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Artigo Original

Preference and torque asymmetry for elbow joint

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Abstract: Extensively unilateral recruitment for daily activities may determine performance asymmetries in favor of the preferred side eliciting functional adaptation. Our study evaluated asymmetries in elbow torque output between preferred and non-preferred limbs. Eighteen subjects performed maximal elbow flexor and extensor isometric contractions at five different elbow joint angles (0°, 30°, 60°, 90°, 120°) and five different angular velocities (60, 120, 180, 240, 300°.s^{-1}) on an isokinetic dynamometer. Higher flexor torque in favor of preferred arm was observed at 90° of flexion ($p<0.05$), which also corresponded to the highest torque produced ($p<0.05$). The fact that joint angle influenced torque asymmetries, whereas angular velocity did not, suggest that the observed asymmetry is likely related to preferential recruitment of elbow flexors at a 90º joint angle for daily tasks requiring high levels of force production. Muscle functional adaptation to frequent stimuli at this joint angle in healthy subjects may explain these results.
Keywords: functional lateralization; learning transference; limb preference; motor learning.

Preferência e assimetria de torque na articulação do cotovelo

Resumo: O frequente recrutamento unilateral de membros superiores pode determinar assimetrias de desempenho em favor do lado preferido, resultando em adaptação funcional. Assimetrias no torque gerado pelos músculos do cotovelo entre o membro preferido e não-preferido foram avaliadas. Dezoito sujeitos realizaram contrações máximas de flexo-extensão do cotovelo em cinco ângulos articulares (0°, 30°, 60°, 90°, 120°) e cinco velocidades angulares (60, 120, 180, 240, 300°.s^{-1}) em um dinamômetro isocinético. Torque flexor mais elevado em favor do lado preferido foi encontrado no ângulo de 90° ($p<0,05$), que também correspondeu ao ângulo de maior torque ($p<0,05$). O fato de o ângulo articular determinar assimetrias no torque (enquanto a velocidade angular não) sugere que o recrutamento preferencial dos flexores do cotovelo em um ângulo de 90° nas tarefas da vida diária que requerem força elevada é responsável pela assimetria. Adaptação funcional a estímulos frequentes nesse ângulo articular pode explicar esses resultados em sujeitos saudáveis.
Palavras-chave: lateralização funcional; transferência de aprendizagem; preferência lateral; aprendizagem motora.

Introduction

Preference and performance are associated, which means that performance of preferred limb is usually more successful than that observed for the contralateral limb (SERRIEN et al., 2006). Additionally, up to 90% of adults (HERVE et al., 2006; HARDYCK; PETRINOVICH, 1977) show right hand preference for a variety of movements (REIO et al., 2004; SHABBOTT; SAINBURG, 2008). In terms of muscle functional adaptation, previous studies showed that long term unilateral use improved resistance to fatigue of *trapezius* muscle (FARINA et al., 2003). Among the plausible explanations to these results are changes in muscle fiber composition towards a prevalence of slow twitch type I fibers in the preferred side (FUGL-MEYER et al, 1982), which would occur associated with reduced firing rates in the preferred side (ADAM et al, 1998). Consistent with these findings is the shorter fatigue recovery time of elbow flexor muscles from the preferred arm (WILLIAMS et al, 2002). These results suggested that limb preference, especially for the upper limb, may be associated with neuromuscular advantages in favor of the preferred side.

Preference could influence aspects related to force production due to long term adaptations from repeated use (SHOEPE et al, 2003). Although previous studies addressed asymmetries in muscle activation, upper limb asymmetries in torque-angle and torque-velocity relations apparently have not been properly addressed. The assessment of force production at different joint angles and angular velocities may allow for the identification of skeletal muscle functional adaptation (DOHENY et al, 2008). Additionally, force production according to the cross-bridge theory (HUXLEY, 1957) is influenced by muscle length changes (GORDON et al, 1966). Muscle length changes can be produced by changing the joint angle, which therefore will change torque output (DOHENY et al, 2008; HANSEN et al, 2003).

