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original article

Gymnasts and non-athletes muscle activation and torque production at the ankle joint

Ativação muscular e torque na articulação do tornozelo entre ginastas e não-atletas

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Abstract – Artistic Gymnasts (AG) execute specific movements that require substantial movement control and force production at the ankle joint. This high demand might change the neuromechanical properties of the ankle joint muscles in these athletes compared to non-athlete girls (NAG). The aim of this study was to compare muscle activation and torque production at the ankle joint between AG and NAG. Ten AG (11.70 ± 1.06 years of age) and 10 NAG (11.70 ± 1.49 years of age) participated in the study. Electromyographic (EMG) signals of medial gastrocnemius (MG), soleus (SO) and tibialis anterior (TA) were obtained simultaneously to the maximal isometric plantarflexion (PFT) and dorsiflexion (DFT) torques of the dominant limb during a maximal voluntary isometric contraction (MVIC) at five different joint angles (20°, 10°, 0°, -10° e -20°). Neuromuscular efficiency was also calculated by the Torque/EMG ratio. AG presented higher PFT ($p<0.01$) and smaller DFT ($p<0.05$) at all joint angles compared to NAG. RMS values from the three muscles were similar between groups ($p>0.05$). In addition, AG showed higher values for plantarflexion neuromuscular efficiency and smaller values of dorsiflexion neuromuscular efficiency compared to the NAG ($p<0.01$). Higher sports demands of AG determined higher PFT, higher plantarflexor efficiency, smaller DFT but similar activation of MG, SO and TA compared to NAG.

Key words: Electromyography; Gymnastics; Torque; Training.

Resumo – *Ginastas artísticas (GA) executam movimentos específicos que exigem grande controle do movimento e produção de força na articulação do tornozelo. Essa elevada demanda desse esporte pode alterar as propriedades neuromecânicas dos músculos do tornozelo quando comparado a meninas não-atletas. Objetivou-se comparar a ativação muscular e a produção de torque na articulação do tornozelo entre GA e meninas não-atletas (MNA). Participaram do estudo 10 GA (11,70 ± 1,06 anos) e 10 MNA (11,70 ± 1,49 anos). Sinais eletromiográficos (EMG) dos músculos gastrocnêmio medial (GM), sóleo (SO) e tibial anterior (TA) foram obtidos simultaneamente ao torque isométrico máximo de flexão plantar (TFP) e flexão dorsal (TFD) no tornozelo dominante durante contração voluntária máxima isométrica (CVMI) em cinco ângulos articulares (20°, 10°, 0°, -10° e -20°). Além disso, a eficiência neuromuscular foi calculada por meio da razão Torque/EMG. GA apresentaram maior TFP (p<0,01) e menor TFD (p<0,05) em todos os ângulos articulares comparadas às MNA. Os valores RMS nos três músculos avaliados não diferiram entre os grupos (p>0,05). Além disso, GA apresentaram maiores valores de eficiência neuromuscular de flexão plantar, e menores de flexão dorsal, comparadas às MNA (p<0,01). A maior d emanda do esporte nas GA determinou maior TFP e maior eficiência de flexão plantar, mas menor TFD e igual ativação do GM, SO e TA comparadas à MNA.*

