Original article

Isokinetic strength and vertical jump test in acrobatic skydivers

Ignacio Martínez González-Moro, Rocío Navalón Alcañiz, María José Paredes Ruiz, José L. Lomas Albaladejo, Vicente Ferrer López

Grupo de Investigación Ejercicio Físico y Rendimiento Humano. Universidad de Murcia.

Received: 03.01.2018
Accepted: 07.03.2018

Summary

Introduction: Knees of the parachutists can suffer injuries during the landing that can be avoided with a correct muscular strength. This strength is posible to be evaluated of direct way with isokinetic dynanometers and indirect methods using the test of vertical jump.
Objective: The aim of this study was to determine and analyze, in professional skydivers, the relationship between the values of isokinetic force of quadriceps and hamstrings with height and time of flight in vertical jumps.
Material and method: We studied the fourteen paratroopers belonging to the (patrol acrobatic jumper of the air force) using an isokinetic dynamometer (60°/s and 180°/s) both for concentric work as eccentric, obtaining the peaks maximum of strength and hamstrings/quadriceps ratios. Evaluate, on a platform of contact, the following vertical jumps: Abalakov Jump and Squat Jump, Counter Movement Jump.
Results: The results indicate that the peaks of maximum strength of flexor and extensor muscles of the knee are greater in eccentric mode, and the men's team. Hamstrings/quadriceps ratios show a predominance of the first. AJ is the jump where greater height and time of flight is achieved. There is a positive correlation between the flight time of all jumps and concentric quadriceps strength. The height of jump by body weight (Work = Kg x m) correlates with the peaks of concentric and eccentric strength of the quadriceps. The ratio is higher in the higher speed. The eccentric strength of hamstrings does not correlate with the height of flight, but the concentric strength.
Conclusions: We can conclude that the knees of the skydivers have a predominance of the hamstrings what is considered positive for the activity carried out, since it helps to improve the stability of the knee and that there are high correlations between the peaks of force isokinetic and the work done in the jumps vertical.

Key words:
Isokinetic dynamometry. Vertical jump. Peak force. Hamstrings/quadriceps ratio. Skydivers.

Fuerza isocinética y test de salto vertical en paracaidistas acrobáticos

Resumen

Introducción: Las rodillas de los paracaidistas pueden sufrir lesiones durante la toma de tierra que se pueden prevenir con una adecuada fuerza muscular. Esta fuerza se puede evaluar de manera directa con dinamómetros isocinéticos y con métodos indirectos mediante el test de salto vertical.
Objetivo: El objetivo del estudio fue determinar y analizar, en paracaidistas profesionales, las relaciones entre los valores fuerza isocinética máxima de cuádriceps e isquiosurales con la altura y el tiempo de vuelo en saltos verticales.
Material y método: Valoramos a los catorce paracaidistas pertenecientes a la Patrulla Acrobática Paracaidista del Ejército del Aire mediante un dinamómetro isocinético (a 60º/s y 180º/s) tanto para el trabajo concéntrico como excéntrico, obteniéndose los picos máximos de fuerza y las ratios isquiosurales/cuádriceps. Evaluamos, sobre una plataforma de contacto, los siguientes saltos verticales: *Squat Jump, Counter Movement Jump* y *Abalakov Jump*.
Resultados: Los resultados indican que los picos de fuerza máxima de la musculatura flexo-extensora de la rodilla son mayores en modalidad excéntrica, y en el equipo masculino. Las ratios isquiosurales/cuádriceps muestran un predominio de los primeros. *Abalakov Jump* es el salto donde mayor altura y tiempo de vuelo se consigue. Existe una correlación positiva entre el tiempo de vuelo de todos los saltos y la fuerza concéntrica del cuádriceps. La altura de salto por el peso corporal (Trabajo = Kg x m) se correlaciona con los picos de fuerza concéntrica y excéntrica del cuádriceps. La relación es mayor en la velocidad más alta. La fuerza excéntrica de isquiosurales no se correlaciona con la altura de vuelo, pero sí la fuerza concéntrica.
Conclusiones: Podemos concluir que las rodillas de los paracaidistas presentan un predominio en la fuerza de los isquiosurales, lo que se considera positivo para la actividad que realizan ya que contribuye a mejorar la estabilidad de la rodilla y que hay altas correlaciones entre los picos de fuerza isocinético y el trabajo realizado en los saltos verticales.

