34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Effect of inclined support surface on postural strategy during anterior-posterior platform translations

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Abstract— **Previous studies have reported that postural coordination patterns change as a function of translation frequency. However, the effect of inclined support surface on postural strategy was not clear. Therefore, the purpose of this study is to investigate the influence of inclined support surface on postural strategy during platform translations. Eight healthy adults maintained their balance in stance during support surface translations in the anterior–posterior direction at two different frequencies (0.2 and 0.8[Hz]) and at three different base of support condition (LV: Level, TD: Toe Down, TU: Toe Up). For the kinematic data at slow frequency, subjects rode the platform depending on the movement of platform itself, while at fast frequency subjects fixed their head and center of mass (COM) in space. For the kinetic data at slow frequency, the ankle moment amplitude is similar among all support surface conditions, while at fast frequency the ankle moment amplitude for TU is significantly larger than LV. Result shown that the effect of inclined surface on postural strategy changed according to frequency of support surface translations.**

I. Introduction

Human bipedal stance is inherently unstable, because a large body mass is located high above a relatively small base of support. Therefore, an advanced facility of the postural-control system is required for maintaining upright posture. Humans are able to select distinct strategies depending on task requirements.

According to previous studies, in upright bipedal posture two primary coordination modes have been identified through a range of discrete perturbations and control conditions. One mode is an ankle strategy where, in effect, the postural system is viewed as an inverted pendulum with motion about the ankle joint. A second mode is a hip strategy where the motion at this joint preserves the postural stability in the face of particular constraints to posture [1]. Other study by Marin et al. [2] evaluated multi-segmental postural strategies used to achieve supra-postural task. The supra-postural tracking task used requires that subjects follow periodic movements of visual target with the head. This experimental paradigm leads to different coordination patterns around the hip and ankle joints. For slower oscillation frequencies or lower amplitudes of displacement, ankle and hip joints moved simultaneously in the same direction (in-phase mode). And for faster oscillation frequencies or greater motion amplitudes, the two joints oscillated simultaneously in opposite direction (anti-phase mode). In addition Buchanan et al. [3] have examined the effect of frequency of sinusoidal platform translation on postural movement. They have demonstrated that support surface allow subjects to remain in upright stance and ride the platform with little motion about the ankles, knees, or hips for slow translation frequencies. For fast translation frequencies, a different postural pattern emerges, with the head and upper trunk fixed in space relative to the moving platform with extensive motion about the ankles, hips, and knees. They suggested that fixing the head in space is important to remove the visual scene oscillation produced by the translating support surface, thus allowing vision to aid in high frequency postural control. Therefore human upright posture is maintained by the central nervous system via integration of complex afferent and efferent control signals, based on body orientation and motion information, which are provided by the vestibular, visual and somatosensory systems.

On the other hand, Sasagawa et al. [4] investigated the active stabilization mechanism by inclined surface on quite standing. As a result, they found electromyogram(EMG) activity change as a function of support surface conditions, indicating that increased (decreased) passive contribution required less (more) extensor torque generated by active muscle contraction. From this reason, it is important the effect of support surface condition on postural strategy. However previous studies examined principally linear motion of body segments and, in a number of cases, had a limited range of experimental perturbations. For example, the surface of platform translation has not been manipulated systematically with changes in platform translation frequency.

Therefore, the purpose of this study is to investigate the influence of inclined support surface on a postural strategy with changes in platform translation frequency.

II. Experiment

Fig.1 shows the experiment systems. Eight healthy male subjects (age: 22.9±1.6 [year], height: 171.1±5.1 [cm], weight: 64.0± 1.7[kg]) participated in this study. None of the participants had a history of motor disorder. Informed consent was obtained from all participants prior to their participation in this study. The experimental procedure used was approved by the local ethics committee. Subjects stood on the three different support surfaces of TU:Toe Up, LV: Level, and TD: Toe Down (Fig.2). The support surface was translated sinusoidally in the anterior – posterior direction at two