Palavras-chave: *Eletromiografia; Ginástica; Torque; Treinamento.*

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INTRODUCTION

The functional demand has been suggested as responsible for the production of specific adaptations in the neuromuscular system and improving performance[1-3]. According to Herzog et al.[1], these adaptations might be associated with intrinsic muscular force producing structures, with changes in muscle activation, or with a combination of the two phenomena, as both affect our ability to generate force. Frasson et al.[2] showed that ballet dancers have higher torque capacity and activation in the plantar flexors (PF) compared to volleyball players, mainly due to the greater number of exercises performed ¨en point¨ or on the tip of their toes. Similarly, artistic gymnasts (AG) execute specific movements that require high force production of the ankle joint muscles. In tumbling, for example, there is an important participation of the ankle joint muscles, especially in the thrust and landing phases[4-6]. According to the literature, the jump landing is the movement with higher prevalence of ankle sprains in AG[6-8]. Therefore, muscle imbalance might be a risk factor for these injuries in gymnasts[7,9]. The repetitive motion that leads to performance improvement during specific routines of the artistic gymnastic can also leads to specific mechanical demands that can alter the neural and mechanical properties of the muscle groups across the ankle joint. Thus, the aim of this study was to compare the neuromuscular activation, torque production and neuromuscular efficiency of plantarflexors and dorsiflexors between AG and non-athletes girls (NAG).

METHODOLOGICAL PROCEDURES

Ten female AG (mean ± standard-deviation age: 11.7 ± 1.06 years, body mass: 37.6 ± 5.85 kg, height: 144 ± 0.08 cm) and ten NAG (mean ± standard-deviation age: 11.7 ± 1.49 years, body mass: 40.4 ± 5.91 kg, height: 148 ± 0.05 cm) were recruited for this study, which was approved by local University Ethics Committee in Human Research (2008/167). Pubertal stages were determined according to the criteria of Tanner by a female researcher[10]. A written informed parental consent was obtained prior to the youngsters' participation in the experiment. The gymnasts group consisted of young high performance (elite) gymnasts at the national competition level who had at least five years of training (with a minimum of six hours of practice, six times a week). Two gymnasts represented Brazil at international competitions. The NAG group had physical education classes (50 min), twice a week during regular school activities. Girls were excluded if they were currently injured at the ankle joint or had any prior injury in the six months preceding the study.

Peak torque of the plantar- and dorsiflexor muscles was evaluated for maximal voluntary isometric contractions obtained at five different ankle angles (-20°, -10°, 0°, 10°, 20°; negative angles = dorsiflexion) using an isokinetic dynamometer (Biodex Medical System, Shirley, NY, USA).

All subjects performed a series of submaximal contractions at different ankle angles for warming up and familiarization with the dynamometer prior to the tests.

Subjects were placed in a sitting position on the dynamometer chair, with the knees extended. The dominant foot[11] was fixed onto a footplate by Velcro straps. The ankle joint axis, defined by a line connecting the lateral and medial malleolus, was aligned with the machine's axis of rotation.

The plantarflexion torque (PFT) was assessed first, followed by the dorsiflexion torque protocol (DFT). A one-minute interval was observed between protocols, with both protocols performed at the same joint angles. Subjects were instructed to reach their maximal force in approximately five seconds, and to hold the maximal effort for at least one more second before relaxing. If subjects felt that the contraction was not maximal, or if the contraction was not maintained for at least one second, the test was repeated. The order of the joint angles was random for each subject, and two-minute intervals were observed between contractions to avoid fatigue[2,12].

Electromyographic (EMG) signals (AMT-8, Bortec Biomedical, Canada) of the medial gastrocnemius (MG), soleus (SO) and tibialis anterior (TA) muscles were collected simultaneously to maximal torque during the maximal voluntary isometric contractions. Bipolar surface EMG signals (Kendall Meditrace-100, Canada; inter-electrode distance = 1 cm) were collected using standard procedures according to the criteria by SENIAM (1999)[13]. Before placing the electrodes, the electrical impedance of the skin was reduced by hair shaving and skin cleaning with an alcohol swab in order to remove dead cells and oil at the site of electrode placement. A ground reference electrode was placed over the tibia. The EMG signals were recorded at a frequency of 2000 Hz per channel using an analogue-to-digital converter (Windaq, Dataq Instruments, Akron, OH, USA; 16 bits) and playback software DI-720 (DATAQ Instruments Inc., Akron, USA), and stored on a computer for later analysis.