According to the relationship between the shortening velocity and the force a muscle can exert (HILL, 1938), elbow flexor torque should decrease hyperbolically as the angular velocity increases (UCHIYAMA; AKAZAWA, 1999). Assuming that a muscle adapts to the functional demands it is subjected to as shown when comparing different athletes (e.g. HERZOG et al., 1991; FRASSON et al., 2007), a similar behavior would be expected in terms of adaptation between the preferred and non-preferred limbs even if no significant differences in fiber type composition occur. Additionally, increased unilateral use is related to mechanical driven bone growth and asymmetric remodeling between limbs of racquetball and tennis players (LAZENBY, 2002). Since sports eliciting pronounced use of one side of the body (such as baseball, handball and basketball) would be expected to increase performance asymmetries in favor of the preferred side (TEIXEIRA et al, 2003), we hypothesized that non-trained subjects should present similar between-limbs performance in terms of maximal elbow torque production due to a similar functional demand between preferred and non-preferred limbs.

To the best of our knowledge, there is no previous study comparing upper limb asymmetries for torque-angle and torque-velocity relations at elbow joint. The purpose of this study was to verify whether there is asymmetry in elbow flexor and extensor torques in healthy right-handed subjects. This between-limb asymmetry was evaluated by elbow flexor and extensor torques obtained (1) at different joint angles and (2) at different shortening velocities.

Methods

Design

The elbow flexor and extensor torque-angle and torque-velocity relations were obtained bilaterally through maximal isometric and isokinetic contractions, respectively. Lateral asymmetries were investigated by comparing preferred and non-preferred limbs. All tests were performed in one day. Ethical approval was obtained from the local Institutional Ethics Research Committee. Participants signed an informed consent form according to the Declaration of Helsinki before starting their participation in the experiments.

Participants

Eighteen male subjects (mean ± standard deviation for age 28 ± 6 years old; height 1.78 ± 0.08 m; body mass 82 ± 5 kg) volunteered for this investigation. Previous studies (GLOBE et al., 2006; GLOBE; BROWN, 2010) that evaluated upper limb asymmetries used a similar (or smaller) number of individuals. Only right-handed subjects (determined by the preferred hand to write and/or draw) were included in the study. Subjects with a history of physical trauma or surgery, neuromuscular injury and previous physical training for the upper extremity were excluded.

Testing protocols

Right and left elbow flexor and extensor torques were evaluated by means of an isokinetic dynamometer (Cybex NORM, Lumex & Co., Ronkonkoma, NY, USA). After calibration of the dynamometer according to the manufacturer's specifications, subjects were positioned supine and had the trunk stabilized using hip and chest straps. The elbow joint axis of rotation 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 subject by an experienced researcher.

During testing, the active range of motion ranged from full elbow extension (set as 0°) to maximal elbow flexion at approximately 120°. A mechanical range of motion stop was used to prevent hyperextension of the elbow. Prior to the tests, subjects warmed up by actively flexing and extending the elbow joint throughout the total range of motion for a period of five minutes (KAROLCZAK et al., 2009). Torque signals were recorded at a sampling rate of 100 Hz, and were gravity corrected through the overall range of motion using the Cybex NORM® software.

Torque measurements

Torque-angle relation: three maximal isometric flexor and extensor contractions were executed with the elbow joint fixed at five different angles: 0°, 30°, 60°, 90° and 120°. The joint angles order during the test was randomly chosen for each subject. From the three maximal voluntary contractions for each joint angle, the contraction with the highest torque value among the three trials was selected for data analysis (KAROLCZAK et al., 2009).

Torque-velocity relation: torque-velocity trials were conducted for flexion-extension concentric contractions at five different angular velocities: $60°.s^{-1}$, $120°.s^{-1}$, $180°.s^{-1}$, $240°.s^{-1}$ and $300°.s^{-1}$. The angular velocities order was randomly chosen for each subject during the isokinetic test. Three maximal concentric contractions were performed at each of the five different angular velocities (LABARQUE et al., 2002), and the contraction with the highest torque value among the three trials was selected for data analysis.

A resting period of 120s was observed between consecutive contractions to avoid fatigue (LABARQUE et al., 2002). At the end of each protocol, the first trial was repeated to control for possible 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 subject was asked to repeat the protocol on a different day.

