



Article Hamstring Torque, Velocity and Power Elastic Band Measurements during Hip Extension and Knee Flexion

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Abstract: The quantitative dynamic monitoring of the performance of hamstring muscles during rehabilitation and training cannot currently be undertaken using elastic resistance bands. Hip extension with a fully extended knee involves hamstring agonists, while knee flexion involves only the hamstring. The purpose of this study is to provide normative values of torque, velocity and power involving hamstring muscles opposing elastic bands. Twenty amateur athletes aged 25.7 ± 4.9 , were studied during two motor tasks—hip extension and knee flexion, both isometric & dynamic—with an elastic resistance band and DINABANG portable instrument. We compared the peak isometric torque in hip extension with agonists (2.93 Nm/kg) and without them (1.21 Nm/kg): the difference is significant. The peak angular limb velocity—starting at 50% of the maximum torque—is smaller in hip extension with agonists (215.96 °/s) than in a knee flexion without them (452.56°/s). The combination of peak torque and peak velocity estimates power and there is no difference (p = 0.051) with and without agonists: 452.56 °Nm/s.kg without agonists and 542.13 °Nm/s.kg with them. This study opens the possibility of monitoring torque–velocity–power profiles for hamstring exercise in open chain.

Keywords: hamstring exercise; maximum isometric effort; maximum velocity

1. Introduction

Human locomotion relies heavily upon the hamstring muscle group, for example, during fundamental movements involving gait and sprinting [1]. The hamstring acts as both a hip extensor and as a knee flexor, in which its special morphology and muscle components are utilized [2,3]. The hamstring consists of several muscles acting in synergy and, therefore, is frequently treated as a muscle unit, such as a knee flexor or a hip extensor (except for the short *biceps femoris*, which only acts as a knee flexor) [4].

The two most serious sport injuries in the lower limb [5] are hamstring strains and anterior cruciate ligament (ACL) ruptures [6,7]. Hamstring injuries account for 12–16% of all lesions reported by athletes, with a high proportion (22–34%) of re-injury [5]. Anterior cruciate ligament injuries account for an additional 6% of sports injuries [6] such as in hockey or soccer. It is important to foster preventive programs aiming to protect athletes



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). from these two injuries, and namely to avoid anterior tibial translation, which is involved in these two types of injuries.

Once either of these injuries happen and the anterior crucial ligament is reconstructed, one of the main objectives of the physiotherapist is to rehabilitate the hamstring group of muscles. Current hamstring rehabilitation practices start with gentle movements keeping all effort on the safe side. However, during the last phases of rehabilitation, the exercises involve high levels of force and elevated muscular contraction velocity [8,9] which constitute a risk of re-injury.

Isotonic exercises or therapist-controlled movements with elastic bands are a simple way to limit force based on the selection of the weight or the experienced feeling of the physiotherapist; but no velocity information is available, thus turning these rehabilitation exercises prone to re-injury or inefficient movements.

Exercises using elastic resistance bands or tubes are used during rehabilitation from hamstring injury or during knee rehabilitation after ACL surgery, among other clinical situations. The evidence supporting this mode of rehabilitation is recent [10,11] since previous reports are limited to anecdotes for which no biomechanical assessment is included [12].

Although widespread, the use of mechanical equipment such as isokinetic and isoinertial devices or weight machines might not be accessible to everyone, which could be considered a limiting factor. During standard rehabilitation field training with Elastic Bands (EB), the physiotherapist has no quantitative evaluation of the intensity of exercise nor any indication of objective performance of the sports person or patient. A qualitative approximation is the mechanical characteristic of the bands usually evidenced by color code. Consequently, we did not include any description of simple and inexpensive methods to be used with EB to perform specific motor tasks with varying degrees of resistance [13].

