	,000
N of Valid Cases		60			

Academic performance

The school grades were required of the teachers to measure the academic performance of the students. The required school grades were: Spanish Language, Maths, Natural Sciences, Social Sciences, Physical Education, Arts, Music and English Language. The school grades were presented in a range of 0-10. Finally, the average was calculated that was the score used for the statistical calculations. School grades as a reliable measure to determine academic performance, have been supported by authors such as Lambating & Allen (2002) and Allen (2005) who determine that school grades justify the student's learning objectives.

Procedure

Once the appropriate permits were obtained from the schools and the informed consent from the parents, the different tests were administered. Two separate sessions were conducted by a trained researcher. The GHDT was evaluated during the first test session, in the school classroom and in the presence of the teacher. The examiner gave the children two sheets, one to draw the man and another to draw the woman. The students were previously instructed to draw with as much detail as possible but through free draw. In the second session, the anthropometric measures (weight and height) were carried out followed by the Leger test. Before the execution of this test, a demonstration of how they should execute it was made. The children performed a typical warm-up consisting of 5 minutes of smooth running and 5 minutes of general exercises (i.e., jumping, raising the legs, side and front races, arm rotations, etc.). Each child was evaluated individually. Both physical and cognitive tests were evaluated by a previously trained researcher. Children were encouraged to achieve the highest possible performance by motivating them with a small reward such as extra credit for those classes if they participated in the study. Finally, school grades were required of the teachers to measure the academic performance.

Statistical Analysis

Data were analysed using the program SPSS (version 21, SPSS Inc., Chicago, Ill.) for Windows. The significance level was set at $p<0.05$ and $p<0.01$. The data are shown as descriptive statistics including mean, standard deviation (SD) and percentages. Tests for normal distribution and homogeneity (Kolmogorov-Smirnov & Levene's, respectively) were conducted on all data before analysis. Analysis of variance (ANOVA) was conducted for the genders comparison. Additionally, effect sizes for group differences were expressed as Cohen's *d* (Cohen, 1988); effect sizes of less than 0.4 represented a small difference, whereas effect sizes of 0.41–0.7 and greater than 0.7 represented moderate and large differences, respectively (Thomas, Silverman, & Nelson, 2015). Pearson correlation was carried out among intellectual maturity, BMI, academic performance and cardiorespiratory resistance. In addition, a scatter plot was developed between cardiorespiratory endurance and intellectual maturity with genders adjust. In the end, regression analyses were developed between intellectual maturity and academic performance.

Results

Table 3 shows the results of age, anthropometric characteristics, cardiorespiratory endurance, intellectual maturity and academic performance with gender adjust. Boys showed greater cardiorespiratory resistance than girls, but no significant differences were found in the other variables.

Table 3

Age, anthropometric characteristics, cardiorespiratory endurance, intellectual maturity, academic performance in relation to gender

	Girls Mean (SD)	Boys Mean (SD)	F	p-value	Cohen's *d*
Age (years)	10.72 (0.74)	10.67 (0.72)	0.232	0.631	0.0684
Weight (Kg)	38.74 (7.33)	41.46 (10.96)	3.06	0.082	0.2917
Height (m)	1.45 (0.80)	1.46 (0.80)	0.364	0.547	0.0125
BMI (kg/m^2)	18,17 (3,06)	19.07 (3.83)	2.45	0.120	0.2596
Leger test (number of periods)	3.13 (1.44)	3.98 (1.65)	11.113	0.001	0.5902
$V0_2$ (ml/kg/min)	43.89 (3.69)	45.95 (4.13)	10.11	0.002	0.5260
Average crude score GHDT (0-73)	35.03 (8.32)	32.64 (9.78)	2.40	0.123	0.2632
Average school grades	7.69 (1,76)	7.45 (1.85)	1.195	0,432	0,1349

Note: SD (Standard deviation); BMI (Body mass index); V02 Oxygen consumption); GDHT (Goodenough-Harris Drawing Test)

In Table 4, the intellectual maturity of the students is positively associated with cardiorespiratory resistance, specifically with VO_2max ($r = 0.415$, $p < 0.01$). In addition, BMI and intellectual maturity show a negative association ($r = -0.313$, $p < 0.01$). Regarding academic performance, it is also positively associated with the Leger test ($r = 268$, $p < 0.01$) and intellectual maturity ($r = 799$, $p < 0.01$).

