Joint torque parameters of lower limbs and the relationship with postural balance in young adults: a cross-sectional study

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HIGHLIGHTS
- Joint torque is associated with postural control in young adults.
- Hip torque was the one most associated with postural control.
- Ankle torque was associated with postural control only in semi-tandem.
- Muscle power was more associated with postural control than peak torque.

ABBREVIATIONS
- apMAD: Mean amplitude of displacement in the anteroposterior direction
- apVEL: Mean velocity of displacement in the anteroposterior direction
- AREA: Elliptical area of CoP displacement
- BRSEC: Bipedal base on rigid surface with eyes closed
- BUSEC: Bipedal base on unstable surface with eyes closed
- BUSSEO: Bipedal base on unstable surface with eyes open
- CoP: Center of Pressure
- mILMAD: Mean amplitude of displacement in the mediolateral direction
- mVEL: Mean velocity of displacement in the mediolateral direction
- Mx: Anteroposterior direction
- My: Mediolateral direction
- Mz: Vertical direction
- STREC: semi-tandem base on rigid surface with eyes closed
- STREO: semi-tandem base on rigid surface with eyes open
- STUEC: semi-tandem base on unstable surface with eyes closed
- STUEO: semi-tandem base on unstable surface with eyes open
- totalDISP: Total CoP displacement in millimeters
- totalVEL: Total mean velocity

BACKGROUND: Different factors can influence the performance of postural control (PC), one of them being muscle function, which emerges as the neuromuscular capacity to generate tension adaptable to postural disturbances in the lower limbs.

AIM: To investigate the influence of joint torque parameters of the lower limbs (hip, knee, and ankle) on the variables of postural balance, analyzed by static posturography in young adults.

METHOD: This study included 25 young adults (23.08 ± 4.44 years) who were submitted to motor tasks alternating; the base of support; the surface and vision conditions on a force plate. Joint torque was measured using an isokinetic dynamometer.

RESULTS: The hip-adduction, -abduction, and -extension torques were negatively associated with the variables of center of pressure displacement in several conditions, both the most challenging and the least challenging ones. The ankle torque (dorsiflexion and plantar flexion) was negatively associated with postural control only in the semi-tandem condition with a rigid surface and eyes open. The other hand, the knee torque was positively associated with the center of pressure displacement. Power measurements were more associated with postural control than peak torque.

CONCLUSION: In young adults, there seems to be a greater use of the hip strategy, with greater influence of hip torque in relation to ankle torque for postural balance control. Therefore, the strengthening of hip muscles could have an impact on postural control in young adults.

KEYWORDS: Muscle strength | Muscle power | Postural control | Balance

INTRODUCTION

Postural control can be defined as the ability to control the position of the body in space and is crucial for the performance of daily tasks and sports1. It involves orientation and stability functions, which are required according to the particular task and the
environment in which it is performed. Thus, orientation is defined as the ability to maintain an appropriate relationship between body segments and between the body and the environment, while postural stability or balance is the ability to control the center of mass in relation to the base of support, through the control of internal and external forces acting on the body².

Postural stability depends on coordinated movements and the production of torque in multiple joints, especially in the lower limbs. Therefore, maintaining balance involves a process coordinated by neural commands, which activates muscle synergies and produces hip, knee, and ankle joint torque to stabilize the forces that act on the center of mass, according to the postural task in question³.

In the ankle strategy, center of mass movement is controlled especially through movement in the ankle joint, with minimal movement in the knee and hip joints, causing the body to oscillate like a simple inverted pendulum. To some extent, ankle joint intrinsic stiffness contributes to stability, but also to muscle co-contraction around this joint, with activation of muscle synergies in the lower limb and trunk occurring from distal to proximal⁴. This strategy is used mainly to maintain balance in undisturbed upright posture or in mildly disturbed conditions and on a firm support surface. The hip strategy, on the other hand, controls center of mass movement through rapid and wide movements in the hip joint with small rotations of the ankles, causing the body to oscillate like an inverted double pendulum and activating the muscle synergies of the lower limb and the trunk from proximal to distal direction. Therefore, the hip strategy is used mainly to maintain balance in response to larger and faster perturbations, or when the support surface is narrow and/or flexible¹-⁵.

