EVALUATION OF THE LEVEL OF PHYSICAL ACTIVITY THROUGH MUSCULO-ARTICULAR STIFFNESS IN YOUNG ADULTS

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ABSTRACT

The purpose of the study is to evaluate the level of physical activity of young adults by means of the Musculo-articular stiffness and to analyse its correlation with the physical performance measured in jump capacity. The proposed protocol includes a Muscle-articular test of both legs, a test of maximum voluntary contraction in isometric conditions (MVCi), a countermovement jump test *(CMJ)*, and a drop jump (DJ) protocol from different heights (20, 40 and 60 cm). 21 healthy young adult subjects (12 males and 9 females). The mechanical variables are: force *(f)*, Muscle-articular stiffness *(k)* and Muscle-articular Unitary stiffness (k_U). Physical variables: Jump flight height *(h)* and force generated *(f)*. An Anova of repeated measurements was performed to analyse the influence of gender and laterality and a Pearson correlation to analyse the relationship between mechanical and physical parameters. The results obtained show a clear symmetry in physical and mechanical parameters. There were significant differences between men and women (*f* and *k*) (p<0.05) being in absolute terms higher in men than in women but not in relative terms (k_U). A clear correlation was obtained between mechanical parameters and *MVCi* in absolute terms (p<0.05). K_U allows comparisons between different subjects but its interpretation is not as intuitive as in absolute terms due to the application of the Hill's model on the mechanical response of muscle-tendon complexes that establishes a nonlinear relationship between *f* and *k*.

KEY WORDS: Stiffness, Viscoelastic properties, laterality, drop jump.

RESUMEN

El propósito del estudio consiste en evaluar el nivel de actividad física de adultos jóvenes mediante la obtención de la rigidez Musculo-articular y analizar su correlación con el rendimiento físico medido en capacidad de salto. El protocolo propuesto engloba un test Músculo-articular de ambas piernas, un test de Máxima contracción isométrica (MCIV) voluntaria en las mismas condiciones, un test de salto de contramovimiento, y un protocolo de salto de drop jump desde diferentes alturas (20, 40 y 60 cm). 21 sujetos adultos jóvenes sanos (12 hombre y 9 mujeres) conforman la muestra. Las variables mecánicas son: fuerza *(f)*, Rigidez Músculo-articular (*k)* y rigidez Músculo-articular Unitaria *(*k_U*)*. Variables físicas: Altura de vuelo de salto *(h)* y fuerza generada *(f).* Se llevó a cabo un Anova de mediciones repetidas para analizar la influencia del género y lateralidad y una correlación de Pearson para analizar la relación entre parámetros mecánicos y parámetros físicos. Los resultados obtenidos muestran una simetría clara tanto en parámetros físicos como en parámetros mecánicos. Se obtuvieron diferencias significativas entre hombres y mujeres (*f* y *k*) ($p<0.05$) siendo en términos absolutos mayores en hombres que en mujeres pero no en términos relativos *(*k_U*)*. Se obtuvo una clara correlación entre parámetros mecánicos y MCIV términos absolutos ($p<0.05$). K_U permite comparar entre diferentes sujetos pero su interpretación no es tan intuitiva como en términos absolutos debido a la aplicación del modelo de Hill sobre la respuesta mecánica de los complejos músculo-tendón que establece una relación no lineal entre *f* y *k*.

Palabras clave: Rigidez, Propiedades viscoeláticas, lateralidad, drop jump.

INTRODUCTION

In the majority of the sports and mainly daily movement there are hoping and landing jumps. In this kind of movement the legs can be modeled as a simple mass-spring model and their efficiency can be determine from the mechanical response of the system used to describe them (Hobara et al., 2008). Basically, when the legs are flexed during the gait or jumping, all elastic elements are subjected to a stretching (joints, tendons and muscles). All these elements have the property to resist to the deformation. This represents the stiffness of the elastic element.