Table 4
Pearson correlation between intellectual maturity, BMI, the Léger test, VO_2max and academic performance

	Intellectual maturity	BMI	Leger test	VO_2max	Academic performance
Intellectual maturity	1.000	-0.313**	0.410**	0.415**	0.799**
BMI		1.000	-0.436**	-0.422**	-0.120
Léger test			1.000	0.983**	0.268**
VO_2max.				1.000	0,067
Academic performance					1.000

Note: BMI (Body Mass Index); V02max (maximum oxygen consumption); GDHT (Goodenough-Harris Drawing Test). ** p <0.05

Figure 1 shows the scatter plot between intellectual maturity and VO2max according to gender. As the cardiorespiratory endurance of the students increases, their intellectual maturity increases.

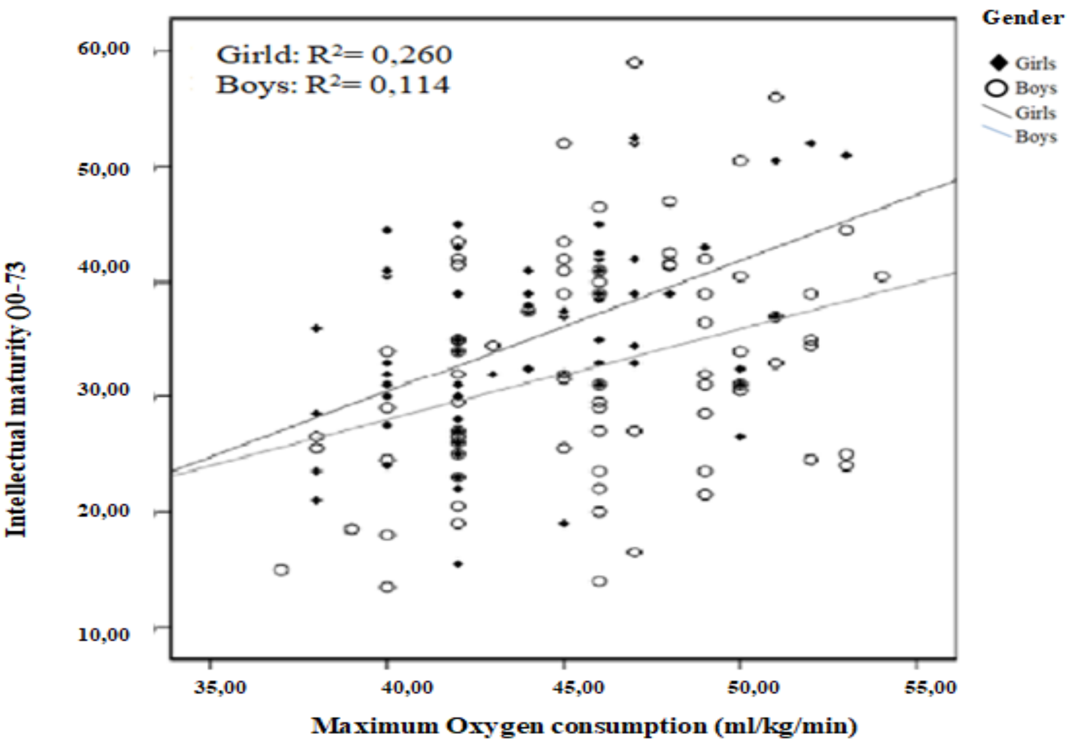

Figure 1. Dispersion figure between intellectual maturity and VO2max adjusted by gender

The intellectual maturity is a good indicator of academic performance in children of school age. For this, the linear regression model (Table 5) shows that intellectual maturity is positive predictor of academic performance (R^2=0.638, p<0.05).

Table 5
Multiple linear regressions between intellectual maturity and academic performance

	B	T	p-value	95% cofidence interval	
				Higher limit	Lower limit
Academic performance	2,861	16.139	0.000	0.125	0.160
Intellectual maturity	0,142	9.301	0.000	2.253	3.468
R^2			0.638		

Figure 2 shows the drawings of a woman and a man made by an 11-year old girl in 6th grade of primary education with high scores on the GHDT and high average school grades. Those scores agree with an appropriate VO2max according to the references of Hamlin et al. (2014). On the other hand, the drawing of another girl from the same school year with low GHDT score and low average school grades is also associated with an inappropriate VO2max.

