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Yoshimi Katayama* Masuo Senda† Masanori Hamada‡
Masaki Kataoka** Mai Shintani†† Hajime Inoue‡‡

*Okayama University,
†Okayama University,
‡Okayama University,
**Okayama University,
††Okayama University,
‡‡Okayama University,

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Abstract

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KEYWORDS: postural balance, woman, lower extremity, muscle power

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Original Article

Relationship between Postural Balance and Knee and Toe Muscle Power in Young Women

Yoshimi Katayama[a]*, Masuo Senda[b], Masanori Hamada[b], Masaki Kataoka[a], Mai Shintani[a], and Hajime Inoue[a]

[a]*Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine and Dentristry, Okayama 700-8558, Japan, and*
[b]*Division of Physical Medicine & Rehabilitation, Okayama University Hospital, Okayama 700-8558, Japan*

Muscle power in the lower extremities and body sway were measured in 57 healthy young women volunteers in their 20's. Body sway was measured with a stabilimeter for 30 sec during two-leg standing, and for 10 sec during one-leg standing with the eyes open or closed, alternating between right and left legs (5 times each). The measured parameters of body sway were locus length per time unit, locus length per environmental area, environmental area, rectangle area, root mean square area, and the ratio of sway with eyes closed to sway with eyes open. Knee flexor and extensor power and toe flexor and abductor power were the measures representing lower extremity muscle power. The increase in sway with the eyes closed was more marked during one-leg standing than two-leg standing, as expected. We found that 36 of 57 subjects (62%) were unable to maintain one-leg standing with their eyes closed, and this failure correlated with marked body sway (*P* = 0.0086). Many subjects had one leg that was classified as stable and the other leg classified as unstable. Clearly, testing of both legs alternately with eyes closed is necessary to measure the full range of sway in subjects. Lower extremity muscle power did not appear to be the dominant factor in maintaining balance in these young subjects.

Key words: postural balance, woman, lower extremity, muscle power

In the elderly, injuries from falling are considered to be the result of age-related physiological changes. However, the causes vary, with many factors interacting in a complex manner. Physiological risk factors include decreased muscle power, equilibrium disturbance, gait disturbance, visual impairment, decreased locomotion ability, decreased cognition, and orthostatic hypotension [1]. The risk of falls increases with an increase in the number of these factors present in a given person's situation. The incidence of falls differs between men and women and is higher in the latter [2, 3]. This difference has been attributed to poorer balance function in women than in men [4], or to biomechanical factors such as poorer muscle power and range of motion of joints in women [5]. There have been many studies of the relationship between falls and muscle power, or biomechanical factors. In this study, we measured body sway, which is an element of equilibrium disturbance. In the presence of body sway beyond a certain degree, maintenance of posture becomes impossible, resulting in falls.

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*Corresponding author. Phone: +81-86-235-7752; Fax: +81-86-235-7752
E-mail: katachan@md.okayama-u.ac.jp (Y. Katayama)

Many studies have shown the relationship between falls and lower extremity muscle power or between falls and body sway [6, 7], but few studies have been published on the influences of lower extremity muscle power on body sway. The authors of the current study believe that lower extremity muscle power is an important factor required to maintain balance and that this power would be reflected in knee flexor/extensor power and toe flexor/abductor power. In this basic study we evaluated the relationships among these measures of lower extremity muscle power and body sway in young healthy women, expecting that the measures would approximate the norms for healthy females of that age group.

Materials and Methods

Subjects. The subjects were 57 women volunteers including medical students, rehabilitation students, and nurses in their 20's without recent history of drug administration, surgery, or physical therapy treatment. Their mean age was 23.4 ± 2.1 years (range 20–29 years), the mean height was 157 ± 4.9 cm (range 147–167 cm), and the mean body weight was 49.7 ± 5.7 kg (range 42–65 kg). The mean body mass index (BMI, body weight (kg)/height $(m)^2$) was 20.0 ± 1.9 kg/m^2 (range 18.2–24.9 kg/m^2) (Japan Society for the Study of Obesity; 1999). The BMI was 18.5–25, and extremely lean or obese subjects and those receiving special muscle power strengthening training were excluded. All subjects gave written informed consent prior to participation in the study.