EMG data were extracted for segments of one second from the plateau region of the isometric torque signals for each of the five joint angles. EMG signals were band-pass filtered using cut-off frequencies of 10 Hz and 500 Hz, before root mean square (RMS) values were calculated using a custom-written program in MATLAB® (MathWorks Inc., Natick, USA).

In order to compare the torque and RMS values between groups, the PFT and DFT were normalized to the girls' body mass[14], and RMS values were normalized to the RMS obtained in the maximal isometric contraction angle. Furthermore, the absolute torque and RMS values were used to calculate the neuromuscular efficiency (NME) by the ratio (torque / EMG). The plantarflexors' EMG was considered to the sum of the RMS values of MG and SO.

Descriptive statistics was conducted to present data in mean ± SD (torque and NME) and mean ± SE (RMS). Normality of data distribution and homogeneity of variances were assessed via Shapiro Wilk and Levene tests, respectively. The independent t test was used to compare anthropometric variables between groups. A two-way repeated measures ANOVA was used to determine the existence of significant differences in the parameters of torque and RMS with a post-hoc Bonferroni test. Where main effects were observed, t-test for independent samples was used to determine pairwise differences (SPSS, 20.0). Significant differences were defined when $\alpha<0.05$.

RESULTS

All participants were in Tanner stages II-III. AG had higher relative PFT for all ankle angles studied ($p<0.01$; Figure 1A). However, NAG were able to produce relatively higher DFT for all ankle angles, compared to AG ($p<0.05$; Figure 1B). PFT increased with increasing muscle length from 20° to -20° of plantarflexion in both groups, whereas DFT increased from -20° to 10° and remained about constant from 10° to 20° of plantarflexion.

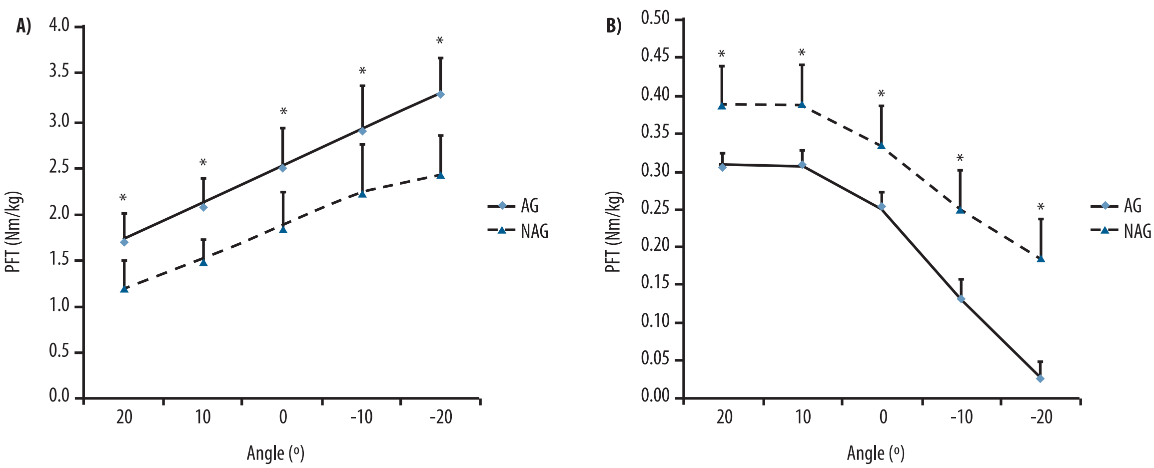

Figure 1. A) Comparison of the plantarflexion torque (PFT) normalized by total body mass (mean ± SD) between groups (artistic gymnasts - AG and non-athletic girls - NAG. * $p<0.01$). B) Comparison of the dorsiflexion torque (DFT) normalized by total body mass (mean ± SD) between groups (artistic gymnasts - AG and non-athletic girls - NAG. * $p<0.05$).

The normalized RMS values of MG, SO and TA were similar between groups in all joint angles ($p>0.05$; Figure 2). RMS values increased with increasing MG and SO muscle length, but remained about constant for TA with muscle length changes.