In this context, one assumes that there is a relationship between lower limb muscle strength/power and postural control, but previous scientific investigations report conflicting results. Billot et al.⁶ found an association between maximum capacity of ankle torque production and static balance in young adults and a systematic review showed that hip abductor strength is associated with better performance on balance tests in young adults⁷. In other hand, a systematic review with meta-analysis⁸ did not show significant associations between lower limb muscle strength/power and static balance in this population. Such associations could depend on the task (more or less challenging)⁹,¹⁰ and on the joint in which the torque is evaluated, as the postural demand differs with the degree of difficulty of the task. Thus, tasks with different levels of postural instability can cause variations in the postural control strategies and joint torques involved in the control of postural balance. It is, therefore, necessary to analyze the influence of hip, knee, and ankle muscle strength and power in different postural tasks, which has not been yet fully elucidated in the literature¹,²,⁶,¹¹.

Given the above, the aim of this study was to investigate the influence of joint torque parameters of the lower limbs (hip, knee, and ankle) on the variables of postural balance analyzed by static posturography in young adults. Based on these considerations, we ask what is the relationship between hip, knee, and ankle torque in the performance of postural control in different postural tasks?

Thus, we expect: i) to find a significant negative relationship between hip, knee, and ankle torque parameters on the variables of postural control performance; ii) that the level of difficulty of the postural task influences the association between muscle strength and power and postural balance; and iii) to find a greater association between ankle and knee torque and postural balance in less challenging tasks, and of hip torque in more challenging tasks (with reduced base of support and disturbance in the visual and somatosensory system).

MATERIAL AND METHODS

A total of 25 young adults participated in this cross-sectional observational study (age: 23.08 ± 4.44 years; 14 females and 11 males). All participants were recruited in the city of Vitória/Brazil. They were undergraduate and graduate students and were recruited through posters, internet and verbal contact at the Federal University of Espírito Santo. After consenting to participate in the study, they all signed a Free and Informed Consent Term, according to the norms established in Resolution No. 466/12 of the National Health Council. The study was approved by the Research Ethics Committee of the Federal University of Espírito Santo, with opinion number 2.061.608. Exclusion criteria were: neurological, vestibular and musculoskeletal diseases that prevent the performance of motor tasks, neoplasms, severe visual deficit, loss of plantar skin sensitivity, and use of orthoses or prostheses and medications that affect postural balance.

Before the experimental task, the participants were evaluated regarding: (a) sociodemographic information on their current health status through anamnesis; (b) anthropometric assessment, with subsequent calculation of the body mass index; (c) level of physical activity through the Baecke Questionnaire¹², and (d) plantar skin sensitivity, through physical examination with an esthesiometer¹³.

Experimental protocol

To assess postural balance, we used a force platform (EMGSystem of Brazil) with a signal acquisition frequency of 100 Hz and a low-pass filter of 10 Hz. In the conditions for assessing postural balance with an unstable surface, a viscoelastic foam (RM Produtos)
was placed on the force plate.

The force platform consists of a board in which four force sensors are distributed to measure the three components of the moment of force, Mx, My and Mz (anteroposterior, mediolateral and vertical directions, respectively) acting on the plate. The Center of Pressure (CoP) data is related to a measure of position given by two coordinates on the plate surface dependent on the orientation of the subject assessed. Based on the signals measured by the force platform, the CoP position in the anterioposterior (ap) and mediolateral (ml) directions are calculated as CoPap=\((-h*F_x-My)/F_z\) and CoPml=\((-h*F_y+Mx)/F_z\), in which h is the height of the base of support above the force plate; and Fx and Fy were the component forces.

From these data collected over 30 seconds, the dependent variables used to assess postural balance were calculated: (a) total CoP displacement in millimeters (totalDISP); (b) mean amplitude of displacement in the anterioposterior (apMAD) and mediolateral (mlMAD) directions in centimeters; c) total mean velocity (totalVEL) in centimeters/second; (d) mean velocity of displacement in the anterioposterior (apVEL) and mediolateral (mlVEL) directions; (e) elliptical area of CoP displacement (AREA) in m².