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different frequencies: 0.2 and 0.8 Hz. Marin et al. [2] reported that postural coordination patterns switched from in-phase to anti-phase mode from 0.5 to 0.6[Hz]. So we selected 0.2[Hz] as slow translation frequencies and 0.8[Hz] as fast translation frequencies. The support surface translation was fixed at 100 mm peak to peak, for the duration of 70 sec. The support surface translation and slopes were induced by motion base (MB-150, COSMATE, JAPAN) which is a parallel link mechanism with six degrees of freedom. Center of pressure (COP) in anterior –posterior direction was calculated from force platform (9286A, KISTLER, JAPAN) data. The COP was recorded by 1000 Hz sampling frequency. Reflective markers attached to the platform and subject. Markers were attached to the following landmarks: top of head, acrominon, pelvis, great trochanter, lateral condyle, external condyle, and platform. Center of mass (COM), ankle and hip joint angles were calculated from the coordinates of reflex markers measured by motion capture device (HWK-200PT, Motion Analysis, USA). The sampling frequency of motion capture device was 200 Hz.

To test statistically the difference among the support surface conditions, one way ANOVA with repeated measures was used. The Scheff test was used for past hoc analysis. $P<0.05$ was defined as a level of significance.

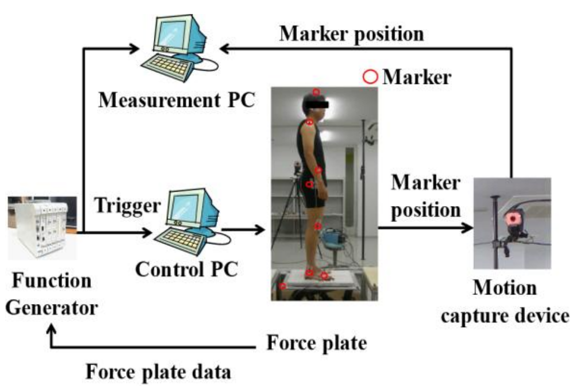

Fig.1 Experiment system

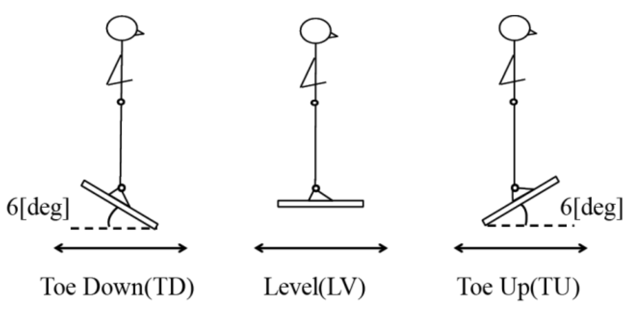

Fig.2 Schematic diagrams of the experimental set-up and definition of the inclined support surface angle.

III. RESULT

Fig.3 A and C shows a typical example of one cycle stick figures on each surface condition during moving platform. Fig.3 A and B shows subject applied translational sway at 0.2 Hz and Fig.3 C and D shows subject applied translational sway at 0.8 Hz. Fig.3 B and D shows the typical example of average head trajectory and average platform signal for 7 trial. For slow translation frequencies of 0.2 Hz, subjects rode the platform with little damping of head and trunk anterior–posterior motion at all surface conditions. And for fast frequencies of 0.8 Hz, subjects damped head and trunk motion extensively at the translation frequency at all surface conditions. Fig.4 shows the mean amplitude of the head and COM of anterior–posterior as a function of surface condition and translation frequency. The mean amplitude of the head and COM from two coordination system is considered in order to investigate which stability either in space or in base of support. Absolute coordinate value is a distance from origin of coordinate system to head and COM position. Relative coordinate value is distance from platform marker position to head and COM position. Head amplitude in absolute coordinate value had no significant difference at surface conditions. However, in 0.2 Hz, head amplitude in relative coordinate system at TU increased significantly compared to the LV. Amplitude in relative coordinate value at TU also had increased significantly compared to the LV at 0.2 Hz COM and in absolute coordinate system, TU had decreased significantly as compared to those of LV. In addition, COM amplitude in absolute coordinate system at TU increased significantly as compared those of LV at 0.8 Hz.

