Original article (short paper)

Bilateral assessment of knee muscle relationships in healthy adults

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Abstract—Asymmetric performance of flexor and extensor muscles of the knee may be a risk factor for knee injuries, especially the anterior cruciate ligament. Additionally, asymmetries in power and work may have correlations with fatigue and performance during functional tasks. Among untrained individuals, such asymmetries may be of potential interest for training prescription. Here, we investigated the bilateral performance of knee flexors and extensors muscle groups of untrained individuals. We quantified the torque-angle and torque-velocity relationships, as well as work, power and asymmetry indexes in 20 untrained male (25 ± 4 years old; height 1.74 ± 0.05 m; body mass 76 ± 9 kg). No significant asymmetry was observed for torque-angle and torque-velocity relationships, work and power output for knee flexor and extensor muscle groups ($p < .05$). Our results suggest that untrained male present symmetry in the knee flexion and extension bilateral performance. Changes in this behavior due to physical training must be monitored.

Keywords: leg, injury, performance, muscle contraction, muscle strength, physical education and training

Resumo—"Avaliação bilateral de relacionamentos de músculos do joelho em adultos saudáveis." Assimetrias na produção de força de músculos flexores e extensores do joelho são fatores de risco para lesões de joelho, especialmente do ligamento cruzado anterior. Assimetrias na potência e trabalho produzido podem ter correlação com fadiga e desempenho em tarefas funcionais. Se existentes em sujeitos não treinados, assimetrias podem ser importantes para a prescrição de treinamento. Neste estudo investigamos o desempenho bilateral dos grupos musculares flexor e extensor do joelho em sujeitos não treinados. Nós quantificamos as relações torque-ângulo e torque-velocidade, bem como o trabalho, a potência e índices de assimetrias em 20 homens saudáveis, não treinados (25 ± 4 anos, estatura de 1,74 ± 0,05 m e massa corporal de 76 ± 9 kg). Nenhuma assimetria significativa foi observada para as relações torque-ângulo, torque-velocidade, trabalho ou potência produzida para flexão e extensão do joelho ($p < 0,05$). Nossos resultados sugerem que sujeitos não treinados apresentaram simetria no desempenho bilateral para flexão e extensão de joelho. Mudanças nestas características em resposta ao treinamento físico devem ser monitoradas.

Palavras-chave: pernas, lesões, contração muscular, força muscular, treinamento físico

Resumen—"Evaluación bilateral de las relaciones de músculos de la rodilla en adultos sanos." Asimetría en el rendimiento de los músculos flexores y extensores de la rodilla es un factor de riesgo en la lesión de rodilla, especialmente en la lesión del ligamento cruzado anterior. Asimetrías en potencia y trabajo pueden tener correlaciones con fatiga y un menor rendimiento en tareas funcionales. Se ha observado en sujetos desentrenados, como las asimetrías pueden ser un interés potencial en la prescripción de entrenamiento. El presente estudio investigó el rendimiento bilateral de los grupos musculares flexores y extensores de la rodilla en sujetos desentrenados. Se cuantificaron las relaciones entre el ángulo de torque y la velocidad de contracción, así como el trabajo, potencia e índices de asimetría en 20 hombres desentrenados sanos (edad: 25 ± 4 años; altura: 1,74 ± 0,05 m; peso: 76 ± 9 kg). No se observaron asimetrías significantes para la relación entre el ángulo de torque y la velocidad de contracción, el trabajo y la potencia de los grupos musculares flexores y extensores de la rodilla ($p < 0{,}05$). Nuestros resultados sugieren que sujetos desentrenados presentan simetría en el rendimiento bilateral de flexión y extensión de rodilla. Cambios en este comportamiento en respuesta al entrenamiento físico deberían ser estudiados.