Palabras clave:
Dinamometría isocinética. Salto vertical. Pico de fuerza. Ratio isquiosurales/cuádriceps. Paracaidistas.

Correspondence: Ignacio Martínez González-Moro
E-mail: ignaciomgm@um.es

Introduction

Skydiving is a physical-sporting activity prone to causing both acute and chronic injuries[2]. Recent studies suggest that injuries to the lower limbs are the most frequent, making up 65% of total injuries[3], and within this region knee joint injuries are particularly noteworthy.

Just as in other sports, acute injuries are caused by trauma or sporting accidents; whilst chronic injuries - or overload – are linked to diverse aetiological factors, including abnormal anatomical alignment[4], reduced strength in the hip or thigh muscles[5,6], or faulty mechanism in the lower extremities whilst undertaking specific activities[7].

Identifying and correcting imbalances in lower extremity muscle strength is one of the key components in preventing and treating sporting injuries[8]. To do this, this strength must be quantified and measured using dynamometers and specific protocols. As it is not always possible to measure the muscle strength generated during sporting activity in real situations, these tests are often carried out under controlled laboratory conditions[9]. Of all the different demonstrations of strength, the most frequently used ones for assessing athletes are explosive strength and isokinetic strength. Explosive strength can be assessed using a test and with sporting apparatus, such as the vertical jump on specific platforms[10], whilst isokinetic strength can be measured using functional assessment devices such as specific dynamometres[11].

The isokinetic method is an assessment system that uses information and robotised technology to obtain and process muscle strength in quantitative data, obtaining its maximum values in the entire range of movement and establishing the position in which the strength peak is obtained[12]. This enables it to be measured in both concentric and eccentric activation, and comparisons can be established[13]. The advantage over other methods is the possibility of objectively assessing the dynamic qualities of the muscle group responsible for the movement of a particular joint. It can be applied in fields such as rehabilitation[14], muscle training[15] and biomechanical analysis[16].

Explosive strength as a motor skill, is one of the determining factors in the success of all activities that require high muscle strength expression as quickly as possible, playing a vital role in a wide range of sports linked to jumps and propulsion, which is why it forms part of training in almost all modalities[17]. A very common way of quantifying it is using the well-known jump tests. The first jump tests, which are still used today, were performed without platforms, such as the "Détente Vertical"[18] or the "Sargent test"[19], which reveal the benefits of using the arms whilst jumping. Today, jump and/or strength platforms are used with tests, based on and adapted to Bosco systems, such as the Squat Jump, the Counter Movement Jump and the Drop Jump[20].

Tests based on the vertical jump aim to assess the functional and neuromuscular characteristics of the extensor muscles of the lower limbs depending on the heights obtained in the various tests. These are strictly standardised maximum tests and two phases can be seen: eccentric and concentric[21,22]. Assessing strength and strength training using vertical jumps is known as plyometry[23]. The biomechanical parameters of the lower limbs are the factors that determine the height of the jump, including the use of elastic energy, the shortening cycle, muscle contraction speed and power[24,25].

The landing in manual release-chute skydiving, and more specifically in the sport, is performed standing, with the skydiver taking more or less quick steps from the moment he/she touches the floor until complete standstill (Figure 1). This instant is particularly stressful for the knees as it combines the effect of the forces of action (weight of the skydiver) and reaction (contact with the ground), with the run to stop the movement, on a possibly irregular surface, as well as the likely rotation due to the traction of the parachute in the wind current. Furthermore, in the "precision jump" modality, the skydiver's feet must make contact with a specific point marked on a mat. This leads the skydiver to prioritise precision over stability to achieve the highest score, which leads to awkward contact positions with the consequent risk of injury (Figure 2). At this point the skydiver makes a quadriceps contraction to maintain his/her position and to avoid falling, which causes knee extension and a tendency to displace the tibia over the femur, stretching the anterior cruciate ligament (ACL). The sum of all these elements entails risk factors for ACL injury, which can be controlled using proprioception and muscle strength training, paying particular attention to the muscle balance between quadriceps and the hamstring muscles[26].