AG showed higher plantarflexion NME values at all joint angles evaluated ($p<0.01$). However, the dorsiflexion NME values were significantly higher for NAG at all ankle angles compared to AG ($p<0.01$; table 1).

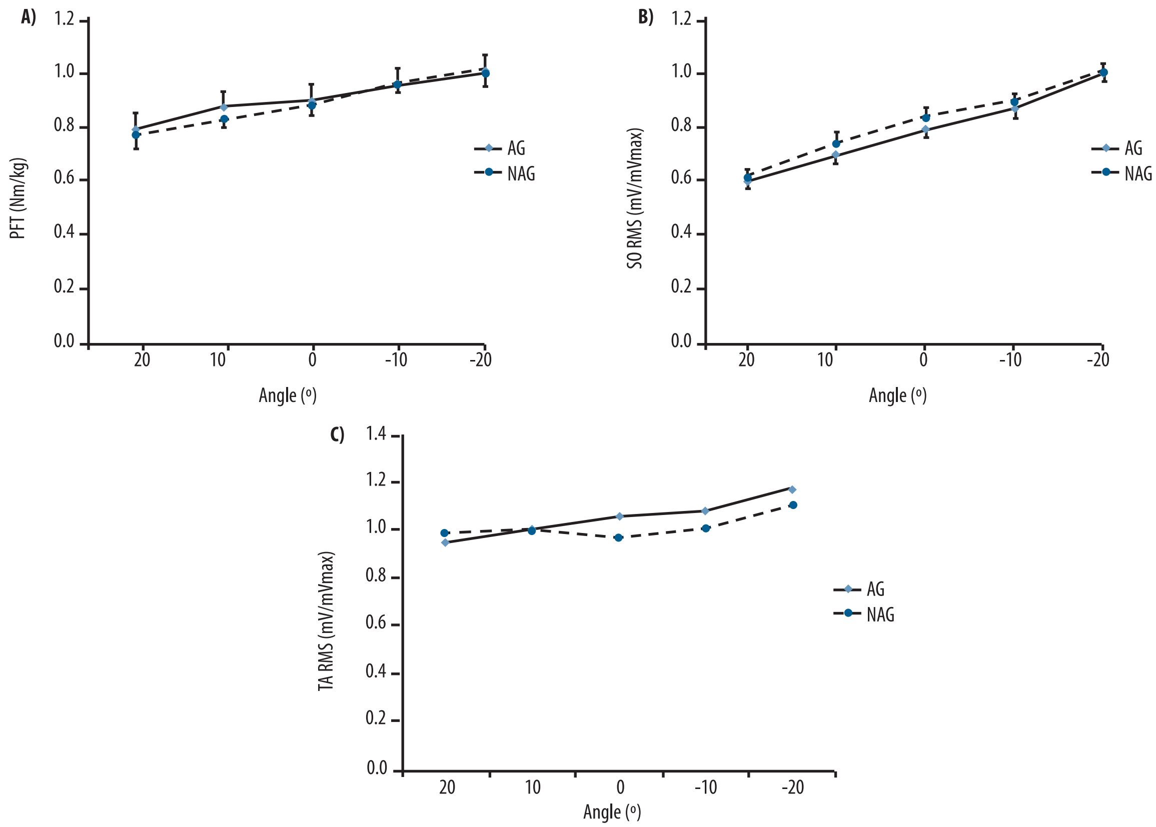

Figure 2. Comparison of normalized RMS values (Mean ± SE) between artistic gymnasts (AG) and non-athletic girls (NAG). A) Medial gastrocnemius (MG) muscle, B) Soleus (SO), C) Tibialis Anterior (TA). RMS values were normalized by the RMS value obtained at the angle of greater force production for each muscle group.

Table 1. Neuromuscular efficiency (Mean ± SD) of the plantar and dorsiflexion for the two groups. * = p<0.01.