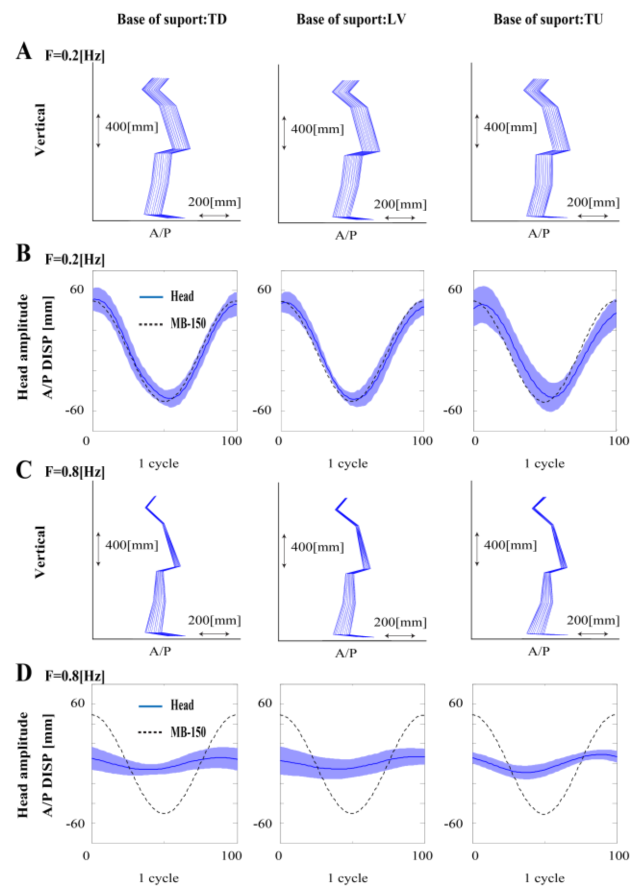

Fig.3 Typical examples of stick figures and head trajectory during platform translations for each slope condition.
A and B shows typical example during moving platform at 0.2 Hz. C and D shows typical example during moving platform at 0.8 Hz. Anterior-posterior (A/P) and vertical scales for the stick figures are labeled in A and C. In B and D, Head trajectory is shown by the use of solid line. Platform signal is shown by the use of dash line. Shaded areas around the average trajectories represent 1 SD.

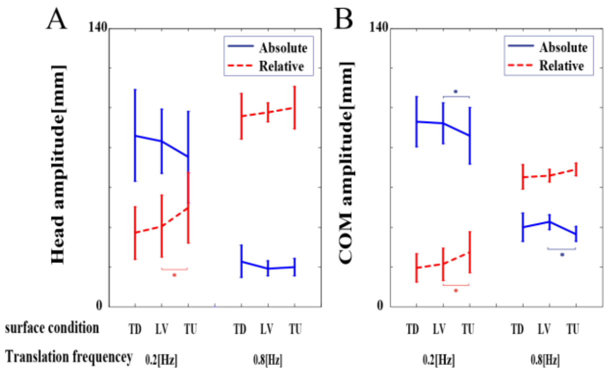

Fig.4 Head and COM amplitude as a function of support surface condition and translation frequency

Group means of anterior-posterior peak-to-valley head and COM aptitude are plotted as a function of support surface condition and translation frequency. Solid lines shows head to origin of coordinate system distance and COM to origin of coordinate system distance (i.e. absolute coordinate value), and dashed lines shows head to platform marker and COM to MB marker (i.e. relative coordinate value). Error bars represent means SD in A and B. *indicates the significant difference (P<0.05).

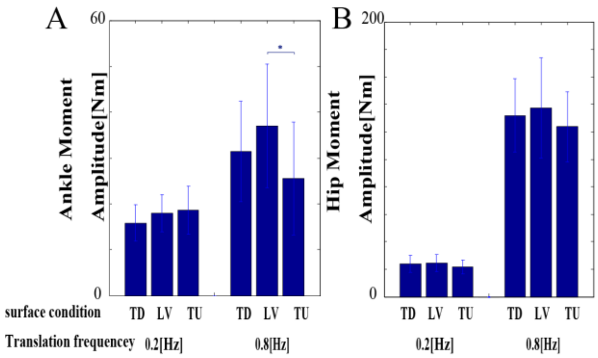

Fig.5 Ankle moment and hip moment amplitude as a function of support surface condition and translation frequency

Group means of peak-to-valley ankle moment and hip moment aptitude are showed as a function of support surface condition and translation frequency. Error bars represent means SD in A and B. *indicates the significant difference (P<0.05).

Fig.5 A and B shows the mean amplitude of the ankle moment and hip moment as a function of surface condition and translation frequency. Regardless of surface conditions, both joints moment in 0.8 Hz were greater than those of 0.2 Hz. While, both joints moment had no significant difference at surface conditions at 0.2 Hz. However, in 0.8 Hz, hip moment amplitude at TU decreased significantly as compared those of LV.