A simple way to define the stiffness is the relationship between an applied load and the amount of elastic deformation that occurs in a structure. In the last decades the concept of stiffness associated to the muscle-tendon units (MTU) to describe the mechanical response of the muscles has been frequently used. Since one stiffer MTC exhibit more resistance to deformation, it can store more energy, (Ditroilo, Watsford, Murphy, & De Vito, 2011). The stiffness of the muscle–tendon unit (MTU) is related to performance during fast and slow stretch shortening cycle (SSC) movements (Wilson, Murphy, & Pryor, 1994).This concept of stiffness can be applied to bigger structures likes the legs. Defining the legs as spring-mass model, its mechanical response depends of the Leg stiffness (Butler, 2003; Shorten, 1987). Leg stiffness is defined as the ratio of maximal ground reaction force to maximum leg compression at the middle of the stance phase (Butler, 2003; Farley, Blickhan, Saito, & Taylor, 1991).

Different proposals set the dependence of the leg stiffness to the stiffness of torsional joint spring (related to ankle articulation). This joint stiffness, is defined as the ratio of the maximal joint moment to the maximum joint flexion at the middle of the stance phase, dynamic analysis) (Hobara et al., 2008). In addition, other author suggest the relation between leg stiffness and stiffness of the ankle articulation during different task as hopping or jumping (a Arampatzis, Schade, Walsh, & Brüggemann, 2001; Farley & Morgenroth, 1999). This concept of stiffness related to the articulation is defined as Musculo-articular stiffness (MAS) by Ditroilo et al. (Ditroilo, Watsford, Murphy, & De Vito, 2013). In this sense, the free vibration technique has been demonstrated to be a reliable and valid way to obtain the MAS (Ditroilo, Watsford, & De Vito, 2011; Ditroilo, Watsford, Murphy, et al., 2011; Fukashiro, Noda, & Shibayama, 2001; McLachlan, Murphy, Watsford, & Rees, 2006; Murphy, Watsford, Coutts, & Pine, 2003; Walshe, Wilson, & Murphy, 1996)

The sport performance analysis (based on velocity of running or power response) or even the analysis of different task as the capacity of jumping with or without of previous landing goes through the knowledge of the values of MAS (Harrison, Keane, & Coglan, 2004; Hobara et al., 2008; Laffaye, Bardy, & Durey, 2005). Some authors, focusing on getting more and more specific training, carried out biomechanical studies where bilateral analysis between dominant and non-dominant side are made. This biomechanical differences between both sides linked to the ankle joints during physical activities may be related to the physiological and anatomical symmetries or asymmetries of lower extremities (Niu, Wang, He, Fan, & Zhao, 2011).

The relationship between sport performance and stiffness of the lower limbs is well known in the scientific literature being significant correlations between them. Several authors have studied this correlations considering the same profile of the athletes (A. Arampatzis et al., 2006; Karamanidis et al., 2011; Kongsgaard, Nielsen, Hegnsvad, Aagaard, & Magnusson, 2011; Scholz, Bobbert, Soest, Clark, & Heerden, 2008). Others, have compared different profile of athletes (power-trained athletes and endurance-trained athletes) (Harrison et al., 2004)

About the sport performance, the sport injuries justify the necessity to carry out works to study the cause of them. It is well known that higher values of stiffness are correlated with higher probabilities of bones injuries (Butler, 2003; Kevin P Granata, Wilson, & Padua, 2002; Williams III, Davis, Scholz, Hamill, & Buchanan, 2004). In this sense, the current researches are focused to establish variables that may influence the stiffness of the lower limbs (Ditroilo, Watsford, & De Vito, 2011; Ditroilo et al., 2013).

Therefore, the aim of the present work is to carry out a parametric study of different variables as laterality, gender or anthropometrics characteristics on the MAS around the ankle articulation of a set of subjects obtained by the free vibration technique and their correlation with physical performance measured by standardized jumping protocol.