ANGLES		20º	10º	0º	-10º	-20º
PF	AG	138 ± 12.2*	171 ± 17.7*	178 ± 22.8*	192 ± 21.2*	195 ± 21.7*
	NAG	126 ± 10.3	149 ± 7.8	158 ± 7.2	172 ± 11.9	173 ± 12.1
DF	AG	29 ± 11.3	27 ± 10.2	20 ± 12.0	10 ± 8.7	1 ± 2.4
	NAG	49 ± 14.6*	48 ± 14.2*	42 ± 7.7*	33 ± 11.3*	21 ± 5.5*

AG: Artistic gymnasts; NAG: Non Athletes Girls; PF: plantarflexion; DF: dorsiflexion

DISCUSSION

According to the literature, people in general have about 50° of plantarflexion range of motion[15,16], although rarely perform tasks with high force demands at maximal plantarflexion. In artistic gymnastic, on the other hand, movements like tumbling, vaulting and jumping require substantial flexibility and great force production of the plantarflexors[4,16], mainly at maximal plantarflexion. Thus, AG are required to always be in plantarflexion during many sports skills, and generally the gymnastic' physical training has a higher focus in flexibility and strength of the calf muscles[17,18]. Therefore, the fact that AG had a greater PFT than NAG was expected, due to high mechanical demands of the artistic gymnastic.

However, this higher degree of plantarflexion that gymnasts develop seems to limit the athlete's ability to move into dorsiflexion. In this study, AG had lower DFT than NAG, and several gymnasts failed to produce torque at the shortest dorsiflexion position (angle of -20° of plantarflexion). However, dorsiflexion movements are important, especially in landing when the body weight pushes the athlete's ankle into hyper dorsiflexion, many times above the ankle angle of 25° forcefully[19,20]. Lund and Myklebust[5] showed that 84% of injuries occur in the landing phase of the gymnastic skill. When the AG lands with her "knees over toes" (or not using the entire lower limbs to absorb impacts), this may create high forces through the ankle joint[21]. Therefore, poor mobility and strength in the dorsiflexors have also been suggested as risk factors for injury in gymnasts.

The fact that the EMG activity of the MG, SO and TA was similar between AG and NAG reveals that the differences in force production are not related to the neural component of muscle force production, and led to different NME between the two groups. AG demonstrated higher plantarflexion NME, but lower dorsiflexion NME compared to NAG.

According to Herzog et al.[1], force capacity may be associated with differences in stimulation/activation processes, differences in intrinsic muscular force production, or a combination of the two phenomena. The results of our study allow to speculating that the differences in the torque production between the two groups are based in intrinsic muscle adaption by the gymnastic functional demands.

Studies show that rhythmic gymnasts and female dancers have lower range of motion and dorsiflexion force compared to non-athletes[22-24]. Similarly, our results demonstrate that the AG has a large degree of flexibility and stronger plantarflexors, but weak dorsiflexors, which is probably due to the large amount of time spent performing plantarflexor exercises. The plantarflexor/dorsiflexor imbalance here observed for the AG compared to NAG creates an overload at the ankle joint for structures such as joint capsule and proprioceptors, which may also cause deficiencies in neuromuscular control or impairment of movement skills, increasing the chances of joint injury[23]. Thus, we suggest that athletes and coaches should add exercises to increase the dorsiflexor range of motion and dorsiflexors strengthening during routine training. This might correct antagonistic imbalances and decrease the risk for injuries at the ankle joint.

CONCLUSION

AG has higher PFT, lower DFT and similar EMG activation of the MG, SO and TA muscles compared to NAG. Furthermore, AG showed higher plantarflexor NME, but lower dorsiflexor NME compared to NAG. This imbalance of antagonistic muscles at the ankle joint are a result from the higher functional demands of the AG at this joint, and may constitute a risk factor for joint injury in these athletes.

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