Palabras clave: pierna, lesión, rendimiento, contracción muscular, fuerza muscular, educación física y entrenamiento

Introduction

Lower extremity asymmetries have been suggested as a risk factor for muscular and joint injuries. Asymmetry in knee abduction moment was 6.4 times higher in a group of women who have suffered injury of anterior cruciate ligament (ACL) compared to uninjured women (Hewett *et al.*, 2005). Athletes who suffered ACL tear presented lower hamstrings to quadriceps concentric force in the injured side compared to the contralateral (Soderman, Alfredson, Pietila, & Werner, 2001). Additionally, asymmetry in the ratio between dorsal flexion and plantar flexion force predicted the side of the injury in college athletes (Baumhauer, Alosa, Renstrom, Trevino, & Beynnon, 1995a). It has been postulated that bilateral differences for torque, work and maximal power higher than 15% may elicit impairments in performance or predisposition to injury among athletes (Zabka, Valente, & Pacheco, 2011). The origin of these injuries may rely on the repetitive higher load experienced by one side due to the asymmetries during performance (Oliveira, 2007). Therefore, while these asymmetries most likely are resultant of continuous training and functional adaptation, in untrained individuals asymmetries should not be observed.

Skeletal muscle functional adaptation can be verified by quantifying the force production during contractions at different joint angles and angular velocities (Doheny, Lowery, FitzPatrick, & O'Malley, 2008). The force output is influenced when the muscle length changes (Gordon, Huxley, & Julian, 1966). These changes are associated with alteration in joint angles, which finally reflect differences in torque output across the joint range of motion (Doheny *et al.*, 2008). Considering healthy untrained individuals, possible effects of skeletal muscle functional adaptation in the upper extremity due to daily preferential use in functional tasks were suggested as an explanation for asymmetries in the elbow flexor isometric peak torque (Carpes, Geremia, Karolczak, Diefenthaeler, & Vaz, 2012).

The preferential unilateral use reported for upper extremity among untrained individuals may not be observed for the lower extremity, as for most of the tasks healthy individuals recruit both legs in an equivalent way (e.g., during walking, running, stair locomotion). However, there are some evidences suggesting asymmetries indexes related with injury (Zabka *et al.*, 2011). Asymmetry in the performance of flexor and extensor muscles of the knee is a risk factor for knee ligament injury (Knapik, Bauman, Jones, Harris, & Vaughan, 1991; Schache, Crossley, Macindoe, Fahrner, & Pandy, 2011). In other hand, asymmetries in power and work may have correlations with fatigue and performance of functional tasks (Carabello, Reid, Clark, Phillips, & Fielding, 2010). Additionally, work output is a good indicator of the muscle's capability to perform daily life activities. On the other hand, power output provides a measure of the work rate intensity and permits to infer how quickly force can be produced. From a practical point of view, evaluating such asymmetries in untrained individuals before starting participation in sport routines could significantly help to minimize risks for injuries during the time course of exercise and training.

Here we proposed to investigate bilateral performance of knee flexors and extensors muscle groups by quantifying the torque-angle and torque-velocity relationships, as well as work, power and asymmetry indexes in untrained healthy individuals. For such purpose, performance was compared between preferred and non-preferred sides.

Methods

Design

Knee flexor and extensor torque-angle and torque-velocity relationships, were obtained bilaterally through maximal voluntary isometric and isokinetic concentric contractions (MVCs), respectively. Leg asymmetries were investigated by comparing preferred and non-preferred sides. All tests were performed in one day. Ethical approval for our study was obtained from the local Institutional Ethics Research Committee (protocol number 2007791). Participants signed an informed consent form according to the Declaration of Helsinki before starting participation in the experiments.

Participants

Twenty male individuals (mean ± standard deviation for age: 25 ± 4 years; height: 1.74 ± 0.05 m; body mass: 76 ± 9 kg) volunteered for this investigation. Participants completed a questionnaire for the purpose of identifying history of physical trauma or surgery, neuromuscular injury and previous strength training for the lower extremity, all considered exclusion criteria for the experiment. All the participants performed up to three familiarization trials for each condition in the laboratory in the day before the tests. During the time of the experiment and the six months prior to testing none of the individuals was involved in regular physical activity programs aiming at strength and power development (e.g., strength training, athletics, and gymnastics).