METHODS

Subjects

Twenty-one healthy active students of university (12 males and 9 females) [(mean ± SD) age 23.38 ± 3.01 years, mass 67.48 ± 13.78 kg, height 173.86 ± 9.97 cm] (Table 1). Subjects volunteered to participate in the current study. All subjects were medically screened to determine their health and exercise habits prior to testing, and to ensure no previous injury to the lower body musculature. Prior to testing, all subjects attended a familiarization session which involved the performance of all test items with particular attention given to the lower body stiffness test. In addition, no participant reported any type of vestibular disorder. Each individual gave written informed consent to participate in the study, which was approved by the University Ethics Committee of University Pablo de Olavide.

Table 1.
Subject's characteristics.

SUBJECTS	number of subjects n=21	weight (kg) Mean (SD)	height (cm) Mean (SD)	Age (years) Mean (SD)
Males	n=12	77,1 (8,2)	180,5 (8,5)	24,8 (3,0)
Females	n=9	57,3 (9,7)	166,1 (7,2)	21,5 (0,3)
Left- handed	n=5	74 (7,4)	179 (5,3)	25,4 (3,0)
Right-handed	n=16	65,4 (13,1)	172,3 (9,7)	22,8 (2,3)

Testing procedure

In one session, all the outcomes measures considered were obtained to the present work. Primarily, a several physiological measurements were obtained as the unilateral musculo-articular stiffness (MAS) by the free vibration technique for both sides (left leg (LL) and right Leg (RL) and the unilateral maximal voluntary contraction in isometric condition (MVCI) to the muscles involved in the plantarflexion. To obtain these two measures, the subjects adopt the same position at the ad hoc measurement device designed previously by the same authors (París-García, Barroso, Cañas, Ribas, & París, 2013). The position of the subject and the development of the measurement device are based on previous studies (Cavagna, 1970; Shorten, 1987) as earlier proposals and as the latest proposals that obtain the same variables (Babic & Lenarcic, 2004; Faria, Gabriel, Abrantes, Brás, & Moreira, 2009; Fukashiro et al., 2001; McLachlan et al., 2006; Murphy et al., 2003; París-García et al., 2013) (Basically, related to the position, the subjects were asked to keep angles of 90 degree at ankle, knee and hip articulation). The details of the procedure to obtain these measures are described at 2.3 MVCI test.

No systematic bias was detected in all experimental variables indicating that a learning effect was not present and that participants were sufficiently familiarized with the experimental protocol. The subjects were instructed to refrain from vigorous lower body exercise for 48 h prior to each test day and the recovery time between different trial and test were enough. The warm-up carried out were similar to the reviewed proposal (Ditroilo, Watsford, & De Vito, 2011; Murphy et al., 2003) based on cycling 5 minutes at 100 maintaining cadence between 70-80 rpm. During the warm-up the rest of the experimental protocol were explained. Then, a unilateral MAS test and MVCI were taking and finally a standardized jump protocol was made (countermovement jump (CMJ) and drop Jump at 20, 40 and 60 cm of height (DJ20, DJ40 and DJ60 respectively). The limb dominance was set by having participants performing a single-leg landing from a 30-cm-high box. Therefore, the dominant limb is defined as the self- selected lower extremity limb on which the participant landed (Padua & Carcia, 2005). All tests were conducted in the biomechanical Laboratory of the Andalusian Centre of Sport Medicine of Seville.

Unilateral Maximal Voluntary Contraction in isometric conditions (MVCI Test)

To obtain the maximum value of force developed by the muscle involved in the plantarflexion of the ankle articulation, a maximum isometric voluntary contraction test was carried out in the same condition of MAS Test (angles of 90 degree in ankle, knee and hip articulation) (Fig.1).

