Muscular co-contraction during walking and landing from a jump: Comparison between genders and influence of activity level

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Abstract

Background: Women have higher rates of knee ligament injury than men. Co-contraction of knee muscles is proposed to be an important mechanism to protect the joint from injuries.

Hypothesis: Females have lower co-contraction levels when compared to males.

Study design: Exploratory, cross-sectional design.

Methods: Thirty-six men and women equally divided into four groups according to gender and activity level (sedentary and athletic) were compared in relation to vastus lateralis and biceps femoris co-contraction before heel strike during level walking and before floor contact during landing from a jump. Muscular co-contraction was assessed by surface electromyography. Correlations between co-contraction and ligament laxity, extensor and flexor work, and flexion/extension torque ratio were also analyzed.

Results: No differences between genders were found in the studied situations ($p \geq 0.381$). During walking, co-contraction was greater in sedentary women compared to athletic women ($p = 0.002$). A moderate inverse correlation was found between co-contraction during walking and women extensor ($r = -0.613; p = 0.007$) and flexor ($r = -0.575; p = 0.012$) work. During landing from a jump, no variables correlated to co-contraction in any of the groups tested ($r \leq 0.477; p \geq 0.061$). Co-contraction levels were not different between genders. Results suggest that women compensate strength deficits by means of increasing activation levels, possibly to generate adequate joint stiffness to meet stabilization demands. However, this is not evident in a more stressful activity like landing from a jump.

Conclusion: Co-contraction levels were not different between genders. Results suggest that women compensate strength deficits by means of increasing activation levels, possibly to generate adequate joint stiffness to meet stabilization demands. However, this is not evident in a more stressful activity like landing from a jump.

Clinical relevance: This study contributes to a better understanding of the factors related to joint protection in females, who are at a greater risk of ligament injuries.

Keywords: Co-contraction; Muscular performance; Joint stability; Gender

1. Introduction

Several authors have reported differences in the incidence of ligament injuries between genders [3,16,20]. According to these authors, women demonstrate a two- to eightfold higher incidence of anterior cruciate ligament (ACL) injury than men. Differences in factors such as neuromuscular control, anthropometric measures and hormonal changes have been proposed to explain this higher injury risk in females [20,21,24]. However, there is not a total understanding of the factors that might contribute to the higher rate of ACL injuries in women [20,24].
The loads normally imposed to the knee during sports activities exceed the tensile strength of the ACL [34,42]. Therefore the maintenance of joint stability must involve mechanisms other than those relying on the mechanical properties of the ligaments [26]. Several studies emphasize the importance of neuromuscular mechanisms to joint stability [1,23,26,30,36,37]. Johanson et al. [25,26] suggested that joint stability is achieved by the contribution of sensory receptors, through the γ-muscle-spindle system, to the continuous adjustment of muscle activity around the joint (co-contraction). Markolf et al. [30] observed that the simultaneous contraction of quadriceps and hamstrings generates compressive forces that improve contact between joint surfaces and increase knee stiffness (resistance against perturbations) up to 10 times, thus enhancing mechanical joint stability [1,29]. The increased knee stiffness attained with muscle co-contraction can reduce the stress placed on passive structures, thus decreasing the risk of ligament tears. The modulation of joint stiffness through the continuous regulation of co-contraction is possibly an efficient mechanism to protect the joint against potentially harmful loads [12]. Decreases in muscle co-contraction levels could predispose an individual to ligament injuries.

It has been demonstrated that males and females differ in relation to activation patterns of the muscles acting at the knee joint [23]. Such differences may be related to the increased number of injuries in women [14,15,23]. Some factors have been suggested to be associated with alterations in neuromuscular mechanisms. Rozzi et al. [37] suggested that the differences in the activation patterns found in women would be a compensation for the greater knee laxity observed in this population. Another factor related to neuromuscular alterations in females would be the presence of muscular imbalances. According to Griffin et al. [17], the knee flexion-extension torque ratio is lower in women as compared to men. Strength imbalances between quadriceps and hamstrings have been shown to be associated with lower co-activation levels of these muscles [1]. This reduced co-activation level was observed during isokinetic extension of the knee, and there is no evidence that it occurs during functional activities. Additionally, preventive neuromuscular training programs that included strengthening exercises for female athletes have reduced the incidence of knee ligament injuries in this population [22]. It was suggested that the neuromuscular alterations observed in association with strength increases in trained women were related to the observed reduction of the number of injuries. Thus, the increase in strength associated with training may also have an impact in muscular activation patterns. Therefore, the level of physical activity performed by the individual may influence the neuromuscular patterns due to differences in muscle strength between sedentary and athletic individuals.

