行政院國家科學委員會專題研究計畫　成果報告

站立支持面干擾之姿勢反應的肌電圖與生物力學分析

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中文摘要

關鍵字：站立平衡、姿勢干擾、肌電圖、運動學

姿勢控制是一個複雜的過程，包含接受與組織感覺輸入，計畫並經由促動協同的姿勢反應來執行動作以達到維持平衡之目標，也就是在所處的感覺環境中控制重心於支撐底面積內。姿勢干擾是指突然的改變狀態使個案偏離平衡狀況，姿勢干擾可包括生理性干擾、訊息性干擾及力學干擾。力學干擾可經由對個案之身體如頭、軀幹或肢體等部位施加外力以干擾其平衡，而臨床或實驗中最常見的力學干擾是支持面的干擾，也就是移動個案之站立支撐底面積，以引發維持平衡的姿勢反應。這些支持面干擾正如個案滑倒、絆倒、站在不規則地面或站在車子裏突然的加速或減速。

文獻中有一些關於姿勢對支持面干擾的反應的研究，給予的干擾包括前/後平移、趾向上/向下(踝背屈/蹠屈)旋轉、多方向干擾及連續性正弦曲線干擾等。這些研究的結果顯示不同的支持面干擾引發不同的姿勢反應，但針對平移與旋轉之姿勢反應如肌肉活化潛伏期及活化順序則沒有一致的結論，且文獻中少有結合不同干擾形式的支持面干擾研究。

本研究目的在利用肌電圖及運動學分析法檢驗二十五位正常青年針對各種支持面干擾的姿勢反應，支持面干擾由三軸向姿勢干擾平台提供。此平台可以提供支持面前/後平移、趾向上/向下旋轉及左右旋轉等單軸干擾及結合不同軸向的二、三軸干擾。本研究使用前/後平移及趾向上/向下旋轉等四個單軸干擾及前/後平移分別結合趾向上/向下旋轉形成四個雙軸干擾。我們相信了解維持平衡所需要的肌電圖及運動學因素將有利於設計增進姿勢平衡的治療方法及預防跌倒的策略。

Abstract

Keywords: standing balance, postural perturbation, EMG, kinematics

Balance is a complex process involving the reception and organization of sensory inputs, planning and execution of movement by activating postural response synergy, to achieve a goal requiring uptight posture. It is the ability to control the center of gravity over the base of support in a given sensory environment. A postural perturbation is a sudden exposure to off-balanced conditions that displaces the body away from equilibrium. These perturbations could consist of physiological, informational and mechanical perturbations. Mechanical perturbations can be applied on any body part such as push to the trunk, head or limbs. The most common experimental approach is to perturb the support surface, which displaces the base of support upon which a subject is standing. These support surface perturbations are like to a slip, trip or acceleration or deceleration of support surface during vehicular motion.

In the literature, several studies have examined postural responses to support surface perturbation. The types of perturbation include anterior/posterior translation, toe up/own rotation, multi-directional perturbation and continuously sinusoidal translation. The results of these studies showed that different types of perturbation result in different response organizations, however, there were no confirmed conclusions about the muscle activating latency and sequence of postural responses to translational and toe up/down rotational perturbations. In addition, there have been few studies that investigated postural responses to combinations of translational and rotational perturbations.

The purpose of this study was to explore the postural responses to various types of support surface perturbations by twenty-five healthy young adults with no physical conditions that would compromise their ability necessary for maintaining standing stance. The support surface perturbations were provided by the tri-axial postural perturbation platform. The developed tri-axial postural platform was controlled in six degrees of freedom movements including forward/backward translation, toe up/down rotation, and clockwise/counterclockwise rotation. It can provide uni-axial perturbations and combinations of different axial perturbations. In this study, we applied four uni-axial perturbations including forward/backward translation and toe up/down rotation and four bi-axial perturbations including combinations of support surface translation and rotation. Electromyography (EMG) and kinematics were applied to analyze postural responses. It was believed that a basic understanding of the EMG and kinematic factors required for balance will lead to better therapeutic methods for improving posture and balance, and to strategies that can be used to prevent falls.

Research Background

Postural stability is the ability to maintain the center of mass (COM) over the base of support (BOS) and is required for daily living activities(Horak, 1987). Postural stability has been divided into static postural stability and dynamic postural control. The static postural stability indicates the ability to balance in a static posture such as standing or sitting position. The dynamic postural control indicates the ability to balance during movements such as performing arm movement, walking, or responding to an external perturbation (Maki & McIlroy, 1997; Westcott *et al.*, 1997).

