RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DOI: http://dx.doi.org/10.5007/1980-0037.2014v16n3p307

original article

Isometric muscle force, rate of force development and knee extensor neuromuscular efficiency asymmetries at different age groups

Assimetrias na força muscular isométrica, taxa de desenvolvimento de força e na eficiência neuromuscular de extensores do joelho em diferentes faixas de idade

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Abstract – The aim of this study was to evaluate force, rate of force development and knee extensor neuromuscular efficiency asymmetries in children, adults and elderly. Each subject performed maximal isometric voluntary contractions (MIVC) and submaximal trials (15% and 30% MIVC). Maximal force, rate of force development (RFD) and neuromuscular efficiency were evaluated and compared between groups and between preferred and non-preferred lower limb. Children (mean age 8.4, SD 0.7 yrs), female adults (mean age 23.2, SD 3.5 yrs) and elderly (mean age 65.9 SD 7.0 yrs) were evaluated. RFD was higher in young adults, and similar between children and elderly. Neuromuscular efficiency decreased significantly with aging (P<0.05). Inter-limb asymmetries were observed for force and RFD in favor of the preferred lower limb in the elderly (P<0.05). Force and RFD asymmetries in the elderly are supported by the right hemisphere-aging model contributing to increased motor asymmetries. It was suggested that both physical assessment and training in the elderly should consider asymmetries that apparently are inherent to the aging process. A simple protocol for maximal and submaximal force assessment may be useful for delineating impairments in force and power in the elderly.

Key words: Aging; Functional lateralization; Isometric contraction; Lower limbs.

Resumo – *Neste estudo, avaliamos assimetrias na força, taxa de desenvolvimento de força (TDF) e eficiência neuromuscular de extensores de joelho em crianças, adultos e idosos. Cada sujeito realizou contrações isométricas voluntárias máximas e submáximas (15% e 30% da contração isométrica voluntária máxima). Força máxima, TDF e eficiência neuromuscular foram avaliadas e comparadas entre os grupos e entre perna preferida e não-preferida. Foram avaliadas crianças (média de idade de 8,4 ± 0,7 anos), adultos (média de idade de 23,2 ± 3,5 anos) e idosos (média de idade de 65,9 ± 7,0 anos), do sexo feminino. A TDF foi maior em adultos jovens, e similar entre crianças e idosos. A eficiência neuromuscular diminuiu significativamente com o envelhecimento (P<0,05). Foram observadas assimetrias em força e TDF em favor da perna preferida em idosos (P<0,05). Assimetrias em força e TDF em idosos podem ser justificadas por fatores neurais, como a mudança em favor do hemisfério cerebral direito, levando a assimetrias motoras. Este resultado sugere que tanto a avaliação física quanto o treinamento em idosos deve levar em consideração assimetrias, que parecem ser inerentes ao processo de envelhecimento. Assim, um protocolo simples para avaliar a força máxima e submáxima pode ser útil para quantificar déficits de força e potência em idosos.*

Palavras-chave: *Contração isométrica; Envelhecimento; Lateralização funcional; Membros inferiores.*

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Received: 20 June 2013
Accepted: 01 December 2013

INTRODUCTION

In the next decades, elderly will represent up to 20-25% of the population in Belgium, 6-20% in South America and 10-18% in the United States[1]. Mobility impairments are among the factors influencing health and quality of life in the elderly, as well as the need for further assistance from health services and professionals. The impact of aging on motor control is in general influenced by deficits in proprioception[2], cognition[3], brain structure and function[4], and neuromuscular impairments. The latter plays a major role in falling events. It has been demonstrated that subjects older than 65 years may fall at least once a year, which can happen again for up to 50% of cases[5]. Falls potentiate the occurrence of bone fractures and the post-fall syndrome, with higher risk for subjects with osteoporosis, which negatively decreases mobility and increases rigidity, affecting independence, quality of life and engagement in regular physical activity programs[5].

