〔Chiba Medical J. 88E：13 ～ 18, 2012〕

〔 **Original Paper** 〕

Dynamic postural control: Repetitive alternative rotation of the head and thorax

Ichiro Shimoyama[1], Yumi Asano[2], Atsushi Murata[2]

Yoshinori Higuchi[3], Tomoyuki Uchiyama[4], Hitoshi Shimada[5]

Hiroshi Oouchi[6,7], Kazuhisa Takahashi[7] and Satoru Kuwabara[4]

[1] Frontier Medical Engineering, Chiba University, Chiba 263-8522.
[2] Division of Rehabilitation, Chiba University Hospital, Chiba University, Chiba 260-8677.
[3] Department of Neurological surgery, Graduate School of Medicine, Chiba University, Chiba 260-8670.
[4] Department of Neurology, Graduate School of Medicine, Chiba University, Chiba 260-8670.
[5] National Institute of Radiological Sciences, Chiba 263-8555.
[6] Department of Sports Medicine, Kameda Medical Center, Kamogawa 296-8602.
[7] Department of Orthopedic surgery, Graduate School of Medicine, Chiba University, Chiba 260-8670.

（Received November 18, 2011, Accepted December 19, 2011）

SUMMARY

Accidental falls may cause serious outcomes for the aged. Motor and sensory systems decay with aging, so reaction time as a placing reflex becomes delay to abrupt changes of the posture. Dynamic postural balance may provide more information than static postural balance. Dynamic postural balance was studied for proprioception of the neck and trunk, and for eyes control. Seven healthy volunteers participated in this study after informed consent. Repetitive alternative rotation of the head（M1）and of the head and thorax synchronized（M2）; gazing at a projected point from a laser pointer set on the head, gazing at a fixation point on a screen and closed eyes; comfortable pace（P1）for repetitive alternative rotation, a faster pace than P1, and a slower pace than P1 were asked to do for 20 sec in every combination. A force plate was used for the center of foot pressure, and a wireless 3 axes accelero-meter were set on the top of the head for head motion. Powers were discussed at the same frequency as the head and/or thorax movements. Powers in M2 were significantly higher than those in M1. Neck proprioception should be important than that of thorax for dynamic postural balance.

Key words: **Postural balance, head rotation, trunk rotation, vestibule-ocular reflex, proprioception**

Ⅰ. Introduction

Accidental falls have caused serious outcomes for the aged[1-3]. Vestibular function, vision[4-7]and proprioception deteriorated with aging[8,9], and muscle strength and nerve conduction velocity deteriorate with aging. Motor and sensory systems decay with aging, sensory-motor feed-back, feed-forward were important, and vestibulo-ocular and -spinal reflexes work to stabilize the postural balance[10]. Signals from the proprioceptors of the muscles and the joints are essential to all the

Address correspondence to Dr. Ichiro Shimoyama.
Frontier Medical Engineering, Chiba University, 1-33, Yayoi-cho, Inage-ku, chiba city, Chiba 263-8522, Japan.
Phone: +81-43-290-3118. Fax: +81-43-290-3118.
E-mail: ichiro@faculty.chiba-u.jp

Abbreviations: COP: center of foot pressure reflexes and volitional movements.

Reaction time as a placing reflex is critical to abrupt changes of the posture. Dynamic postural balance should prepare much information, which had been reported for arm movements[11,12], for rotation on ankles, hips, and shoulders[13]. Coordination between a neck and trunk have been reported important between a neck and trunk [14-17], and between eyes and a neck[18]. Dynamic postural balance was studied with the volitional neck and trunk motion with eyes controlled for healthy volunteers.

Ⅱ. Materials and Methods

Seven healthy volunteers participated in this study after informed consent. They showed no neurological deficit, aged 43 years (mean) ±11.4 (standard deviation).