Most skydiving injuries occur upon landing[27], which is why the more jumps performed, the greater the possibility of injury. One of the groups to perform the most jumps in Spanish skydiving is the Acrobatic Parachuting Patrol of the Spanish Air Force (PAPEA). Its main activities

Figure 1. Running landing.

Figure 2. Standing landing in a precision jump.

are acrobatic exhibitions and sporting competition in representation of the Air Force. Given their specific training, these skydivers perform 4-5 jumps each day and each skydiver accumulates thousands of jumps. This large number of jumps means that their knees are at a high risk of injury, especially the anterior cruciate ligament, which is why studies and injury prevention activities should be carried out[28].

The publication of results regarding the assessment of knee strength using different techniques is increasingly widespread, and the diversity of methods used makes it difficult to compare findings in terms of strength peaks and their possible application as predictors of sporting or motor skills[29-31], which is why we consider it to be particularly interesting to see the relationships between both measurements.

As such, our aim is to establish and analyse the isokinetic strength parameters of the flexor-extensor muscles of the knee involved in injury prevention among teams of professional acrobatic skydivers, and the relationship between height and the time spent in flight in different vertical jumps.

Material and method

Participants

In this study, all the members of the PAPEA were analysed: nine males and five females, comprising the male and female teams. Exclusion criteria included the presence of an acute injury or discomfort to the lower limb, which impeded the development of maximum strength during the tests. The military authorities granted permission, and the Research Ethics Commission of the University of Murcia gave approval.

Procedure

Our study is descriptive, transverse and observational.

All the subjects were informed about the study objectives and method and they all signed the corresponding informed consent document. After accepting the conditions, an anamnesis was carried out, in which subjects gave information about any previous injuries, personal data (age) and information about their skydiving experience.

The isokinetic dynamometer used was the Chattanooga KIN-COM AP, with the software provided by the manufacturer to calculate the strength peak, both in concentric and eccentric contractions. The dynamometer allows a maximum strength peak of 2000 Newton and a maximum speed of 250º/s.

To assess the vertical jump, the GLOBUS Ergojump contact platform was used. This apparatus works like a stopwatch, which is activated when the athlete, with both feet positioned on the platform, jumps up, and which stops when the subject lands back on the platform. It measures the flight time of the jump and immediately calculates the equivalent height of the jump.

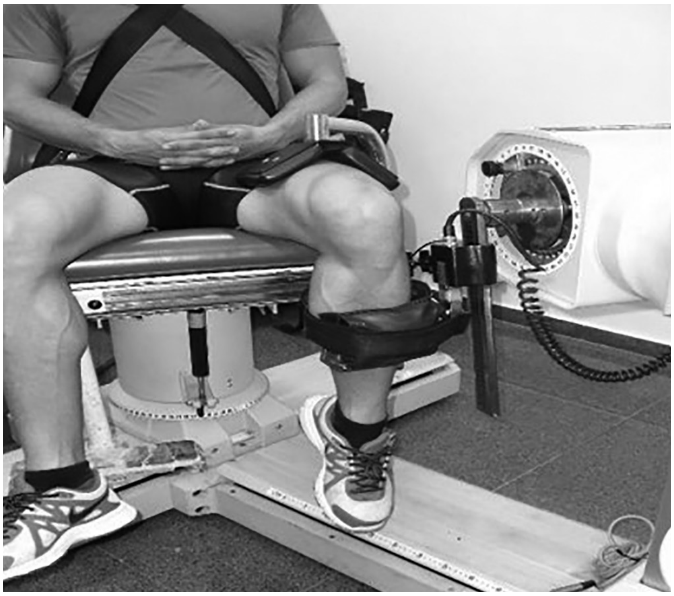
Before performing the tests, a quantitative measurement was made of height and weight using the SECA 813 weighing scale and the SECA 213 height measuring device. After a five-minute warm up on a cycle ergometer, the isokinetic assessment was carried out following the protocol used by our group[32]. A week later, to avoid the effects of fatigue, three jumps were performed, detailed in the Bosco protocol on a contact platform: Squat Jump (SJ), Counter Movement Jump (CMJ) and the Abalakov Jump (AJ).

