Biomedical Research 27 (2) 55-60, 2006

Dynamic movement of center of gravity with hand grip

Hideki MOMIYAMA[1, 2], Masahito KAWATANI[1], Katsuaki YOSHIZAKI[3], and Hiroko ISHIHAMA[1]
[1] Department of Neurophysiology, [2] Department of Physical Therapy, and [3] Department of Nursing, Akita University School of Medicine, 1-1-1 Hondo, Akita, Akita 010-8543, Japan

(Received 12 December 2005; and accepted 13 January 2006)

ABSTRACT

We studied the movement of center of gravity (CG) in young and aged subjects during maximum grip of right or left hand. Body-sway was recorded with stabilometry in rest-stand position and in maximum grip. The data from right-or left-handed young subjects were analyzed. Maximum grip power was not different between dominant hand and un-dominant hands. Total length (LNG) and total movement area of CG (REC AREA) during the measurements were significantly larger in maximum grip than in rest-stand. In right-handed subjects, LNG increased to 245% and 250% of rest-stand value, and REC AREA increased to 589% and 633% in right and left hand grip, respectively. In left-handed subjects, LNG increased to 186% and 188% of rest-stand value, and REC AREA increased to 400% and 533% in right and left hand grip, respectively. No significant difference of LNG and REC AREA was observed between right and left hand grip in either hand dominant subject. Maximum grip did not affect CG in rest-stand. In aged subjects, maximum grip power was significantly less than in young subjects (48%). LNG and REC AREA in rest-stand were significantly larger in aged subjects than in young subjects (220% and 400%, respectively). They were not different during maximum grip with either hand. While aged subjects have difficulty of controlling CG in rest-stand, they have less problems to stabilize CG during maximum grip. These data indicated that dynamic movement of CG might be important to understand person's activity of daily living.

The shift of center of gravity (CG) in rest-stand has been considered a key factor of daily living, since unbalanced movement causes tumbling or dizziness (1, 3). The fact that eye closing increased CG movement suggested that sensory inputs were important for CG stability (8). Signals from the cerebral cortex and cerebellum to individual muscles were another important factor in CG control (3, 9). Dynamic body movement required coordination of many muscle contractions and/or relaxations (9). Different parts of the brain were activated during dynamic movement, including the primary motor cortex, sensory cortex, striate body and cerebellum (3). Since many muscle contractions are integrated in the nervous system, CG might sway during dynamic movement.

Measurements and analyses of CG have been developed over the past two decades (2, 5, 7, 8). The concept of "body-sway" has been widely used; while a subject stood at the computer-operated stabilometry, CG was analyzed instantaneously. Total movement of CG during the measurement was traced by a computer and calculated. At the same time, moving area, horizontal component and vertical component were calculated (5). This newly developed stabilometry could demonstrate dynamic movement of CG more accurately than ever before.

Address correspondence to: Dr. Hideki Momiyama
Department of Physical Therapy, Akita University School of Medicine, 1-1-1 Hondo, Akita 010-8543, Japan
Tel: +81(18)884-6530, Fax: +81(18)884-6500
E-mail: hidekimo@ams.akita-u.ac.jp

Writing in Japanese and using scissors are easier for right hand but not for left hand. While dominancy of hand is important in everyday life, CG data from right- and left-handed subjects have not been studied. In general, aging changes a person's posture and power of muscle contraction (1, 11). Tumbling might occur more frequently in aged subjects (1). Thus, dynamic movement of CG with maximum grip in aged subjects might be different from that in young subjects.

The alteration of posture with voluntary movement of upper limb was consciously controlled (11). This alteration should be linked to the dynamic movement of CG. However, no reports have demonstrated the detection of CG during voluntary movement of upper limb. Here we report the relationship between dynamic movement of CG and grip power of right- or left-handed, young and aged subjects. Preliminary data have been published as an abstract (6).

SUBJECTS AND METHODS

We recruited 21 young students in Akita University, 10 males and 11 females. Among them (averaged age: 24.3 y), 13 subjects were right-handed and 8 subjects were left-handed. None had episodes of vertigo, dizziness or hearing loss. All subjects had informed consent of these studies from principle investigator. Their characteristics were shown in Table 1.

We also recruited 29 aged subjects who visited our rehabilitation clinic for prevention of physical disorders. They (averaged age: 77.5 y) were able to visit the clinic by themselves, without nursing. We did not include data when we observed no grip-power (GP) in one of their hands. They were all right-handed. Their characteristics were shown in Table 2.

