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Postural strategy to keep balance on the seesaw

G.L. Almeida[a,b,*], R.L. Carvalho[c,d], V.L Talis[e]

[a]Departamento de Fisiologia e Biofísica, Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil
[b]Curso de Fisioterapia da, Laboratório de Pesquisas Clínicas em Fisioterapia, Universidade de Ribeirão Preto, Avenida Costábile Romano 2001, Cep 1 4096 380, Ribeirão Preto, SP, Brazil
[c]Departamento de Fisiologia e Biofísica, Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil
[d]Pontifícia Universidade Católica de Minas Gerais Campus Poços de Caldas, MG, Brazil
[e]Institute for Information Transmission Problems, Russian Academy of Science, Bolshoy Karetny 19, Moscow, Russia

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Abstract

This work investigates the kinematic and electromyography (EMG) strategy used by the central nervous system (CNS) to keep equilibrium during anterior–posterior balance on seesaws with different degrees of instability. The movement of hip, knee, and ankle were reconstructed using a 3D motion-analysis system and the EMG activities of selected ankle, knee, and hip muscles were recorded. Balance was kept mainly at the ankle joint. The EMG patterns of the gastrocnemius and anterior tibialis alternated between agonist and antagonist bursts. The agonist burst started before the end of the lengthening phase and was prolonged until the end of the shortening phase. The EMG activities of the muscles crossing the knee and hip joints were characterized by a pattern of generalized co-activation. The movements at these two joints were very small, suggesting a neural or biomechanical constraint underlying the operations of the equilibrium control. Our results also indicate that the strategy to keep balance on the seesaw is qualitatively the same for the different levels of mechanical demands in terms of the seesaw's instability.

Keywords: Balance; Seesaw; Posture; Strategy

1. Introduction

An experimental approach to study how the central nervous system (CNS) reacts to maintain balance in response to external forces involves disrupting the equilibrium of an individual standing on a force platform and recording the resulting muscle responses [1,2,3,4,5]. Such studies have revealed muscle activation patterns known as muscle synergies [2] or movement strategies [4]. Many types of postural strategies have been well-characterized [6,7,8]. The CNS chooses the best strategy to maintain equilibrium according to the mechanical demand of the task. The latter varies with the type of platform, such as standing on a rigid floor [9], on a movable base of a support [10], or on a seesaw [1,11].

During quiet stance on a flat, stable platform, individuals sway slightly and the body oscillates around the ankle–joint axis, similar to an inverted pendulum [12]. On the other hand, when standing on a seesaw, humans project the center of gravity onto the seesaw's point of contact with the floor [11,13]. Studies using seesaws [11] have shown marked modulation of the electromyography (EMG) activities characterized by increased activation of the soleus during the muscle-shortening phase, but not during the muscle-lengthening phase. However, the authors did not analyze the kinematic and EMG patterns of the agonist and antagonist muscles crossing the focal (ankle joint) and non-focal joints (i.e., knee and hip).

We still do not know when and how the agonist and antagonist activities change to project the center of gravity onto the seesaw's point of contact with the floor. Nor do we

* Corresponding author. Tel.: +55 16 603 7968/7965; fax: +55 16 603 7025.
E-mail address: gla@odin.unaerp.br (G.L. Almeida).

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know the effect that different degrees of seesaw instability have on the modulation of these EMG activities.

The aim of this study is to describe the kinematic and EMG activities of the focal and non-focal joints necessary to keep the center of gravity on the seesaw's point of contact with the floor during anterior–posterior balance. We describe when and how these activities change as the muscles shift from the lengthening to the shortening phase, and how these changes are affected by different degrees of seesaw instability. We also describe the kinematic movements at these three joints during balance.

The effect of training on the externally imposed movements on the seesaw platforms was studied in a variety of patients [14,15]. However, there is no study about the use of free balance on the seesaw, even though it is a common tool used in Physical Therapy practice. The free balance is also an inexpensive and readily available tool and this study is necessary to support the decision for its use as an appropriate treatment.

2. Material and methods

Six individuals (three male and three female, average age 24.5 years) were studied after they had signed an institutional (UNICAMP) term of informed consent. The individuals balanced on nine moveable seesaws (30 cm wide × 45 cm long) that varied in radius (30, 60, and 120 cm each) and height (7, 12, and 17 cm). The seesaws were based on their radius and height to provide an index of difficulty (ID) for balancing (Table 1) (Fig. 1).

2.1. Kinematic data

The X, Y and Z coordinates of the LED marks were recorded using a 3D-motion-analysis system (OPTOTRAK 3020). The LED marks were attached on the left side of the shoulder (lateral aspect of the humerus), hip (between the greater trochanter and superior iliac crest), knee (lateral condyle), ankle (external malleolus), foot (head of the fifth metatarsal), and on the seesaw. The light emitting diodes (LED) coordinates were recorded at 100 Hz and used to calculate the ankle, knee, and hip angular displacements.

2.2. EMG activities

The activities of the gastrocnemius medialis (GM), tibialis anterior (TA), biceps femoris (BF), rectus femoris (RF), erector spinae (ES) at the L4 level and the rectus abdominis (RA) were recorded using bipolar surface EMG electrodes (DeLSys). All data were band pass filtered (45–450 Hz), amplified (2000×) and digitized at 1000 Hz. The EMG signals were rectified and smoothed using a second order Butterworth filter with 10 Hz cut-off frequency.

Table 1
The radius and height of all nine seesaws

Index of difficult	1	2	3	4	5	6	7	8	9
Radius (cm)	120	120	120	60	60	60	30	30	30
Height (cm)	7	12	17	7	12	17	7	12	17

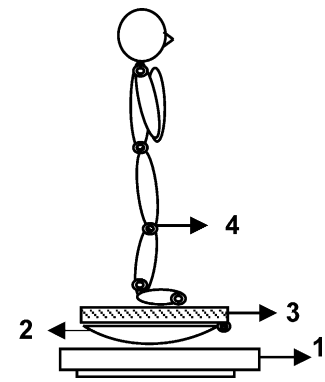

Fig. 1. Illustration of the experimental setup: (1) fixed force platform; (2) seesaw; (3) block of polystyrene; (4) LED marks.

2.3. Procedure

The seesaw was centered on a force platform and the location was marked and constantly checked to avoid seesaw translation. The investigator helped the individual to stand on a seesaw and ensured that his/her feet were proportionately arranged on the center of the seesaw. Initially, the individual was blindfolded with a mask and his/her ankle was kept in a neutral position, with the top of the seesaw parallel to the floor. From this initial position, the individual could start balancing with no external support or constraint. Also, during the balance, the individual held each shoulder with the opposite hand, keeping the upper limbs crossed and in contact with the chest. Plantar flexion (PF) and dorsal flexion (DF) are the major movements observed at the ankle joint and, because of that, we chose to analyze the data just at the anterior–posterior displacement.

Two trials of 10 s each were recorded for each seesaw, proceeding from the easiest (ID = 1) to the most difficult (ID = 9). This sequence was used to guarantee the safety of the subject who might fall off the most unstable seesaw. After two trials of balancing without getting off, the individual was evaluated on the subsequent seesaw. No instruction was given as to how to keep balance and each individual was free to choose any strategy.

2.4. Data quantification

The Matlab routine was used to calculate the maximum plantar and dorsal ankle flexion and the corresponding angular displacement of the hip and knee joints during this time. The activities of the six muscles cited above were integrated during 50 ms, just before and 50 ms after the maximum dorsal and plantar flexion time. The EMG values were normalized to the values obtained during stationary standing.