Fig.6 shows the relations between ankle moment and ankle joint angle. This shows a linear relationship between ankle moment and ankle joint angle. Therefore, stiffness is consisted:

$$F = KdX. \quad (1)$$

where F is the ankle moment , dX is ankle sway angle. Therefore, ankle stiffness during passive sway as mechanical property was calculated by the slope of linear regression line between torque and sway angle.

Fig.7 shows an ankle stiffness as a function of surface condition and translation frequency. Ankle stiffness at all surface condition was significantly higher in 0.2 Hz than those of 0.8 Hz. In addition, even though ankle stiffness in 0.2 Hz had no significant difference at surface conditions, ankle stiffness in 0.8 Hz at TU decreased significantly compared to the LV.

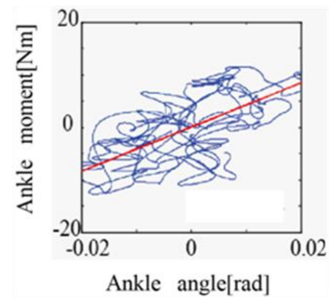

Fig.6 The relations between ankle moment and ankle joint angle.
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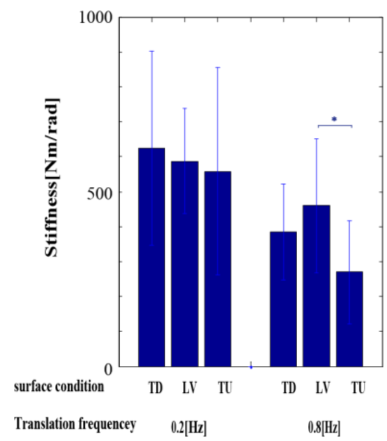

Fig.7 Ankle stiffness as a function of support surface condition and translation frequency

Group means of ankle stiffness are showed as a function of support surface condition and translation frequency. Error bars represent means SD. *indicates the significant difference (P<0.05).

IV. Discussion

In latest experiment, regardless of support surface, subjects ride platform depending on the movement of platform itself at 0.2 Hz, and subjects fix their head and COM in space at 0.8 Hz. Result shown that the postural coordination patterns changed by a function of translation frequency, but it were unchanged among the three support surface inclinations. Therefore, these results agreed with Buchanan et al. [3]. Buchanan et al. [3] suggested that fixing the head in space is important to remove the visual scene oscillation produced by the translating support surface, thus allowing vision to aid in high frequency postural control. With the head fixed in space, a very stable platform is also provided for the vestibular system so that it may react to either slower or faster frequency perturbations than those at the surface driving frequency.

In absolute coordinate system, head and COM amplitude in 0.8 Hz were significantly smaller than that of 0.2 Hz. On the other hand, in relative coordinate system, head and COM amplitude in 0.2 Hz were significantly smaller than that of 0.8 Hz. Therefore, it suggests that the head and trunk's fixed position in space to provide obvious information of vision and somatosensory.

In 0.8 Hz, ankle moment and stiffness at TU decreased significantly as compared those of LV. It indicates that changing information from proprioceptive organ by inclined surface at TU effected a change in ankle moment and stiffness. Ankle stiffness at 0.2 Hz degreased significantly as compared those of 0.8 Hz, and in 0.8 Hz, hip moment increased significantly as compared those of 0.2Hz. It suggests that postural coordination patterns changes to anti-phase at 0.8 Hz, and hip joint angle and moment made a sizable contribution to maintain balance. Therefore ankle stiffness is changed according to effect of hip joint.

In conclusion, at slow frequency subjects rode the platform depending on the movement of platform itself to get the stability in relative coordinate system, and ankle moment amplitude is similar among all surface conditions. At fast frequency subjects fixed their head and COM in space to get the stability in absolute coordinate system. For this case, the ankle moment amplitude for TU is significantly smaller than LV. Therefore, the effect of inclined support surface on postural strategy is changed according to frequency of support surface translations.

ACKNOWLEDGMENT

We thank H.Obata and T. Hideaki, M.Azuwan Mat Dzahir for their helpful advice. This work was supported by KAKENHI: Grant-in-Aid for Scientific Research (B) 21300202

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