Muscle strength can be greatly enhanced using EB provided that quantitative evaluation is available to guide physical therapists and/or athletic trainers and to avoid injuries due to over exercise or a lack of effect due to insufficient effort. As an example of muscle strength increase (isometric and velocity) emulating functional skills, trainers specify motor task that include hip extension with extended knee, which emulates the late swing phase during running [14]. It is nevertheless an activity with no quantitative evaluation except the number and frequency of repetitions, as well as the color (resistance) of the band in use.

As an intrinsic part of using EB, any method using them faces the difficulty of the lack of information to quantify the deployed force during exercise [15]. Extensive documentation on expensive machine exercise and free-weight protocols with dose/response data are commonly described [16]. But these machines are not suitable for field used. Elastic resistance exercises require more investigation because of the lack of quantitative standardization. In other words, the resistance applied in each exercise is subjectively based on the physiotherapist's perception, whether for rehabilitation or training [10,13].

Although rehabilitation programs exist, there are no validated functional programs for emulating *muscle-specific* motor tasks and to record objective measurements [17,18]. Hence, there is a need for functional programs with objective guidelines, including measurements, which are useful for accurate follow-up.

To address this undetermined use of strength, which can lead to either further injury or ineffective training, we developed a novel device, DINABANG, which is a portable instrument with a small footprint that can be used to quantify torque and velocity (shown in Figure 1) [14,19]. This device can be conveniently transported and used to measure lower limb performance on location, e.g., in sports fields, which is not possible using traditional isokinetic or another laboratory equipment [20].

The main purpose of this study is to provide the first numerical values for deployed hamstring torque, velocity and power during two single-joint motor tasks: (i) hip extension and (ii) knee flexion, both in open chain. Additionally, we compare these hamstring parameters in men and women, dominant vs non dominant limb as well as in both motor tasks.



Figure 1. DINABANG in use during sport training supervision. Note the lightweight device tied to the elastic band. During this hip extension hamstring muscles as well as agonists are active.

2. Materials and Methods

DINABANG (Figure 1) is an original portable instrument used to measure instant torque, and instant velocity of lower limbs during selected mother tasks. We previously calibrated DINABANG against standard weights [21] and we used it to set normal values of isometric hamstring torque with elastic resistance bands in a supine position [14].

2.1. Participants and Study Design

Healthy amateur sportspersons were asked to perform two motor tasks under the direct supervision of a physiotherapist. The measurement of torque and velocity of the hamstring muscles was made using gold Thera-Band[®] [10] elastic bands tied to the ankle and to the DINABANG instrument. The elastic resistance band provides a calibrated resistance to the movements.

The exclusion criteria included having any (lifelong) history of hamstring lesion, sports injuries in the past six months [6], cardiovascular disease or other conditions that could limit or preclude maximum muscular contraction. Volunteers were contacted verbally and signed an informed consent. The participants were active sportspersons at the time of the study. The sportspersons practiced some form of physical activity at least three times a week for at least half an hour per session (Tegner activity level \geq 5) [22]. The protocol was approved by the Ethics Committee of the *Hospital de Clínicas* in March 2019 (approval number: 18-069) in accordance with the Declaration of Helsinki.

Twenty healthy students and athletes volunteered after hearing a call during a Sports Academic event in Maldonado, Uruguay, in September 2019, as part of a convenience sampling approach. The mean and standard deviation were 25.7 years of age (SD 4.9), 172.0 cm of height (SD 8.3) and 68.9 kg of weight (SD 14.4), as shown in Table 1.

	Male (<i>n</i> = 13)	Female (<i>n</i> = 7)	Difference (95% CI)			
Age (years)	26.31 (5.89)	24.43 (2.07)	1.88 (-3.00; 6.76)			
Height (cm)	176.46 (5.33)	163.71 (6.02)	12.74 (7.26; 18.23)			
Body mass (kg)	74.85 (14.16)	57.86 (5.76)	16.98 (5.14; 28.8)			
$BMI (kg/m^2)$	23.89 (3.60)	21.60 (2.05)	2.29 (-0.82; 5.42)			
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Table 1. Demographic data.