CG deviation was measured during maximum GP of right or left hand, using a stabilometry (MG100; ANIMA Co, Tokyo, Japan). CG measurements were started at rest-stand position in one hand without force (Smedlyey's dynamometer). Subjects stood comfortably with their legs straddle on stabilometry (Fig. 1). Stabilometry sensed the gravity from each of their legs and calculated the movement of CG by computer program. The subject stood at 3 m in front of a visual target (3 cm diameter). Then, maximum grip test was performed randomly with either hand. After control measurement (1 min), each test was performed for 10 seconds. A total of 3 sets of measurements were done for either hand.

Parameters of CG were summarized as body-sway. Total movement of CG during the measurement was calculated as total length (LNG). Movement area of CG during the measurement was calculated as rectangle area (REC AREA). The horizontal (X direction) movement of CG during measurement was calculated as deviation of center of mean X (DEV OF MX). The vertical (Y direction) movement of CG during the measurement was calculated as deviation of center of mean Y (DEV OF MY).

Data were statistically analyzed with ANOVA or Wilcoxon test. Correlation was analyzed with Fisher correlative analysis. The level of statistical significance was $p < 0.05$.

RESULTS

Young right-handed subjects

In rest-stand, body-sway was evaluated as follows (Table 3): total length (LNG) was 7.5 ± 2.0 cm, rectangle area (REC AREA) was 0.9 ± 0.5 cm^2, deviation of center of mean X (DEV OF MX) was −0.2 ± 0.9 cm and deviation of center of mean Y (DEV OF MY) was −4.6 ± 2.4 cm.

When CG was measured with maximum GP at right hand grip, averaged maximum GP was 33.9 ± 9.4 kg. Body-sway was evaluated as follows (Table 3): LNG was 18.4 ± 9.0 cm, REC AREA was 5.3

Table 1 *Summary of young subjects' background*

	Young	
Dominancy	Right-handed	Left-handed
Number (Male, Female)	13 (6, 7)	8 (6, 2)
Age	21.2 ± 3.9	20.6 ± 3.9
Height (cm)	163.7 ± 6.2	166.1 ± 7.2
Weight (kg)	53.8 ± 7.5	57.5 ± 10.1

(Mean ± SD)

Table 2 *Summary of aged subjects' background*

	Aged
Dominancy	Right-handed
Number (Male, Female)	29 (8, 21)
Age	77.5 ± 7.1
Height (cm)	150.0 ± 8.0
Weight (kg)	50.0 ± 8.9

(Mean ± SD)

± 3.8 cm^2, DEV OF MX was −0.1 ± 0.6 cm and DEV OF MY was −4.6 ± 2.5 cm. LNG and REC AREA were significantly increased compared with rest-stand (245% and 589%, respectively).

In contrast, averaged maximum GP was 33.6 ± 9.3 kg when they gripped with maximum GP at left hand. Body-sway was evaluated as follows (Table 3): LNG was 18.8 ± 9.0 cm, REC AREA was 5.7 ± 4.6 cm^2, DEV OF MX was −0.7 ± 1.0 cm and DEV OF MY was −4.9 ± 2.3 cm. Similar to right hand grip, LNG and REC AREA were significantly increased compared with rest-stand (250% and 633%, respectively).

Horizontal component of CG (DEV OF MX) at right hand grip was not altered from rest-stand (Fig. 2A). In contrast, DEV OF MX at left hand grip was significantly different (Fig. 2A). That is, CG did not shift horizontally when they gripped with right hand, but did shift when gripped with left hand. Vertical component of CG (DEV OF MY) did not alter when they gripped with either hand.

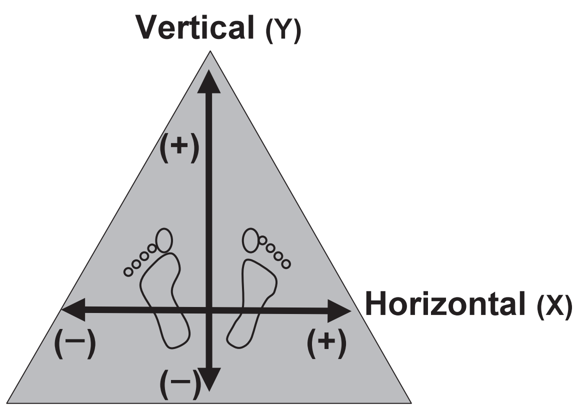

Fig. 1 Measurement of center of gravity. Drawing of stabilometry showed the position of feet and directions. Right side was positive (+) in horizontal direction, and toe side was positive (+) in vertical direction.