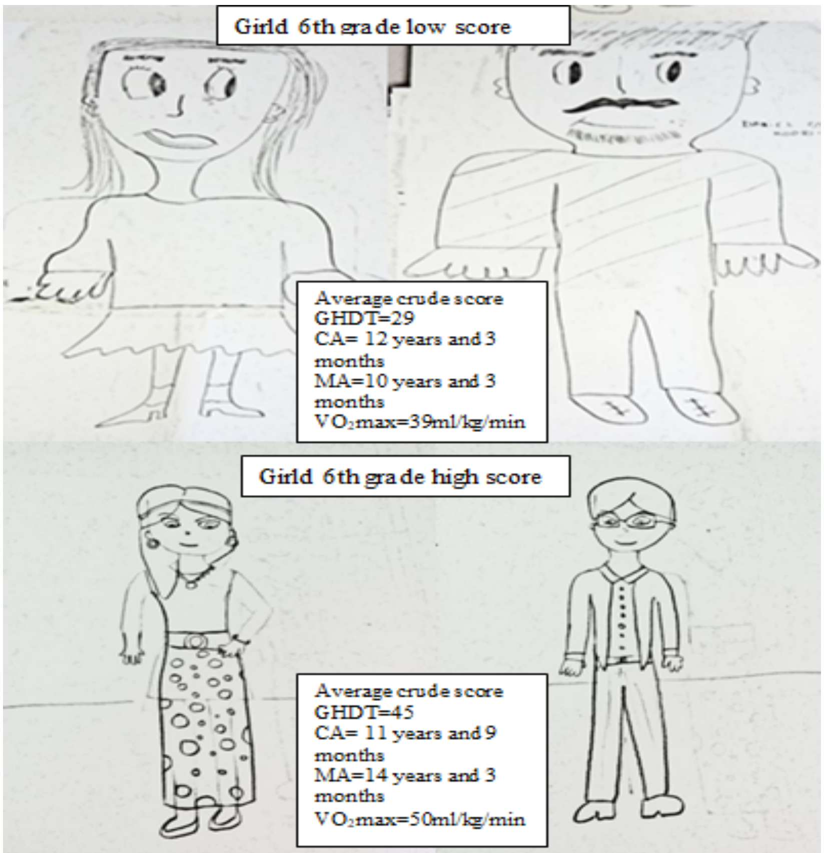

Figure 2. Drawings of girls in 6th grade of Primary Education

Note: Chronological age (CA); Mental age (MA); maximum oxygen consumption (VO2max)

Discussion

The purpose of this study was to analyse the relationship between intellectual maturity and cardiorespiratory resistance in children 10-12 years old. The main finding shows that children's intellectual maturity is associated with cardiorespiratory resistance. In addition, intellectual maturity is a predictor of academic performance.

In a similar study, Latorre et al. (2016) found significant associations between GHDT and physical fitness in preschool children; thus, from an early age, physical-motor performance and intellectual maturity are linked, being the physical fitness a good tool to determine it.

In turn, several authors have found an association between cognitive and motor development in children aged 5 to 12 years (Chaddock, Pontifex, Hillman & Kramer, 2011; Niederer et al., 2011). However, this relationship may be direct or may be affected by other factors, such as the influence of parents. Wassenberg et al. (2005) showed the parallel development of cognitive and motor-specific performance in children during normal or late development; some specific brain structures, such as the basal ganglia or frontal cortex and the transmission of dopamine, develop in parallel with some cognitive aspects. Niederer et al. (2011) found that increased cardiorespiratory fitness, motor skills and dynamic balance correspond with a better memory of spatial work and attention in school-age children. Additionally, Krombholz (2006, 2013) found positive correlations between the measures of physical growth and physical performance and between motor performance and cognitive performance, physical fitness, body coordination and manual dexterity in children, which improved with age.

On the other hand, BMI was negatively correlated with the GHDT and the cardiorespiratory fitness test. According to a study about nutritional status and intelligence quotient (IQ), a better nutritional status was associated with a higher IQ (Suvarna & Itagi, 2009). Likewise, Li et al. (2008) found that an increase in body weight is related to a reduction in the general mental ability in children. Gunstad et al. (2008) noted that high BMI is not associated with cognitive function in healthy children and adolescents. Likewise, Latorre et al. (2016) did not find a relationship between BMI and GHDT in preschool children. Therefore, the results are controversial and require more research to clarify the association between weight status and cognition in children.