After setting all the parameters of the measuring device according with the characteristics of the subject, the frame where the weights were placed was locked with a strap. Thus, when the subject tries to raise the position of the hindfoot respect to the forefoot area, the subject develops a voluntary isometric contraction. As in the previous test, subjects must put his arms crossed over his chest and look straight ahead without moving his shoulders generating the maximum force on the tested leg for about 5 seconds (Wilson et al., 1994). 2 trials performed with each leg alternately with 3 minutes of recovery between trials. The highest value of both trials was chosen.

Jumps Protocols

The protocol jump consists in different types of jumps: with countermovement (CMJ) and with previous drop (DJ) at different heights (20, 40 and 60 cm). All of the jumps chosen develop movements with SSC and were registered with the Optojump® device.

Counter movements jumps

In order to assess physical performance of the lower body series of series of three counter movement jumps (CMJ) were performed. Subjects were instructed to adopt a neutral initial position with their hands in contact with their hips. The only restriction to jump were to keep their hands in contact with their hips during the fly phase to avoid any inertia from upper limb and the jumps must be performed in the target area or measurement area of the optojump device. All the trials were registered but only the best one (in height of jump) was considered to the statistical analysis. Two minutes recovery periods were designated between all jumps.

Drops Jumps (20, 40 and 60 cms of height)

The criteria chosen to carry out the DJ protocol was to establish an increasing height protocol. The bilateral DJ consists in to step off the box of the designed height and then perform a maximum vertical jumps without any pause (break, stop, interruption).

Subjects were instructed to adopt a neutral initial position with their hands in contact with their hips. To commence the jump, subjects were instructed to shift their mass onto the non-dominant leg and to step off the box with their dominant leg. This minimisation of contact time discouraged knee flexion, hence encouraging use of the triceps-surae musculature. The only restriction to jump were to keep their hands in contact with their hips during the fly phase in order to avoid any inertia from upper limb and the jumps must be performed in the target area or measurement area of the optojump device.

Statistical Analysis

All data were analyzed using SPSS version 20 statistical software. Descriptive data include means and standard deviation (SD) of all variables.

One-way ANOVA with repeated measures was used to detect the significant effects of the laterality and gender effect on to *MVCi*, stiffness (*k*), Unitary Stiffness (*k/f*) and force registered.

F-values in the ANOVA, Tukey's post hoc test of critical difference were used to locate significance between means. To assess the relationship between, MAS variables and performance variables measured as capacity to jump (in different types (*CMJ*, DJ_{20}, DJ_{40} and DJ_{60}), Pearson product-moment correlations were carried out between them. The level of significance was set at $p<.05$.

RESULTS

The values of *f*, *K* y K_u (mechanical response) and Maximum voluntary contraction in isometric condition (MVCI) are displayed in table 2 and table 3: i) Taking into account if the subject is right-handed or left-handed (table 2); ii) taking to account differences across gender (table 3). In both tables are shown: Mean values, standard deviation (SD), Typical error and the value of F in Anova analysis. The significant differences are shown by the value of *p* being significant when this is lower than ,05.

Table 2.
Values of f, k, ku and MVCI taking to account the laterality.

					ANOVA ONE FACTOR (LATERALITY)	
PARAMETERS	Laterality	N	Mean (SD)	Typical errors	*F*	*p*
f (*N*)	Left hand	10	1252,93 (207,19)	65,52	1,72	,20
	Right hand	32	1112,80 (315,8)	55,83		
	Total	42	1146,17 (297,45)	45,90		
K (*KN/m*)	Left hand	10	277,54 (59,98)	18,97	0,00	,99
	Right hand	32	277,79 (97,90	17,31		
	Total	42	277,72 (89,65)	13,83		
K_u (k/f) (($10^{-3}\cdot m^{-1}$))	Left hand	10	0,23 (0,03)	0,01	1,61	,21
	Right hand	32	0,25 (0,05)	0,01		
	Total	42	0,24 (0,04)	0,01		
Maximun Voluntary isometric Contraction developed in the test MVCi (N)	Left hand	10	79,88 (22,69)	7,17	0,78	,38
	Right hand	32	71,85 (25,84)	4,57		
	Total	42	73,7629 (25,09)	3,87		

