

## CLINICAL SCIENCE

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### CAN QUIET STANDING POSTURE PREDICT COMPENSATORY POSTURAL ADJUSTMENT?

Gabriel Bueno Lahóz Moya, Cássio Marinho Siqueira, Renê Rogieri Caffaro,  
Carolina Fu, Clarice Tanaka

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**OBJECTIVE:** The aim of this study was to analyze whether quiet standing posture is related to compensatory postural adjustment.

**INTRODUCTION:** The latest data in clinical practice suggests that static posture may play a significant role in musculoskeletal function, even in dynamic activities. However, no evidence exists regarding whether static posture during quiet standing is related to postural adjustment.

**METHODS:** Twenty healthy participants standing on a movable surface underwent unexpected, standardized backward and forward postural perturbations while kinematic data were acquired; ankle, knee, pelvis and trunk positions were then calculated. An initial and a final video frame representing quiet standing posture and the end of the postural perturbation were selected in such a way that postural adjustments had occurred between these frames. The positions of the body segments were calculated in these initial and final frames, together with the displacement of body segments during postural adjustments between the initial and final frames. The relationship between the positions of body segments in the initial and final frames and their displacements over this time period was analyzed using multiple regressions with a significance level of  $p \leq 0.05$ .

**RESULTS:** We failed to identify a relationship between the position of the body segments in the initial and final frames and the associated displacement of the body segments.

**DISCUSSION:** The motion pattern during compensatory postural adjustment is not related to quiet standing posture or to the final posture of compensatory postural adjustment. This fact should be considered when treating balance disturbances and musculoskeletal abnormalities.

**CONCLUSION:** Static posture cannot predict how body segments will behave during compensatory postural adjustment.

**KEYWORDS:** Musculoskeletal Equilibrium; Posture; Movement; Biomechanics; Physical Therapy (Specialty).

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#### INTRODUCTION

Postural control is a complex sensorimotor skill that is designed to support postural orientation and equilibrium. It is this skill that allows us to accomplish a task in a stable way by integrating sensory information and planning the execution of a movement.<sup>1</sup> However, the postural control system is affected even by simple events, such as breathing.<sup>2</sup>

Using a movable support surface, Horak and Nashner (1986)<sup>3</sup> described balance strategies utilized during the maintenance of posture in response to backward and forward perturbations.

Mixed strategies for maintaining balance have also been reported.<sup>3</sup> Interestingly, in this regard, more recent studies have indicated the involvement of body segments that were never previously thought to play a role in balance strategies.<sup>4,5</sup>

Quiet standing balance has been described as the control of a multi-link pendulum<sup>6</sup> that uses the movement of all major body segments to stabilize the center of mass.<sup>5</sup> Compensatory postural adjustments have also been described as the control of a multi-link pendulum<sup>3</sup> in which all body segments assist in maintaining stability.<sup>7</sup>

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Department of Physical Therapy, Communication Science, and Disorders and Occupational Therapy, Faculdade de Medicina da Universidade de São Paulo - São Paulo/SP, Brazil

Emails: gabiblm@yahoo.com.br/ gabriel.moya@hu.usp.br  
Tel: 55 11 3069.6867

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In the context of the quiet standing condition, postural misalignments can be related to a variety of diseases, including osteoarthritis,<sup>8</sup> patellofemoral pain,<sup>9</sup> medial tibial stress syndrome,<sup>9</sup> iliotibial band friction syndrome,<sup>9</sup> stress fractures of the tibia,<sup>9</sup> and anterior cruciate ligament injury.<sup>10</sup> In addition, postural adjustments play an important role in clinical practice. Alterations of postural adjustments are related to the risk of falls,<sup>11</sup> vertebral fracture<sup>12</sup> and musculoskeletal diseases such as patellofemoral pain,<sup>13</sup> low back pain<sup>14</sup> and clinical neck pain.<sup>15</sup>

It is generally accepted in clinical practice that posture during quiet standing, as well as during postural adjustment, plays a significant role in musculoskeletal function. However, to our knowledge no evidence exists to resolve whether static posture is related to postural adjustment. The postural adjustment analyzed in this study was the response to a controlled but unexpected postural perturbation. The aim of this study was to determine whether quiet standing posture is related to compensatory postural adjustment.