Methods. Body sway, knee flexor/extensor power, and toe muscle power were measured each weekday between 10:00 am and 15:00 pm in spring and autumn. Handedness was recorded as right or left dominant.

Stabilometric test procedures (Fig. 1) Body sway was measured using a Gravicorder GS11 (ANIMA Co., Tokyo, Japan) according to the criteria of the Japan Society for Equilibrium Research [8] in a quiet room with uniform brightness. The room temperature was not controlled. The subjects stood barefoot, placing the center of measurement at the manufacturer's recommended reference point on the examination platform. For two-leg standing, the subjects stood with right and left feet placed side by side with the upper extremities in natural contact with the body sides. For one-leg standing, the second toe and the center of the heel were placed on

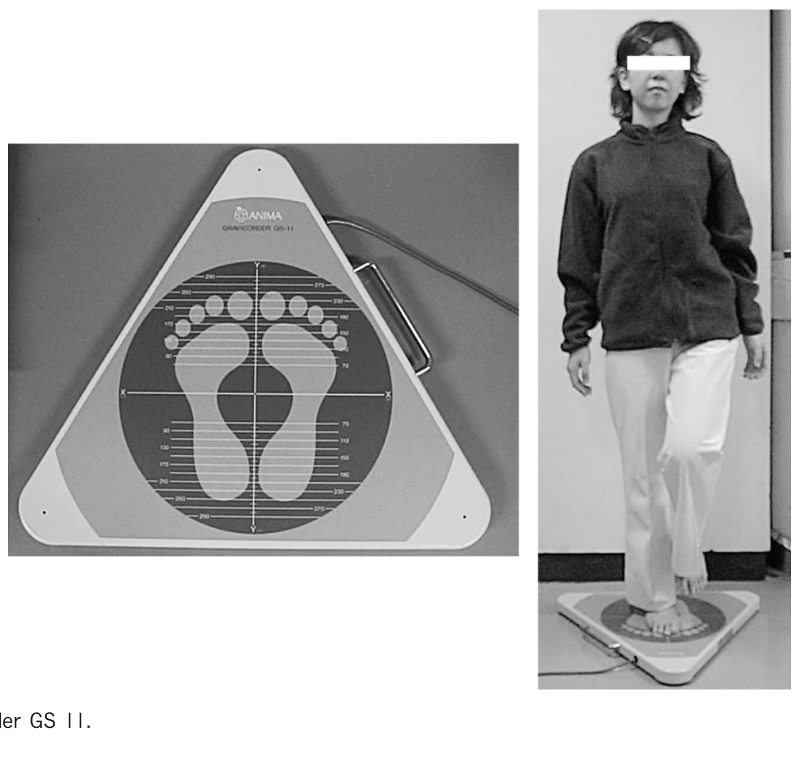

Fig. 1 ANIMA Gravicorder GS 11.

the vertical axis of the examination platform, and the upper extremities were placed in the same position as that for two-leg standing. In the test with the eyes open, the subjects gazed at a visual point placed 1 m in front of them at the level of their eyes so that moving objects could not disturb the visual field.

Body sway was measured for 30 sec during two-leg standing and for 10 sec during one-leg standing with the eyes open or closed. In one-leg standing tests, measurements alternated between right and left legs (5 times each), and the mean of the 3 intermediate values was used in the analysis. The measured parameters of body sway were (1) locus length per time unit (LNG/TIME), which represented the rate of body sway; (2) locus length per environmental area (LNG/E), which represented the fine postural control function by proprioceptive reflexes; (3) environmental area (ENV.AREA), which represented the degree of equilibrium impairment; (4) rectangle area (REC.AREA), which represented the rectangular area enclosed by the maximum distances of front/back and right/left sway; (5) root mean square area (RMS. AREA); and (6) Romberg ratio, which represented the ratio of sway with eyes closed/sway with eyes open.