The reduced use of skeletal muscle accelerates sarcopenia or atrophy in the elderly[6], contributing to reduce knee extensor power[7]. Rate of force development (RFD) and power[8], muscle activation[9], and bilateral asymmetries[7,10] have been described as potential tools when screening for risk of falls in the elderly. Indeed, loss of power predicts functional performance in older adults, especially those with mobility-related impairments[11].

Perry et al.[7] reported knee extension force asymmetries around 10% for young subjects and 14% in the elderly, without significant differences between fallers and non-fallers. Portegijs et al.[10] reported high leg extension power asymmetries associated to lower gait speed and impaired postural control in the elderly. Assessments of performance asymmetries in children, young adults and elderly could be a satisfactory strategy to understand if asymmetries are related to the aging process.

Here, asymmetries were evaluated in the maximal voluntary force production, RFD and neuromuscular efficiency (NME) between children, young adults and elderly. The EMG/force ratio was used to quantify NME[12,13]. Our primary hypothesis was that aging would negatively impact force production, RFD and NME, and leg asymmetries would be found among older adults. The hypothesis of asymmetries in the elderly is consistent with the right hemisphere-aging model, related to greater age-related decline in the right cerebral hemisphere contributing to increased motor asymmetries[14].

METHODOLOGICAL PROCEDURES

Experimental Design

Each subject was assessed in a single session at home, school or recreation center using a portable setup. Leg preference was verified using the Waterloo inventory[15]. To assess neuromuscular function, subjects performed (a) three unilateral maximal isometric voluntary contractions (MIVC) during knee extension, (b) three submaximal contractions at 15% MIVC, and (c) three submaximal contractions at 30% MIVC. The order of submaximal assessments was alternated to avoid training effects. MIVC was always tested first, but the first leg to perform the MIVC was alternated between subjects. Subjects warmed-up by walking during 5 min at a comfortable self-selected speed on a treadmill. After warm-up exercise, subjects were prepared for the tests and instructed to exert maximal effort to extend the knee against a load cell at the verbal signal from the researcher.

A three-minute interval was observed between each contraction, and a five-minute interval was observed between trials. All measurements were conducted with subjects comfortable seated on a chair, with trunk, hip and thigh stabilized, and hip, knee and ankle joints positioned at 90° of flexion. According to instructions from the researcher, subjects should fully contract their quadriceps to extend the knee unilaterally. Foot position was guided by the researcher to ensure that the knee was slightly extended against the cable at the beginning of the contraction with a pre-tension that was kept at minimum level (less than 7 N) in order to eliminate any slack from the load cell cable. This pre-tension level was controlled in the acquisition software to ensure that the subject was not applying higher tension to the cable. The contractions lasted 5 seconds. For each leg, a familiarization trial was performed before data collection. All subjects signed the informed consent form approved by the local ethics committee (protocol number 2007791). For children, parents or legal guardians were requested to sign the form.

Subjects

Thirty-four female subjects recruited from the local community volunteered for this study. Subjects were distributed into the following groups: children (n=8), young adults (n=11) or elderly (n=15). Subjects should not be involved in any regular physical activity program in the last 3 months, should be free from orthopedic problems affecting posture, should not have any previous fall, and should not have any balance or other health problems that could affect gait or upright position. All subjects had right footedness. Physical characteristics of the subjects are described in table 1.

Table 1. Physical characteristics of subjects presented as mean ± standard deviation for each group. BMI: body mass index.