## MATERIALS AND METHODS

### Participants

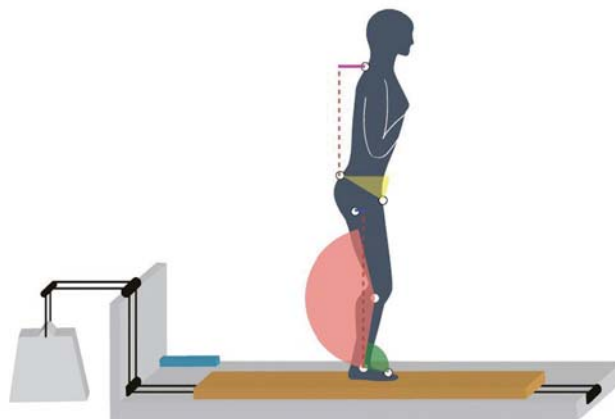
Twenty able-bodied young females (mean age  $22.9 \pm 3.0$  years; BMI  $20.14 \text{ kg/m}^2 \pm 1.5$ ) participated in the study. Participants were healthy university students who had no severe postural misalignments or conditions requiring medication, and who did not play competitive sports. Exclusion criteria included neurological, musculoskeletal or respiratory pathology, sensory system diseases, previous surgery in lower limbs or trunk, dizziness, cognitive impairments, consumption of alcohol 24 hours prior to the test, or complaints of any pain or fatigue on the day of the test. All participants read and signed an informed consent form that had previously been approved by the Ethics Committee at our institution.

### Instrumentation

To provide a standardized perturbation to the participant's posture, we designed a movable support surface (Figure 1) triggered by a mechanical system connected to a known weight. This apparatus was able to generate forward and backward movements of up to four centimeters.

Kinematic data were collected using a 60 Hz Panasonic™ PV-GS250 digital camcorder placed to the right of the participant. Spherical landmarks covered by retro-reflective tape (3M™ high gain 7610) were placed between the metatarsal heads I and II, lateral malleolus, fibula head, greater trochanter, anterior superior iliac spine (ASIS),

posterior superior iliac spine (PSIS) and the spinous process of the 7<sup>th</sup> cervical vertebra (C7), all on the participants' right sides. Subjects were wearing proper athletic attire (Figure 1). Four control landmarks with known locations were used for the appropriate 2D spatial calibration.



**Figure 1** - The movable support surface provided forward and backward standardized perturbations with a mechanical trigger. The variables measured included ankle angle, knee angle, pelvic antepulsion, pelvic anteversion and trunk position

### Procedure

Once all the landmarks had been appropriately positioned, participants were asked to stand naturally on the support surface in such a way that the platform's movement would be aligned with the participant's sagittal plane. Their arms remained crossed over the chest. Postural perturbations were applied in such a way that the participant was unaware of both the direction and the starting moment of the perturbation. The applied perturbations were as follows:

- 1) Backward Postural Perturbation: triggered by a weight equivalent to about 15% of the participant's body weight, promoting a movement of the support surface with a mean velocity of 23.2 cm/s.
- 2) Forward Postural Perturbation: triggered by a weight equivalent to about 10% of the participant's body weight, resulting in a movement of the support surface with a mean velocity of 17.6 cm/s.

Experimental trials in each direction were performed to establish the amount of weight that was sufficient to induce a postural adjustment, but not so heavy as to cause the individual to compensate by suddenly stepping backwards or forwards.

Three 7-second trials were recorded for each type of perturbation, separated by resting intervals between trials. During the first 3 s of each trial, the participant stood quietly on the stationary platform. The perturbation direction was randomized, within the series of six trials per participant.

**Data processing**

The acquired images were then transferred to a personal computer and the APAS software package was used for data digitization.

A 2D-kinematic analysis was performed for all trials; the variables measured were: 1) ankle angle, formed between the horizontal and lateral malleolus-fibula head lines; 2) knee angle, formed between the lateral malleolus-fibula head and greater trochanter-fibula head lines; 3) pelvic antepulsion, in terms of the horizontal distance between the lateral malleolus and the greater trochanter in the sagittal plane; 4) pelvic anteversion, formed between the horizontal and the ASIS-PSIS lines, and; 5) trunk position, in terms of the horizontal distance between C7 and the PSIS in the sagittal plane. Figure 1 shows the variables analyzed in this study.

An initial frame and a final frame from the video recording of any given trial were defined based on the beginning and the end of the lateral malleolus horizontal displacement. During the time interval between the initial and final frames, there were compensatory postural adjustments that helped maintain the participant’s equilibrium. The initial frame represents the quiet standing posture, and the final frame represents the extent of compensatory postural adjustment. Figure 2 illustrates a participant during the 7 s trial, highlighting the initial and final frames.