Assessment and isokinetic variables

Both extremities were analysed with the subject in seated position. The order for carrying out the test was random, depending on the initial provision of the machine. The subjects were attached to the seat and to the backrest of examination seat the using adjustable straps. The thigh was kept next to the seat using a suitable support. The arm rotation axis of the dynamometer was positioned laterally to the external femoral epicondyle, and the mobile end was attached to the middle part of the leg, 22 cm from the rotation axis (Figure 3). The muscle groups examined were the quadriceps and hamstrings using both concentric and eccentric flexor-extensor movements of the knee. The range of motion was between 80º and 10º of knee flex (0º = complete extension), and the speeds of 60º/s and 180º/s were examined. The type of register used is called "overlay" or contraction to contraction. Valid movements are considered to be those in which the greatest strength is achieved (with a minimum of three maximum attempts), requesting sub-maximum efforts to reach the greatest possible, by following the strength/angular position curves.

The isokinetic variables have been described for the dominant (D) and non-dominant (ND) sides, both for the quadriceps (Q) and the hamstrings (H), the speed (60º/s and 180º/s) and the strength peaks in concentric (con) and eccentric (ecc) modality of the assessed limb. The conventional quotients - or ratios - were obtained by dividing the concentric strength of the hamstrings by that of the quadriceps (Hcon/Qcon), and the functional ratios were obtained the same way but using the eccentric strength of the hamstrings (Hecc/Qcon)[33].

Figure 3. Position for the isokinetic assessment.



Execution and assessment of the vertical jumps

The following jumps were carried out: Squat Jump, Counter Movement Jump, and Abalakov Jump. SJ consists in jumping from a 90º knee-flex, avoiding a countermovement so as not to accumulate elastic energy. The trunk must be straight and hands positioned on the hips during the test. During the flight phase the legs must be extended, and when the feet come back into contact with the platform the first point of contact must be the metatarsal and then the back part, the calcaneal. The CMJ is performed the same way as the SJ, but with the subject starting from an upright position, so that during the eccentric phase to reach a 90º knee-flex, the potential elastic energy is stored in the spring elements in series, enabling them to be reused as mechanical work during the concentric phase. The Abalakov Jump (AJ) is performed the same way as the CMJ but with the upper limbs released to be used in coordination and synchronisation with the flexor-extension action of the legs to achieve maximum flight.

To establish the plyometric variables, the time (T) and flight height (H) must be considered in each of the jumps. The work has been obtained from the product between the weight of the subject and the height achieved.

Statistical analysis of the data

With the data obtained, an Excel sheet was drawn up in which each line is a subject (case) and each column is a variable. From here, the data was exported to an SPSS v.19 statistics package. The quantitative variables were described using minimum and maximum values (range), average, typical deviation, and variation coefficient. The qualitative variables were described using absolute and relative frequencies (percentages). The normal distribution of the initial characteristics of the sample was checked using the Saphiro-Wilk test, and the equality of the variances using the Levene test. The comparison of averages for independent variables was performed using the T-student test. The comparison of the averages of related variables was performed using the T-paired study. The correlation between variables was established using the Pearson test. Statistical significance was considered to be present when $p \leq 0.05$.

Results

The average age of participants is 34.4 years for the male team and 35 for the female team. The anthropometric characteristics and skydiving experience are displayed in Table 1, separated by team. Significant differences ($p \leq 0.05$) can be seen in all the variables apart from age.

The results of the isokinetic assessment of the strength peaks of the quadriceps and hamstrings are displayed in Table 2, in concentric and eccentric modality, at the speeds of 60º/s and 180º/s separated by sex. It is worth noting that strength in eccentric modality exceeds that of concentric, for the two speeds assessed and for both teams. In all the strength pairs there is significant difference between men and women ($p \leq 0.05$), with higher figures displayed in the male teams. There are no bilateral differences. The ratios between the hamstrings and the

Table 1. Anthropometric variables and skydiving experience of each team.