Measurement of knee flexor and extensor power The subjects performed a knee bending-stretching exercise using their full strength at an angle/speed of 60 deg/sec 6 times using a Cybex II (SAKAI Co., Tokyo, Japan), and the maximum values of the peak torque of the right and left knee extensor and flexor power/body weight were used for analysis.

Measurement of toe flexor and abductor power (Fig. 2) Toe muscle power was measured using a toe myometer developed in the department of one of the authors. Yamamoto *et al*. [9] evaluated the reliability of this apparatus. Flexion power of all toes, abduction power of the hallux, and abduction power of the little toe were measured using a strain gauge (OG Co., Okayama, Japan). The sensor data was amplified and AD converted (analog to digital), and digital output was measured in 0.1-kg units. The lower leg was immobilized from the mid-tibia to the metatarsal phalangeal joint, and measurement was performed twice at an ankle dorsiflexion and plantar flexion of 0°. The maximum value of the total of flexion power, hallux abduction power, and little toe abduction power was used for analysis.

Stable and unstable groups. When one-leg standing with the eyes closed could not be maintained for 10 sec, measurement was repeated, and values in 5 successful measurements were used as successful data. A maximum of 10 attempts were possible. When standing could not be maintained for 10 sec during any of the 5 measurements, balance for the leg was classified as unstable. Standing for 10 sec during all the 5 measurements was classified as stable.

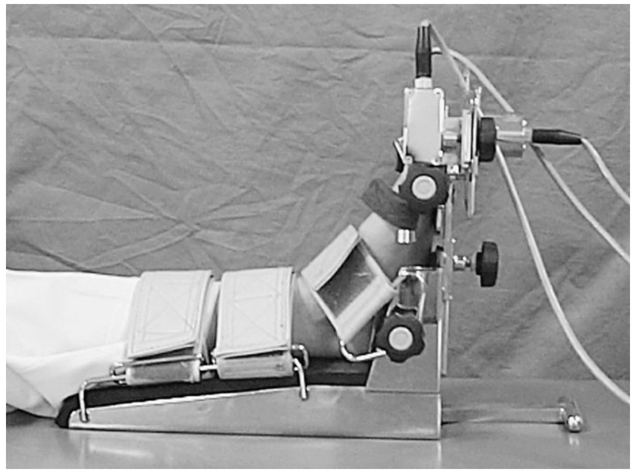

Fig. 2 Toe myometer.

Statistical methods. Differences in body sway values and each item of muscle power between the stable and unstable groups were analyzed using Student's t-test. We calculated the relation coefficient between the item of body sway and lower extremity muscle power in the stable and unstable groups. A value of $P < 0.05$ was considered to be significant. The measurement data were processed using StatView 5.0 (SAS Institute Inc., Cary, NC, USA), and $P < 0.05$ and 95% confidence intervals were considered to be significant.

Results

Measurement of body sway (Table 1). The mean LNG/TIME, LNG/E, and ENV.AREA (± SD) were 1.13 ± 0.33 cm/s, 19.81 ± 6.10 cm, and 1.85 ± 0.76 cm^2, respectively, during 30-sec two-leg standing with the eyes open. The same parameters were 1.52 ± 0.52 cm/s, 20.65 ± 6.90/cm, and 2.45 ± 1.26 cm^2, respectively, with the eyes closed. The mean LNG/TIME with the eyes closed was 1.36 times that with the eyes open, which was a significant difference ($P < 0.0001$). The LNG/E with the eyes closed was 1.09 times that with the eyes open, which was less than a significant difference ($P = 0.39$). However, the ENV. AREA with the eyes closed was 1.35 times that with the eyes open, which was a significant difference ($P = 0.003$).