Participants were instructed to stand, barefoot, with an upright and quiet posture on top of a force plate, arms extended along the body, head immobile, and the gaze fixed on a determined target one meter away at eye level. We evaluated eight conditions: Condition 1 (BRSEO): bipedal base on rigid surface with eyes open; Condition 2 (BRSEC): bipedal base on rigid surface with eyes closed; Condition 3 (BUSEO): bipedal base on unstable surface (foam) with eyes open; Condition 4 (BUSEC): bipedal base on unstable surface (foam) with eyes closed; Condition 5 (STREO): semi-tandem base on rigid surface with eyes open; Condition 6 (STREC): semi-tandem base on rigid surface with eyes closed; Condition 7 (STUES): semi-tandem base on unstable surface (foam) with eyes open; Condition 8 (STUEC): semi-tandem base on unstable surface (foam) with eyes closed.

In the bipedal base conditions, the feet were positioned parallel and roughly aligned with the shoulders. In the semi-tandem base conditions, the feet were positioned one in front of the other, with the dominant foot in front and the hallux touching the medial edge of the heel of the contralateral foot. All conditions were randomized and for each of them three 30-sec trials with 1-min intervals were performed.

To assess muscle function, we used a BIODEX System 4 Pro isokinetic dynamometer (Biodex Medical System, Shirley, NY, USA). Initially, participants performed a warm-up section on a cycle ergometer for five minutes with self-selected load. Next, they were positioned and stabilized in the isokinetic dynamometer according to the manufacturer’s recommendations. Hip abduction and adduction, hip flexion and extension, knee flexion and extension, and ankle plantar flexion and dorsiflexion were evaluated in a randomized order for each individual. Participants performed five submaximal repetitions at each speed to familiarize themselves with the test. The evaluation consisted of concentric isokinetic contractions with a sequence of predetermined speeds and repetitions of 60°/s (five repetitions), 120°/s (ten repetitions), and 180°/s (15 repetitions). Thus, in the assessment of muscle function, the dependent variables were: peak torque at 60°/s angular velocity, time to peak torque at 60°/s, and mean power at 120 and 180°/s.

Subjects were verbally encouraged to develop maximum strength during the test. They were allowed to rest for 60 seconds between the different assessment speeds. Measurements were collected on the dominant limb (the one used to kick a ball). Calibration and gravity correction procedures were performed according to the manufacturer’s recommendations.

Statistical analysis

To verify the influence of torque parameters (peak torque and time to peak torque at 60°/s and mean power at 120 and 180°/s) of the hip (flexion, extension, abduction, adduction), knee (flexion, extension), and ankle (dorsiflexion, planter flexion) joints in the CoP displacement variables (AREA, totalDISP, apMAD, mlMAD, apVEL, mlVEL, and totalVEL), we performed a linear regression analysis. The significance level adopted for all analyses was p ≤ 0.05.

RESULTS

The participants were moderately active (Baecker score: 8.9 ± 1.4) and had a body mass index of 23.4 ± 2.9 Kg/m². Table 1 shows posturographic data of the sample.

The results of the linear regression analysis showed a significant association between the torque parameters of the dominant lower limb and the CoP displacement variables in several postural tasks. Table 2 shows only the torque variables that were significantly associated with posturographic data.

Mean hip abduction power was inversely associated with mlMAD, apVEL, and totalVEL in the BRSEC condition. On the other hand, the time to peak torque in hip abduction was directly associated with totalDISP and AREA in the STUEC condition.
addition, the time to peak torque in hip adduction was directly associated with totalDISP, AREA, and mlMAD in the BRSEC condition. In the BUSEC condition, mean hip extension power was inversely associated with mlVEL, while the time to peak torque in hip extension was directly associated with mlVEL. Torque parameters in hip flexion were not associated with posturographic measurements.