The identification of possible differences in co-contraction regulation between men and women would contribute to a better understanding of the neuromuscular mechanisms that might be related to the difference in knee injury rates among genders. The present study compared muscular co-contraction levels during walking and landing from a jump between healthy men and women of different activity levels. Additionally, this study verified whether there is an association between co-contraction levels and ligament laxity, muscle imbalance and strength. Since women have higher ACL injury incidence as compared to men, this study hypothesis was that women would present lower co-contraction levels than men in both studied situations.

2. Methods and measures

2.1. Subjects

Thirty-six volunteers, 18 men and 18 women, with age varying from 18 to 29 years (22.3 ± 2.5 years) without history of injury to the knee or to the lower extremities took part in this study. In order to evaluate the influence of activity level on co-contraction levels, the individuals were further divided into two subgroups according to their activity level. Only individuals classified by the Cincinnati Scale [2] as level I (individuals who participate in sports activities 4–7 days a week) and level IV (individuals who do not participate in any sports activities) were selected to participate in this study. Thus, four groups of nine individuals were analyzed: nine athletic men (22.6 ± 3.4 years), nine sedentary men (22.1 ± 2.1 years), nine athletic women (22.8 ± 1.8 years) and nine sedentary women (21.8 ± 2.9 years). All volunteers signed an informed consent term and had their rights secured by the Committee of Ethics in Research of the Universidade Federal de Minas Gerais, COEP.

2.2. Instrumentation

In order to quantify ligament laxity, the knee ligament arthrometer KT1000 (Medmetric Corporation, San Diego) was used. The validity and reliability of this instrument was demonstrated in methodological studies [8,19,38].

Muscle activation was monitored by an electromyographer MP100WSW (Biopac System Inc., Goleta) at a frequency of 1000 Hz in order to quantify dynamic co-contraction. Two amplifiers connected to a microcomputer were used in this study. The amplifiers have input impedance of 2 MΩ and CMRR of 1000 MΩ and allow data acquisition at frequencies from 10 Hz to 2 MHz.

An isokinetic dynamometer Biodex System 3 Pro (Biodex Medical System Inc., New York) was used to
assess muscle performance and to position the subjects for maximum voluntary contraction (MVC) tests. Maximum electromyographic activity was registered during these tests for normalization purposes.

Foot switches with force transducers (Biopac System Inc., Goleta) were used in the calcaneus and first metatarsal head for determination of heel strike during level walking and foot contact during landing from a jump.

A treadmill (Moviment RT 200, Sao Paulo) and a 30 cm platform were used for co-contraction assessments during level walking and landing from a jump, respectively.

2.3. Procedures

Initially, the KT1000 knee arthrometer was used by an experienced examiner to measure knee joint laxity of the subjects. The positioning parameters described by manufacturer were followed. The mean value of five measures of the dominant leg at 134 N was used for analyses.

Data for quantification of co-contraction were collected only for the dominant leg, which was determined by asking the subjects to kick a ball [6]. Surface electrodes (Ag/AgCl) were placed in pairs over the vastus lateralis and biceps femoris, to represent the activity of the quadriceps and hamstrings, respectively, with an interelectrode spacing of 2 cm center to center. Skin preparation included shaving, abrading, cleaning the skin with alcohol, and drilling prior to electrode application [5]. Inter electrode impedance was less than 10 KΩ. Cable sway was minimized by the use of adhesive tape.

Before data collection, each subject had a habituation time of 6 min in the treadmill. It has been demonstrated that after 6 min there are no differences in the kinetic and kinematic patterns between ground and treadmill walking [31]. Walking speed for each subject was determined according to a Froude number of 0.2. The Froude number is a nondimensional parameter that takes gravity (g) and leg length (l, measured from the greater trochanter to the floor) into consideration to calculate walking speed (s), which is obtained by the formula \( Fr = \frac{s^2}{2gl} \) [9]. The determination of walking speed using this parameter guarantees dynamic similarity of locomotion between subjects considering their anthropometric differences [10]. Subjects walked barefoot, with a pair of foot switches fixed with adhesive tape to their calcaneus and first metatarsal head to allow determination of the moment of heel strike simultaneously with electromyographic acquisition. Electromyographic activity was registered for a 30 s period during walking in the treadmill. The three most regular strides were used for analyses. In order to quantify co-contraction during landing from a jump, participants jumped six times (the three first as practice trials) from the 30 cm platform to the floor with the dominant leg. Floor contact was determined by the foot switches placed in the foot.