The mean ($\pm$ SD) of the parameters LNG/TIME, LNG/E, and ENV.AREA during 10-sec one-leg standing with the eyes opened was: LNG/TIME 3.30 ± 0.77 cm/s (right) and 3.17 ± 0.84 cm/s (left); LNG/E 23.04 ± 4.65/cm (right) and 22.44 ± 3.85/cm (left); and ENV.AREA 1.63 ± 0.71 cm^2 (right) and 1.47 ± 0.49 cm^2 (left), respectively. The mean ($\pm$ SD) of the same parameters during 10-sec one-leg standing with the eyes closed was: LNG/TIME 6.57 ± 1.45 cm/s (right) and 6.34 ± 1.44 cm/s (left); LNG/E 16.43 ± 2.95/cm (right) and 16.66 ± 3.22/cm (left); and ENV.AREA 4.22 ± 1.34 cm^2 (right) and 4.17 ± 1.71 cm^2 (left), respectively. The LNG/TIME with the eyes closed was 2.05 times (right) and 2.08 times (left) that with the eyes open. LNG/E with the eyes closed was 0.73 times (right and left) that with the eyes open. ENV.AREA with the eyes closed was 2.97 times (right) and 2.95 times (left) that with the eyes open. The differences among the 3 parameters were significant ($P < 0.0001$). The distance and area of sway with the eyes closed were about 3 times those with the eyes open. No significant differences were observed in any parameter between the right and left sides.

Stable and unstable groups. The unstable group (36 subjects) during one-leg standing with the eyes closed consisted of 46 legs (27 right legs and 19 left legs). The distribution of right and left legs between the 2 groups did not correlate with handedness.

The LNG/TIME during one-leg standing with the eyes closed was 6.82 ± 1.55 cm/s in the unstable group and 6.08 ± 1.39 cm/s in the stable group. The latter was significantly less in the stable group ($P = 0.0086$). The ENV.AREA during one-leg standing with the eyes closed was 4.63 ± 1.52 cm^2 in the unstable group and 3.92 ± 2.10 cm^2 in the stable group. The former was significantly larger in the unstable group ($P = 0.013$) (Figs. 3 and 4).

Measurement of knee flexor and extensor power. The knee extensor power/body weight was 193.04 ± 35.26 N/kg in the right knee and $191.23 \pm$

Table 1 Results of Summary Analysis

	Both legs	Right	Left
Eyes open			
LNG/TIME	1.13 ± 0.33	3.30 ± 0.77	3.17 ± 0.84
LNG/E	19.81 ± 6.10	23.04 ± 4.65	22.44 ± 3.85
ENV.AREA	1.85 ± 0.76	1.63 ± 0.71	1.47 ± 0.49
REC.AREA	4.43 ± 2.12	5.91 ± 2.19	5.67 ± 2.22
RMS.AREA	1.34 ± 0.65	1.91 ± 0.71	1.86 ± 0.73
Eyes closed			
LNG/TIME	1.52 ± 0.52	6.57 ± 1.45	6.34 ± 1.44
LNG/E	20.65 ± 6.90	16.43 ± 2.95	16.66 ± 3.22
ENV.AREA	2.45 ± 1.26	4.22 ± 1.34	4.17 ± 1.71
REC.AREA	5.99 ± 2.96	17.29 ± 5.45	17.21 ± 5.97
RMS.AREA	1.54 ± 0.83	5.60 ± 1.82	5.65 ± 2.19
Romberg ratio			
LNG/TIME	1.36 ± 0.32	2.05 ± 0.46	2.08 ± 0.53
LNG/E	1.09 ± 0.39	0.73 ± 0.15	0.73 ± 0.12
ENV.AREA	1.35 ± 0.44	2.97 ± 0.84	2.95 ± 0.91
REC.AREA	1.44 ± 0.57	3.27 ± 1.21	3.40 ± 1.30
RMS.AREA	1.30 ± 0.65	3.28 ± 1.13	3.34 ± 1.15

Each value represents mean ± SD.
LNG/TIME, locus length per time; LNG/E, locus length per environ area; ENV.AREA, environmental area; REC.AREA, rectangle area; RMS.AREA, root mean square area.