Groups	Age (years)	Body mass (kg)	Height (m)	BMI (kg/m^2)
Children	8.4 ± 0.7	27.75 ± 5.80	1.32 ± 0.05	15.70 ± 2.15
Young adults	23.2 ± 3.5	55.87 ± 4.10	1.59 ± 0.03	22.03 ± 1.25
Elderly	65.9 ± 7.0	74.12 ± 14.28	1.57 ± 0.04	29.91 ± 5.70

Force assessment

The force-time series produced during isometric knee extension were recorded using a load cell (Miotec Biomedical Inc., Porto Alegre, Brazil) fixed to the chair by a stainless steel cable and comfortably attached to the subjects' ankle joint using adjustable cuff that allowed correct alignment of the load cell cable perpendicular to the subjects' shank. Signals were sampled at 2000 Hz with resolution of 14-bit (Miograph system, Miotec

Biomedical Inc., Porto Alegre, Brazil). Off-line force signal analyses were conducted with a custom-written Matlab low-pass filter (Butterworth, cut-off frequency of 10 Hz) routine (MATLAB 7.0, Mathworks Inc.). The MIVC of the highest force was used to determine submaximal trials as 15% and 30% of MIVC force. The MIVC force was analyzed considering a time domain approach with maximal force being determined by the highest value achieved during the plateau of the force-time curve during MIVC. The rate of force development (RFD) was determined by the highest force value achieved within the first 200 ms after MIVC starts, similar to procedure described in Amaral et al.[12]. For all subjects, the beginning of contraction was considered as the moment when the force produced was higher than 7 N. In the submaximal trials, visual feedback was provided to guide the subjects while producing 15% and 30% of MIVC. Force was normalized to the individual's body weight. Signals were recorded in the same way for all trials and subjects, with central window of 3 seconds of contraction considered for further analysis (Figure 1).

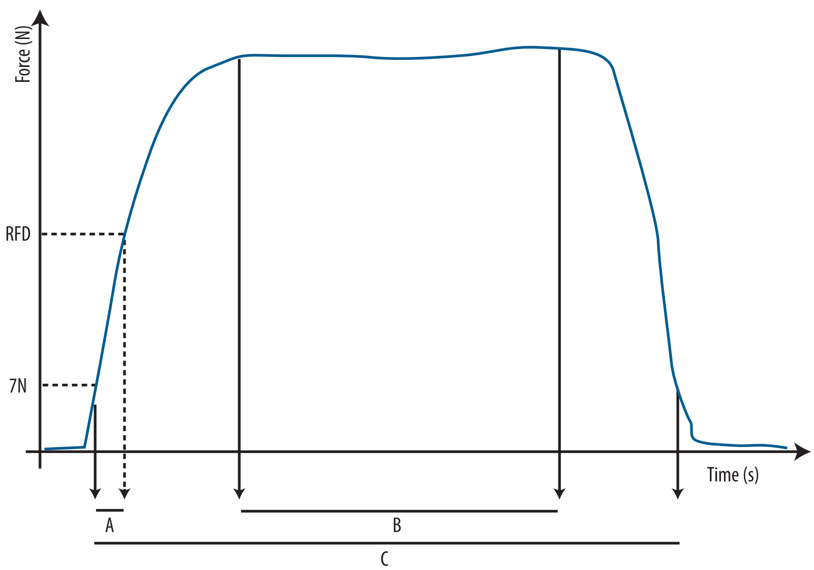

Figure 1. Schematic representations of the MIVC force contraction and ENM computation. A represents the interval of 200ms considered to compute the rate of force development. B represents the central 3- second window considered for computation of the neuromuscular efficiency and C represent the total trial duration, considering the moment when force was higher than 7N as the beginning of contraction and the moment when force was lower than 7N as the end of contraction.

Muscle activation analysis

The electrical activation of the vastus lateralis (VL) and vastus medialis (VM) muscles from the preferred and non-preferred lower limb was monitored using surface electromyography synchronized to force signals. Ag/AgCl electrode pairs (bipolar configuration; diameter of 22 mm; Kendall Meditrace Inc., Canada) were positioned on the skin after careful shaving and cleaning of the area with abrasive cleaner and alcohol swabs to reduce skin impedance[16]. A reference electrode was placed over the acromion skin as a neutral site. The electrodes were placed over the muscle belly, parallel to the muscle fibers orientation and all procedures for EMG recording were according to SENIAM[17]. Data were collected for all subjects considering the same protocol and positioning in order to ensure proper comparisons between legs and between groups.