Testing protocols

Right and left knee flexor and extensor torques were evaluated by means of an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical Systems, Shirley, NY). Participants were positioned on the dynamometer according to the manufacturer's recommendations for knee evaluations with hip angle fixed at 85° and their trunk, hips and thighs firmly strapped to the apparatus. The knee joint axis of rotation (considering the lateral condyle of femur) was aligned with the axis of rotation of the dynamometer arm. Tests were repeated for the contralateral limb by recording the lever arm length, elevation of the dynamometer head and seat position for each participant by an experienced researcher. The resistance was located at the more distal point of the lower leg, supported in the ankle. Afterwards, the attachment was firmly fixed to the participants' segment. Positioning was careful controlled to be consistent among all the participants.

Participants were verbally encouraged to perform their maximal effort during MVCs. At the end of each protocol, the first trial was repeated to verify fatigue effects. If the torque at the final trial decreased more than 10% with respect to the initial trial, a fatigue effect was assumed to be present and the participant would be invited to repeat the protocol on a different day. In this study no participant was requested to come back to the lab as we did not observed fatigue effects.

During testing, the active range of motion ranged from full knee extension to maximal knee flexion (0° = full active knee extension). Torque signals were sampled at 100 Hz, and were gravity corrected through the overall range of motion using the Biodex software. Leg preference was verified using the revised version of the Waterloo's inventory (Elias, Bryden, & Bulman-Fleming, 1998). After verifying the leg preference, legs were named as preferred and non-preferred (NP).

Torque measurements

Torque-angle relationship: maximal isometric flexor and extensor contractions were executed with the knee joint fixed at five different angles: 30°, 60°, 75°, 90° and 105° (Baroni *et al.*, 2013). The order of joint angles tested was random. For each angle two repetitions were performed and the contraction with the highest peak torque produced was considered for further analysis. Each isometric contraction lasted 5 s, and a 2 min interval was observed between the consecutive contractions.

Torque-velocity relationships: torque-velocity trials were conducted for flexion-extension isokinetic contractions at five different angular velocities: $60°.s^{-1}$, $120°.s^{-1}$, $180°.s^{-1}$, $240°.s^{-1}$ and $300°.s^{-1}$ (Baroni *et al.*, 2013). The order of angular velocities tested was random for each participant during the isokinetic test. For each angular velocity three flexion-extension isokinetic contractions were performed and the highest peak torque produced during flexion and extension movements was considered for further analysis. A 2 min interval was observed between the consecutive contractions.

Work and power determination: total work was computed considering the amount of force output maintained throughout isometric trials. Power was computed during isokinetic trials considering the amount of total work output divided by the time to complete that total work.

Asymmetry index

An asymmetry index ($AI_{\%}$) describing the relative difference in strength between the preferred and non-preferred leg was calculated using Equation 1 (Chavet, Lafortune, & Gray, 1997). This equation provides the magnitude and direction of bilateral asymmetry considering leg preference. Negative $AI_{\%}$ values indicated higher torque for the non-preferred limb.

$$AI_{\%} = \left(\frac{P - NP}{P}\right) \cdot 100 \quad (1)$$

where: $AI_{\%}$ means asymmetry index, considering the ratio between measurements in the preferred (P) and non-preferred (NP) leg.

Data analysis

Torque values were expressed as mean and standard-deviation for the group. Data normality was verified using Shapiro-Wilk test. A two-way analysis of variance (5 angles/velocities x 2 legs) was used to evaluate the effects of angles/angular velocities and leg on peak torque, power and work. A paired *t*-test was used to compare torque values obtained at the first and last trials in order to observe any fatigue effect. The significance level was set at .05 for all comparisons using a statistical package (SPSS 17.0, SPSS Inc., Chicago IL, USA).