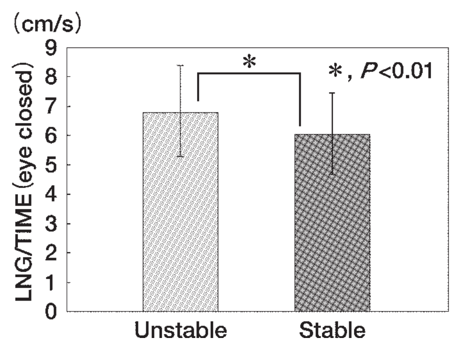

Fig. 3 LNG/TIME (eyes closed) of unstable group and stable group.

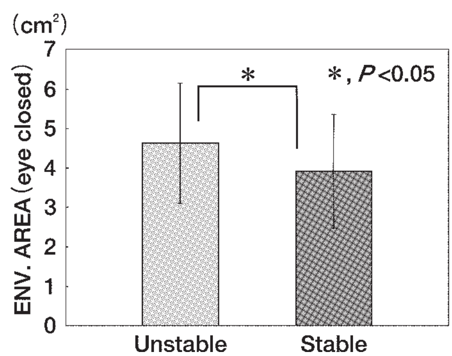

Fig. 4 ENV.AREA (eyes closed) of unstable group and stable group.

35.23 N/kg in the left knee. The knee flexor power/body weight was 91.65 ± 25.87 N/kg in the right knee and 93.96 ± 29.82 N/kg in the left knee. The flexor/extensor power ratio was 47.28 ± 9.41% in the right knee and 48.66 ± 10.44% in the left knee. There were no significant differences between the right and left knees.

The knee extensor power/body weight was 190.81 ± 36.07 N/kg in the unstable group and 186.22 ± 34.19 N/kg in the stable group. The knee flexor power/body weight was 96.11 ± 24.34 N/kg in the unstable group and 90.85 ± 24.54 N/kg in the stable group. The flexor/extensor power ratio was 50.51 ± 9.79% in the unstable group and 48.70 ± 8.97% in the stable group. No significant difference was observed in any item between the stable and unstable groups ($P = 0.60$, $P = 0.34$, $P = 0.33$).

Measurement of toe muscle power. The toe flexor power was 14.44 ± 4.03 kg on the right side and 13.88 ± 4.06 kg on the left, and the toe abductor power was 2.01 ± 1.42 on the right and 2.08 ± 1.23 kg on the left. There was no significant difference between the sides. The toe flexor power was 14.80 ± 4.66 kg in the unstable group and 14.29 ± 4.80 in the stable group. The toe abductor power was 1.97 ± 1.45 kg in the unstable group and 2.14 ± 1.35 kg in the stable group without significant differences between the groups ($P = 0.62$, $P = 0.52$).

Body sway measurement values and lower limb muscle power. In the 70 limbs in the stable group, the toe abductor power correlated with LNG/E during one-leg standing with the eyes open ($r = 0.27$, $P = 0.024$), with ENV.AREA during one-leg standing with the eyes open ($r = 0.25$, $P = 0.041$), and with LNG/E during one-leg standing with the eyes closed ($r = 0.25$, $P = 0.041$). The knee extensor power/body weight and knee flexor power/body weight correlated with LNG/E during one-leg standing with the eyes open ($r = 0.25$, $P = 0.036$; and $r = 0.33$, $P = 0.007$; respectively). The knee flexor/extensor power ratio also correlated significantly with LNG/E during one-leg standing with the eyes open as well as with the eyes closed ($r = 0.27$, $P = 0.026$; and $r = 0.29$, $P = 0.017$; respectively) (Figs. 5 and 6).

In the 46 unstable legs, no significant relationship was observed between lower extremity muscle power and body sway.