Muscle activity was monitored throughout all trials, differentially amplified and sampled at 2000 Hz with 14-bit resolution, common rejection mode of 120 dB and impedance input of 1TΩ (Miograph system, Miotec Biomedical Inc, Porto Alegre, Brazil). The raw EMG signals were smoothed with a 4th order band-pass Butterworth digital filter at 10-500 Hz. From the full-wave rectified signals, the mean was calculated from the individual time series. After full-wave rectification and offset correction, the onset and offset of the EMG activity were determined by two standard-deviations above the baseline value recorded at rest before EMG burst[18]. Off-line signal analyses were developed with custom-written Matlab routines (MATLAB 7.0, Mathworks Inc) considering a time domain approach. The average root mean square (RMS) values were calculated from a 5-second window during maximal and submaximal contractions. From this time window, first and last seconds were excluded and then the average RMS was used as an indicator of muscle activation magnitude[19].

Neuromuscular efficiency

Neuromuscular efficiency was computed for each MIVC and submaximal trials. For each trial, NME was computed considering the ratio between the average muscle activation and force output during a time window of 3 seconds. The neuromuscular efficiency (NME) obtained from each trial was therefore averaged for MIVC, 15% submaximal and 30% submaximal contractions to infer on the muscle activation magnitude required to produce a given level of force as described elsewhere[20].

Statistical Analyses

Data were averaged for group mean and standard-deviation. Shapiro-Wilk, Mauckly and Levene tests were used to verify data normality, sphericity, and equality of variances, respectively. Data regarding force, NME and RFD were compared by analysis of variance (3 groups x 2 legs) with Bonferroni's correction. Where interactions were found, groups were compared using one-way Anova; when leg effects were found, within group comparisons were accomplished using independent t-tests. Statistical power higher than 70% was ensured for all comparisons. The significance level was set at 0.05 for all data analysis using a commercial statistical package.

RESULTS

Children and young adults produced similar normalized force, but higher than that found in the elderly [$F_{(2)}$=7.36; P=0.02]. Force asymmetries were not observed in children [$t_{(7)}$=0.15; P=0.88] and young adults [$t_{(10)}$=0.739; P=0.47]. However, elderly showed normalized force asymmetries [$t_{(14)}$=2.25; P=0.041], with preferred leg producing higher force (Figure 2).

RFD data presented main effect for group. RFD was lower in children compared to young adults [$F_{(2)}$=3.95; P=0.04], but no differences were observed between young adults and older adults (figure 2). RFD was asymmetric for older adults [$t_{(14)}$=2.45; P=0.03]. In this case, the preferred leg presented greater RFD.

There was a main effect for group in the NME (figure 3) measured in the MIVC [$F_{(2)}$=28.44; P=0.01], at 15% MIVC [$F_{(2)}$=10.829; P<0.01] and at 30% MIVC [$F_{(2)}$=17.464; P<0.01]. NME from VM was similar to VL and lower in both muscles for children and elderly compared to young adults. There was no NME asymmetry for VM and VL, despite the lower NME in the elderly.