Notes: Mean value (standard deviation). CI and (95% confidence interval of CI).

The athletes were asked to perform two motor tasks, which were limited to the sagittal plane, three times each to reduce measurement noise. Their maximum force (Newton), and maximum velocity (°/s) were then recorded. Torque was calculated as a tangent force produced at the extremity of the lever arm (Nm) [20]. The lever arm used by DINABANG is taken from the Dempster table [23], which gives the ratio of the segment to the height of the person: lower greater trochanter to extremity medial malleolus and leg femoral condyles to medial malleolus for the hip extension and knee flexion motor tasks, respectively. Velocity was measured by the accelorometre of the IMU, included and force by a strain gauge, both elements included in DINABANG [24].

2.2. Device and Data Processing

The measurements were made using DINABANG [19] to evaluate lower limb kinetics and kinematics in an open kinematics chain. The device includes a magneto-inertial measuring unit, strain gauge, and specific software to evaluate lower limbs during specific motor tasks [24].

The torque measurements were made using an EB with one end tied to the ankle and the other held by the physiotherapist. The EB have both nonlinear and viscous properties, referred to as viscoelastic properties [16]. The magnitude of tension determines the deformation of the EB, with a linear range of up to 300% of the resting band length [25]. In this research, the deformation was assumed to be linear because the maximum stretching was 200%. We used Thera-Band[®] [10,26] EB with middle to high elasticity.

The instantaneous values of torque and velocity were saved as signals in function of time. The maximum isometric peak torque and the maximum velocity were detected for each recorded trial. After three trials were recorded, the mean of the three maximum values was calculated and named "maximum isometric peak torque" and "maximum velocity". Torque was normalized for body mass (Nm/kg) [27] to minimize the effect of athlete body size. Maximum velocity was measured in degrees per second (°/s).

The sampling frequency of force and velocity signals used by DINABANG [28] is 100 Hz, so as to accurately track movement and detect peak velocity and peak force during motor tasks, as recommended by Naruhiro Hori [29] and confirmed by Paolo Bardella et al. [24]. The torque values (Nm) were obtained using a calibrated conversion factor. The specific sensor FX1901 (maximum strength of 900 N) by Measurement Specialties[®] is an active part of the device [30]. The data were analyzed to determine the peak torque and maximum angular velocity using OCTAVE, a programming and numeric computing platform [31].

Both motor tasks (Figure 2) involve a movement favored by gravity, which must be corrected to avoid attributing falsely magnified torque to the muscles. To correct for the gravity effect following the method described by Fillyaw [32], the DINABANG device subtracts the torque produced by the weight of the lower limb or the weight of the shank plus foot, concentrated at the respective centers of mass. Both values (weight and distance to a center of mass) are taken from the Dempster table [23] for the height and body mass of each individual. Implementing this correction for gravity, the maximum value of torque produced by the lower limb was determined. The maximum angular velocity was also measured using a 3-axis gyroscope sensor at a working range of ± 1000 °/s [33].



Figure 2. Motor task symbols: (**a**) the maximum isometric hip extension (MIHE) supine hamstring motor task, which also involves the *gluteus maximus*, acting against the rubber band held by the therapist (not shown); (**b**) the maximum velocity hip extension (MVHE); (**c**) the maximum isometric knee flexion (MIKF) sitting position hamstring motor task, which involves only the hamstring muscle; and (**d**) the maximum velocity knee flexion (MVKF), in which the athlete was asked to curl the leg with maximum velocity.

2.3. Procedures

All subjects received the same instructions during muscle contraction to achieve maximum effort. The subjects previously warmed up via submaximal concentric and eccentric contractions in five repetitions—or rehearsals—of the specific motor task prior to testing. The test consisted of all subjects to perform three maximal trials for each motor task for each leg, during which they were verbally encouraged to achieve maximum effort. A pause of one minute was included from effort to effort to allow for muscle rest. In order to allow for easier movement familiarization, measurements of the dominant limb were first performed in all cases for each leg. The dominant limb was the one considered by the subject to be preferred to kick a ball.