In order to evaluate the MVC, the subjects were seated in the isokinetic dynamometer with their backs supported. The subjects’ knees were positioned in 20° and 100° of knee flexion for vastus lateralis and biceps femoris evaluation, respectively. Before data collection all subjects performed three submaximal contractions as practice trials. After a 5 min rest period, the subjects were instructed to perform three maximum isometric contractions of each muscle for 6 s while EMG signals were recorded. The trial that generated the greatest EMG activity was selected in order to normalize the EMG signals obtained during the co-contraction tests.

After MVC tests, the isokinetic muscle performance of hamstrings and quadriceps of the dominant leg was assessed. Before data collection all subjects performed three submaximal contractions as practice trials. The subjects performed five repetitions of knee flexion and extension from 90° to 0° at 60°/s. During the tests all individuals were verbally encouraged to obtain maximal performance. Isokinetic data were used to determine knee flexor and extensor work normalized by body weight, as well as the knee flexor/extensor torque ratio.

2.4. Data reduction

EMG data were processed using the software Acknowledge (Biopac System Inc., Goleta). Data collected during MVC, walking and landing from a jump were filtered and full wave rectified. Filtering consisted of low-pass and high-pass filters with cut-off frequencies at 500 and 10 Hz, respectively. The EMG signals were normalized to the largest root mean square (RMS) value of activation observed in each muscle, which was taken from the MVC tests [5]. A custom program was used to determine the overlapping area of the normalized EMG signals of the vastus lateralis and biceps femoris muscles, as described by Unnithan et al. [39]. This area of overlap of the percentage of MVC of each muscle investigated represented the simultaneous muscular activation (co-contraction level) of the two muscles tested in the study. As the overlap is determined by the muscle with the lower activation level, in each instant in time the intensity of activation of the muscle with lower percentage of MVC was considered as the instantaneous co-contraction level. Thus, co-contraction mean levels 150 ms before heel strike during walking and before contact during landing from a jump were calculated as the arithmetic mean of the normalized activation levels of the less active muscle in each instant in time. The Intraclass Correlation Coefficient for the test–retest reliability of this method was 0.957 [13].

Heel strike during walking and floor contact during landing from a jump were identified from the signals of the foot switches. Because co-contraction is a continuous
and preparatory mechanism of joint stabilization [12], it was quantified for a 150 ms period before heel strike during walking and 150 ms before foot contact during landing from a jump. The three most regular strides and the last three jumps performed were used to calculate the co-contraction as described above.

Flexor and extensor work values normalized by body weight (W/BW) as well as flexor/extensor torque ratio (FT/ET), both calculated by the dynamometer software, were used for analyses. Work values reflect the capacity of the muscles to generate torque along the range of movement and are obtained by the area under the angle–torque curve. Work values were chosen instead of peak torque because these values better represent force production in dynamic situations [33]. Work of the repetition in which the greatest torque was registered was divided by body weight to obtain W/BW. This normalization was done in order to permit comparisons among individuals and genders. Flexor/extensor torque ratio expresses knee muscle balance and was calculated by dividing peak flexor torque by peak extensor torque.

2.5. Data analysis

Two way analyses of variance (ANOVA) were used to compare genders and activity level groups in relation to co-contraction before heel strike during walking and before floor contact during landing from a jump. This statistical procedure allowed the testing of the main effects gender and activity level, as well as interaction effects. The level of significance was set at $\alpha = 0.05$. Pre-planned focused contrasts were performed to locate significant differences between specific group pairs. Bonferroni corrections were used to adjust the level of significance to the number of comparisons performed, setting the $\alpha$ level to 0.0125.

Pearson product moment correlation tests were used to verify associations between co-contraction levels and the variables ligament laxity, TF/TE and flexor and extensor W/BW.

3. Results

3.1. Co-contraction before heel strike during walking

No differences in co-contraction before heel strike were found between genders ($F = 0.791; p = 0.381$). In relation to activity levels, sedentary individuals had significantly greater co-contraction levels than athletes ($F = 4.334; p = 0.045$). There was a gender x activity level interaction effect ($F = 6.196; p = 0.018$). Contrast analyses have shown that the only significant difference was found in the female group, with sedentary women presenting higher levels of co-contraction than athletic women ($F = 10.784; p = 0.002$). Results regarding main effects (gender and activity level) are presented in Graph 1. Means and standard errors of each of the four groups are presented in Table 1.