Postural perturbation is a sudden exposure to off-balanced conditions that displaces the body away from equilibrium (Horak *et al.*, 1997). Postural perturbations could consist of physiological perturbations, informational perturbations and mechanical perturbations. Mechanical perturbations displace the position of body segments resulting in disequilibrium (Horak *et al.*, 1994). One type of mechanical perturbation is to perturb the support surface, which displaces the base of support upon which a subject is standing. Support surface perturbations are similar to slips, trips or sudden acceleration/deceleration in a bus and that are common causes of falls. Falls often result in significant morbidity and even mortality (Tornetta *et al.*, 1999). Therefore, there have been some studies focusing on examining postural responses to support surface perturbations. (Bachar *et al.*, 1999; Bentley & Haslam, 1998; Cayless, 2001; Lundkvist *et al.*, 1992).Most of the studies investigated postural responses by using uni-axial support surface perturbation including forward/backward translation and toe up/toe down rotation (Diener *et al.*, 1983; Diener *et al.*, 1984; Diener *et al.*, 1988; Horak & Nashner, 1986; Lawson *et al.*, 1994; Nashner, 1977). There were no confirmed conclusions about the muscle activating latency and sequence of postural responses to translation and toe up/down rotation. Allum et al used combinations of support surface rotation and backward translation to induce balance corrections (Allum *et al.*, 2001). Combinations of backward translation and toe-up rotation (BU) yielded an “enhanced” ankle perturbation. Combinations of backward translation and toe-down rotation (BD) yielded a “nulled” ankle perturbation. These types of support surface perturbations seemed to increase task difficulty. However, two additional types of combinations of support surface rotation and forward translation (FU, FD) have not been studied. Therefore, the purpose of this study was to investigate EMG and kinematic responses under various types of support surface perturbations including uni-axial and bi-axial perturbation.

Methods

Subject

Twenty-five young subjects age ranging from 19 to 25 years were recruited from the undergraduate and graduate populations at Cheng Kung University. All subjects had no history of neurological diseases, musculoskeletal injuries of the lower extremities, abnormal vision (eyeglasses for better visual acuity were allowed) or standing balance problems. Informed consent was obtained from each subject.

Instrumentation

Postural perturbation platform

A tri-axial postural perturbation platform (TPPP) (Fig. 1) used in this study was computer controlled and servomotor driven. The TPPP was designed to provide multiple types of support surface perturbation simulating the variability of environmental interference including uni-axial, bi-axial and tri-axial perturbations. In this study, we applied both uni-axial and bi-axial support surface perturbations. Uni-axial perturbations consisted of forward (F) and backward (B) translation; toe up (U) and toe down (D) rotation. Bi-axial perturbations consisted of combinations of forward and rotation (FU, FD), and combinations of backward and rotation perturbations (BU, BD). The velocity and amplitude of platform movement was set at 50 mm/s for 70mm or 50 degree/s for 7 degrees, respectively. These parameters allowed us to obtain equal complete time under the translation, rotation and combination conditions.

Fig. 1 Triaxial Postural Perturbation Platform

EMG

The MA-300 system (Motion Lab Systems, Inc.) was used to collect EMG data. EMG recordings were obtained with surface preamplified electrodes placed over the muscle belly longitudinal to the predicted path of the muscle fibers of medial gastrocnemius (MG), tibialis anterior (TA), biceps femoris (BF), rectus femoris (RF), lumbar paraspinae (L EXT) (segmental level L2-3), abdominal rectus (ABD) (lateral to the umbilicus), thoracic paraspinae (T EXT), pectoralis major (PEC), cervical paraspinae (NK EXT) and neck flexor (NK FLX). EMG signals were sampled at 1000Hz, sampling occurred 1 second prior to perturbation, the .period of acquisition lasted 3 seconds and with synchronization of motion analysis system.

Motion analysis system

Kinematic data were obtained from a 6-camera EvaRT 4.2 motion analysis system (Motion Analysis Corp, rosta senta, CA, USA). Forty-one retro-reflective spherical markers were placed on the subject's body landmarks (Fig.2). Kinematic data were sampled at 200 Hz and stored for post-processing.

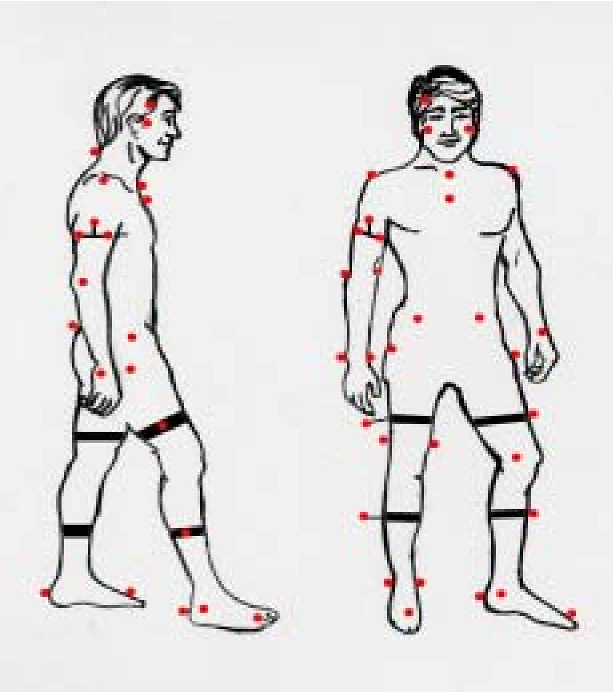


Fig. 2 The markers placement

Procedure

The subjects stood barefooted on the platform; the mid-lines of feet were 12 cm apart and were parallel to the sagittal plane. Tape was placed on the platform to ensure that foot placement would remain consistent from trial to trial. They were instructed to stand as still as possible with their arms freely hanging at their sides. Their knees and hips were fully extended, and their heads held erect to look directly forward on a mark on the wall at a distance of 2m all times.