Results

No fatigue effect was observed when comparing the first and last trials for the different variables we quantified. Torque-angle results indicate that isometric flexor torque was similar between the legs ($F_{1,19}$ = 1.861; p = .189). A main effect for joint angle was observed for the peak isometric flexor torque ($F_{4,76}$ = 359.66; p < .001) (Figure 1). In the same way, asymmetries

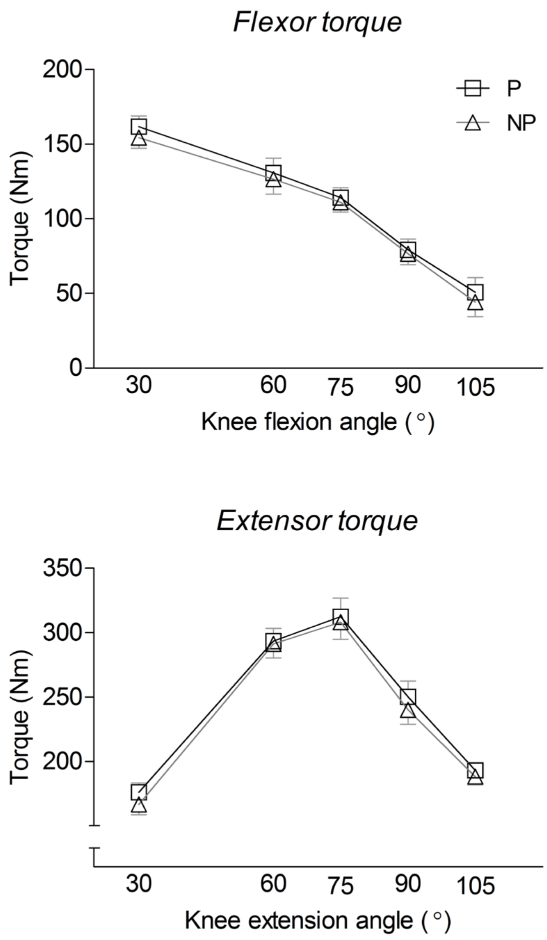

Figure 1. Torque-angle relationship for knee flexors (top) and extensors (bottom) during isometric trials.

between legs were not observed for extensor isometric peak torque ($F_{1,19}$ = 2.808; p = .110). A main effect for joint angle was observed in the isometric peak extensor torque ($F_{4,76}$ = 81.063; p < .001) (Figure 1). Torque-angle relationship for knee flexors and extensors during isometric trials followed a pattern already described in the literature (Frykberg *et al.*, 2006).

Isokinetic torque-velocity results indicated that isokinetic flexor peak torque was similar between legs ($F_{1,19}$ = 0.045; p = .835). A main effect for contraction velocity was observed ($F_{4,76}$ = 23.50; p < .001) (Figure 2). Isokinetic extensor peak torque was similar between legs ($F_{1,19}$ = 0.339; p = .567), and a main effect for contraction velocity was observed ($F_{4,76}$ = 334.06; p < .001) (Figure 2). Torque-velocity relationship for knee flexors and extensors during isokinetic trials followed a pattern already described in the literature (Frykberg *et al.*, 2006).

Table 1 presents the magnitudes of asymmetry indexes computed for flexor and extensor peak torques at different joint angles (isometric) and different contraction velocities (isokinetic).