According to Janssen et al. (2010), there are a myriad of not only physical but also cognitive benefits when children perform physical activity; therefore, policies that facilitate the realisation of physical activity for this population are needed. Chaddock et al. (2011) carried out a systematic review in which the importance of physical activity and cardiorespiratory capacity to maximise brain health and cognitive function during development was shown.

The pre-pubertal period offers many opportunities to stimulate cognitive function. However, the relationship between participation in PA and cognitive performance has been a subject of discussion between advocates and sceptics of physical activity, as well as parents concerned about decreases in study and homework time. Additionally, opportunities to be physically active at school are limited because of pressure to perform well academically (Mahar et al., 2006; O'Dwyer et al. 2013). However, participation in physical activity is not associated with less time dedicated to study (Jonatan R Ruiz et al., 2010). An additional curricular emphasis on PE may result in significant gains in cognitive performance. In this regard, the literature suggests that academic achievement, physical fitness and health of children will not be improved by limiting the time allocated to PE and physical activity (Trudeau & Shephard, 2008).

Academic performance and intellectual maturity have been linked according few research (Pérez, 1996; Berrios Aguayo, Latorre Román, & Pantoja Vallejo, 2017). Therefore, this is strength of our research as it demonstrates a little but relevant academic studied issue. If from an improvement of the cardiorespiratory resistance of the students their mental age is increased, this in turn would be making benefits in terms of academic performance.

A limitation of this study is its cross-sectional design, so caution should be exercised in interpreting the associations observed. More studies are needed to provide adequate evidence of causality through longitudinal records. Regarding the development of health in school, it is necessary to emphasise that there is a large connection between body growth, physical fitness and cognition. Therefore, increasing the amount of time spent in physical education can promote cognitive benefits and improve the health of school-age children.

In conclusion, from an early age cardiorespiratory endurance and mental age seem to be related. This link is a good training tool for cognitive development in children 10-12 years old.

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INJURY INCIDENCE IN SOCCER

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Abstract. Soccer is the most universally popular and the most widespread sport, which also means being one of the most II team sports. Injuries negatively affect the performance of the athlete and the team. The objective of this study was to know the injuries produced throughout the 2016/2017 of the Spanish first and second division depending on the type of injury, position of the player, the minute in which the injury happened, and the age of the player.
It is a descriptive study in which the sample was made up of the players of the 42 teams of the Santander League and Liga 123 of Spanish soccer. The most common injuries have been muscle injuries (>50%), increasing in Liga 123 up to 75% of the II. The athletes who suffered the most injuries were the defenders (>40%), while goalkeepers recorded the lowest II (<4%). This fact may be due to the shorter distance run at normal intensity and the distance run at high intensity. Athletes between the age of 21 and 29 suffered a higher number of injuries (>35%) and besides, they happened in large part during the second half of the game.

Keywords: soccer, injury, epidemiology.

INCIDENCIA LESIONAL EN EL FÚTBOL

Resumen. El fútbol es el deporte universalmente más popular y el más extendido, lo que implica, además, ser uno de los deportes de equipo con mayor IL. Las lesiones afectan de manera negativa al rendimiento del deportista y del equipo. El objetivo de este estudio fue conocer las lesiones producidas a lo largo de la temporada 2016/2017 de la primera y segunda división española en función del tipo de lesión, posición del jugador, minuto en que se produce la lesión y la edad del jugador. Se trata de un estudio descriptivo, en el cual la muestra fue conformada por los jugadores de los 42 equipos de la Liga Santander y la Liga 123 del fútbol español. Las lesiones más comunes han sido las lesiones musculares (>50%), aumentando en la Liga 123 hasta el 75% de la incidencia. Los deportistas que más lesiones sufrieron fueron los defensas (>40%) mientras que los porteros registraron el menor IL (<4%). Este hecho se puede deber a la menor distancia recorrida tanto a una intensidad normal como a la distancia recorrida a alta intensidad. Los deportistas comprendidos entre los 21 y los 29 años padecieron un mayor número de lesiones (>35%) y, además, ocurrieron en gran parte durante la segunda mitad del partido.

Palabras clave: fútbol, lesión, epidemiología.