The two motor tasks, each divided in torque and velocity emphasis tasks (i.e., four motor tasks in all), are shown in Figure 2 and are defined as follows:

2.3.1. Maximum Isometric Hip Extension (MIHE)

As shown in Figure 2a, this exercise consists of asking the athlete to adopt a supine position on the mat with both arms at the sides of the trunk, with one fully extended knee and the other flexed, one leg at a time surrounded by a rubber band held by the therapist behind the head of the athlete. The position familiarization phase consists of selecting the most comfortable hip flexion angle for the active limb, which is around 80°. This angle depends on the hamstring flexibility of the volunteer. The limb is pushed from the comfort angle towards 0°, extending the hip with the knee kept fully extended. The position of the limb is held still at the comfort angle with the deployment of increasing isometric force as the athlete is asked to activate their hip extension muscles while keeping the leg extended and stretching the rubber band. The therapist increases the tension of the band until the athlete cannot hold the 80° position anymore. At this point, the participants produced an extensor moment at the hip, and the athletes were asked to remain still and were not

allowed to twist, extend their back, nor to compensate for the action (such as pushing the mat with their arms). Compensation was monitored and avoided by expert physiotherapist encouragement actions. This isometric effort involves the hamstring as well as the *gluteus maximus* [34] and other minor hip extension agonist muscles [35].

2.3.2. Maximum Velocity Hip Extension (MVHE)

As shown in Figure 2b, this exercise consists of asking the athlete to adopt a supine position on the mat with both arms at the sides of the trunk, with one fully extended knee and the other flexed, and with the malleolus of the extended leg attached to a rubber band held by the therapist behind the head of the athlete. The initial position is the same as that in MIHE but with torque reduced by 50% with respect to the maximum isometric torque measured in real time. The 50% of maximum torque is obtained with verbal feedback to the athlete by the physiotherapist looking at the DINABANG display. This reduction in initial rubber tension allows the limb to develop additional potential torque in a movement with the highest possible velocity towards full hip extension [36]. The range of motion was between 80° of flexion (measured and displayed in real time by DINABANG) and a neutral position of 0° , which is the end position of the extended limb placed on the horizontal mat.

2.3.3. Maximum Isometric Knee Flexion (MIKF)

As shown in Figure 2c, this exercise consists of asking the athlete to sit on a stable, heavy table with both arms holding the waist, with near complete knee extension (10° knee flexion), and with the malleolus of the extended leg attached to a rubber band held by the therapist facing the athlete. The position familiarization phase consists of selecting the most comfortable knee flexion angle for the active limb, which is around 10° . This angle is associated with the same hamstring muscle fiber length as in the MIHE, but now with a hip flexion of 90° . The position of the leg is held still at this angle (10°) while increasing isometric force is deployed, as the athlete is asked to activate the flexion knee muscles, stretching the rubber band. The therapist increases the tension of the band until the athlete cannot hold the 10° position anymore. At this point, maximum torque is deployed, and the athlete is asked to remain still, not to separate the thighs from the table, and not to perform any trunk compensation.

2.3.4. Maximum Velocity Knee Flexion (MVKF)

As shown in Figure 2d, this exercise consists of asking the athlete to sit on a stable and heavy table with both arms holding the waist, with near complete knee extension (10° knee flexion), and with the malleolus of the extended leg attached to a rubber band held by the therapist facing the athlete. The initial position is the same as that in MIKF but with torque reduced by 50% with respect to the maximum isometric torque measured in real time. This reduction in initial rubber tension allows the leg to develop additional potential torque in a quick movement [36]. The athlete is asked to curl the leg from the initial position towards 90° flexion with the highest possible velocity. The range of motion is therefore from 10° of knee flexion to a hanging position of 90°, which is 80° in range, the same as in the hip extension velocity motor task MVHE.