Discussion

The increasing proportion of elderly persons in industrial nations has created a demand for risk analyses for that population. In terms of the risk of falls, the state of the art is still rudimentary. The list of contributory factors is unrefined, and standard screening tests useful for risk analysis are lacking. Although humans and our ancestors have been walking upright and falling for at least 4 million years, we have not developed the tools and methods to systematically and accurately state the risk of falls. Even the association between body sway measurement values and susceptibility to falls remains unclear

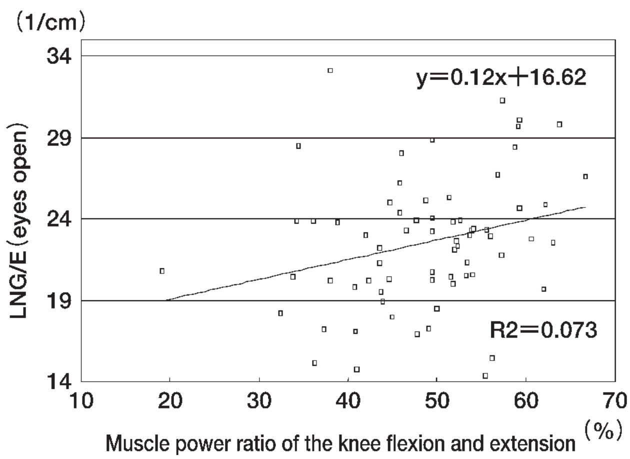

Fig. 5 LNG/E (eyes open) *vs.* Muscle power ratio of the knee flexion and extension.

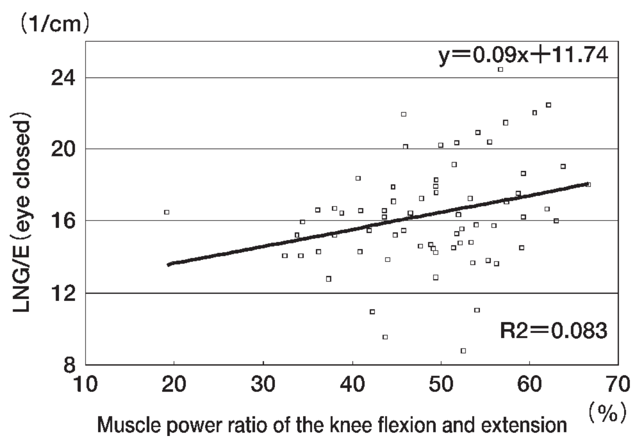

Fig. 6 LNG/E (eyes closed) *vs.* Muscle power ratio of the knee flexion and extension.

[10]. In this study we pursued a line of reasoning that holds that lower extremity muscle power and body sway are key factors in the loss of balance that precedes falls from a standing position [5, 6, 7, 11, 12]. The current study was a small-scale attempt to clarify that relationship. Our hypothesis was that toe abductor power, knee extensor power/body weight, knee flexor power/body weight, and the knee flexor/extensor power ratio would correlate significantly with body sway.

Although the greatest need for the application of tests and tools is in elderly populations, most of the elderly have acquired many conditions and undergone many changes as a result of ageing that present uncontrollable confounding variables, making the results of a small basic study unreliable. Also, healthy norms have not been established through the experimental process. In the current study we sought to approach such a profile of normal characteristics by using healthy, young women who were apparently of average fitness.

Women, in general, have less muscle power than age-matched men and might show more sway. Carter *et al*. [13] reported a greater association between quadriceps muscle power and static/dynamic body sway than age in females with osteoporosis. These findings raise the question of whether younger women normally show greater sway [14, 15, 16]. Before a large prospective study comparing different age groups of men and women is designed, the methods of measurement must be addressed, which was the purpose of the current study. We used standardized tests and equipment.