Furthermore, correlative analysis was studied between maximum GP and any horizontal or vertical shift. Maximum GP was not different in either hand grip. When they gripped with right hand, maximum GP correlated to DEV OF MY ($R = 0.54$, $p < 0.05$). No correlation was found in horizontal shift at right hand grip, or in horizontal and vertical shifts at left hand grip. These results indicated that stronger GP at right hand led anterior movement of the subjects.

Young left-handed subjects

In rest-stand, body-sway was evaluated as follows (Table 3): LNG was 7.7 ± 1.5 cm, REC AREA was 0.6 ± 0.3 cm^2, DEV OF MX was 0.2 ± 0.9 cm and DEV OF MY was −8.1 ± 3.8 cm.

When measurement of CG was performed with maximum GP at right hand grip, averaged maximum GP was 41.6 ± 13.8 kg. Body-sway was evaluated as follows (Table 3): LNG was 14.3 ± 4.0 cm, REC AREA was 2.4 ± 1.0 cm^2, DEV OF MX was 0.3 ± 1.1 cm and DEV OF MY was −8.2 ± 3.7 cm. LNG and REC AREA were significantly increased compared with rest-stand (186% and 400%, respectively). DEV OF MX (Fig. 2B) and DEV OF MY did not alter.

In contrast, averaged maximum GP was 43.4 ± 12.5 kg when they gripped with maximum GP at left hand. Body-sway was evaluated as follows (Table 3): LNG was 14.5 ± 6.2 cm, REC AREA was 3.2

Table 3 *Fundamental value from stabilometry in young subjects*

(1) Right-handed

	Maximum GP (kg)	LNG (cm)	REC AREA (cm^2)	DEV OF MX (cm)	DEV OF MY (cm)
Rest	–	7.5 ± 2.0	0.9 ± 0.5	−0.2 ± 0.9	−4.6 ± 2.4
R-HG	33.9 ± 9.4	18.4 ± 9.0	5.3 ± 3.8	−0.1 ± 0.6	−4.6 ± 2.5
L-HG	33.6 ± 9.3	18.8 ± 9.0	5.7 ± 4.6	−0.7 ± 1.0	−4.9 ± 2.3

(2) Left-handed

	Maximum GP (kg)	LNG (cm)	REC AREA (cm^2)	DEV OF MX (cm)	DEV OF MY (cm)
Rest	–	7.7 ± 1.5	0.6 ± 0.3	0.2 ± 0.9	−8.1 ± 3.8
R-HG	41.6 ± 13.8	14.3 ± 4.0	2.4 ± 1.0	0.3 ± 1.1	−8.2 ± 3.7
L-HG	43.4 ± 12.5	14.5 ± 6.2	3.2 ± 2.1	−0.3 ± 0.9	−8.6 ± 3.8

(Mean ± SD)

GP: grip power, LNG: total length of CG during measurement, REC AREA: area of movement of CG during measurement, DEV OF MX: deviation of center of mean X, DEV OF MY: deviation of center of mean Y, Rest: rest-stand, R-HG: maximum grip in right hand, L-HG: maximum grip in left hand.