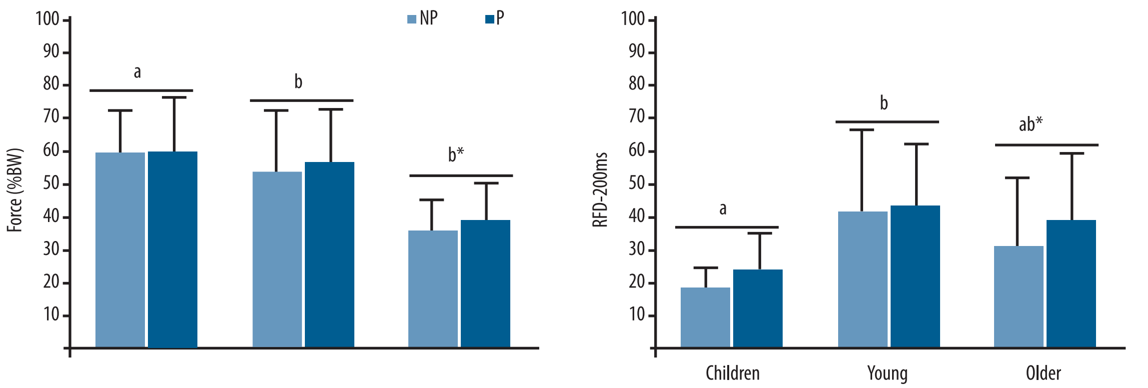

Figure 2. At the top, knee extensor force during MIVC normalized by body mass (%BW) for preferred (P) and non-preferred (NP) limb of children, young adults and elderly subjects. At the bottom, rate of force development (RFD-200ms) obtained during MIVC for P and NP limb in children, young adults and elderly subjects. Different letters indicate statistical significant difference between groups (P<0.05); * indicates significant asymmetry between P and NP limb within each group (P<0.05).

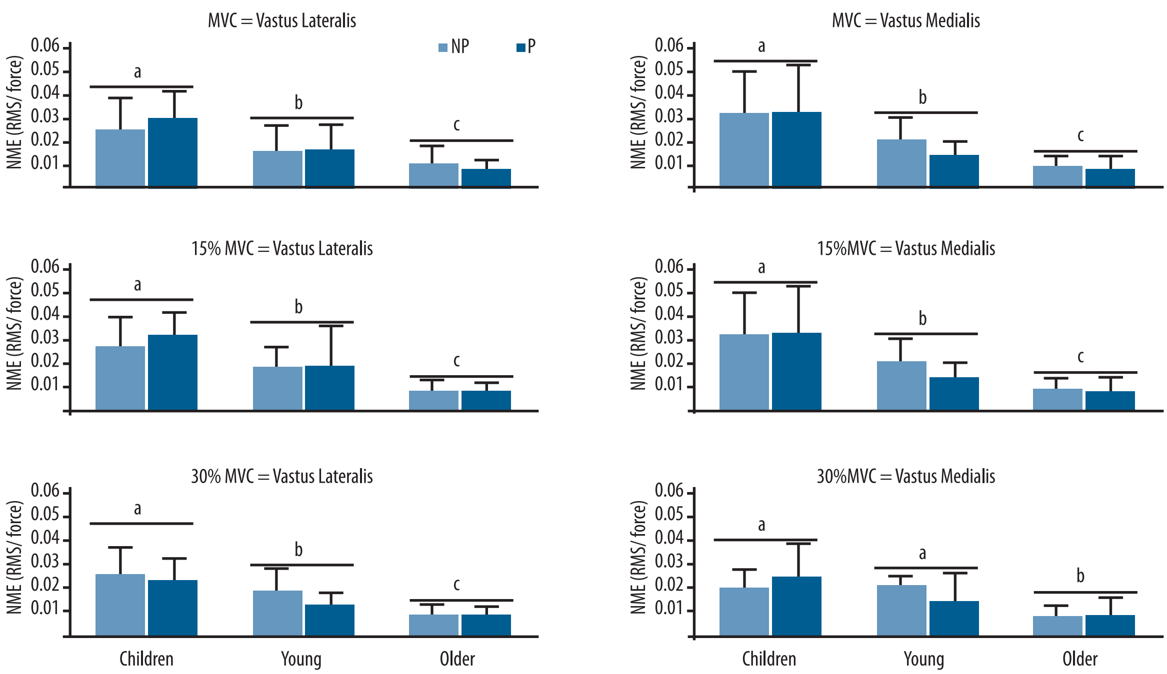

Figure 3. Neuromuscular efficiency (NME) for MVC (top), 15% MVC (middle) and 30% MVC (bottom) of children, young adults and elderly subjects in the preferred (P) and non-preferred (NP) limb. Different letters indicate statistical significant difference between groups (P<0.05).