Figure 1 showed a block diagram to measure the head motion and the center of foot pressure (COP). A subject was standing upright on a force plate-A (LUB-100KB®, KYOWA, Japan), 1.2 m apart in front of a screen. Medio-lateral direction represented as COP-X, and antero-posterior direction did as COP-Y. Signals from the force plate were amplified by amplifiers-B (PCD300A®, KYOWA, Japan), and sampled at 100 Hz

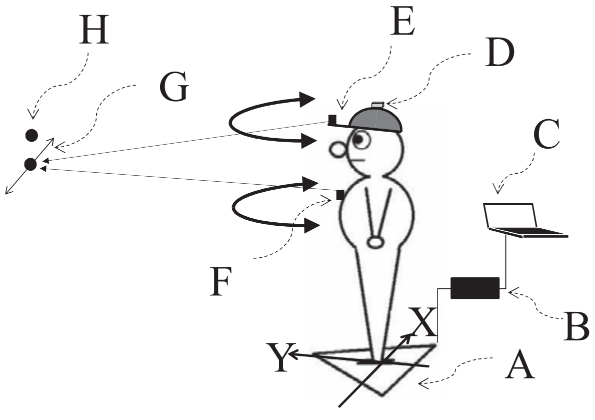

Fig. 1 Block diagram for this study. *A* was a force plate to record the center of foot pressure, and *B* was amplifier for the force plate. *C* was a computer to acquire the head motion and the center of foot pressure. *D* was a wireless accelerometer to measure head motion. *E* and *F* were laser pointers, and *G* was a projected point from a laser pointer. *H* was a fixation point. *X* and *Y* were directions of the axes for the center of foot pressure.

into a computer-C (Pentium IV®). The head movements were measured with a wireless 3 axes accelerometers-D (WAA-006®, Wireless Technology, Japan) and the transmitted signals were received with the computer-C. The accelerometers-D was fixed on the top of a cap, and a laser pointer-E was fixed on the brim of the cap. Another laser pointer-F was set on the thoracic surface. G was a projected point on the screen from a laser pointer, and H was a fixation point. Subjects were asked to rotate repetitively their head only (M1), and asked to do their head and thorax synchronized (M2). Subjects were asked to rotate their head or thorax synchronized repetitively at their comfortable pace (P1), they were asked to do at the faster pace than P1 by 1.2 times (P2), and they were asked to do at the slower pace than P1 by 0.8 times (P3). Subjects were asked to stand still upright gazing at the fixation point and to do with eyes closed for 20 sec respectively (E0). And they were asked to gaze the projected laser point (E1) during the repetitive rotation, and to gaze at the fixation point on the screen (E2), and were asked to rotate their head and thorax with closed eyes (E3), on doing M1 or M2, respectively. Subjects were asked to rotate +/−30 degrees repetitively for 20 sec in every combination. Just before recording the head motion and COP, P1 was measured for respective subjects, and subjects were asked to rehearse to rotate the head or thorax at P1, P2, or P3 for a while.

Recording condition was fixed for all subjects, and powers were obtained with the fast Fourier transform. Powers were discussed at the same frequency as the head motion.

Ⅲ. Results

Mean frequency was 0.5 Hz ±0.05 (standard deviation) for P1, 0.6 Hz ±0.07 for P2, and 0.4 Hz ± 0.05 for P3.

Figure 2 showed examples of the head position and COP at P1 for one subject (42 y/o). The head and COP showed stable enough in standing upright (E0). The head position oscillated rhythmically at 0.6 Hz for M1 (HEAD) and M2 (THORAX), and at E1, E2, and E3. COP in M2 fluctuated frequently than that in M1, and

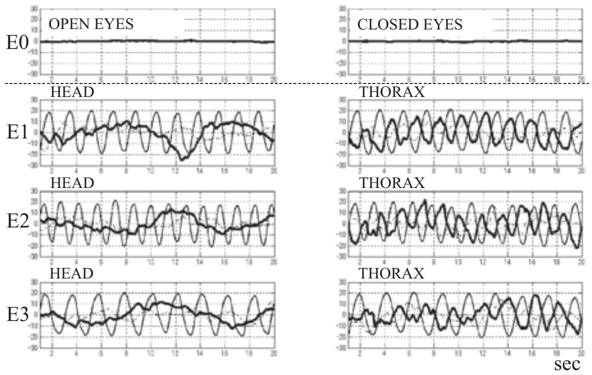

Fig. 2 Examples of the head position and the center of foot pressure at a comfortable pace for one subject, thick traces represented medio-lateral signals, and broken traces did antro-posterior signals of the center of foot pressure. Rhythmical oscillated traces represented the head motion. The abscissas represented time course in sec. A column M1 was for the movements with only the head, M2 for that with the head and thorax synchronized. A row E1 was for the movements in gazing at the laser projected point, E2 for that in gazing at the fixation point, E3 for that with eyes closed, respectively.