Introduction

Soccer is universally the most popular and widespread sport in the world (Luthje et al., 1996; Inklaar, 1994). Soccer (association soccer) is a team sport that incorporates frequent fluctuations between high and low exercise intensities. These unpredictable changes may be accompanied by unorthodox movement patterns and the performance of specific skills that players do not perform in their daily lives (Barry, Atkinson, & Reilly, 2007). These unpredictable changes in game situations cause this sport to have a higher injury rate than other team sports, as seen in (Pascual, Pérez, and Calvo, 2008).

Injuries can negatively affect team performance. It could be observed in the Qatari soccer first division that clubs with a lower incidence of injuries showed a strong correlation with a better league position, higher number of wins, more goals scored as well as a better goal difference and total points (Eirale, Tol, Farooq, Smiley, and Chalabi, 2013). In addition, lower injury burden and higher match availability were associated with an increase in UEFA SCC (coefficient representing a team's performance in European competitions) as shown in Hägglund et al. (2013). There are several definitions of what an injury is in the literature. As stated by Eirale et al. (2017), the most commonly used definition in the elite soccer literature is the definition of "missed or missed time" injury, implying that the injury forces the athlete to miss at least one future training session or the next match. Its main limitation is that players can sometimes continue activity despite an injury. In addition, key players, those who play the most minutes throughout the season, may be forced to play and train despite an injury due to their impact on the team as seen in the study by Eirale et al. (2017).

The injury incidence (II) of professional soccer in training is estimated to be between 1.5-7.6 per 1000 hours of exposure, while II in competition is between 12-35 per 1000 hours of practice (Dvorak and Junge, 2000). Other studies, such as those by Ekstand, Waldén, and Hägglund (2004), and Ekstand, Hägglund, and Waldén (2011), show that II during competition is 5-10 times higher than injury II during training. The bulk of similar research places competition injuries at around 25-28 per 1000 hours of exposure (Noya Salces & Sillero Quintana, 2012). Muscle injuries are one of the main problems for soccer players, occupying 20-37% of all injuries at the male professional level and 18-23% at the male amateur level (Ekstrand, Martin, and Wallden, 2011).

The aim of this study is to know the injuries produced throughout the 2016/2017 season of the Spanish first and second division according to the type of injury (muscular type or not); position of the player (goalkeeper, defender, midfielder, and striker); minute in which the injury occurs (0-15, 15-30, 30-45, 45-60,60-75, and 75-90) and the age of the player (<=20, 21-25, 26-29, 30-32, >=33). Only injuries occurring in match situations were recorded. Finally, it should be noted that our hypotheses are as follows: the most abundant injuries are muscular, forwards are the most injured players, the last 15 minutes of each half are the most favorable for injuries to appear, and older players are more injured than younger players.

Method

This is a descriptive study, in which our sample is made up of the players of the 42 teams of the Liga Santander and Liga 123 of Spanish soccer during the 2016/2017 season. These data have been collected from the different official websites of the soccer teams and other websites, such as transfermarkt or resultados-fútbol, which compile great information of interest for our study. The independent variable of our study is injuries, while the dependent variables are the type of injury, the age and position of the injured player, and the minute in which the injury occurs.

Results

The sample amounted to a total of 1,222 players spread across the 42 teams, 20 from the First and 22 from the Second during the 2016-2017 season.

As for the type of injury, the total number of injuries in the First Division was 179, of which 95 were muscular (53.1%), while in the Second Division the total number of injuries was 170, of which 129 were muscular (75.5%).

Table 1
Number of injuries by position in First Division

	N = 179			
	Goalkeeper	Defense	Midfielder	Forward
No. Injuries (%)	7 (3,91%)	87 (48,6%)	47 (26,25%)	38 (21,22%)

Table 2
Number of injuries by position in the Second Division

	N = 170			
	Goalkeeper	Defense	Midfielder	Forward
No. Injuries (%)	4 (2,35%)	70 (41,1%)	48 (28,3%)	48 (28,3%)

With respect to the injuries recorded by specific position in the First Division, it was observed that defenders (87 injuries; 48.6%) are the players who are injured the most, while goalkeepers, on the other hand, are the ones who were injured the least (7 injuries; 3.91%).

In the Second Division and as in the First Division, defenders are the players who were injured the most (70 injuries; 41.1%) and goalkeepers the least (4 injuries; 2.35%).