	Male Team (n=9)		Female Team (n=5)	
	$\bar{X} \pm \sigma$	Mín – Máx	$\bar{X} \pm \sigma$	Mín – Máx
Age (years)	34.44 ± 4.36	29-41	35 ± 2.64	32-39
Height (cm)	173.6 ± 6.73	162.5-182	158.3 ± 6.135	152.4-168.5
Weight (Kg)	77.18 ± 7.45	65-87	55.8 ± 5.917	48.6-64.7
BMI (Kg/m^2)	25.61 ± 1.93	23.3-28.4	22.24 ± 1.702	19.3-23.7
Fat percentage	20.48 ± 3.92	14-26.2	27.18 ± 2.40	24.5-30.3
Years in PAPEA	8.55 ± 5.59	3-20	5.6 ± 2.88	2-8
No. jumps	3944 ± 2781	1200-10000	2060 ± 1212	600-3200

$\bar{X} \pm \sigma$: Average and typical deviation; Min: minimum; Max: Maximum.

Table 2. Comparison of the isokinetic strength peaks (Newtons) of the quadriceps and hamstrings and conventional and functional ratios between teams and sides.

Speed	Team	Dominant Side		Non-Dominant Side		P
		$\bar{X} \pm \sigma$	p	$\bar{X} \pm \sigma$	p	
Q 60º/s con	Male	763.22 ± 135.91	0.002**	760.77 ± 159.28	0.003**	0.965
	Female	501.2 ± 105.19		478.33 ± 181.58		0.215
Q 60º/s ecc	Male	1232.77 ± 245.28	0.009**	1048.44 ± 167.6	0.02*	0.035*
	Female	862.8 ± 141.27		804.66 ± 276.92		0.280
Q 180º/s con	Male	616.88 ± 89.61	0.0001***	592.22 ± 159.78	0.018*	0.601
	Female	364.2 ± 66.61		396.66 ± 57.36		0.866
Q 180º/s ecc	Male Male	1186.66 ± 203.04	0.026*	1273.33 ± 177.85	0.003**	0.194
	Female	885.8 ± 185.53		862 ± 267.3		0.358
H 60º/s con	Male	604.33 ± 124.27	0.001**	589.22 ± 116.06	0.033*	0.653
	Female	392 ± 35.34		423 ± 90.94		0.375
H 60º/s ecc	Male	741.44 ± 146.81	0.002**	802.22 ± 141.26	0.020*	0.281
	Female	520.2 ± 63.2		566 ± 123.66		0.343
H 180º/s con	Male	536 ± 128.61	0.015*	540.66 ± 48.07	0.001**	0.914
	Female	353 ± 83.67		427.33 ± 44.63		0.442
H 180º/s ecc	Male	735.87 ± 165.16	0.004**	799 ± 115.58	0.008**	0.105
	Female	494.2 ± 28.14		587.33 ± 145.52		0.376
60º/s Hcon/Qcon	Male	0.80 ± 0.16	0.956	0.78 ± 0.09	0.136	0.729
	Female	0.81 ± 0.19		0.96 ± 0.18		0.052
180º/s Hcon/Qcon	Male	0.88 ± 0.21	0.420	0.97 ± 0.27	0.508	0.375
	Female	0.98 ± 0.25		1.06 ± 0.05		0.272
60º/s Hecc/Qcon	Male	0.98 ± 0.17	0.441	1.09 ± 0.26	0.196	0.182
	Female	1.07 ± 0.28		1.31 ± 0.25		0.088
180º/s Hecc/Qcon	Male	1.17 ± 0.28	0.189	1.45 ± 0.23	0.863	0.089
	Female	1.38 ± 0.24		1.50 ± 0.16		0.306

Q = Quadriceps; H = Hamstrings. con = Concentric; ecc Eccentric; X: Average deviation; σ: Typical deviation; Maximum. Statistical significance: * p ≤ 0.05; ** p ≤0.01; *** p<0.001

quadriceps reveal a predominance of the hamstrings, with conventional ratio values exceeding 0.80 and functional ratios greater than 1.