Strength asymmetry index determination

An asymmetry index ($AI_{\%}$) describing the relative strength difference between the preferred (P) and non-preferred (NP) limb was calculated using equation 1 (CHAVET et al., 1997). The ratio between the maximal torque difference of P and NP limbs with respect to the maximal torque of the P limb was used to determine the relative between-limb differences considering input data from the torque-angle and torque-velocity trials. This equation provided the magnitude and direction of bilateral asymmetry and considered the lateral preference. Negative $AI_{\%}$ values indicated higher torque for the NP limb.

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

Where: AI means asymmetry index considering the ratio between maximal torque measurements taken for the preferred (P) and non-preferred (NP) limbs.

Data analysis

Torque values (Nm) were expressed as mean and standard-deviation for the group. Data normality was verified using a Shapiro-Wilk's test. Analysis of variance was used to compare P and NP torques from torque-angle and torque-velocity trials, respectively, using a mixed model (5x2). Where main effects were found, independent t-tests were applied to identify the statistically significant difference between limbs and a one-way analysis of variance to identify differences between angles or between angular velocities. A repeated measures t-test was used to compare torque values obtained at the first and last protocol trials (fatigue assessment). The significance level was set at 0.05 for all comparisons using a statistical package (SPSS 13.0, SPSS Inc., Chicago IL, USA).

Results

No subjects were excluded from the tests nor tests needed to be repeated at a different date due to torque decreases during the protocol. Also, no fatigue effects were observed when comparing the first and last protocol trials. The observed power for all results was greater than 0.7.

The isometric torque produced at 90° of elbow flexion was higher ($p<0.05$) for the P compared to the NP limb, whereas elbow extensor torques were similar between limbs, regardless of joint angle (Figure 1). This angle specific asymmetry corresponded to an AI of 19% in favor of the P arm.

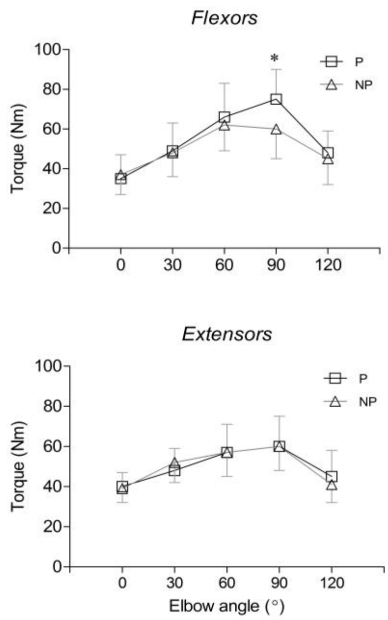

Figure 1. Torque-angle relation for elbow flexor (top) and elbow extensor (bottom) muscles. Asymmetry was observed only for the preferred limb at the elbow joint angle of 90°. (* indicates $p<0.05$; P=preferred; NP = non-preferred).

No differences between P and NP limbs were observed for elbow flexion and extension torque-velocity trials (Figure 2). The asymmetry indexes were smaller than those found for isometric trials, i.e. -0.01±0.03% for flexion torque and -0.02±0.05% for elbow extension torque, respectively (Table 1).

The asymmetry index across the different joint angles was highly variable, ranging from -5.09% at 0° up to 19.82% at 90° for the elbow flexors, and from -8.99% at 120° up to 0.57% at 60° for the elbow extensors. Negative values of AI indicated that asymmetry was towards the NP limb.

The asymmetry index was similar across the different angular velocities with all values below 0.1% for both elbow flexors and extensors.

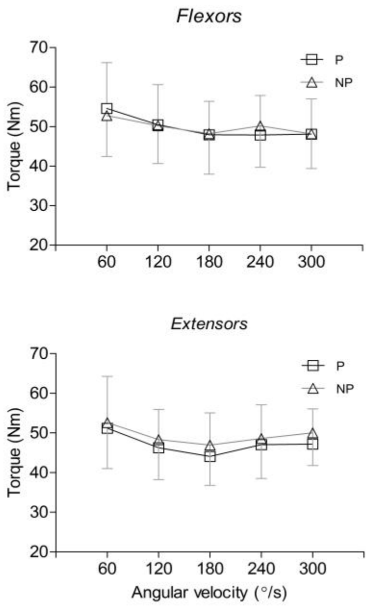

Figure 2. Torque-velocity relation for elbow flexor (top) and elbow extensor (bottom) muscles. No asymmetry was observed between the preferred (P) and non-preferred (NP) limbs.