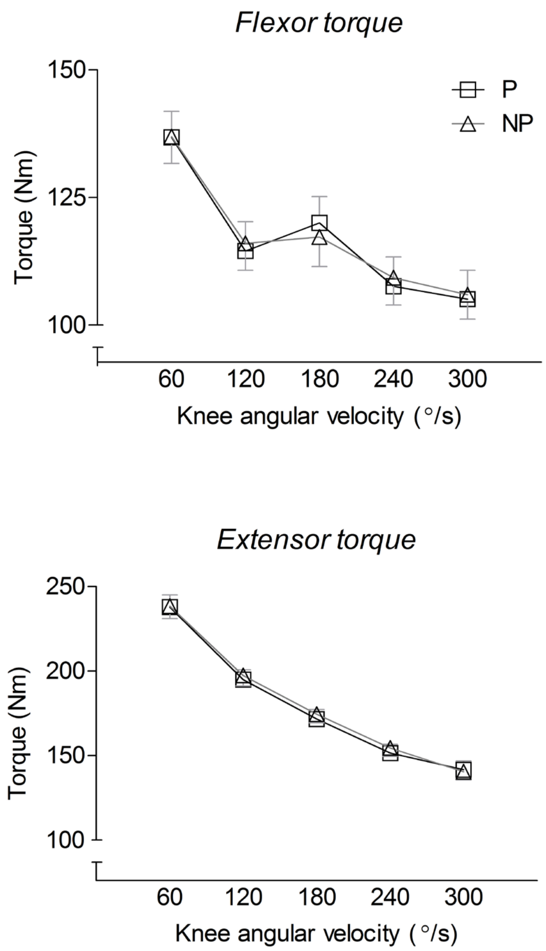

Figure 2. Torque-velocity relationship for knee flexors (top) and extensors (bottom) during isokinetic trials.

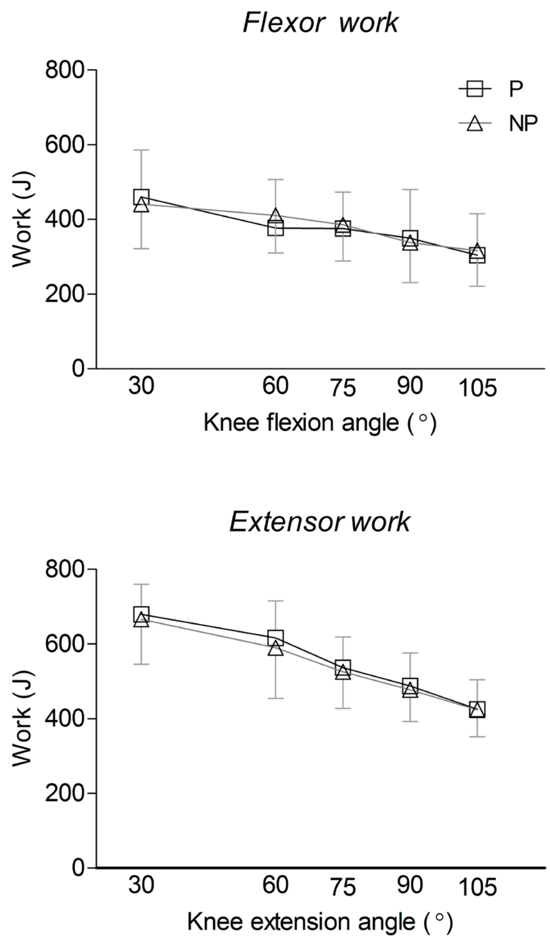

Figure 3. Flexor (top) and extensor (bottom) work done during isometric contractions at different joint angles.

Table 1. Asymmetry indexes (%) for torque-angle and torque-velocity muscle relationship. Data are expressed as mean ± standard-deviation. TxA: torque-angle relationship; TxV: torque-velocity relationship.