Co-contraction did not correlate with the variables of ligament laxity and FT/ET neither in men nor in women ($r \leq 0.351; p \geq 0.167$). In the female group significant moderate correlations were observed between co-contraction before heel strike and extensor W/BW ($r = -0.613, p = 0.007$) and flexor W/BW ($r = -0.575; p = 0.012$). No correlations between co-contraction and these two variables were observed in the male group ($r \leq -0.292; p \geq 0.256$).

3.2. Co-contraction before landing from a jump

No significant differences in co-contraction before foot contact during landing from a jump were found between genders ($F = 0.011; p = 0.919$), activity levels ($F = 0.001; p = 0.984$) or in the gender x activity level interaction ($F = 0.005; p = 0.945$). Results regarding main effects (gender and activity level) are presented in Graph 1. Co-contraction before heel strike during walking: comparison between genders and activity levels.

Table 1

<table>
<thead>
<tr>
<th>Muscular co-contraction</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>Athletica</td>
<td>Sedentaryb</td>
</tr>
<tr>
<td>Walking</td>
<td>4.1 (0.7)</td>
<td>3.9 (0.4)</td>
</tr>
<tr>
<td>Landing from a jump</td>
<td>10.5 (2.1)</td>
<td>10.3 (1.7)</td>
</tr>
</tbody>
</table>

a Individuals who participate in sports activities 4–7 days a week.
b Individuals who do not participate in any sports activities.
* Statistically different from athletic women ($p = 0.002$).
Graph 2. Means and standard errors of each of the four groups are presented in Table 1.

Co-contraction did not correlate with the variables ligament laxity, FT/ET and flexor or extensor W/BW neither in men nor in women ($r \leq 0.477$, $p \geq 0.061$).

Graph 2. Co-contraction before foot contact during landing from a jump: comparison between genders and activity levels.

4. Discussion

This study was conducted with the objective of identifying possible gender differences in the neuromuscular mechanisms employed by men and women to meet the joint stabilization demands of functional activities. Joint stiffness regulation through co-contraction occurring in a continuous and preparatory manner contributes to joint stabilization [26]. Information from various sources as muscle spindles and receptors from ligaments, skin and joint would be used to adjust γ-motorneurons sensitivity. This adjustment would influence muscle activation and stiffness, allowing regulation of joint stiffness according to the demands imposed by functional activities [26].

Results of the present study did not support the hypothesis of a difference between genders in knee muscular co-contraction levels before heel strike during walking and before contact during landing from a jump. Co-contraction differences were found only between activity level groups, and between sedentary and athletic women before heel strike during walking. The difference between activity level groups in co-contraction during walking reflected an existing difference between athletic and sedentary women. Sedentary women demonstrated higher levels of co-contraction than athletic women. This result in isolation could lead to an interpretation that sedentary women would be more prepared to meet stabilization demands during this activity than athletic women. However, this interpretation is not in agreement with evidence showing that neuromuscular training is effective for prevention of ligament injuries [22]. The association found between work production and co-contraction during walking could explain this finding. A significant moderate negative correlation was found between flexor and extensor work and co-contraction during walking in the female group. This result indicates that women with lower work producing capability have higher levels of co-contraction, which suggests that women compensate for weakness by means of higher muscle activation levels. Such interpretation is supported by evidence showing that increases in muscle strength result in a lower requirement of electromyographic activity in order to achieve the same force output [18]. The suggested compensation in weaker women probably occurs in an attempt to generate adequate joint stiffness to counterbalance the effects of external loads.

In the male group, no differences in dynamic co-contraction were found between athletic and sedentary men. This lack of a difference in co-contraction levels could explain the absence of association between work and co-contraction during walking in the male group, as correlation tests are influenced by intra-group variability [7]. Apparently, because of the similarity in strength values between athletic and sedentary men analyzed in this study, compensatory increases in co-contraction levels in order to generate adequate joint stiffness were not necessary.