Table 1. Asymmetry index found for different joint angles and angular velocities for flexion and extension peak torque. A negative value means direction of asymmetry to the non-preferred arm. Observe the higher variability for AI obtained for the different joint angle as opposed to the almost non-variant AI obtained for the different angular velocities.

Joint angle (°)	$AI_{\%}$ *flexion*	$AI_{\%}$ *extension*	Velocity (°/s)	$AI_{\%}$ *flexion*	$AI_{\%}$ *extension*
0	-5.09	-3.90	60	0.03	-0.03
30	1.03	0.08	120	0.00	-0.04
60	5.32	0.57	180	-0.01	-0.07
90	19.82	-0.74	240	-0.05	-0.03
120	6.97	-8.99	300	0.00	0.06

Discussion

The aim of this study was to verify whether between-limbs asymmetries can be determined when evaluating flexor-extensor elbow mechanical properties by means of the torque-angle and torque-velocity relations. More specifically, we wanted to know if asymmetries are more pronounced at isometric compared to isokinetic muscle actions across the elbow joint. Our main findings are that: (1) asymmetry is present at the elbow joint angle of 90°; (2) asymmetry is higher for the elbow flexors compared to the elbow extensors during isometric contractions at different joint angles; (3) asymmetry is absent at different angular velocities for both flexors and extensors during concentric muscle actions. To the best of our knowledge, even though force-length and force-velocity relations have been extensively addressed in the literature, this was the first investigation with specific concern on lateral asymmetries while evaluating these two different muscle relations.

The choice to evaluate untrained subjects was determined in order to evaluate between-limb asymmetries that would reflect a similar condition to that of the general population. Also, the idea was to determine if daily life activities would be responsible to determine some kind of mechanical adaptation between preferred and non-preferred limbs. As mentioned above, our main findings showed no significant shortening velocity effect on elbow torque asymmetry, but asymmetric elbow flexion torque production in favor of the preferred limb at a joint angle of 90°. Torque asymmetry as obtained for the isometric trials appears to be dependent on (a) muscle length and on (b) the level of force production.

Muscles working as agonists for elbow flexion (*biceps brachii, brachialis and brachioradialis*) have their optimal force production expected to occur at the elbow joint angles of 110°, 100° and 50°, respectively (CHANG et al, 1999). Therefore, the angle of 90° where asymmetry was observed in our study can be considered inside the range where maximal elbow flexor torque production is observed (i.e., somewhere between 110° and 50° of elbow flexion) (KOO et al, 2002). It is interesting to observe, however, that maximal torque production was obtained at an elbow joint angle of 90° for the preferred limb, whereas it occurred at a joint angle of 60° for the non-preferred limb (Figure 1). This suggests that torque is probably produced at a higher range of motion for the preferred limb, whereas the range of motion for torque production seems to be smaller for the preferred limb.

These results also suggest that the preferential use of one limb during daily life activities performed by the general population leads to an asymmetric use of the upper limb. Therefore, activities such as carrying a book or a bucket; raising some heavy objects from the ground or pull a door in a building entrance is most likely executed by the preferred limb. For all these cases, an elbow angle of approximately 90° of flexion seems to be naturally selected for the preferred limb. Additionally, when the task is performed unilaterally and requires confidence, the preferred limb will be chosen. Therefore, it appears that the repeated recruitment elicits a muscular adaptation that might change the structural properties of skeletal muscles as determined by changes in muscle architecture (LIEBER; FRIDÉN, 2001), which is reflected in the torque-angle relation.

Although not evaluated in the present study, learning transfer between limbs seems to occur while performing motor actions, and may have influenced our results. Between-limbs learning transfer seems to be influenced by the force level required to perform different motor tasks (TEIXEIRA; CAMINHA, 2003). There are two general explanations for learning transfer asymmetry: (a) one hemisphere and/or limb would have a superior capacity for motor learning, or (b) following training, the access of the two limb' controllers to memory resources might be asymmetrical (WANG; SAINBURG, 2006).