			Torque-angle (isometric peak torque) Angles		
	30°	60°	75°	90°	105°
TxA flexor (%)	4.6±10.5	3.3±9.9	2.8±8.3	3.5±1.9	12.6±5.3
TxA extensor (%)	5.4±10.9	0.7±10.4	1.4±7.7	4.1±5.9	2.5±6.6
			Torque-velocity (isokinetic peak torque) Velocities		
	60°/s	120°/s	180°/s	240°/s	300°/s
TxV flexor (%)	-0.1±5.2	-1.3±8.6	5.4±11.0	-1.6±6.7	-0.8±15.8
TxV extensor (%)	-0.3±0.4	-1.3±6.0	-1.7±11.8	-2.0±6.0	0.8±4.1

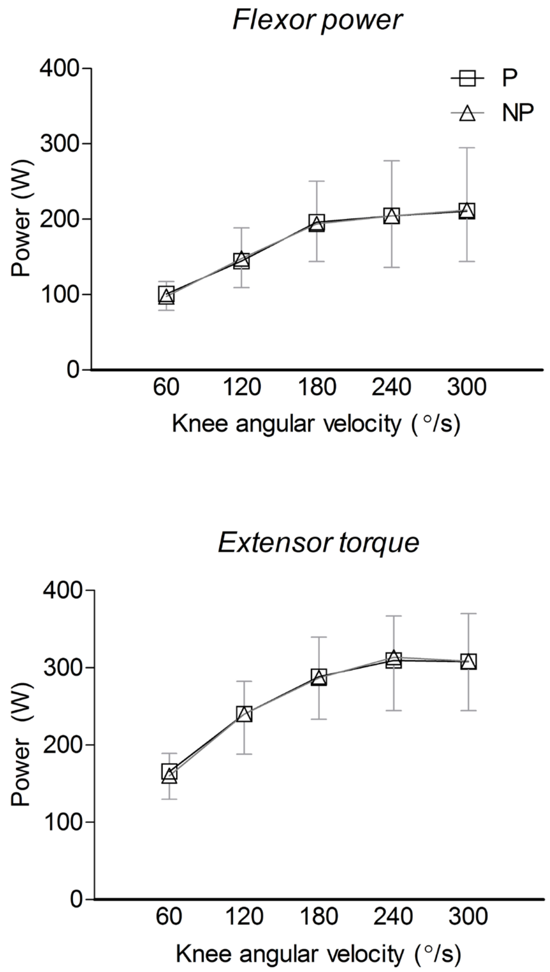

Figure 4. Flexor (top) and extensor (bottom) power output during isokinetic contractions at different contraction velocities.

Work performed during both knee flexion ($F_{1,19}$ = 0.210; p = .652) and extension ($F_{1,19}$ = 1.163; p = .294) during isometric trials was similar between legs. A main effect for joint angle was observed for knee flexion ($F_{4,76}$ = 20.449; p < .001) and extension ($F_{4,76}$ = 75.207; p < .001) (Figure 3). Similar results were observed for power output measured during isokinetic trials. The power was similar between legs for both flexion ($F_{1,19}$ = 0.001; p = .970) and extension ($F_{1,19}$ = 0.007; p = .935). A main effect for contraction velocity was observed for both flexion ($F_{4,76}$ = 53.818; p < .001) and extension ($F_{4,76}$ = 157.784; p < .001) (Figure 4).

Discussion

Information on leg asymmetries in untrained individuals may be useful to describe a baseline condition prior to engagement in regular physical training. Such information may interest participants and coaches before starting participation in a routine of sport or physical training. The information on leg asymmetries can significantly help to minimize risk for injuries, as well as to understand changes in asymmetry indexes resultant of long-term training. Here we evaluated the bilateral performance in torque-angle and torque-velocity muscle relationships, work, power, compared preferred versus non-preferred leg, and computed asymmetry indexes for knee flexor and extensor muscles in non-trained participants. No statistical significant asymmetry was observed in our study.

Power and work were similar between the legs. It was expected since maximal isometric peak torques and maximal isokinetic peak torques were similar between legs. Therefore, participants evaluated in our study did not present evident adaptations that influence torque production at the knee joint eliciting advantage for preferred leg over the contralateral. The differences observed between the joint angles and contraction velocities are expected in this type of assessment (Andersen *et al.*, 2005). Additionally, discussion of such results was not among the purpose for this study and they are not further discussed here. Discussion on this topic can be found in the literature (Frykberg *et al.*, 2006).