During landing from a jump muscular co-contraction was not different between groups. Additionally, there was no correlation between work producing capability and co-contraction before floor contact in the female or male groups. In line with the interpretation of results related to walking, this lack of association in the female group would suggest that the compensatory capacity of women would reach a limit in more stressful activities. If this were the case, in stressful activities weaker women would not be able to generate adequate joint stiffness and thus could be at a greater risk of ligament injuries. The compensation for weakness with higher levels of muscle activation to achieve adequate joint stiffness would not be necessary for men, as they present higher strength values when compared to women [41]. However, the analysis of the association between the level of co-contraction and dynamical joint stiffness as well as the analysis of the association between joint stiffness and injury rate need further investigation.

Wojtys et al. [41] verified differences between genders in the capacity to increase static joint stiffness through maximum co-contraction of knee muscles. Women increased static knee stiffness by 212%, whereas men produced a 379% increase. In the sample studied by these investigators males and females differed significantly in relation to strength values, but not in relation to electromyographic activity. Thus, with the same electromyographic activation levels, women generated lower
stiffness probably because of having less muscle mass. Muscles with smaller cross-sectional area have less contractile proteins [35], and this causes a reduction in the capacity to actively generate tension to resist deformations [28,32], which is essential to produce joint stiffness and maintain stability [11,40].

Granata et al. [15] demonstrated that women have smaller active muscle stiffness values for knee extensors and flexors when compared to men. Moreover, passive muscle stiffness (the stiffness of a silent muscle), which is also associated to muscle volume, is lower in female individuals [4]. These findings reinforce the importance of trophism and strength gains in women to revert these gender differences and improve the ability to maintain joint stability and resist potentially harmful external loads.

Co-contraction levels in the female and male groups were not associated with ligament laxity or muscle imbalance expressed by the FT/ET ratio, as no correlation was found between these two variables and co-contraction before heel strike during walking or during landing from a jump. The compensatory alterations in activation patterns due to increased ligament laxity suggested by Rozzi et al. [37] were not confirmed by the results of the present study. Additionally, the lack of association between muscle imbalance and co-contraction contrasts with the findings of Baratta et al. [1], who reported lower quadriceps and hamstrings co-activation levels during isokinetic movement in individuals with muscle imbalance. The specificity of neuromuscular strategies for joint stabilization in dynamic weight bearing situations such as those analyzed in the present study [9] as well as differences in the method of quantification of co-contraction may account for the contradictory results in relation to the previously cited studies.

During weight bearing activities like walking and landing from a jump, differences in movement patterns between groups could be related to specific muscle activation strategies [27]. Kinematic data from the lower limbs during these activities were not obtained in the present study. Therefore, influences of joint biomechanics in the results cannot be excluded. Kerrigan et al. [27] observed that women have less knee extension before heel strike during walking, which suggests an increased need of quadriceps activation to counteract a higher external flexor moment. However, as co-contraction level in this study was determined by the lower level of activation of two simultaneously activated muscles (the muscle with lower normalized activation level determines the overlap area used for co-contraction calculation) an increase in only quadriceps activation level would not impact on the intensity of co-contraction.

Future studies should investigate neuromuscular stabilization strategies in association with the analysis of kinematic aspects of functional movements.

Results of the present study demonstrate that co-contraction levels before heel strike during walking and before foot contact during landing from a jump are not a factor of differentiation between men and women. Co-contraction is important to promote better contact and congruency between joint surfaces, increasing stiffness and protecting the joint [12]. However, this mechanism must be considered in a broader context that involves other factors such as kinematic patterns in addition to strength, volume and stiffness of the muscles involved in the stabilization of the joint. Muscle properties could contribute to achievement of joint stability necessary for performance of functional activities, decreasing the demands over active mechanisms such as dynamic co-contraction. Other studies that directly quantify the association between neuromuscular mechanisms and dynamic joint stiffness as well as the association between joint stability and injury rate are necessary to further understand the difference in knee ligaments injury rates between genders.

5. Conclusion

Results of the present study add evidence regarding neuromuscular mechanisms associated with stability and demonstrate absence of a difference between genders in relation to muscular co-contraction. Sedentary women showed higher co-contraction before heel-strike during walking than athletic women, and the level of co-contraction in the female group was associated with knee flexor and extensor work production. The results suggest the existence of a compensatory mechanism for strength deficits in the female group through higher muscle activation during walking. However, it appears that this compensation is not present in a more stressful activity like landing from a jump. In this case, individuals with lower capacity to generate muscle work would not be able to obtain adequate joint stiffness during activities that place higher stabilization demands and pose greater risks of injury.

References

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