Table 3
Number of injuries according to age range in the First Division

N = 592					
	≤ 20 years	21-25 years old	26-29 years old	30-32 years	≥ 33 years
No. Players (%)	70 (11,82%)	225 (28%)	175 (29,56%)	87 (14,67%)	35 (5,91%)
No. Injuries (%)	4 (2,23%)	68 (37,99%)	70 (39,11%)	27 (15,08%)	10 (5,59%)

Table 4
Number of injuries by age range in the second division

N = 592					
	≤ 20 years	21-25 years old	26-29 years old	30-32 years	≥ 33 years
No. Players (%)	66 (10,48%)	254 (40,32%)	147 (23,33%)	90 (14,29%)	73 (11,59%)
No. Injuries (%)	5 (2,94%)	61 (35,88%)	47 (27,65%)	35 (20,59%)	22 (12,94%)

The third variable analyzed total injuries as a function of the age of the athlete. They were grouped into <= 20 years, 21-25 years, 26-29 years, 30-32 years, >=33 years. In the first division, there were a total of 592 players, of which 70 players were within the <= 20 group (11.82% of the total players), 225 players in the 21-25 group (38%), 175 players in the 26-29 group (29.56%), 87 players in the 30-32 group (14.67%), and 35 players in the >= 33 group (5.91%). In the second division there were a total of 630 players, of which 66 players were within the <= 20 group (10.48% of the total number of players), 254 players in the 21- 25 group (40.32%), 147 players in the 26-29 group (23.33%), 90 players in the 30-32 group (14.29%), and 73 players in the >= 33 group (11.59%).

In the First Division, the 26-29 age group had the highest number of injuries (175 injuries; 29.56%), being the second age group with the second highest number of players (175 players; 29.56%), while the age group under or equal to 20 years old had the lowest number of injuries (4 injuries; 2.23%), being the fourth age group with the highest number of players (70 players; 11.82%).
In the Second Division, the 21-25 age group had the highest number of injuries (61 injuries; 35.88%), being the age group with the highest number of players (254 players; 40.32%), while the under 20 age group had the fewest injuries (5 injuries; 2.94%), being the age group with the lowest number of players (66 players; 10.48%).

Table 5
Number of injuries according to minutes of play in the First Division

N = 179						
	Part 1			Part 2		
	0-15	16-30	31-45	46-60	61-75	76-90
No. Injuries (%)	15 (9,49%)	26 (14,52%)	31 (17,32%)	39 (21,79%)	41 (22,9%)	25 (13,97%)

Table 6
Number of injuries according to minutes of play in the second division

	N = 170					
	Part 1			Part 2		
	0-15	16-30	31-45	46-60	61-75	76-90
No. Injuries (%)	13 (7,65%)	15 (8,82%)	34 (20%)	34 (20%)	35 (20,59%)	39 (22,94%)

In the First Division, the time period with the most injuries was between 61' and 75', with 41 injuries (22.90% of the total injuries), while the first 15 minutes of the first half was when the least number of injuries appeared (15 injuries; 9.49%). As for the Second Division, the period of time when the most injuries appeared was in the last 15 minutes of the second half with a total of 39 injuries (23% of the total number of injuries), while the first 15 minutes of the first half was when the least number of injuries appeared (13 injuries; 7.65%).

Discussion and conclusions

Soccer shows a higher II than the rest of sports, as shown by Stevenson, Hamer, Finch, Elliot, and Kresnow (2000), hence the aim of this study is to know the injuries produced throughout the 2016/2017 season of the Spanish first and second division according to the type of injury (muscular type or not); position of the player (goalkeeper, defender, midfielder, and forward); minute in which the injury occurs (0-15, 15-30, 30-45, 45-60,60-75 and 75-90), and the age of the player (<=20, 21-25, 26- 29, 30-32, >=33).

After analyzing the results, it can be seen that the most predominant type of injury in soccer, both in first and second division, are muscular injuries (Arnason et al., 2004; Leventer, Eek, Hofstetter, and Lames, 2016; Olmedilla Zafra et al., 2009; D. Hawkins and W. Fuller, 1999; Volpi, Melegati, Tornese, and Bandi, 2004 and (Hawkins, Hulse, Wilkinson, Hodson, and Gibson, 2001). Muscle injuries exceed 50% of those recorded in this work, these results being similar to those obtained by Noya Salces, and Sillero Quintana (2012) in the 2008-2009 season. The rate of muscle injuries continues to increase progressively year after year, while the II of other types of injuries is maintained over the years (Dauty and Collon, 2011).