p>,05 for signifcant differences

[b]p<,05 for significant differences

*p<,001 for very significant difference

In table 2, it can be observed slight differences being not significant between right-handed and left-handed related to *f* , *k*, k_u, and *MVCi* values (p_f=.20, p_k=.99, p_{ku}=.21 and p_{MVCi}=.38). The analysis of the difference across gender for the same variables can be observed in table 3. On the one hand, there are significant difference for *f*, *k* and *MVCi* (p_f<.001, p_k<.001, and p_{MVCi}<.001). On the other hand, the differences obtained for K_u are not significant (*p*=0.14) being slightly higher for females.

Table 3.
Values of f, k, ku and MVCi taking to account the gender difference.

SUBJECTS	GENDER	N	Mean (SD)	Typical errors	*F*	*p*
	Males	12	1318,61 (264,50)	53,99		
f (*N*)	Females	9	916,24 (144,11)	33,96	33,94	,00*
	Total	21	1146,16 (297,45)	45,89		
	Males	12	310,75 (95,1)	19,41		
k (*KN/m*)	Females	9	233,68 (59,95)	14,04	15,36	,000*
	Total	21	277,72 (89,64)	13,83		
	Males	12	0,236 (0,3074)	0,00627		
K_u (k/f) (m^{-1})	Females	9	0,256 (0,5609)	0,1322	2,22	,14
	Total	21	0,244 (0,4401)	0,0067		
Maximun Voluntary isometric Contraction developed in the test MVCi (N)	Males	12	87,109 (23,66)	4,82	25,17	,000*
	Females	9	55,96 (13,23)	3,12		
	Total	21	73,76 (25,09)	3,87		

p>,05 for signifcant differences

[b]p<,05 for significant differences

*p<,001 for very significant difference

Also, a Pearson correlation coefficient analysis was carried out between mechanical parameter and physical parameters (MVCi, and jumpings parameters) showed in table 4, *f* values displayed a positive and significant correlations with all the parameter, being low with jumpings values ($r_{bilateral}$<.42*) and being high and very significant with *MVCi* values ($r_{bilateral}$>.7**). *k* values showed a positive and significant correlation with *MVCi* values ($r_{bilateral}$=.569**). The tendency of k_u values was not very clear respect to *MVCi* values but showed a slightly negative and significant correlation with all jumping's parameters (r@-.28*).

Table 4.
Pearson's correlation coefficients between mechanical variables (f, k and Ku) and performance variables (MVCI (unilateral and Bilateral), DJ20, DJ40 Y DJ60).

	CMJ (cm)	**DJ_{20} (cm)**	**DJ_{40} (cm)**	**DJ_{60} (cm)**	**MVCi**			
	BILATERAL	BILATERAL	BILATERAL	BILATERAL	LEFT LEG	RIGHT LEG	BILATERAL	
	,387*	**,372***	**,356***	**,411****	**,712****	**,823****	**,726****	Pearson's correlation
f (*N*)	,011	,015	,021	,007	,000	,000	,000	*p* value
	42	42	42	42	21	21	42	N
	,153	**,125**	**,198**	**,133**	**,501***	**,709***	**,569****	Pearson's correlation
(*KN/m*)	,332	,430	,536	,400	,021	,000	,000	*p* value
	42	42	42	42	21	21	42	N
	-,227	**-,266**	**-,292**	**-,315***	**-,244**	**,081**	**-,77**	Pearson's correlation
Ku (k/f) (m^{-1})	,149	,089	,061	,042	,286	,729	,626	*p* value
	42	42	42	42	21	21	42	N

ignificance of the correlation is *p*<,05

Very significance of the correlation is *p*<,001

DISCUSSION

The purpose of the present study is to perform a parametric analysis of the values of musculo-articular stiffness and unitary musculo-articular stiffness analyzing differences through different parameters and its relationship with physical performance.