The order in which the motor tasks were performed is shown in Figure 2, and in order to avoid any fatigue effect, five minute rests [37] were taken between the hip and knee tests. Within the hip activity, a one-minute rest was allowed between the isometric (MIHE) and the dynamic (MVHE) movements. Similarly, for the knee activity, one minute separated MIKF from the subsequent MVKF. One-minute rest was given based on Parcell [37] who states that 60 s is sufficient time to recover. From one motor task to the next, we have given five minutes' rest.

In our paper, we define maximum power as the product of maximum torque and maximum velocity, though this is not formally correct since maximum torque and maximum velocity do not necessarily occur at the same time. For both the hip extension and knee flexion motor tasks, torque is initialized at 50% of the maximum isometric torque. To do so, the physiotherapist looks at the DINABANG monitor (or tablet) as the individual adjusts his or her strength at 50% of the maximum value they can produce.

2.4. Statistical Analysis

Torque, velocity, and power were analyzed by R software [38] in layers according to four independent variables:

- (i) Hamstring motor task (either hip extension or knee flexion)
- (ii) Lower limb laterality (either dominant or non-dominant)
- (iii) Gender
- (iv) Movement type (either maximum isometric torque or 50% of maximum torquemaximum velocity).

The statistical analysis of angular velocity is limited to the situations described as the alternatives of the first three independent binary variables: (i), (ii), and (iii). In variable(iv), only one alternative is used because the athlete has no chance to develop any velocity when deploying maximum isometric torque.

Multiple regression analysis was performed to highlight the differences in the outcomes of interest (maximum torque, maximum velocity, and maximum power) that can be explained by the independent binary variables: either four variables for torque (motor task, dominant limb, gender, and speed) or three variables for velocity and power (motor task, dominant limb, and gender).

A statistical significance was attributed when the observed alpha error probability was below p = 0.05, known as the 5% significance level. The results have been double checked with SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

3. Results

The results of the study are presented as mean and standard deviation of torque, velocity and power of hamstring muscles during MIHE, MVHE, MIKF, and MVKF motor tasks. Table 2 reports the measurements of the maximum values of torque, velocity, and power obtained by averaging three successive trial values during the hamstring muscles exercises, as DINABANG gives the maximum value of these measurements for each motor task instance.

Male		Fer	Female						
Motor Task	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant and Non-Dominant				
Maximum Torque (Nm/kg)									
MIHE	3.07 (0.75)	2.90 (0.74)	2.87 (0.62)	2.77 (0.56)	2.93 (0.68)				
MVHE	2.46 (0.57)	2.34 (0.61)	2.48 (0.49)	2.42 (0.51)	2.42 (0.54)				
MIKF	1.25 (0.33)	1.19 (0.33)	1.21 (0.15)	1.16 (0.14)	1.21 (0.27)				
MVKF	1.10 (0.29)	1.06 (0.28)	1.06 (0.14)	1.03 (0.13)	1.07 (0.23)				
Maximum Velocity (°/s)									
MVHE	214.64 (40.56)	212.38 (48.65)	222.17 (29.09)	218.16 (37.88)	215.96 (39.69)				
MVKF	418.17 (86.38)	408.52 (67.67)	437.80 (41.28)	414.16 (69.84)	452.56 (79.72)				
Maximum Power (°Nm/s.kg)									
MVHE	553.59 (227.55)	527.81 (263.50)	553.86 (141.43)	535.30 (164.20)	542.13 (209.27)				
MVKF	471.17 (236.65)	438.38 (204.59)	464.88 (77.49)	432.65 (109.73)	452.56 (179.73)				

Table 2. Normalized torque, velocity, and power of the hamstring muscles.

Note 1: Values are given as mean (standard deviation). Note 2: Knee flexion motor tasks (MIKF and MVKF) involve only a concentric hamstring effort, while hip extension with an extended knee (MIHE and MVHE) involves hamstring and agonist muscles in a concentric effort. Torque and Power values are normalized by body mass in Nm/kg and °Nm/s.kg.