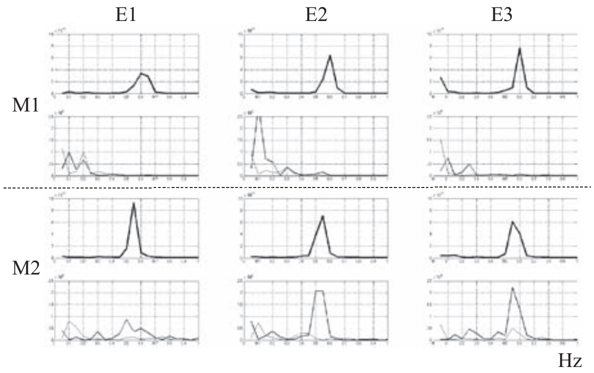

Fig. 3 Examples of the power spectra for the head motion and the center of foot pressure at a comfortable pace for one subject. Upper 2 rows M1 were power spectra with only the head, the uppermost row were those for the movements with the head only, and the second upper row were those for the center of foot pressure. Lower 2 rows M2 were power spectra with the head and thorax synchronized, the second lower row were those for the movements with the head only, and the lowermost row were those for the center of foot pressure. Thick traces for the center of foot pressure were represented for the medio-lateral oscillation, and thin traces did for the antro-posterior oscillation. Column E1 represented for the movements in gazing at the laser projected point, E2 for that in gazing at the fixation point, E3 for that with eyes closed, respectively. The abscissas represented frequency in Hz.

spectral powers showed increased at 0.6 Hz.

Figure 3 showed examples of the spectral powers for the head motion and COP at P1 for a subject (42 y.) Peak frequency was 0.6 Hz in M1, and 0.55 Hz in M2 for the head motion. Spectral powers at 0.6 Hz showed low at noise level in M1, but powers at 0.55 Hz were noted in M2.

Table-1 showed means and standard deviations for the total powers of COP-X and -Y in m^2. The analysis of variance showed significant between powers in standing still upright and those in the trunk motion ($P<0.005$), and no significance was noted between powers with eyes open and closed.

Table-2 showed mean powers and standard deviations at the peak frequency of the head motion in m^2. The analysis of variance showed significant between powers for M1 and those for M2 ($P<0.0001$), significant between those of COP-X and COP-Y ($P<0.001$). No significance was noted among powers for E1, E2 and E3, among those for P1, P2 and P3.

Ⅳ. Discussion

Compensation should keep postural balance stable for the volitional trunk movements, COP showed significant oscillation for the repetitive alternative rotation of the thorax synchronized with the head. Preparatory

Table 1 Mean and standard deviation for total power

	STANDING UPRIGHT	TRUNK MOTION
OPEN EYES	3.3 ± 4.24	15.0 ± 13.17
CLOSED EYES	3.2 ± 3.58	17.0 ± 13.90

Table-1. Table showed means and standard deviations of the total powers of the rolling and pich in m^2. Total powers of the center of foot pressure were significantly higher with trunk movements than those on standing still upright ($P<0.005$).

Table 2 Peak Powers for Center of Foot Pressure in m^2 (mean ± standard deviation)

COP	EYES	M1 P1	M1 P2	M1 P3	M2 P1	M2 P2	M2 P3
	E1	3.2 ± 2.33	1.7 ± 2.56	1.7 ± 1.57	56.6 ± 75.20	116.5 ± 131.70	42.8 ± 46.68
-X	E2	2.1 ± 2.63	1.4 ± 1.06	3.3 ± 2.53	33.3 ± 29.45	150.1 ± 232.03	61.5 ± 61.78
	E3	5.3 ± 7.19	2.6 ± 2.70	4.7 ± 7.49	62.2 ± 86.46	74.0 ± 65.00	96.0 ± 149.24
	E1	0.9 ± 0.63	0.7 ± 0.49	1.4 ± 0.82	14.8 ± 21.26	20.5 ± 13.52	15.5 ± 13.43
-Y	E2	1.1 ± 0.84	1.4 ± 1.78	1.6 ± 0.88	28.5 ± 32.29	36.2 ± 44.75	29.5 ± 30.44
	E3	1.5 ± 2.02	1.1 ± 1.34	6.1 ± 5.09	23.8 ± 18.63	18.5 ± 24.43	15.7 ± 15.19