The first hypothesis is related to a proficiency model which postulates superiority of the dominant hemisphere (contralateral to the P limb), which would result in more information transferred to the NP limb following dominant arm learning (PARLOW, KINSBOURNE, 1989). In other words, as we acquire new motor abilities with the preferred limb, part of this learning process is transferred to the non-preferred limb through the neural network that crosses to the contralateral side.

The second hypothesis concerns the callosal access model. It suggests that information obtained during learning of a new task with both arms is stored in the dominant brain hemisphere, which would predict better transferring to the preferred limb due to more direct intra-hemispheric access (TAYLOR, HEILMAN, 1980). Recent investigation provided evidences for a supplementary motor area-based mechanism supporting the process of inter-manual transfer when learning a motor skill (PEREZ et al, 2007), which probably involves the mechanisms proposed in the two previously abovementioned theories. Indeed, when tasks that did not require high force production (finger movements) were assessed, learning transfer was observed for tasks requiring similar movements, regardless of performance asymmetries between hands, and independent of whether the trained hand was the right or left (TEIXEIRA; OKAZAKI, 2007).

Despite of the evidences of learning transfer in the literature, our study does not allow for the identification of this process or how it may have interfered with our results. However, if the daily life motor actions are executed preferentially by one of the limbs, peripheral adaptations are expected to occur, and they will determine different force production capacities despite of motor learning.

Assuming that we use our two upper limbs with different joint range of motion during daily tasks, the limb that is used with higher muscle excursion will most likely adapt the optimal angle of force production to the midrange of the range of motion as based on the force-length relationship (GORDON et al., 1966). This means that both in parallel and in series sarcomerogenesis may occur in the preferred limb, leading to higher ability to produce force at a specific joint angle, and torque asymmetry would emerge despite of learning transfer. Our data support this assumption since asymmetry was found at a joint angle similar to that often recruited during daily life activities, and in favor of preferred limb. It would also imply that when the system becomes asymmetric (such as during the training with asymmetric forces), a progressive decline in the transfer effects is expected (TEIXEIRA; CAMINHA, 2003). Further investigation addressing bilateral electromyographic measurements would be able to show if the preferred limb showed improved neuromuscular efficiency, which would endorse this hypothesis.

In the other hand, no effects of angular velocity were observed on flexor and extensor torque asymmetry. While running, there is a reduction in kinetic parameters asymmetries during take-off as running velocity increases (CAVAGNA, 2006). A reasonable explanation to the symmetry improvement as velocity increased is the decrease in the participation of contractile components for work output, minimizing possible between-limbs asymmetry. Our results, however, do not support this hypothesis, as a decrease in asymmetry should be observed with increasing angular velocities. The fact that (1) the asymmetry index was similar amongst the different angular velocities and that (2) no decrease in asymmetry index was observed with increasing angular velocity goes against the evidences observed for increasing running velocity. However, differences in preference between upper and lower limbs should be better explored in future studies, as lower limb actions during daily life activities seem to be more symmetrical compared to that of upper limbs.

The fact that the asymmetry index was different for different joint angles leads to the hypothesis that the preferred limb would have more sarcomeres in series in the flexor muscles due to the larger capacity of force production at a more extended elbow position (90°) as compared to the non-preferred limb (60°). This would mean that changes in the asymmetry index should be different with increasing angular velocity between the preferred and non-preferred limb, which was not the case in our study. Therefore, inter-limb asymmetry seems to be a complex phenomenon whose mechanisms have not been fully elucidated yet. New studies looking into the structural (muscle architecture), neural (electromyography) and functional (torque) limb asymmetries may shed light and help to better define the exact mechanisms responsible for asymmetries during isometric and dynamic actions.

Conclusion

In summary, the asymmetry in skeletal muscle force-length (or torque-angle) relation parameters suggests that lateral preference should be considered when performing unilateral investigations as well as when developing unilateral therapies considering maximal strength of elbow flexors. This observation may be of special importance for unilateral sports, where the unilateral practice may reinforce this effect, and should be further tested in trained subjects. The symmetry of force-velocity relations between preferred and non-preferred limbs did not support the presence of shortening velocity effects on torque asymmetries for untrained subjects.

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