All subjects were tested under eight types of perturbations with 3 trials of each perturbation. Four types of uni-axial perturbations were tested first then four types of bi-axial perturbations. These perturbations were delivered in a random sequence and commenced 1 second after the start of the data collection. Following each perturbation the platform was returned to the midposition slowly over a five-second interval. The time interval between each trial varied randomly from 15 to 30s. Subjects were instructed to respond to the disturbance without moving their feet. No pretest information regarding perturbation type, amplitude, or sequence was provided. Occasional steps did occur during the experiment, additional trials will be tested and subsequent analyses are confined to the trials without steps.

Data Analyses

Postural responses were divided into two phases: an early passive imposed postural sway due strictly to the platform movement, and a later active automatic postural reaction phases.

EMG

EMG signals were pre-amplified, full-wave rectified, and band-pass filtered (40-400 Hz) then notch filtered (60 Hz). Moving average (window width with 50 points) was used to smooth EMG signal. The frequency of occurrence, onset latency and amplitude of burst of EMG activity were obtained.

Kinematics

COM

The kinematic data were low-pass filtered with at a cutoff frequency of 6 Hz. The whole body's COM was calculated using a weighted sum average of a 13-segment biomechanical mode. The effects of the different types of perturbation on the kinematics of COM were interpreted from the horizontal and vertical trajectories, velocity and acceleration of the whole body's COM.

Angular motion

Euler angle system was used to measure joint kinematics. Angular relationships between the body segment, and global laboratory coordinate system were defined by the relationships between local coordinate systems aligned with each body segment. The local coordinate systems were aligned with the body segment using three non-collinear markers attached to the respective body segments.

In our study, an angle of 0° indicated that the body segment of head, trunk and pelvis were collinear. Joint angle values increased in the positive direction with increasing joints flexion and increased in the negative direction with increasing joints extension.

The maximal excursion of imposed postural sway and automatic postural reaction phase were calculated. The maximal angular excursion of imposed postural sway phase was defined as the difference in magnitude of the angle at the time of platform movement onset and at the instantaneous maximal angular value. The maximal angular excursion of postural reaction was the difference in magnitude of the angle at the instantaneous maximal angle value and the lowest angle value in postural reaction phase.

Statistical Analyses

Descriptive statistics was applied to measure latency and amplitude of EMG activity, the mean values and the standard deviations were calculated and presented. Maximal COM trajectory and angular excursion in imposed postural sway and automatic postural reaction phases were calculated. A series of one-way analyses of variance with repeated measures were performed to determine whether varying types of perturbation altered the postural responses.

Preliminary Results and Discussion

Kinematics

COM

The data of **nineteen subjects** (12 males, 7 females; ages 19-26 years) were presented here. There were no significant differences of the maximal medial-lateral COM displacement among various types of perturbation, and the means of medial-lateral COM were around 10 mm. **Table1** presents the horizontal and vertical COM displacement of uni-axial perturbations. During uni-axial perturbation, all the four types of perturbation induced quite a large horizontal COM displacement, while the forward and backward translation induced larger displacement than the upward and downward rotation ($F=62.52$, $p<0.01$). In automatic postural reaction phase, translational perturbation recovered more horizontal displacement than rotational tests ($F=139.37$, $p<0.01$). Because rotational tests changed the end COM positions by bringing the COM forward in D test and backward in U test (**Fig. 1**).

Platform rotation (U and D) induced more vertical COM displacement than translation ($F=11.50$, $p<0.01$) (**Fig. 2**). Keshner presumed that during platform rotation, the COM is shifted in the vertical rather than the horizontal plane (Keshner *et al.*, 1988). This result partly validated the previous assumption, but a commensurable large horizontal COM displacement also induced during rotational perturbation. In automatic postural reaction phase, B and U initiated larger vertical COM displacement than F and D ($F=6.74$, $p<0.01$). There existed a large rebound and then return response. It may be due to the B and U stretched the gastrocnemis inducing reflex-based plantar flexion before regain balance.