Table 3 is the result of a multiple linear regression analysis of all data collected for this paper. Three dependent variables are displayed column wise, whereas the independent variables are shown line wise: gender, age, lateral dominancy, type of motor task and inclusion of agonist muscles in the movement.

Table 3. Multivariate regression analysis of torque, velocity, and power.

	Maximum Torque		Maximum Velocity		Maximum Power	
	Estimate Nm/kg	<i>p</i> -Value	Estimate °/s	<i>p</i> -Value	Estimate °Nm/s.kg	<i>p</i> -Value
Intercept	2.851	< 0.001	314.245	< 0.001	551.672	< 0.001
Centred Age (25 years)	0.001	0.890	-3.593	0.015	-6.491	0.214
Gender (Female)	-0.044	0.590	-5.494	0.677	8.563	0.856
Lower Limb Laterality (Dominant)	-0.085	0.266	-8.853	0.483	-27.852	0.539
Movement Type (Isometric)	-0.327	< 0.001	_	_	_	_
Hamstring Motor Task (Hip Extension)	-1.535	< 0.001	202.38	< 0.001	-89.569	0.051

Note 1. All voluntary data included (13 men and 7 women). Note 2. Motor tasks: knee flexion (MIKF and MVKF) as well as hip extension (MIHE and MVHE). Note 3. Movement types: isometric and concentric starting from 50% maximum torque. Note 4. For regression analysis, the central value of age is set at 25 years. Note 5. For the other variables, the reference is the value shown between brackets.

4. Discussion

We studied the performance of healthy subjects with respect to their hamstring muscles during controlled, specific, open-chain motor tasks: hip extension with a fully extended knee in the supine position on a mat (Figure 2a,b) and knee flexion while seated on a table (Figure 2c,d).

The first result of our research is that the isometrically deployed hamstring torque is more than two times greater in a hip extension (2.93 Nm/kg referred to the hip) than in a knee flexion (1.21 Nm/kg referred to the knee), both in open chain. This is due to the fact that the isometric effort in a hip extension involves the *gluteus maximus* and other minor hip extension agonist muscles in addition to the hamstring [35]. The physiological cross sectional area (PCSA) involved in hip extension is therefore larger than that in knee flexion, when no agonist muscles assist the hamstring.

The muscular force generation and the deployed torque depend upon several physiological, biomechanics, and neural factors, including PCSA, muscle length, pennation angle, moment arm, contraction speed, and the involved motor units [39].

The dependence of force and velocity of a muscle on its length has long been established [40,41]. In our case, we devised hip extension and knee flexion movements in such a way as to maintain the same fiber length. The hamstring length–tension relationship is therefore the same in both motor tasks: hip extension with a fully extended knee (MIHE, Figure 2a) and knee flexion (MIKF, Figure 2c). The length of the bi-articulate hamstring muscle is the same during both motor tasks because the hip flexion angle in the supine position (80°) extends the muscle fibers in exactly the same way as in the sitting position (flexed hip to 90°) with a knee flexion angle of 10°.

Therefore, the augmented torque during MIHE with respect to MIKF can be attributed mainly to the augmented muscle PCSA [42] because the agonist muscles are also recruited during the hip extension, while they do not take part in knee flexion. The hamstring agonist muscles involved during hip extension are the gluteus maximus, adductor longus, and adductor magnus [35].

Referring to isometric hip extension with an extended knee (MIHE Figure 2a), we found that the weight-normalized maximum isometric torque does not differ between dominant and non-dominant limbs. In terms of normalized values, no gender-related difference in torque was found.

With reference to Table 3, the normalized torque regression analysis shows no difference with gender (p = 0.590), limb dominancy (p = 0.266), and age (p = 0.890), while the

motor task (p < 0.001) and the type of movement is associated with a significant difference (p < 0.001).