<table>
<thead>
<tr>
<th>Table 1. Mean (standard deviation) of the posturographic variables in the different conditions evaluated in the sample.</th>
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<tbody>
<tr>
<td><strong>Postural Tasks</strong></td>
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<td>BRSEO</td>
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Mean knee extension power was directly associated only with apMAD in the BRSEO condition. In the BRSEC condition, the time to peak torque in knee flexion was directly associated with totalDISP and AREA. In the STREO condition, the mean knee flexion power was directly associated with totalDISP and AREA, while the peak torque was directly associated with apVEL. Ankle torque parameters were associated with posturographic parameters only in the STREO condition: plantar flexion peak torque was inversely associated with totalDISP and AREA, and mean ankle dorsiflexion power was inversely associated with mlMAD.

**DISCUSSION**

This study investigated the influence of joint torque parameters of the lower limbs on static postural balance in young adults. We observed a significant association between the torque parameters of the dominant lower limb and several CoP displacement variables in all postural tasks analyzed on the bipedal base. It was evident that the torque parameters related to muscle power (time to peak torque and mean power) of the lower limbs influenced the performance of postural control of young adults on a bipedal base, regardless of the type of surface and visual condition. However, no significant association was found between peak torque and postural sway variables in any of the tasks analyzed. Thus, muscle power appears to contribute more significantly to balance control in young adults in the bipedal base conditions in relation to muscle strength.

We had hypothesized that the strength and power of the muscles around the ankle would be more associated with the posturographic parameters in the bipedal conditions, while the torque of hip movements would be more associated with posturographic parameters in the semi-tandem conditions. However, our findings did not confirm this hypothesis, since there was no significant association between ankle torque parameters and CoP displacement variables in postural tasks on bipedal support in young adults. This may be explained by young adults presenting ankle torque values above the threshold needed to maintain postural balance. Thus, it is possible that postural control is compromised only when it falls below an ankle torque threshold, which can occur in the elderly, for example. In the systematic review by Muehlabauer et al., associations between static balance and lower limb muscle strength were observed only in a meta-analysis of studies with the elderly population, not in young adults. In the study by Billot et al., there was a negative correlation between the maximum capacity to produce torque at the ankle and the displacement of the CoP in several postural tasks, but the elderly needed more electromyographic activity than young adults to produce the same torque. Thus, in our study, the association between ankle torque and posturographic variables was seen only in semi-tandem conditions because, perhaps, the ankle strategy was used more in these conditions, as they are more challenging for young adults. It must also be considered that the semi-
tandem position imposes hip adduction, which restricts the possibility of hip movement as a postural control strategy and may increase the demand on the muscles around the ankle.

Interestingly, Oshita and Yano\(^\text{15}\), when evaluating voluntary ankle motor control in young adults, measured as sustained isometric force fluctuation at 10% of maximum voluntary contraction with the aid of visual feedback, found a significant association with bipedal postural control. Similarly, Davis et al.\(^\text{16}\) also noted that the most consistent explanatory variable for the variance in sway-area rate was force control (steadiness) of the hip abductors and ankle dorsiflexors during a submaximal isometric contraction. Thus, it is possible that, in the younger population, motor control measures maintain a stronger association with body balance than those involving maximal strength. Unlike the bipedal condition, the regression analysis in semi-tandem base conditions showed a significant association with torque parameters related to strength (peak torque) and muscle power (mean power) and with CoP displacement variables in rigid surface conditions. However, under unstable surface conditions, significant associations were found only between torque parameters related to muscle power (time to peak torque). Altogether, these results point to the importance of muscle power in maintaining postural balance, especially in the most challenging conditions.

Table 2. Beta values (\(\beta\)) of the regression analysis between the torque parameters of the dominant lower limb and the variables of center of pressure (CoP) displacement in several postural tasks. Only significant associations (\(p \leq 0.05\)) are shown.