Table 1 Mean of the maximal horizontal and vertical displacement of the body COM during the passive imposed sway and active postural reaction phases in four types of uni-axial support surface perturbation

Displacement (mm)	**Horizontal**				**Vertical**			
	B	**D**	**F**	**U**	**B**	**D**	**F**	**U**
Imposed Sway	65.88 ±3.12	53.48 ±4.43	-66.67 ±4.35	-57.65 ±3.45	-10.46 ±3.36	14.38 ±4.13	8.13 ±4.29	-13.21 ±3.36
Postural Reaction	-62.40 ±8.10	-26.33 ±4.20	58.52 ±4.54	31.47 ±9.92	13.77 ±4.76	10.74 ±3.30	9.51 ±5.05	14.93 ±5.15

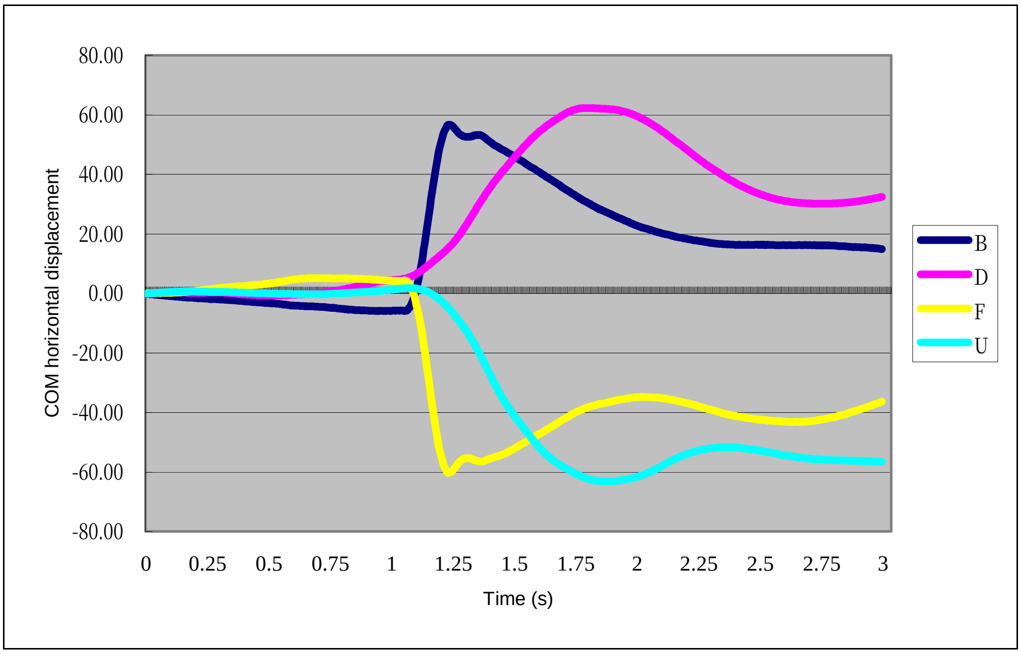


Figure 1 The horizontal trajectory of the body COM of un-axial support surface perturbation. .

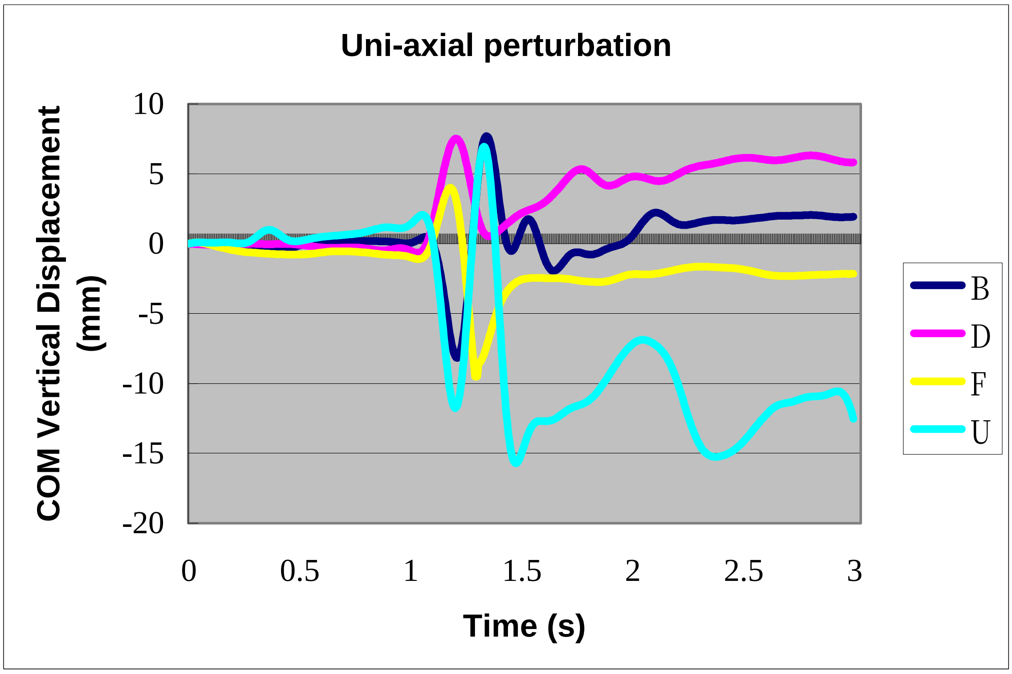


Figure 2 The vertical trajectory of the body COM of un-axial support surface perturbation.