DISCUSSION

The knee extensor function was evaluated in subjects of different ages. Maximal and submaximal knee extensor voluntary force, RFD and NME were assessed for preferred and non-preferred limb in all age groups. The novelty of our study was the assessment of these variables in subjects from childhood to elderly subjects. The lower force production observed in the elderly group was anticipated due to the expected aging effects on the neuromuscular system. This force loss was accompanied by lower NME and RFD compared to children and young adults. Maximal force and RFD asymmetries were observed only in elderly subjects, and always in favor of the preferred limb. Overall, these results suggest a general neuromuscular loss with significant knee extensor asymmetry in the elderly group. While for children and young adults, asymmetry indexes might not be relevant for neuromuscular function assessment, it becomes important when assessing older subjects. Additionally, the results are supported by the right hemisphere-aging model which contributes to increased motor asymmetries.

Muscle weakness observed in the lower limbs, especially after 50 years of age[21], influences pain and/or osteoarthritis, mobility and movement control[6,22]. Lower RFD in the elderly may result from morphological and mechanical tendon changes. Decreased tendon stiffness reduces force transmission from the muscle to the bone insertion[23] and consequently decreases power output[24]. Although still a speculation, RFD and force asymmetries observed in favor of the preferred limb in the elderly might suggest some specific adaptation between limbs, which may influence force transmission during isometric contractions in different ways for each limb and may cause specific imbalances during daily life activities.

While elderly subjects presented a well-defined asymmetry pattern in the knee extension force and RFD, children and young adults did not present significant asymmetry. A plausible explanation for the symmetry observed in the children and young adults is their higher daily involvement in bilateral actions, which contribute to similar ability between limbs[25]. In the case of the elderly, asymmetries could be explained by the right hemisphere-aging model, for which the right cerebral hemisphere shows greater age-related decline than the left hemisphere[14]. From this perspective, an overall magnification of motor asymmetries would be expected with aging[14], which is in agreement with our results. The dependence on the right hemisphere-aging model is still an inference in our study as we were not able to measure cerebral activity during experiments. It could be possible that due to the decreased activity of the right hemisphere, lower muscle activation and consequent force production could be decreased in the left limb, therefore eliciting asymmetries.

Our data are also in agreement with a previous study, which suggested similar NME between vastii muscles[26]. The lower NME observed in the elderly might be a result from higher antagonist muscles co-activation such as the biceps femoris[27]. Additionally, decreased number and firing rate of active motor units in the elderly negatively affects the ability to fully activate the muscle, which also influences NME[28]. Mau-Moeller et al.[29] reported age-related decreased voluntary muscle activation in maximal isometric voluntary torque. However, if the changes in the number and firing rate of active motor units manifest in a specific way for each limb remains unclear.

The physical condition level in the elderly might not be influenced by the magnitude of force asymmetries[11]. No leg preference effects were observed for NME. Considering the force and RFD asymmetries observed in the elderly, further studies on neuromuscular efficiency should consider factors such as antagonist co-activation[27], and degenerative articular diseases such as osteoarthritis[30], which have not been addressed in literature. Among the limitations of this study, (1) assessment of only two muscles in females and (2) assessment of a single knee joint position, which is known to influence the activation magnitude between the muscles evaluated stand out. The application of these results to male subjects may have some limitations since aging has some differences between sexes and older women`s muscle fiber distribution plays an important role in muscle force, RFD and fatigue.

CONCLUSION

In the present study, it was shown that leg preference may significantly affect knee extensor neuromuscular performance in the elderly. The decline in neuromuscular function observed in the elderly is also accompanied by significant leg asymmetries. Force and RFD asymmetries in the elderly are supported by the right hemisphere-aging model contributing to increased motor asymmetries. The implication of these asymmetries for long term joint function should be considered in rehabilitation programs and sports physiotherapy.

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