A NEW DEVICE FOR BALANCE ASSESSMENT AND REHABILITATION

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Abstract: The balance disorders are usually studied by the body sway and the postural adjustments induced by an unexpected perturbation during upright stance. In the last years different experimental and commercial systems for dynamic posturography were proposed. These systems can realize sudden anteroposterior translation or rotation about the ankle axis. Recently a certain number of studies empathized that postural responses in multiple directions have to be assessed to better understand how balance is maintained during everyday life and how it is affected by diseases.

In this paper we present a 2-degree of freedom mobile platform, that can be easily programmed by an user-friendly, mouse-driven, ad hoc realized software. The device is able to perform a wide range of combinations of anteroposterior and mediolateral movements.

Introduction

While gait is one of the most common expression of human movement, the fully understanding of how brain can control and how it can balance complex motor behavior is still a key issue for neuroscience and rehabilitation engineering. However it seems that these key features are based on the adaptive interaction of the two control modalities [1], namely the feed-forward component and the feed-back component.

The feed-forward component is an anticipatory element in which the motor commands are pre-programmed. The feed-back component is a module that corrects the outgoing of the motor command on the basis of the sensorial information.

The clinical investigation of balance disorders is performed by using platforms able to record body sway in quiet conditions (static posturography). It is people experience that subjects can not predict external threats to dynamic equilibrium during gait and sudden postural responses are required to act after an unexpected perturbation [2]. Therefore it is necessary to induce postural perturbations during upright stance (dynamic posturography).

Recently Nashner [3] realized unexpected gait perturbations by using a movable platform in a walkway, Brown and colleagues investigated in how the displacement waveform of the board perturbation is revealed in postural responses [4].

It was established that sudden multi-limb movements tend to enhance pathological features of the balance and a number of studies [5,6,7,8,9] suggest that postural responses have to be studied in multiple directions. Furthermore, it was shown that standing on a continuously moving platform improves balance control in elderslies and in patients with unilateral vestibular deficit [10].

It is to note that in these studies the support can move only along one axis in a predictable fashion. We have therefore designed, realized and tested a mobile platform (figs. 1), that can be easily programmed to perform a wide range of combinations of anteroposterior and mediolateral movements.

Figure 1: the architecture of the 2-degree of freedom mobile platform (120x116x70cm, 80Kg).

Materials and Methods

1. Participants

A male healthy young adult acted in the test study. Man age was 26years, body weight was 67Kg and height was 170cm. He was physically active participating in regular activity a couple times per week.

2. Mobile Platform

We have designed and realized a two degree of freedom mobile platform (mechanical assembly
performed by Officina Lomazzi, v. Umbria 9, Legnano (MI), Italy). It can be easily controlled by the developed software (eTT s.r.l., v. Siffredi 60/21, 16153 Genova, Italy). Axis movements range from 0 mm up to 180 mm and are realized by a brushless engine (maximal torque: 2.4 Nm). The engines can realize different motion behaviors characterized by large ranges of velocity and frequency. We tested instrumentation up to a maximal velocity of 1.2 m/s, in the case of "pulse" perturbation (see paragraph 4), and a maximal frequency of 2Hz, in the case of "harmonic" perturbation. We tested perturbations with a participant standing above the device both in the case of impulse perturbation (max. shifting velocity: 0.4 m/s), and in the case of harmonic perturbation (max. tested frequency: 1.6Hz). The perturbations were unaffected by loading conditions such as subject's weight (fig.2).

![Figure 2: Examples of board movements. Figure reports 15-s recording of the center of the mobile board with respect to one axis during 4 harmonic perturbations of different amplitude and frequency. Movements were performed while a 26 years, 67Kg, 170cm male was standing and balancing above the mobile device.](image)

It is to note that acceleration and deceleration provide the initial and final destabilizing input of balance perturbation and these physical variables of platform motion result from displacement waveform realized by selected behavior [4].

3. Platform Control Software

The perturbations are defined by the control software that was specifically developed for further adaptation and customization [10].