Table 2 presents the COM displacement of bi-axial perturbations. In the imposed sway phase, all the bi-axial perturbation induced more horizontal displacement than uni-axial perturbation (**Fig 3**). Only BD and FU perturbation demonstrated the adding effects of horizontal COM displacement. However, the vertical COM displacement of all the bi-axial perturbation conformed to the expected adding and counterbalanced effects (**Table1, Table 2**).

In postural reaction phase, the subjects recovered larger horizontal and vertical COM displacement in BU and FD perturbation than in BD and FU perturbation (**Fig 3, Fig 4**). It was hypothesized that the "enhanced" ankle input of BU and FD generated greater agonist stretch reflex that stabilizes the posture. Whereas the "nulled" ankle input of BD and FU produced weaker balance-reaction responses regardless of the greater imposed postural disturbance. It was presumed that BD and FU are the more challenge tests for balance control.

Displacement (mm)	**Horizontal**				**Vertical**			
	BD	BU	FD	FU	BD	BU	FD	FU
Imposed Sway	85.97 ±11.24	71.61 ±3.48	-72.06 ±13.01	-81.41 ±15.26	7.61 ±4.95	-15.40 ±3.34	21.88 ±6.18	-12.62 ±3.17
Postural Reaction	-62.10 ±8.04	-72.33 ±6.26	68.32 ±15.04	30.57 ±7.75	14.56 ±3.05	29.12 ±5.84	-22.01 ±6.19	12.59 3.35

Table 2 Mean of the maximal horizontal and vertical displacement of the body COM during the passive imposed sway and active postural reaction phases in four types of bi-axial support surface perturbation

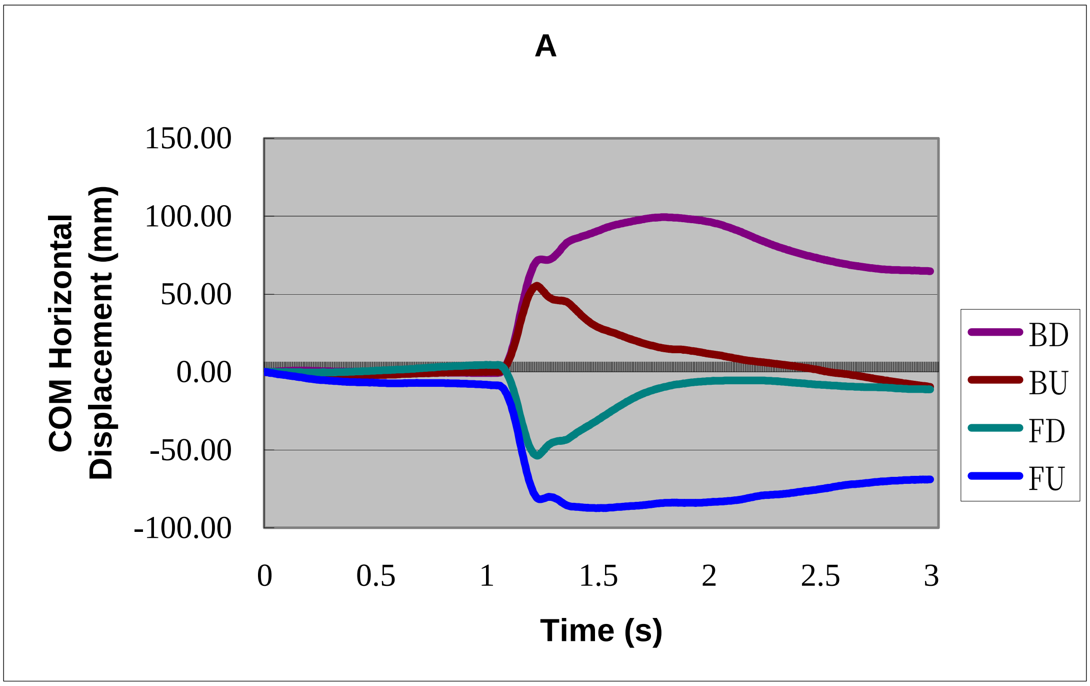


Figure3: The horizontal trajectory (A) and the vertical trajectory (B) of the body COM of eight types of support surface perturbation.