The stabilimeter is widely used to evaluate posture maintenance ability, including equilibrium function [17, 18]. Stabilometers, originally developed for the otorhinolaryngological field, are widely used at present in other fields such ophthalmology and neuromedicine [14], due to their simplification and improvement in precision in recent years. The stabilometric test is a simple, painless test frequently used in clinical practice.

We performed stabilometric tests according to the criteria of the Japan Society for Equilibrium Research [19]. The society recommends 60-sec measurements for two-leg standing in principle but allows 30-sec measurements [19]. The 30-sec measurement is used routinely with patients in the authors' department and was used in the current study to allow future comparisons with patient data.

In 1998, Japan's Ministry of Education, Culture, Sports, Science and Technology adopted the one-leg standing time with the eyes open as a criterion for the evaluation of fitness in persons over 65 years old [20]. Some researchers have noted, however, that decreased visual acuity contributes to falling. Lord *et al*. [7] analyzed the characteristics of elderly persons who repeatedly fell and reported a decrease in quadriceps muscle power in addition to decreased tactile sensation and narrowed visual field. Since visual postural control is present with the eyes open, the authors of the current study regarded as necessary stabilometric tests that deny visual input, and we performed measurement during one-leg standing with the eyes both open and closed.

Yamana *et al*. evaluated the reliability of stabilometric tests during one-leg standing with the eyes open or closed and reported that the mean value in 5 measurements (10 sec each) during one-leg standing was as reliable as the value obtained during two-leg standing [21]. Their method was used in the current study.

During two-leg standing in the current study, body sway with the eyes closed was 1.09–1.35 times that with the eyes open, which is a significant difference ($P <$ 0.001). During one-leg standing, body sway with the eyes closed was about 3 times that with the eyes open. Body sway was significantly greater with the eyes closed than with the eyes open during both one-leg and two-leg standing. These higher scores reflect the increased frequency of postural corrections required to maintain balance. In addition, the increase in sway with the eyes closed was more marked during one-leg standing than in two-leg standing. This finding was expected; however, 36 of 57 subjects (62%) were unable to maintain one-leg standing with eyes closed, and this failure correlated with marked body sway ($P = 0.0086$). Many subjects had one leg that was classified as stable and the other leg classified as unstable. The unstable group included 27 right legs (46.6%) and 19 left legs (32.8%). LNG/TIME and ENV.AREA during one-leg standing with the eyes closed showed significantly more marked sway in the unstable group than in the stable group. It is reasonable to infer that such a marked increase in sway might also increase the risk of falls. The cause of such markedly different sway within individual subjects is not apparent from our findings. Clearly, testing of both legs alternately with eyes closed is necessary to measure the full range of sway in subjects, and to avoid underestimations. While the fitness-screening version of the one-leg standing maintenance time with eyes open is simple to perform, it is not appropriate for risk assessment.

In the stable group, LNG/E, which represents the fine postural control function by proprioceptive reflexes, correlated with toe abductor power, knee extensor power/body weight, knee flexor power/body weight, and the knee flexor/extensor power ratio. As originally hypothesized, this ability was higher with higher muscle power, but only for the stable legs.

Interestingly, the rate of sway (LNG/TIME) and muscle power did not correlate significantly in either group in one-leg standing with eyes open or closed. In general, although body sway as a combined measure was markedly greater in the unstable group, body sway did not correlate significantly with lower extremity muscle power. It would have been convenient to use a simple, non-invasive measure of lower extremity muscle power to approach risk assessment, but we found that our original hypothesis was not fully supported. Lower extremity muscle power did not appear to be the dominant factor in maintaining balance in these young subjects. The failure to maintain balance during the test may also be associated with elements other than sway such as weakening of the feedback system, decrease in postural control cognitive ability, or a high center of gravity. Other muscle groups might play a greater role in balance than was believed. The relative contributions of factors that determine body sway remain speculative, and clarification of the roles of other muscle groups is needed. The current study showed that lower extremity muscle power has a limited role in balance, and one-leg eye-closed testing of both legs is necessary to assess balance in individuals.

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