The present study show of lateral and bilateral results that support indirect evidences of the influence of the laterality on mechanical response. First of all, the set of subject show a clear symmetry between both sides of the body related to the mechanical parameters. Although the chosen sample is heterogeneous in its anthropometric characteristics (height and weight), all of them showed not significant differences (p<0.05) for *f*, *k* and k_u and *MVCi* between LI and LR.

In the analysis of gender differences, very significant differences between men and women for *f*, *k* and *MVCi* (p<0.001) have been found, obtaining higher values for men versus women.

However, k_U values in women were slightly higher (but not significantly, p=0.14) than those found in men. These results display indirect evidence that the stiffness as a parameter is very conditioned by the influence of other variables such as body weight or height and therefore does not allow to compare between different subjects. These results are in line with some of the proposals where they found significant differences between genders for the *k* value (Blackburn, Padua, Weinhold, & Guskiewicz, 2006; Kevin P Granata et al., 2002) where they found the same evidence but justified this evidence by the differences in height between both study groups.

The fact that k_U values are higher in females than males even though the values of *f* and *k* are lower, is the result of the interpretation the Hill model because the relationship between the force recorded and the stiffness obtained is not linear. The results obtained agree with those obtained in other studies comparing both genders being the value of k_U higher in women than in men (Wang, De Vito, Ditroilo, Fong, & Delahunt, 2015).

After analysing the influence of gender, laterality and anthropometric questions on mechanical properties, it is interesting to analyse its correlation with physical performance. First, a positive and significant (p<0.05) global correlation of the force recorded in the measuring device with all the performance variables measured in the experimental protocol (*CMJ*, *DJ20-40* and *CVMi*) can be observed. In this case, the value of *f* recorded is conditioned by body weight. At this point, it can be established that those subjects who have a higher body weight register a greater strength in the MAS test and have a higher performance.

If the relationship between *k* and performance is analysed, it can be observed only a positive and very significant correlation (p<0.01) with *CVMi* (bilateral). However, this relationship does not occur when performance is measured in jump capacity. This may be since the jumping ability depends more on other variables than on the *k* parameter. For instance, the more body weight the more muscle-articular stiffness increase (Faria, Gabriel, Abrantes, Brás, & Moreira, 2010) and conversely, the more weight the lower jumping capacity (Kubo et al., 1999). Therefore, it is predictable that there is no clear correlation between *k* and flight height in the jump test.

Finally, K_U does not present any clear trend regarding *CVMi* values, showing very low and non-significant correlations (p>0.05). On the other hand, when it is compared to jump tests, higher distances of drop height imply higher negative correlations becoming even significant, their r (p_{CMJ}= 0.149; p_{20cm}=0.089; p_{40cm}=0.069; p_{40cm}=0.042). This negative relationship between K_U and performance is the result of the interpretation of the Hill model as discussed above being more determinant in those situations where the contribution of elastic energy is more important for performance.

The obtained *k* gives an idea of stiffness in absolute terms but once the influence of other parameters is analysed, it is better to have a stiffness in relative terms like K_U that allows to carry out comparisons where the weight and the height are contemplated. In the present study, a number of studies have considered to be compared but all of them displays stiffness values in absolute terms taking into account samples from subjects with different characteristics across the different studies (Babic & Lenarcic, 2004; Blackburn et al., 2006; Faria et al., 2009; Fukashiro et al., 2001; K P Granata, Wilson, Massimini, & Gabriel, 2004; Kongsgaard et al., 2011; Kubo et al., 1999; Murphy et al., 2003; Walshe et al., 1996; Zinder, Granata, Shultz, & Gansneder, 2009). Differences in the characteristics of the subjects of the different studies make it impossible to compare the results of stiffness with each other.

Therefore, the parametric analyses of these parameters and their correlation with physical performance must carried out carefully. In absolute term, higher values of *f* and *k* implies higher values of physical performance but in relative terms, this hypothesis is not given due to the application of the Hill model.

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