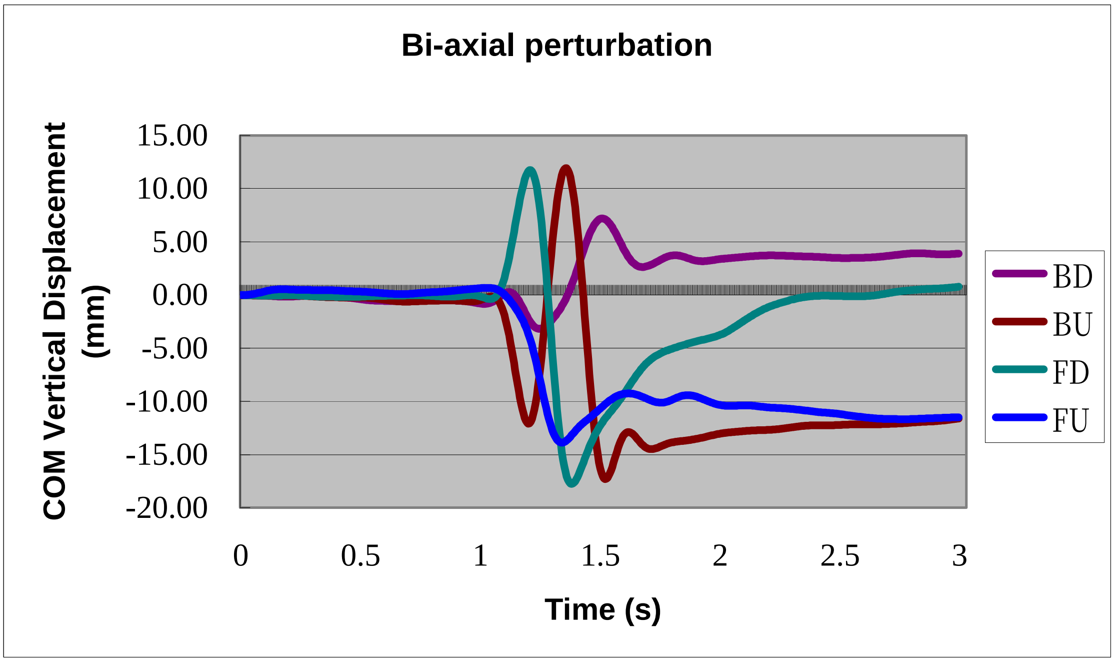


Figure 4: The horizontal trajectory (A) and the vertical trajectory (B) of the body COM of eight types of support surface perturbation.

Angular motion

The data of **six subjects** (4 males, 2 females; ages 19-22 years) were presented here. Most of the angular excursion of head, trunk and lower limbs occurred in sagittal plane. And postural responses demonstrated a symmetry pattern. The data present here focused on angular excursion of flexion and extension in head, trunk and hip, knee and ankle joints on right lower limb (Table 3). The rest of the data are undergoing analysis.

Table 3. Mean maximal angular excursion of joints in sagittal plane during two phases of postural responses to various support perturbation.

Joint (degree)	Head		Trunk		Hip		Knee		Ankle	
Phase	Imposed	Reaction	Imposed	Reaction	Imposed	Reaction	Imposed	Reaction	Imposed	Reaction
B	6.20 ± 4.19	7.67 ± 3.59	-3.01 ± 0.98	5.64 ± 3.07	-3.02 ± 1.01	11.36 ± 4.68	6.14 ± 4.03	-6.59 ± 2.93	3.0 ± 0.84	-3.61 ± 1.11
F	-2.66 ± 1.13	6.46 ± 3.44	4.61 ± 2.31	-5.51 ± 2.80	9.05 ± 3.84	-9.15 ± 4.66	-2.36 ± 0.64	16.80 ± 5.36	-3.15 ± 0.55	7.60 ±3.61
D	2.71 ± 1.31	-3.49 ± 1.44	2.8 ± 0.44	-4.59 ± 1.37	3.10 ± 1.35	-4.52 ± 2.64	8.61 ± 3.70	7.52 ± 3.39	-5.34 ± 0.67	4.81 ±1.81
U	-5.31 ± 3.32	9.69 ± 6.15	-2.44 ± 0.93	5.07 ± 2.38	-5.51 ± 7.42	10.52 ± 3.19	-3.96 ± 2.55	7.74 ± 6.03	3.84 ± 0.57	7.54 ±4.03
BD	2.78 ± 1.11	-4.28 ± 3.43	-3.98 ± 2.97	8.23 ± 5.05	-3.79 ± 2.96	16.15 ± 5.03	4.64 ± 1.99	-6.22 ± 2.51	2.08 ± 0.71	7.98 ± 3.46
BU	-7.79 ± 6.15	9.05 ± 4.33	-5.44 ± 2.33	6.92 ± 2.54	-3.15 ± 1.23	13.22 ± 4.32	2.25 ± 1.20	-6.85 ± 2.25	4.13 ± 1.20	6.96 ± 3.93
FD	4.72 ± 3.97	5.80 ± 2.91	6.46 ± 2.84	-6.50 ± 2.13	9.91 ± 4.08	-9.41 ± 3.32	-2.26 ± 1.29	23.13 ± 6.86	-8.09 ± 1.74	9.99 ± 3.02
FU	-3.40 ± 1.50	8.48 ± 6.16	3.51 ± 2.37	-8.05 ± 6.91	12.35 ± 7.37	-8.12 ± 4.61	-2.25 ± 1.17	9.71 ± 3.94	3.29 ± 2.62	7.01 ± 3.33

Positive values(+) indicate flexion and negative values(-) indicate extension

In imposed postural sway phase, the angular excursion of the head moved downward (flexion) during D and translation combine D (FD, BD), and upward (extension) during U and translation combine U perturbation (FU, BU) **(Fig. 5**). In automatic postural reaction phase, the subjects tended to flex the head in most types of perturbation. It was also found that the subjects usually reflexively watch their feet to check if balance achieved after postural way during experiment. The response of the head movement during perturbations demonstrated higher variability across subjects than the responses of the other joints' movement.