The second main result of the reported research refers to velocity. As shown in Table 2, the angular limb velocity deployed—starting at 50% of the maximum torque—is smaller in hip extension ($215.96^{\circ}/s$) than in knee flexion ($452.56^{\circ}/s$). This may be a consequence of the following concomitant factors:

The quick movement of a hip extension (maximum velocity hip extension, (MVHE) starts at 50% of the previously recorded maximum isometric torque (Figure 2b). During this movement, the maximum torque obtained in such a condition (MVHE) does not differ between dominant and non-dominant limbs.

With reference to Table 3, the normalized torque regression analysis shows no difference with gender (p = 0.667) or limb dominancy (p = 0.483). Velocity significantly varies with age, according to regression analysis (p = 0.015), and the motor task is associated with a significant difference (p < 0.001). This difference is 202.38 °/s quicker in knee flexion with respect to hip extension, according to the regression analysis.

With the values being weight normalized, there is no difference in torque due to gender. In these dynamic conditions, the maximum torque obtained is comparable to the maximum isometric torque, but not as large. By holding the elastic resistance band firmly from the initial 50% of the maximum force, the physiotherapist uses an increasing opposing force to activate the hamstring muscles up to, but not reaching, the maximum isometric torque. The maximum isometric torque is significantly larger than the dynamically deployed torque, acting against the stretching elastic resistance band. The difference is 0.327 Nm/kg, which is approximately 17% less with respect to the mean MIHE torque of 2.93 Nm/kg (Table 2).

During hip extension (MVHE), we also measured the maximum velocity recorded at some time during the 80° span from the initial to neutral positions (i.e., zero degrees or limb against the mat) (Figure 2b). No statistically significant differences were found (Table 3) for maximum velocity, with respect to gender (p = 0.677) and to dominancy of the limb (p = 0.483). From Table 3, we also found an expected result in the sense of slightly faster movements by younger adults, with p = 0.015 dividing subjects as being below or above 25 years of age. The incremental velocity is of the order of 1% slower per year of age (-3.59 out of $314.45^{\circ}/s$).

As suggested by Zivkovic et al. [36], a possible explanation for the higher velocities during knee flexion is that curling the leg while seated is a much more common motor task than extending the hip with a fully extended knee while in the supine position. This represents an adaptive pattern to usual movements [43]. Knee flexion during a leg curl is a usual movement for athletes in a gymnasium, while hip extension starting from 80° in the supine position may be a less common exercise, which confirms our finding of the greater velocity observed despite less muscles being involved.

An additional comment on higher velocities during curls is that hamstring muscles mainly contain quick contraction fibers (white fibers) [44], whereas the agonist muscles (*gluteus maximus, adductor longus,* and *adductor magnus*) include slow contraction fibers. The combination of quick and slow fibers, reaching a greater torque, turns out to have a smaller peak velocity than the velocity of a curl when only the hamstring muscles are involved.

The third important result refers to the combination of torque and velocity. Overall, the figures show that hip extension torque (MVHE) during a quick movement (2.42 Nm/kg) is more than twice the knee flexion torque (MVKF with 1.07 Nm/kg) due to the activation of the *gluteus maximus* and other minor agonist muscles when the limb is extended. On the other hand, and in an inverse relationship, when the athlete sits and curls his or her leg, the maximum velocity is more than twice as large (MVKF: 452.56 °/s) as the velocity in the supine position (MVHE: 215.96 °/s), as shown in Table 2. We multiplied the peak velocity by the peak torque during both motor tasks, MVHE and MVKF. The result is an estimation of the maximum power deployed during the motor tasks. MVKF is quicker than MVHE, while MVHE involves a greater torque than MVKF.