The duration of the postural perturbation (about 200 ms) was sufficient for the occurrence of joint movements due to muscle activation in response to the support surface perturbation.<sup>16</sup> Metatarsus and lateral malleolus vertical displacements were always checked, so that trials in which the stepping strategy took place could be discarded. One representative trial for the backward postural perturbation and one for the forward postural perturbation was analyzed

for each participant. These were selected on the basis of appropriate postural perturbation duration (sometimes the movable surface reached the end of the excursion sooner than the average) in the absence of the stepping strategy.

Kinematic analysis was carried out to verify the positions of body segments during backward and forward postural perturbations. The difference between the positions of body segments (angular or linear) in the initial and final frames of each trial was calculated to evaluate the displacement of the body segments in each trial.

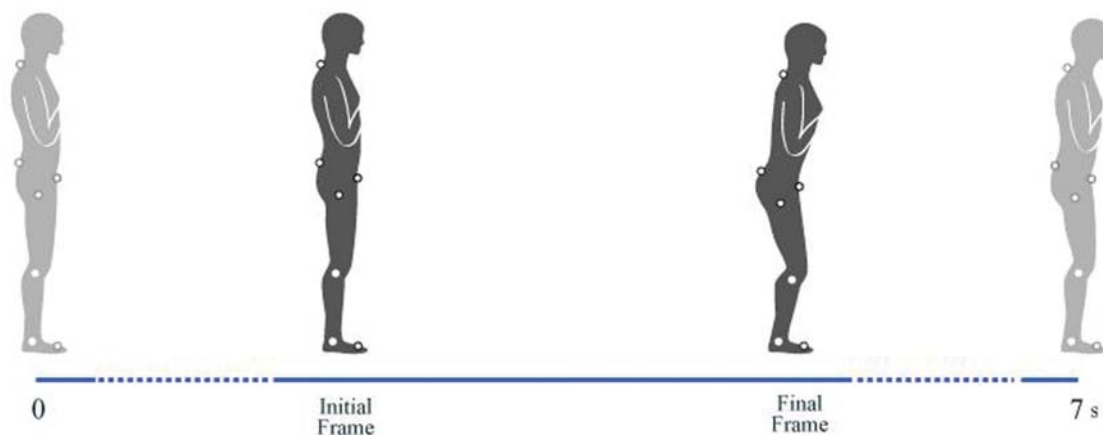
**Data Analyses**

To analyze the relationship between body segment positions in the initial or final frames and the displacement of body segments during backward and forward postural perturbation, we calculated four sets of multiple regression analyses. We considered results statistically significant if  $p \leq 0.05$ .

**RESULTS**

In general, with regard to backward and forward postural perturbations, the displacement of the body segments did not show any correlation with the positions of body segments in the initial and final frames. One exception was in the pelvis, in which the extent of pelvic antepulsion exhibited a linear relationship with ankle angle and pelvic antepulsion in the final frame of the backward postural perturbation.

Table 1 shows our multiple regression analysis data for displacements of body segments during backward and forward postural perturbations in the context of body segment positions in the initial and final frames of the respective postural perturbations.



**Figure 2** - Illustration showing the movement of a participant during the 7 s trial. Gray figures indicate the beginning and end of a trial; black figures indicate initial and final frames

**Table 1** - Significance levels of our multiple regression model for the displacement of body segments during backward postural perturbation (BPP) and forward postural perturbation (FPP) with body segment positions in the initial and final frames of the respective postural perturbations. Significance levels are listed for body segments for the accepted regression

Displacement		Regression Coefficient					
		Model	Constant	Tibio-tarsal angle	Knee	Antepulsion	Anteversion
<b>BPP</b>							
Initial							
	Tibio-tarsal angle	0.19					
	Knee	0.34					
	Antepulsion	0.32					
	Anteversion	1.00					
	Trunk	0.71					
Final							
	Tibio-tarsal angle	0.36					
	Knee	0.09					
	Antepulsion	*	*	*	0.08	*	0.16
	Anteversion	1.00					
	Trunk	0.17					
<b>FPP</b>							
Initial							
	Tibio-tarsal angle	0.71					
	Knee	0.75					
	Antepulsion	0.28					
	Anteversion	0.38					
	Trunk	0.63					
Final							
	Tibio-tarsal angle	0.82					
	Knee	0.78					
	Antepulsion	0.14					
	Anteversion	0.25					
	Trunk	0.62					

\* p ≤ 0.05

## DISCUSSION

### Balance Strategy

Horak and Nashner, 1986<sup>3</sup> started a remarkable discussion about postural control by describing ankle, hip and stepping balance strategies. These balance strategies are required to regain body stability after sudden postural perturbations. However, mixed strategies and strategies that involve other body segments that have not previously been reported can also be employed by the postural control system to maintain or regain balance.<sup>17</sup>