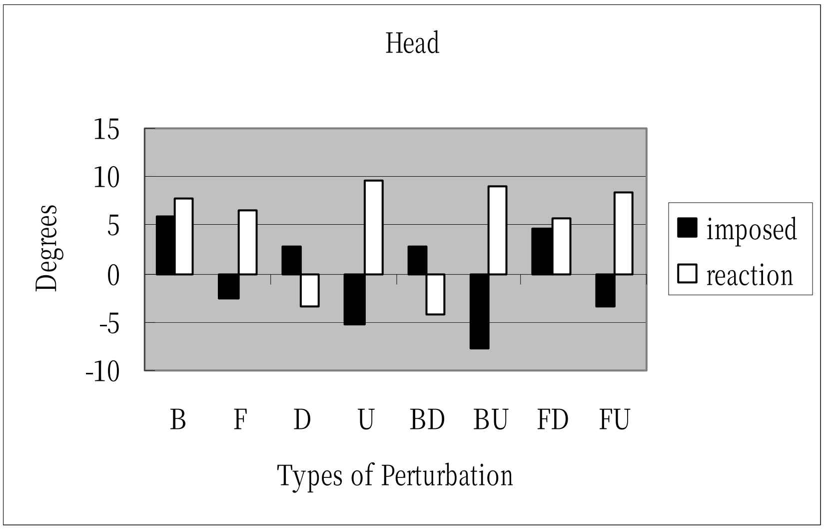


Figure 4.5 Mean maximal angular excursion of head movement in various types of perturbations

Maximal excursion of trunk and hip moved to the same (flexion or extension) fashion. The trunk and hip were imposed to flexion during the platform displaced forward and to extension during the platform displaced backward. Imposed hip flexion excursion during platform displaced forward was larger than imposed hip extension during platform displaced backward. However, in postural reaction phase, hip extension excursion in response to platform translated forward was smaller than hip flexion excursion in response to platform translated backward. The limited range of motion in hyperextension of hip joint can explain this phenomenon. Simultaneous flexion or extension of the hip and trunk, which put the pelvis backward or forward in accordance with the direction of platform displacement, was demonstrated in translational and rotation combined translational perturbations (**Fig. 6, Fig 7**). Therefore, hip strategy (but not pure) rather than ankle strategy was generated to return the posture to balance during all the types of perturbation except U and D. The greatest maximal joint excursion of the trunk was occurred in BD and FU perturbation. This result was consistent with the hypothesis that more imposed postural sway will induced more trunk angular excursion to recover balance.

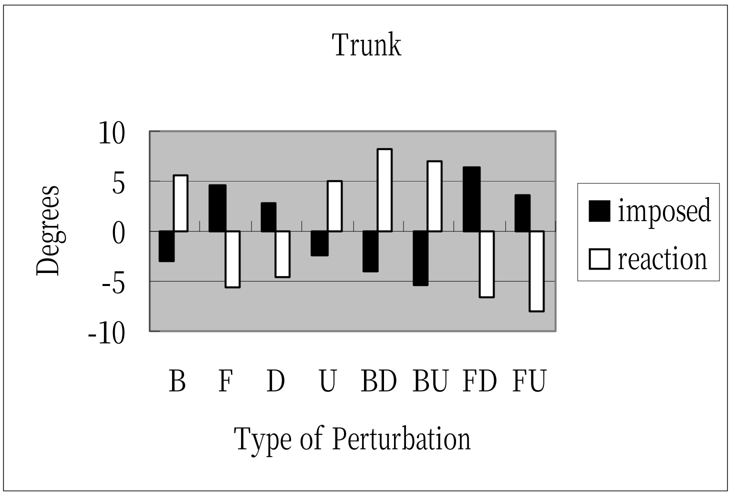


Figure 6 Mean maximal angular excursion of trunk movement in various types of perturbations