Table-2. Table showed mean powers and their standard deviations at the peak frequency of the head motion in m^2. M1 was for the movements with only the head, and M2 was for that with the head and thorax synchronized. P1 was at a comfortable pace, P2 was at a faster pace than P1 (P1 × 1.2), and P3 was at a slower pace than P1 (P1 × 0.8). E1 was for the movements in gazing at the projected laser point, E2 was for that in gazing at the fixation point, and E3 was for that with eyes closed, respectively. COP-X was medio-lateral oscillation of the center of foot pressure and COP-Y was antero-posterior oscillation of the center of foot pressure.

movements and reflex might compensate for the volitional movements. The synchronized movements involved the center of gravity to elicit synchronized oscillation of COP to keep the stance at the same position. The mass and weight of the lower trunk need more energy for the movements than those with only the head. So COP was easily perturbed for the movements with the lower trunk. The signals from the vestibular organ were almost the same for the movements with only the head as the synchronized movements. The posture was controlled in standing upright during this study, and the stances were kept stable. The signals from the vestibular organs were thought to be consistent. But the signals from the proprioception were different between those from the neck or the lower trunk. Visual signals were controlled for all subjects. The movements with only the head perturbed COP poor, dynamic energy was less for those with only the head than that for the synchronized movements. Range of movements for joints was wider for the cervical vertebrae than that for the thoracic vertebrae, an odontoid process is just good to rotate. Repetitive alternative rotation for the thorax and head synchronized was equivalent to the motion with the neck immobilized; i. e., the proprioceptive signals were inhibited from the neck in keeping the postural balance stable. Neck motion was thought to be important to stabilize the postural balance. A neck had been reported to present much information [19], and the signals from the neck were of special importance to positioning the head to the rest of the body [18,20]. Neck proprioception might be important than that of thorax for dynamic postural balance. The neck motion has been reported restricted with aging [21,22], so the aged were used to turn around in rotating the head with help of the lower trunk motion [3], therefore, COP was perturbed easily.

There were no differences among the peak powers at P1, P2 and P3, but compensatory preparatory motion would thoughtfully be more at P1 and less at P2, and the sum of the powers at P1 showed minimum for that of M1 and M2, and of COP-X and -Y, and the sum of those at P2 showed maximum for that of M1 and M2, and of COP-X and -Y. The motion at P2 was thought to be sensitive to keep the balance, so the motion at P2 might be good to evaluate postural balance, because the variance showed increased.

There were no differences among the peak powers with E1, E2 and E3, but visual compensation would thoughtfully work the least with E3 and more with E1 or E2, and the sum of the powers with E3 showed maximum for that of M1 and M2, and of COP-X and -Y, and the sum of the powers at P2 showed maximum for that of M1 and M2, and of COP-X and -Y. The motion with E3 was thought to be sensitive to keep the balance, so the motion with E3 might be good to evaluate postural balance, but the motion with E3 was dangerous for the aged, so the motions with E1 and E2 were safer to evaluate the dynamic postural balance.

Dynamic postural balance at own pace had been reported for arm movements [12,23], for the rotation on ankles, hips, and shoulders [24], and for knees [25,26].

The method to perturb the postural balance could be classified into 2 types in studying dynamic postural balance; one was voluntary movements at own pace [22,27-29] and the other was unexpected perturbation, i. e., sudden displacement of any part of a body with outer force [30-36]. The reports were poor about the repetitive alternative trunk rotation and COP.

In conclusion, repetitive alternative rotation for the trunk might present more information than standing upright still.

Acknowledgements

This work was supported by KAKENHI (No. 23659293), Grant-in-Aid challenging Exploratory Research funded by MEXT, Japan.

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