Recently, postural adjustments in quiet standing have been modeled as a multi-link pendulum, with two simultaneous co-existing excitable balance strategies, one of which may prevail depending on the characteristics of the task and the available sensory information.<sup>6</sup> Other studies suggest an even more complex control structure in quiet standing, proposing that all major body segments are equally

active and exhibit coordinated motions that stabilize the body's center of mass and the head in space as confined by a stable and narrow support surface.<sup>4,5</sup>

Compensatory postural adjustment relies on any available body segments that can assist in maintaining stability without interfering with the task being performed.<sup>7</sup> Despite the latest findings, our understanding of postural control, especially in terms of postural adjustments in the clinical scenario where static posture prevails, remains limited and incomplete.

To conduct this study, we used a controlled unexpected perturbation to analyze postural response. Thus, changes in muscles at the onset of compensatory postural adjustments might not have occurred.<sup>18</sup>

### Can quiet standing posture predict compensatory postural adjustment?

Our results fail to uncover a relationship between the

positions of body segments in the initial or final frames and the displacement of body segments during forward postural perturbation. Similarly, we failed to identify a relationship for the initial and final frames of backward postural perturbation, except in the case of the displacement of pelvic antepulsion in the final frame of backward postural perturbation. We conclude that compensatory postural adjustments cannot be predicted by the simple features of a patient's quiet standing posture. These results are not surprising, because postural adjustments use a different body scheme than does static posture. However, clinical procedures are frequently based on static posture, even when dynamic activities are the target of a given treatment. Our findings reemphasize the importance of carrying out a complete evaluation of posture, including the dynamic component, since postural adjustment cannot be deduced from quiet standing posture alone.

Further studies have attempted to verify the relationship between quiet standing and postural adjustment. By using kinetic analyses, the displacement of the center of pressure during quiet standing posture has been associated with a weak backward postural perturbation at the pelvic level, regardless of age.<sup>19,20</sup>

Postural sway direction in quiet standing at the moment of the postural perturbation has been shown to influence muscle activity onset, electromyography amplitude, and the frequency of the stepping balance strategy in the context of postural adjustment.<sup>21</sup> Researchers have suggested that kinetic analyses of quiet standing and tandem stance may provide information on postural control that can be used to predict the risk of falls among the elderly due to inadequate postural adjustment capabilities.<sup>22,23</sup>

Ankle extensor activity is largely responsible for phasic

control of the anterior–posterior balance in quiet standing.<sup>[24]</sup> The modulation of ankle extensor activity in quiet standing appears to offer a large contribution to velocity information involving body sway.<sup>25</sup> In addition, to stabilize the quiet standing posture, the velocity of body sway is reported to be more accurate than the position of body segments or the acceleration of body sway.<sup>26</sup>

Postural control in quiet standing may not influence the quality or pattern of movement during functional activity. No relationship has been detected to date between responses to different sensory conditions in quiet standing and balance during gait or compensatory postural adjustment.<sup>27</sup>

Although clinical practice is largely based on static posture, postural adjustment seems to be more closely related to dynamic aspects of postural control than to static aspects. Our results support the concept that compensatory postural adjustment is not associated with the alignment of body segments. Clinical procedures involving functional tasks should not be based solely on the positions of body segments; instead, one must also consider the dynamics of body segments.

A comprehensive understanding of postural adjustment may be gained by building on this study with assessments of movement patterns in the coronal and transverse planes, as well as of the roles of the upper limbs and head in postural control.

## CONCLUSIONS

Static posture cannot predict how body segments will behave during compensatory postural adjustment. This should be considered when treating balance or musculoskeletal abnormalities.