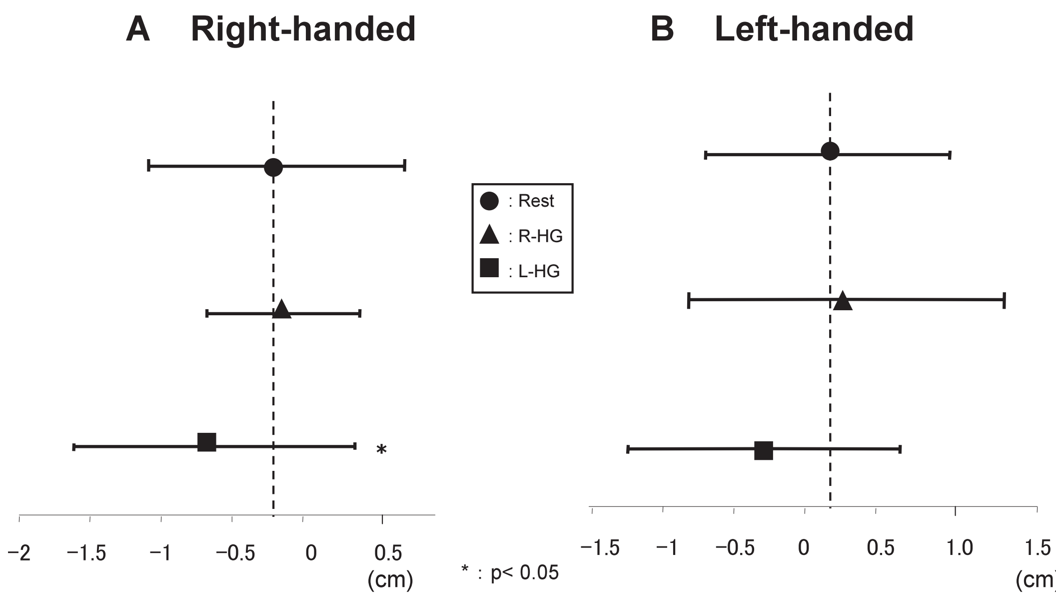

Fig. 2 Horizontal shifts of CG (DEV OF MX) during maximum grip in right-handed subjects (A) and in left-handed subjects (B). Dotted line showed CG in rest-stand. Note: Significant movement of CG was observed with left hand grip in right-handed subject (*). Rest: rest-stand, R-HG: maximum grip in right hand, L-HG: maximum grip in left hand.

Table 4 *Fundamental value from stabilometry in aged subjects*

	Maximum GP (kg)	LNG (cm)	REC AREA (cm^2)	DEV OF MX (cm)	DEV OF MY (cm)
Rest	–	16.6 ± 9.4	3.6 ± 4.5	−0.4 ± 1.7	−0.3 ± 2.4
R-HG	16.6 ± 9.0	23.4 ± 11.5	6.7 ± 4.6	−0.3 ± 1.8	−0.1 ± 2.6
L-HG	15.5 ± 7.1	22.7 ± 12.0	6.6 ± 5.9	−0.6 ± 1.6	−0.4 ± 2.7

(Mean ± SD)

GP: grip power, LNG: total length of CG during measurement, REC AREA: area of movement of CG during measurement, DEV OF MX: deviation of center of mean X, DEV OF MY: deviation of center of mean Y, Rest: rest-stand, R-HG: maximum grip in right hand, L-HG: maximum grip in left hand.

± 2.1 cm^2, DEV OF MX was −0.3 ± 0.9 cm and DEV OF MY was −8.6 ± 3.8 cm. Similar to right hand grip, LNG and REC AREA were significantly increased compared with rest-stand (188% and 533%, respectively). DEV OF MX (Fig. 2B) and DEV OF MY did not alter.

Furthermore, correlative analysis was studied between maximum GP and any horizontal or vertical shift. Maximum GP was not different in either hand grip. No correlation was found in horizontal or vertical shift with either hand grip.

Aged subjects

In rest-stand, body-sway was evaluated as follows (Table 4): LNG was 16.6 ± 9.4 cm, REC AREA was 3.6 ± 4.5 cm^2, DEV OF MX was −0.4 ± 1.7 cm and DEV OF MY was −0.3 ± 2.4 cm.

When CG was measured with maximum GP at right hand grip, averaged maximum GP was 16.6 ± 9.0 kg. Body-sway was evaluated as follows (Table 4): LNG was 23.4 ± 11.5 cm, REC AREA was 6.7 ± 4.6 cm^2, DEV OF MX was −0.3 ± 1.8 cm and DEV OF MY was −0.1 ± 2.6 cm. All parameters did not alter compared with rest-stand.

In contrast, averaged maximum GP was 15.5 ± 7.1 kg when they gripped with maximum GP at left hand. Body-sway was evaluated as follows (Table 4): LNG was 22.7 ± 12.0 cm, REC AREA was 6.6 ± 5. 9 cm^2, DEV OF MX was −0.6 ± 1.6 cm and DEV OF MY was −0.4 ± 2.7 cm. All parameters did not alter compared with rest-stand.

Furthermore, aged subjects' data were compared with those of young subjects. Maximum GP with right and left hand grip decreased to 47% and 49%, respectively. LNG and REC AREA in rest-stand increased to 220% and 400%, respectively. However, LNG and REC AREA did not alter with either hand grip. DEV OF MX and DEV OF MY did not alter.

DISCUSSION

When we studied the movement of CG in either hand grip with maximum power in young subjects, LNG and REC AREA increased significantly in both right- and left-handed. In our study, a trace of CG movement was detected close to control point, because muscle contraction on one side of arm with hand grip required posture maintenances.