Table 3 displays the average values of time and flight height in the three jump modalities, separated by sex. Slightly higher values can be observed in all the jumps for the male team, though significant differences were only found in the SJ. As foreseen, AJ is the jump in which the greatest height and flight time is achieve in both teams.

To analyse the relationship between the flight times in each jump and the strength peaks, the values from both sides have been added together and have been correlated to the seconds of flight. As such, a positive and significant correlation is only obtained for the quadriceps at 180º/s with the flight time of males in the three jumps: SJ r=0.738 (p=0.023); CMJ r=0.873 (p=0.002) and AJ r=0.910 (p=0.001). Upon analysing the demographic as a whole, we can see that there is a positive correlation between the flight time in all the jumps and the concentric strength of the quadriceps, being the most significant at 180º/s. Upon correlating the jump height to body weight (Work = Kg x m) with the strength peaks, a positive correlation is obtained with the concentric and eccentric strength peaks of the quadriceps, also higher at the highest speeds. The strength peaks of the hamstrings are positively related in its concentric form with the three jumps, but not in its eccentric form (Table 4).

Discussion

We have assessed the isokinetic strength of the quadriceps and the hamstrings both concentrically and eccentrically in all members of the PAPEA – an elite group of international skydivers. Their strength and power in vertical jumps has also been quantified using three tests. There are no studies that describe this kind of strength in skydivers, and few that relate both modalities in other sporting modes. In 2002, Tsionakos *et al*[34], performed a study on young physical education students, and

Table 3. Times (s) and flight height (m), by teams in vertical jumps.

	Male team			Female team			*p*
	$\bar{X} \pm \sigma$	cv	Mín – Máx	$\bar{X} \pm \sigma$	cv	Mín – Máx	
SJ (s)	0.5 ± 0.05	9.79	0.45-0.5	0.44 ± 0.03	7.62	0.39-0.48	0.041*
SJ (m)	0.31 ± 0.06	20.04	0.25-0.31	0.24 ± 0.04	15.16	0.19-0.29	0.048*
CMJ (s)	0.52 ± 0.04	8.28	0.45-0.52	0.47 ± 0.04	8.19	0.41-0.51	0.051
CMJ (m)	0.33 ± 0.05	16.46	0.25-0.33	0.28 ± 0.05	16.95	0.21-0.32	0.103
Abalakov (s)	0.57 ± 0.06	10.01	0.48-0.57	0.52 ± 0.03	6.63	0.48-0.57	0.132
Abalakov (m)	0.4 ± 0.08	20.06	0.29-0.4	0.34 ± 0.04	13.22	0.28-0.4	0.13

$\bar{X}$: Average deviation; σ: Typical deviation; cv: Variation coefficient; Min: Minimum; Max: Maximum; SJ: Squat Jump; CMJ: Counter Movement Jump; Statistical significance: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Table 4. Pearson's correlation and significance (p) between the time in the air (s) and the work performed in the vertical jumps (Kg x m) with quadriceps and hamstring strength peaks at both speeds.

	Quadriceps		Hamstrings	
60º/s	**Concentric**	**Eccentric**	**Concentric**	**Eccentric**
SJ (s)	0.568 (0.034)*	0.557 (0.038)*	0.418 (0.155)	0.301 (0.318)
SJ (Kg x m)	0.731 (0.006)**	0.689 (0.006)	0.576 (0.039)*	0.499 (0.083)
CMJ (s)	0.611 (0.020)*	0.470 (0.090)	0.428 (0.144)	0.289 (0.338)
CMJ (Kg x m)	0.786 (0.001)**	0.658 (0.011)	0.597 (0.031)*	0.518 (0.070)
AJ (s)	0.616 (0.019)*	0.478 (0.084)	0.500 (0.082)	0.352 (0.238)
AJ (Kg x m)	0.767 (0.001)**	0.660 (00.10)	0.633 (0.020)*	0.545 (0.054)
180º/s				
SJ (s)	0.781 (0.002)**	0.541 (0.056)	0.513 (0.073)	0.361 (0.225)
SJ (Kg x m)	0.912 (0.000)***	0.717 (0.006)**	0.684 (0.010)*	0.474 (0.102)
CMJ (s)	0.774 (0.002)**	0.487 (0.092)	0.462 (0.112)	0.233 (0.444)
CMJ (Kg x m)	0.920 (0.000)***	0.737 (0.004)**	0.684 (0.010)*	0.436 (0.137)
AJ (s)	0.835 (0.000)***	0.636 (0.020)*	0.462 (0.112)	0.318 (0.289)
AJ (Kg x m)	0.944 (0.000)***	0.774 (0.002)**	0.682 (0.010)*	0.465 (0.109)