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## REFERENCES

- Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age Ageing*. 2006 Sep;35 Suppl 2:ii7-ii11.
- Hodges PW, Gurfinkel VS, Brumagne S, Smith TC, Cordo PC. Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res*. 2002;144:293-302.
- Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configurations. *J Neurophysiol*. 1986;55:1369-81.
- Krishnamoorthy V, Yang JF, Scholz JP. Joint coordination during quiet stance: effects of vision. *Exp Brain Res*. 2005;164:1-17.
- Hsu WL, Scholz JP, Schoner G, Jeka JJ, Kiemel T. Control and estimation of posture during quiet stance depends on multijoint coordination. *J Neurophysiol*. 2007;97:3024-35.
- Creath R, Kiemel T, Horak F, Peterka R, Jeka J. A unified view of quiet and perturbed stance: simultaneous co-existing excitable modes. *Neurosci Lett*. 2005; 29;377:75-80.
- Scholz JP, Schoner G, Hsu WL, Jeka JJ, Horak F, Martin V. Motor equivalent control of the center of mass in response to support surface perturbations. *Exp Brain Res*. 2007;180:163-79.
- Elahi S, Cahue S, Felson DT, Engelman L, Sharma L. The association between varus-valgus alignment and patellofemoral osteoarthritis. *Arthritis Rheum*. 2000;43:1874-80.
- Krivickas LS. Anatomical factors associated with overuse sports injuries. *Sports Med*. 1997;24:132-46.
- Bonci CM. Assessment and Evaluation of Predisposing Factors to Anterior Cruciate Ligament Injury. *J Athl Train*. 1999;34:155-64.

11. Maki BE, Cheng KC, Mansfield A, Scovil CY, Perry SD, Peters AL, et al. Preventing falls in older adults: new interventions to promote more effective change-in-support balance reactions. *J Electromyogr Kinesiol.* 2008;18:243-54.
12. Greig AM, Bennell KL, Briggs AM, Wark JD, Hodges PW. Balance impairment is related to vertebral fracture rather than thoracic kyphosis in individuals with osteoporosis. *Osteoporos Int.* 2007;18:543-51.
13. Stensdotter AK, Grip H, Hodges PW, Hager-Ross C. Quadriceps activity and movement reactions in response to unpredictable sagittal support-surface translations in women with patellofemoral pain. *J Electromyogr Kinesiol.* 2008;18:298-307.
14. Mok NW, Brauer SG, Hodges PW. Failure to use movement in postural strategies leads to increased spinal displacement in low back pain. *Spine.* 2007;32:E537-43.
15. Falla D, Farina D. Neuromuscular adaptation in experimental and clinical neck pain. *J Electromyogr Kinesiol.* 2008;18:255-61.
16. Runge CF, Shupert CL, Horak FB, Zajac FE. Ankle and hip postural strategies defined by joint torques. *Gait Posture.* 1999;10:161-70.
17. Alexandrov AV, Frolov AA, Horak FB, Carlson-Kuhta P, Park S. Feedback equilibrium control during human standing. *Biol Cyber.* 2005;93:309-22.
18. Jacobs JV, Fujiwara K, Tomita H, Furune N, Kunita K, Horak FB. Changes in the activity of the cerebral cortex relate to postural response modification when warned of a perturbation. *Clin Neurophysiol.* 2008;119:1431-42.
19. Hsiao-Wecksler ET, Katdare K, Matson J, Liu W, Lipsitz LA, Collins JJ. Predicting the dynamic postural control response from quiet-stance behavior in elderly adults. *J Biomech.* 2003;36:1327-33.
20. Lauk M, Chow CC, Pavlik AE, Collins JJ. Human Balance out of Equilibrium: Nonequilibrium Statistical Mechanics in Posture Control. *Phys Rev Lett.* 1998;80:413-6.
21. Tokuno CD, Carpenter MG, Thorstensson A, Cresswell AG. The influence of natural body sway on neuromuscular responses to an unpredictable surface translation. *Exp Brain Res.* 2006;174:19-28.
22. Pajala S, Era P, Koskenvuo M, Kaprio J, Tormakangas T, Rantanen T. Force platform balance measures as predictors of indoor and outdoor falls in community-dwelling women aged 63-76 years. *J Gerontol A Biol Sci Med Sci.* 2008;63:171-8.
23. Piirtola M, Era P. Force platform measurements as predictors of falls among older people - a review. *Gerontology.* 2006;52:1-16.
24. Borg F, Finell M, Hakala I, Herrala M. Analyzing gastrocnemius EMG-activity and sway data from quiet and perturbed standing. *J Electromyogr Kinesiol.* 2007;17:622-34.
25. Masani K, Popovic MR, Nakazawa K, Kouzaki M, Nozaki D. Importance of body sway velocity information in controlling ankle extensor activities during quiet stance. *J Neurophysiol.* 2003;90:3774-82.
26. Jeka J, Kiemel T, Creath R, Horak F, Peterka R. Controlling human upright posture: velocity information is more accurate than position or acceleration. *J Neurophysiol.* 2004;92:2368-79.
27. Shimada H, Obuchi S, Kamide N, Shiba Y, Okamoto M, Kakurai S. Relationship with dynamic balance function during standing and walking. *Am J Phys Med Rehabil.* 2003;82:511-6.