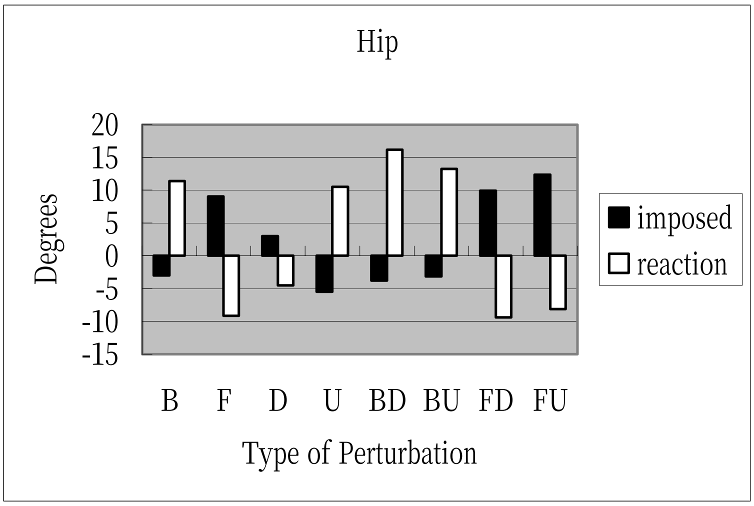
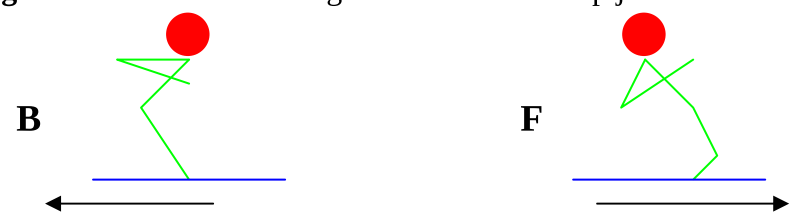


Figure 7 Mean maximal angular excursion of hip joint in various types of perturbations



Knee joint was also imposed to varied degrees of flexion or extension during perturbations. Knee flexion paired with hip extension and vice versa, knee extension paired with hip flexion in postural reaction phase during all types of perturbation except D (**Fig 8)**. This finding indicates that the subjects did not use pure hip strategy for balance by adding knee joint movement to hip strategy. The result was consistent with previous experimental description of mixed strategy with high velocity (Hughes *et al.*, 1995). It was assumed that knee flexion accompany with hip extension will contribute to bring the COM forward in compensation to the limited hip extension mentioned above.

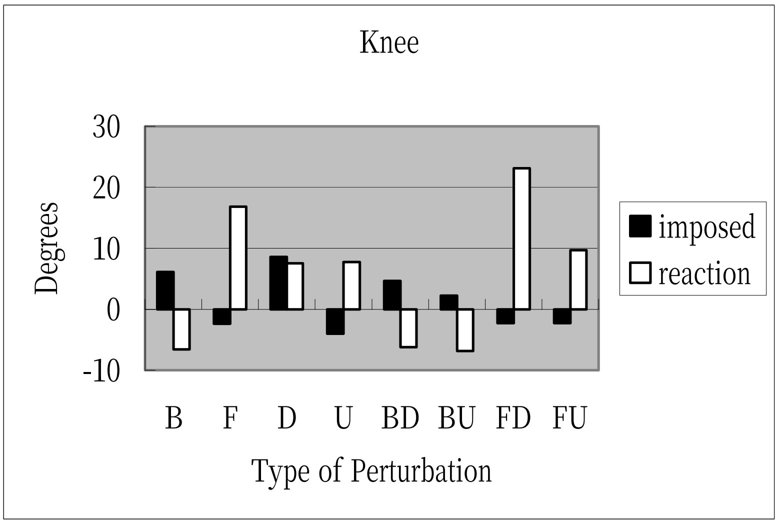


Figure 8 Mean maximal angular excursion of knee joint in various types of perturbations

The largest imposed maximal angular excursion of ankle joint was occurred during FD. However, larger maximal excursion was not found in BU perturbation as hypothesized. It is because stretch reflex induced early by ankle dorsiflexion inhibited the increasing joint excursion. Similarly, the imposed maximal angular excursion of ankle joint was larger in D than in U. The "nulled" ankle perturbation also induced some degrees of joint excursion (**Fig 9**).

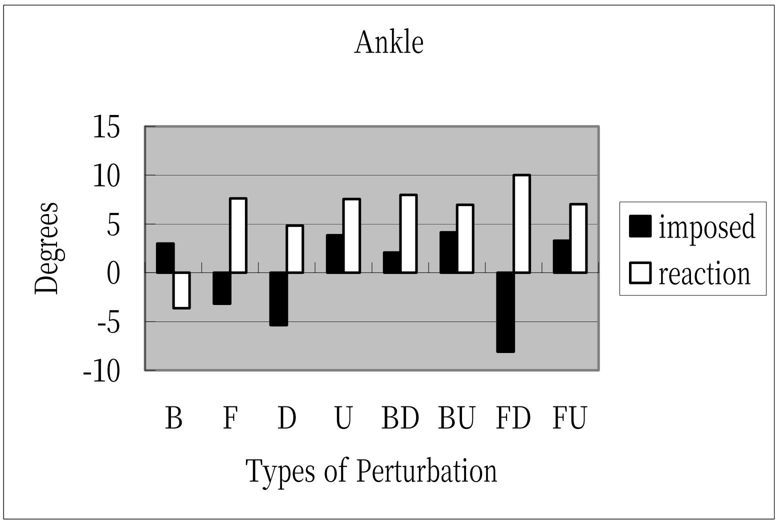


Figure 9 Mean maximal angular excursion of ankle joint in various types of perturbations

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