Several studies show how the type of injury suffered by the athlete differs depending on the demarcation he/she occupies, as can be seen in (Ekstand, Waldén, and Hägglund 2004; Carling, Orhant, and LeGall 2010; Hawkins and Fuller 1996; Hodgson Phillips 2000; Faude, Meyer, Federspiel, and Kindermann 2009; and Ryynänen et al. 2013), while other studies claim the opposite (Morgan and Oberlander, 2001; Dauty and Collon, 2011; Dvorak and Junge, 2000; and Hawkins and Fuller, 1998). Attending to player demarcation, we note that in both Noya Salces and Sillero Quintana (2012), Andersen, Tenga, Engebretsen, and Bahr (2004), midfielders and forwards, and Carling, Orhant, and LeGall (2010), Price, Hawkins, Hulse, and Hodson (2004), Ryynänen et al. (2013) are athletes who have a high II, in contradiction to Morgan and Oberlander (2001), where forwards do not suffer too many injuries.

Regarding our study, the results we have obtained have been that the position that suffers more injuries are the defenders, a result that we can contrast in Hawkins and Fuller (1996), Hawkins and Fuller (1999), and Peterson, Junge, Chomiak, Graf-Baumann, and

Dvorak (2000), so we can say that if we attend to the injuries according to the position that occupies a soccer player on the field there are discrepant results. Where there is total agreement is in stating that the position with fewer injuries is the goalkeeper (Ryynänen et al., 2013) (Faude, Meyer, Federspiel, and Kindermann, 2009).

With regard to injuries depending on the age of the soccer player, there is little literature. Majewski, Susanne, and Klaus (2006) study in their case the knee injuries during 10 years of a large number of athletes of different modalities and show how the athletes between 20 and 29 years of age are the ones who suffered the most injuries, almost doubling in number the next age range, which includes athletes between 30 and 40 years of age. Although this study does not focus solely on soccer, it coincides exactly with the results of our study, where athletes aged 21 to 25 years and 26 to 29 years are those who suffer more injuries, as in Stevenson, Hamer, Finch, Elliot, and Kresnow (2000), where it is found that athletes between 26 and 30 years have a higher II. Morgan and Oberlander (2001) analyzed the influence of different variables in the MLS, including age, reaching the conclusion that the age of the athlete is not a determinant in terms of injury incidence, adding that it is also not a determinant for the severity of the injury.

Regarding the minute in which the injury occurs, we can observe that in the Spanish first division during the 2016/2017 season the time period in which a greater number of injuries occur is between minutes 61 and 75 followed by the period between 46 and 60, so it is in the second half where the greatest number of injuries occur (Dvorak, Junge, & Derman, 2011). This agrees with the studies of Hawkins, Hulse, Wilkinson, Hodson, and Gibson (2001) and D. Hawkins and W. Fuller (1999) where a higher frequency of injuries was observed during the last 15 minutes of the first half, seen in Dvorak, Junge, and Grimm (2007) and the last 30 minutes of the second half. With respect to the data from our study on the Spanish second division, where the period of time in which more injuries appear is in the last 15 minutes of each half, we do see that there is a concordance with the rest of the literature, as shown by Junge, Dvorak, and Graf-Baumann (2004). There is strong agreement across the literature, as in Sul Yoon, Chai, and Won Shin (2004), Junge, Dvorak, and Graf-Baumann (2004), Hawkins, Hulse, Wilkinson, Hodson, and Gibson (2001), and D. Hawkins and W. Fuller (1999) that fewer injuries occur in the first 15 minutes of play than during the rest of the game. With respect to the type of injury and according to the results obtained in our study, we can conclude that the most common injuries in the first and second division during the 2016/2017 season have been muscle injuries, being higher in the second division than in the first division.

If we talk about the position of the players on the field, we conclude that the players who suffered the most injuries during the 2016/2017 season in first and second division were the defenders, followed by midfielders and forwards, and in last place the goalkeepers, which are well below the rest. Regarding the age of the footballers, we deduce that the age ranges where there is a higher number of injuries were 21-25 years old and 26-29 years old, which are also the ones that encompass a higher number of players compared to the rest of the ranges.

Finally, if we talk about the minute in which the injury occurs, we have come to the conclusion that in the Spanish first division during the 2016/2017 season the period of time with more injuries was between 61' and 75', followed by 46'-60', while in the second division they were in the last fifteen minutes of each part.

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