The product of peak velocity and peak torque favors MVHE as a more powerful motor task. At variable velocities with peak values of 215.96 °/s and 452.56 °/s for MVHE and MVKF, respectively, the power estimates are 452.56 °Nm/s.kg and 542.13 °Nm/s.kg, respectively. The difference, as shown in Table 3 to be in the order of 89.569 °Nm/s.kg, is borderline significant (p = 0.051). This highlights the fact that during MVHE, agonists are recruited in addition to the hamstring muscles. Since the muscle fibers in both motor tasks, MVHE and MVKF, act from a similar fiber length, hip extension produces more torque but knee flexion produces more velocity, resulting in a small increase in power during hip extension, making use of a greater PCSA [42] active in hip extension. The similar length of fibers was mentioned in the comments on the first results of this research, and the fact that only quicker fibers are active as part of the second results.

Incidentally, no real difference (-0.044 Nm/kg in 2.851 Nm/kg, about 1.5%) was found between men and women, which was expected because torque was normalized to body mass. The velocity is also the same for men and women, with differences below 2% (-5.494° in 314.245°/s, about 1.7%). Consequently, the maximum weight normalized power of men and women are also similar because of body mass normalization.

Special care is necessary when prescribing a rehabilitation, prevention, or maintenance program, in the sense of adapting them to everyone [8,45]. The MVHE motor task mimics the swing phase of running, which is when most injuries occur [1,17]. For this reason, we suggest that the quantitative evaluation of parameters is of paramount importance during hamstring rehabilitation and training. A simple instrument, such as DINABANG, used together with an elastic resistance band, can be of great help in the sports field to closely monitor athletes ´ evolution, with little risk of either inefficient movements or overdose. The measurements described in this paper cannot be recorded with a simple dynamometer [46], which does not calculate torque nor velocities.

To mention methodological limitations, the reader should take necessary caution when interpreting our results because the relatively small sample size of this study could have resulted in bias we did not investigate eccentric contractions due to the risks involved when muscles are extended. To avoid iatrogenic injuries, a longer familiarization stage would have been better, which we will include in further research and clinical application.

As for practical applications, isokinetic assessment is the most accurate method for the evaluation of muscular activity [47]. The measurement is made with a computerized system that allows for movement at a constant previously determined angular velocity. This expensive piece of equipment, called an isokinetic device, is still the gold standard for quantifying torque and power during isokinetic control. DINABANG, with its EB, could be a handy complement for field work as its price is two orders of magnitude less and it can be conveniently carried around as a kind of "physiotherapist's stethoscope", much better than a simple field dynamometer.

Future work will address the exact modes of neurological and musculoskeletal adaptations of training using specific motor tasks and EB, as this sequence has not been completely described [45].

Dumbbells use gravity to create isotonic resistance and, thus, are limited regarding the diversity of exercises to which they can be applied, allowing for only one per machine. By contrast, EB do not rely on gravity but, rather, on how much the band is stretched and, therefore, they offer great versatility and several exercise options. Elastic bands together with DINABANG provide an interesting spectrum of training options, including its use in terms of wellness, for all individuals, whether they are old adults, middle-aged, or young adolescent.

Once the numerical characterization of torque, velocity and power deployed by healthy individuals with EB is available, the novel DINABANG device will include them as standards to be used with patients and athletes in training.

5. Conclusions

We have obtained normative values of torque, velocity, and power during two singlejoint motor tasks involving the hamstring muscles, to be used with DINABANG and EB. The isometrically deployed hamstring torque was more than two times greater in hip extension with agonists (2.93 Nm/kg) than in knee flexion involving the hamstring alone (1.21 Nm/kg). We also found that the deployed angular limb velocity—starting at 50% of the maximum torque—was smaller in hip extension with agonists (215.96 °/s) than in knee flexion with the hamstring alone (452.56 °/s). Finally, the combination of torque and velocity shows that at variable speed the power estimates with and without agonists do not differ (p = 0.051): 452.56 °Nm/s.kg without agonists and 542.13 °Nm/s.kg with them. This study opens the possibility of monitoring torque–velocity–power profiles for hamstring exercising in an open chain before, during, and after a hamstring injury using a simple, portable, and affordable device.

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