Limb preference involves genetic and environmental components that work towards the preferential use of a given limb. However, it is known that the environmental component has greater influence to the consolidation of limb preference (Teixeira, 2001). In this regard, training may contribute to onset of asymmetries, as the highest asymmetry index we observed was 12.6±5.3%, which is lower than the 15% suggested as a risk factor among athletes (Zabka *et al.*, 2011).

When untrained individuals were evaluated for the torque-angle and torque-velocity relationships of elbow flexor and extensor torque, the only asymmetry reported occurred at the flexor isometric peak torque at the angle where highest peak torque was produced, in favor of the preferred limb (Carpes *et al.*, 2012). The results were discussed considering that even among untrained individuals there is a preferential recruitment of the preferred arm for weight sustaining tasks, and for mostly of cases it happen with elbow flexed at 90º, angle where asymmetry was reported. Therefore, asymmetries observed for elbow flexors may rely on angle-specific muscle adaptations, which we have not observed for the knee joint in our study.

In general, lower extremity asymmetries have been useful to predict injury risk (Baumhauer, Alosa, Renström, Trevino, & Beynnon, 1995b; Knapik *et al.*, 1991; Rauh, Koepsell, Rivara, Rice, & Margherita, 2007; Söderman, Alfredson, Pietilä, & Werner, 2001; Zifchock, Davis, & Hamill, 2006). An association between knee strength asymmetries and joint angle has been reported during jump tasks in college athletes (Kobayashi *et al.*, 2013), for joint torques in long jumpers performing squat exercise (Kobayashi *et al.*, 2010), and strength imbalances in athletes for both knee flexor and extensor muscle groups (Deli *et al.*, 2011). During locomotion of healthy participants, kinematic asymmetries at knee were found (Maupas, Paysant, Datie, Martinet, & Andre, 2002), although no relationship between asymmetry and lateralization was found (Maupas *et al.*, 2002). Additionally, isokinetic strength of knee flexors and extensors was not correlated with laterality (Maupas *et al.*, 2002).

Our results showed similar peak torque across the different contraction velocities tested, which was also observed for power and work. However, considering athletes performing single-leg jumps, despite the similar isokinetic strength, significant correlations were observed for bilateral asymmetry index of isokinetic knee strength at 180°/s. Correlations were also observed when considering bilateral symmetry indexes for maximum flexion angle and mean knee joint torque during single-leg jumps (Kobayashi *et al.*, 2013). Additionally, court sport players presented weaker preferred leg (determined by preference to kick a ball) when considering hamstrings working at low ($60°\cdot s^{-1}$) and high ($300°\cdot s^{-1}$) contraction velocities, whereas hamstrings to quadriceps ratio was significantly larger at preferred leg among field players (determined by preferential leg to kick a ball) at a contraction velocity of $60°\cdot s^{-1}$ and in their non-preferred leg at $300°\cdot s^{-1}$ (Cheung, Smith, & Wong del, 2012). These results reinforce the concept that sports training may lead to specific muscular adaptations, which may have a leg preference effect leading to asymmetries.

In summary, the main contribution of our study is to describe the characteristics of a group of untrained male considering knee isometric and isokinetic performance, to show that among untrained individual asymmetries were not observed. Such result is important when considering further engagement in regular exercises that may influence asymmetries as described in previous studies mentioned. Among the limitations in our study we highlight the small sample size and the consideration of only male individuals for the testing.

Conclusion

Bilateral torque production in healthy untrained participants show no significant asymmetries for torque-angle and torque-velocity relationships, work and power output for knee flexor and extensor muscle groups. Therefore, healthy individuals who are not involved in specific training for the lower extremity present no evidence of adaptation at the knee joint that may elicit advantage for the preferred leg over the contralateral leg.

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