The user can define a “protocol” that consists of a series of different perturbations at different time delays. Each perturbation is described by the number of axis (one or both), the engine dynamic (pulse or harmonic), the amplitude (expressed in mm), the frequency or the velocity of the movement and the duration of the perturbation.

![Figure 3: The managing software: in the top user can select perturbation characteristics, while in the middle and in the bottom of the control panel axis motion feedbacks are reported.](image)

4. Motion Dynamics

"Pulse" is a working definition of a trapezoidal perturbation (fig. 4) defined by the shifting velocity from the starting position of the platform center to the final position, the plate au time duration and the platform going back velocity to the initial position of the perturbation.

"Harmonic" consists of a periodic motion (fig. 2), performed at the perturbation frequency, between to extremes (that are defined by the perturbation amplitude).

To standardize evaluation or rehabilitation procedures, it is possible to save an “experimental session”.

![Figure 4: Pulses perturbations. Black line shows a 5cm, 0.12 m/s pulse. Grey line is a 5cm, 0.04 m/s pulse.](image)

5. Platform Control Hardware

The protocols are performed by the brushless engines. Each of the engines are controlled by a servo drive (Kollmorgen SERVOSTAR PicoDrive). The servos receive the motion paths from the IOG1800 (Robosystem). This control board is the external interface of the Galil DMC1822 (www.galilmc.com), and it is located in the “power and control sub-system” (fig. 1). The Galil DMC1822 is a PCI multi axis motion controller board.
The perturbations are analogically represented by voltage potentials (+/-10V) regulated by two linear potentiometers. The system provides external TTL triggers that permit the synchronization with external body movement analysis systems (such as the EMG recording device).

Discussion

In general the balance is studied under two condition, namely: i) during quiet standing, and ii) under large postural perturbations used to induce postural adjustments to prevent the fall. The study of short perturbations, that don’t force adaptive strategies from the postural control system [11], is a key issue.

The analysis of the EMG tracks of the muscles groups (identified as being meaningful for postural control), in respond to straight or rotational movement of standing platform, suggested that multidirectional postural control is much more complicated than unidirectional postural control. The multidirectional postural control can’t be described simply by a set of discrete synergies as reported in the case of separately in either antero-posterior or medio-lateral perturbations.

Furthermore it was shown that standing on a continuously moving platform improves balance control [6,10]. For these reasons we have developed a new device and it can be very useful for a better understanding how balance is maintained during everyday life and how it is affected by disease.

This system is able to perform both harmonic and impulsive perturbation and the directions of the perturbation are not restricted in the XY plane (fig.5, fig. 6).

Figure 5: Example of two axes synchronous movement. Platform was performing the following 2 harmonics: a 150mm sine at 0.5Hz along X axis and a 150mm sine at 1Hz along Y axis. Figure reports 30-s recording of the center of the mobile board. Movements were performed while a 26 years, 67Kg, 170cm male was standing and balancing above the mobile device.

Figure 6: Example of two axes asynchronous movement. Platform was performing the following perturbations: a 60mm sine at 0.6Hz along Y axis, started after the delivering of a 50mm pulse at 0.1m/s along X axis. Movements were performed while a 26 years, 67Kg, 170cm male was standing and balancing above the mobile device.

The managing of the mobile platform by a Graphical User Interface (GUI) makes easy to define, try and store different sequences of perturbation, and it offers an high reproducible procedure for the diagnosis and the rehabilitation as well.

It answers the need of standardization of platform perturbations between laboratories that utilize translating platform system to disturb quiet standing balance.

Furthermore, providing external triggers, it is easy to synchronize the starting of the perturbation with external devices devoted to acquire and analyze body segments motion and/or muscles electrophysiological activity.

Brown and colleagues well reported how different acceleration and deceleration characteristics, referred to different translating waveforms, significantly altered neuromuscolar responses [4].

Nowadays there is a lot of work to be done to understand which parameter, i.e. perturbation velocity, motion amplitude etc., more affects the balance.

Our next goal will consist in the detailed characterization of body answer, under different conditions of perturbation, where one parameter at time is changed, and we will try to classify if it is a biomechanical or if it is a neurophysiological behavior.

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References