CG would shift during muscle contraction of upper limb, because body-sway may help lessen the risk of tumbling or giving way (1, 11). In this study, 3 out of 4 tests demonstrated no change of CG during maximum GP, however, a significant shift to the left of CG was observed when right-handed subject gripped with left hand. Thus, it is not conclusive and we need further study. Kato *et al*. demonstrated that CG shifted to grip side during maximum GP (4). They studied under straight standing position with both hand grips. We speculated that CG should move when subjects did not have enough spaces to vend or rotate.

In right-handed young subjects, stronger GP shifted their CG toward anterior. This might be due to the contraction of abdominal and related muscles for forcing their power (1, 9). On the other hand, left-handed subjects did not exhibit any correlation between GP and horizontal or vertical deviation. This might be due to training of both hands, since some of the left-handed subjects used their right hands for writing or throwing. Thus, left-handed subject might have better experiences for balancing their body under forced stress of upper limb.

Aged subjects showed a significant decrease in maximum GP with either hand grip. LNG and REC AREA in rest-stand position were larger than in young subjects. In contrast, LNG and REC AREA during maximum GP with either hand grip did not increase in aged subject. These data indicated that aged subjects had less control of CG. Since aged subjects lost many neurons and networks in the cerebral cortex and cerebellum, controlling CG might be more difficult than young subjects (3, 13). However, controlling CG during maximum grip in aged subjects was not difficult in our results. Aged subjects may be protected from tumbling by gripping something in their hands. They should still have many neuronal networks in brain to control CG during dynamic movement.

New computer-operated stabilometry demonstrated larger movement of CG during maximum grip than rest-stand in young subjects. Some of patients did not have problem in rest-stand position but were unbalanced during moving or catching (12). These results indicated that CG with maximum grip could move significantly in pathological conditions. Similar experiment demonstrated that Meniere's disease increased horizontal movements and ataxia increased vertical movements (12).

Practically, CG stability is important for many sports (10). Training with exercise machines is mainly designed to develop individual muscles. When baseball players throw faster ball and tennis player serve more aces, individual muscles are coordinated to demonstrate their skill efficiently, that needed CG stability. Thus, dynamic movement of a person's CG must be included in athletes' training regimens.

In conclusion, dynamic movement of CG might be more important to understand person's activity of daily living than CG in rest-stand.

Acknowledgements

This work was supported by a Grant-in-Aid for scientific research (16500258) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

REFERENCES

1. Fukui K and Maeda S (1999) *Aged Rehabilitation*, 5th ed., Igakushoin, Tokyo.
2. Kikumoto T, Ito T, Suzuki H, Sarasina N, Sirato K and Hoshi F (1993) The influence of position difference on grip strength. *Hokkaido Rigaku* **10**, 50–52. (In Japanese)
3. Kandel ER, Schwartz JH and Jessell TM (2000) *Principles of Neural Science*, 4th ed., Mc Graw Hill, NY.
4. Kato T, Miyamoto K and Shimizu K (2004) Postural reaction during maximum grasping maneuvers using a hand dynamometer in healthy subjects. *Gait and Posture* **20**, 189–195.
5. Mochizuki H and Mineshima T (2000) Reliability and validity of the index of postural stability using forceplates. *Rigakuryouhougaku* **27**, 199–203. (In Japanese)
6. Momiyama H, Kawatani M and Ishihama H (2004) Movement of center of gravity during maximum grip power. *Abstracts for Society for Neuroscience* 306.13
7. Nagayama I (1983) Measurement of deviation using posturography. *Jibiinkoukarinsyou* **76**, 197–222. (In Japanese)
8. Nakagawa H, Ohashi N, Watanabe Y and Mizukoshi K (1993) The contribution of proprioception in posture control in normal subjects. *Acta Otolaryngol Suppl* **504**, 112–116.
9. Nakamura R, Saito H and Nagasaki H (2003) *Fundamental Kinesiology*, 6th ed., Ishiyakushuppan, Tokyo.
10. Rankin JK, Woollacott MM, Shumway-Cook A and Brown LA (2000) Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. *J Gerontol A Biol Med Sci* **55**, M112–119.
11. Refshauge K, Ada L and Ellis E (2005) *Science-Based Rehabilitation*, Elsevier, London.
12. Yagi K (1989) Multivariate statistical analysis in stabilometry. In human uprights standing (second report) —pattern

recognition of a stabilogram. *Nippon Jibiinkoka Gakkai Kaiho* **92**, 909–922. (In Japanese)
13. Yamada S and Hukunaga T (1996) Biochemical and Physiological adaptation to physical training in skeletal muscle. *NAP*, Tokyo.