<table>
<thead>
<tr>
<th>Postural Tasks</th>
<th>totalDISP</th>
<th>AREA</th>
<th>apMAD</th>
<th>mlMAD</th>
<th>apVEL</th>
<th>mlVEL</th>
<th>totalVEL</th>
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<td>BRSEO</td>
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<td>Mean power at 120°/s - Knee Extension</td>
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<td>Mean power at 120°/s - Hip Abduction</td>
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<td>0.91</td>
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<tr>
<td>Mean power at 120°/s - Hip Flexion</td>
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<td>0.06</td>
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<td>Mean power at 180°/s - Hip Abduction</td>
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<td>1.16</td>
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<td>-1.13</td>
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<tr>
<td>Mean power at 180°/s - Hip Adduction</td>
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<td>1.20</td>
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<td>Time to peak torque at 60°/s - Hip Adduction</td>
<td>-0.62</td>
<td>-0.58</td>
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<td>-0.57</td>
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<tr>
<td>Time to peak torque at 60°/s - Knee Flexion</td>
<td>0.55</td>
<td>0.50</td>
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<td>Mean power at 180°/s - Hip Adduction</td>
<td>-0.99</td>
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<td>-1.09</td>
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<td>Mean power at 120°/s - Hip Extension</td>
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<td>0.94</td>
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<td>Time to peak torque at 60°/s - Hip Extension</td>
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<tr>
<td>Peak torque at 60°/s - Ankle Plantar Flexion</td>
<td>-0.58</td>
<td>-0.57</td>
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<td>Mean power at 120°/s - Ankle Dorsiflexion</td>
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<td>0.90</td>
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<td>Mean power at 180°/s - Hip Adduction</td>
<td>-1.16</td>
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<td>Peak torque at 60°/s - Knee Flexion</td>
<td>0.96</td>
<td>0.90</td>
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<td>1.39</td>
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<td>Mean power at 180°/s - Knee Flexion</td>
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<td>Time to peak torque at 60°/s - Hip Abduction</td>
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BRSEO: bipedal on a rigid surface with eyes open. BRSEC: bipedal on a rigid surface with eyes closed. BUSEO: bipedal on unstable surface with eyes open. BUSEC: bipedal on unstable surface with eyes closed. STREO: semi-tandem on a rigid surface with eyes open. STREC: semi-tandem on a rigid surface with eyes closed. STUCE: semitandem on unstable surface with eyes closed. totalDISP: total CoP displacement. AREA: CoP displacement area. apMAD: mean amplitude of CoP displacement in the anteroposterior direction. mlMAD: mean amplitude of CoP displacement in the mediolateral direction. apVEL: mean velocity of CoP displacement in the anteroposterior direction. mlVEL: mean velocity of CoP displacement in the mediolateral direction. totalVEL: total mean velocity of CoP displacement. -- Non-significant association (\(p > 0.05\)).
Still on the semi-tandem base, ankle torque was shown to influence balance control in the least challenging condition (STREO), while hip torque influenced the control of postural sway both in less stable (STREO) and in more stable (STUEC) tasks. Postural stability may depend on the coordinated production of torque at the hip, knee, and ankle joints. Thus, postural control is likely to be dependent on a combination of ankle and hip strategies (mixed strategies) that vary in dominance depending on the demands of the tasks. However, hip muscle torque significantly influenced performance in postural balance control in tasks with different levels of instability, highlighting the importance of hip torque for balance control in young adults.

We have also hypothesized that the direction of the association between joint torque and CoP displacement parameters would be negative, that is, the greater the muscle strength or power, the smaller the CoP displacement. This was the case with the associations that included ankle and hip torques. However, knee torque variables (muscle power for flexion and extension) had a positive association with totalDISP, AREA, and MAD. Likewise, Katayama et al. evaluated the muscle power (N/kg) of knee flexors and extensors in young women and found that unstable young women (who could not remain 10 seconds in unipedal stance with eyes closed) had greater power than stable young women, although the difference is not statistically significant. What could explain the association between greater muscle power of knee extensors and flexors with worse postural control? When postural control is assessed in situations with the knee locked in extension, the knee flexor and extensor muscles play a role in the hip strategy. That should be further investigated in future studies.

The study has some limitations. The associations investigated may be influenced by other variables not included here, such as physical conditions, participation in sports or recreational activities, joint flexibility and/or muscle trophism.

CONCLUSION

The analysis of the relationship between the production of muscle torque in the lower limbs and postural sway in young adults showed that the torque of the lower limbs influences postural balance control in this population. In addition, there seems to be a greater use of the hip strategy in young adults, with greater influence of hip torque in relation to ankle torque for postural balance control. Therefore, the strengthening of hip muscles could have an impact on postural control in young adults.

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