Statistical significance: *$p \leq 0.05$; ** $p \leq 0.01$; ***$p \leq 0.001$

like us, they discovered a solid relationship between the isokinetic strength of the quadriceps and that obtained in the jump, especially when it was calculated depending on body weight (work). They only used concentric values, whilst we also discovered this with eccentric values. This relationship has also been described in young football players by Lehnert *et al*[13], but indications show that it differs throughout the season and is higher at greater speeds.

The average age of our demographic is higher than that of the majority of studies published about athletes, which generally oscillates between 16[13] and 27[35] years of age. This is because skydiving is a sport that is performed at adulthood, and there are no junior categories. As the female and male teams belong to the same military unit, and as they follow the same training routine, the effects of training can be compared and the same physical preparation principles can be adopted.

Isokinetic strength has been measured at both extremities, looking for differences or asymmetries. We did not find any in either team. Likewise, González-Ravé *et al*[35], with a study of handball players, also failed to find any significant differences between the dominant and non-dominant side, whilst Menzel *et al*[36] do describe differences. Although the majority of authors prefer to use the "the moment" or torque as the physical magnitude to assess isokinetic strength, we preferred to use "strength" as we have used a constant distance between the point of application of strength and the axis of the joint, which is why this factor does not have an influence when calculating the ratios and the differences, and what truly makes a difference in the muscles is the strength used, regardless of where it is executed.

In alignment with Alemdaroğlu[37], we have used two speeds for the isokinetic assessment – 60º/s and 180º/s – and a jump test for anaerobic power, finding that the strength values at the high speed are lower than at the low speed, though this author did not find any relationship with the jump height, whereas we did find one.

We have proven, just like other authors, that eccentric strength exceeds concentric strength in all cases, and including its determination in assessing the knee, it allows us to obtain useful information to understand its development and function[38], and to calculate functional ratios[33]; in other words, the relationship between the maximum concentric strength of the quadriceps to maintain a standing position, and that of the hamstrings in eccentric movement to slow down the hyperextension movement and the anterior displacement of the tibia.

Using hamstring/quadriceps ratios we observe that there is a predominance of the hamstrings over the quadriceps, which indicates that the knees, especially the anterior cruciate ligament (ACL) are protected as the agonist action of this muscle with the ACL[33] prevails over the activity of the quadriceps and avoids the distension of the ACL with the rapid displacement of the tibia over the femur upon landing and possible breakage. The individual study of each skydiver using these ratios enables us to customise their physical preparation, focusing on preventing injuries caused by landing and the predisposing factor of muscle imbalance[39]. Having powerful hamstrings in eccentric mode contributes to slowing down this displacement and protects the ligament[26].

We only carried out a bilateral assessment of the vertical jump, whereas Laudner *et al*[40] also performed a unilateral assessment, which is why we have added the isokinetic strength of both extremities to correlate it with the flight heights. According to studies, the most used jumps to carry out plyometric assessment and to establish a posterior correlation with the isokinetic measurement, are the CMJ[36,40,41], and the SJ[34,36,37]. Of all the studies consulted, we only found one that used the Abalakov Jump as we did, which was used alongside the CMJ[35]. We did not find any studies in which all three jumps were compared with the isokinetic measurement. We believe that analysing the three is of particular interest when verifying the influence of elastic energy accumulation during the jump, as well as the collaboration of the upper body, as these are determining factors in most sporting movements. Other authors use the Drop Jump from different heights, allowing the muscles to act depending on the shorten-stretch cycle[41].

In our study we have assessed and compared both concentric and eccentric work, and the relationship between this and the vertical jump, in contrary to most authors consulted, who have only related the vertical jump to concentric strength[35-37] or to isometric stength[42]. Following the Bosco concept[20], we believe that it is more interesting to also study eccentric work because via the reflex activated by the eccentric phase, a reinforced innervation is obtained which can strengthen the elastic characteristics of the muscle-tendon system and lead to a more important activation of the concentric phase. This can generate greater levels of strength than an isolated concentric contraction[43]. Furthermore, it is the eccentric strength of the hamstrings that is taken into account to calculate the functional ratio related to the balance of the knee and ACL protection[33].

The highest strength peaks were obtained during eccentric work on both teams. As foreseen, our data reveals that males generate more isokinetic strength than women in all modalities, a fact analysed many times with similar outcomes in previous studies[36,40,44]. On the contrary, the only jump test in which the males jump higher than women is the SJ, in the others there are no significant differences. This may be due to the fact that having to overcome the resistance of body weight relativizes the strength exercised by the extremities. Upon analysing the work and multiplying height by weight, the differences between men and women reappear.

We found higher correlations in eccentric work at 180º/s than at 60º/s. These correlations are clearer between the eccentric isokinetic strength of the quadriceps and the work performed in the vertical jump than with the flight height. Wilheim *et al*[41] refer to a correlation of height in the CMJ with the strength of the quadriceps of $r=0.513$, $p<0.001$, similar to our findings ($r=0.659$, $p=0.010$).

All the jump modalities analysed maintain a high correlation with the strength peak of the quadriceps. The highest relationship that we found is between concentric strength at the speed of 180º/s and the work of the CMJ and AJ ($r>0.9$ $p<0.001$). This data coincides with that found by Lehnert *et al*[13], who also indicate that the maximum relationship is established at higher angular speeds, specifically at 180º/s for the CMJ and at 180º/s and 360º/s for the AJ. These two jump modalities were also related to isokinetic strength by Alemdaroğlu[37], who found a significant correlation with the same angular speeds as in our study.

With regards to the work of the hamstring muscles, our data reflects a relationship between the strength peak in concentric mode and the three jumps, but expressed in the form of work (height achieved by body weight) and not just upon analysing the flight time, the correlation is also greater at the highest isokinetic speed. In vertical jumps the activity of the hamstring muscles can be considered as secondary, as the main action falls upon the quadriceps. The presence of these correlations reflects the importance of preventive work of knee flexors to maintain the muscular balance of the knees and to contribute to protecting the anterior cruciate ligament.

The relationship between both types of test is considered useful for assessing strength and functional capacity in subjects with anterior cruciate ligament injuries[40], and can be useful for rehabilitation follow-up. We would add that this would be more useful if there were values available taken prior to the injury that reveal the presence of asymmetries between antagonist muscles and between sides.

Overall, the data from our demographic coincides with those referenced, indicating that the maximum strength peaks of the knee muscles present higher values in the eccentric modality than in the concentric modality in both muscle groups, and that they are greater in the male team. The influence of upper body participation and accumulated elastic energy significantly affect the height and time achieved in the different jumps. We can also affirm that the correlation between the characteristics of isokinetic strength on the knee with the vertical jump performance is higher between the strength peaks of the extensors during the concentric work at a faster speed.

On the other hand, a significant relationship has not been objectified in any of the parameters corresponding to the vertical jump test with the eccentric strength of the hamstrings, on any team or at any speed. For this reason, the jump tests cannot substitute isokinetic assessment in the determination of ACL injury risk factors, though they are useful for displaying the strength of the quadriceps among skydivers.

For all the above, we conclude that skydivers' knees reveal a predominance in hamstring strength, which is considered positive for the activity they undertake, as it improves the stability of the knee and can help prevent ACL injuries. The isokinetic strength of the hamstrings in eccentric modality has no correlation with the work carried out in vertical jumps, whilst the concentric and eccentric strength of the quadriceps and the concentric strength of the hamstrings do correlate.

Acknowledgements

To PAPEA, the Air Army Acrobatic Skydiving Patrol.

Conflict of interests

The authors claim to have no conflict of interests whatsoever.

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