The Effect of Aging on the Backward Stepping Reaction as Estimated from the Velocity of Center of Foot Pressure and Muscular Strength

Yahiko Takeuchi1,4, Yasuyuki Tanaka2, Yoshihiro Shimomura3, Koichi Iwanaga1 and Tetsuo Katsuura3

1) Graduate School of Science and Technology, Chiba University
2) Health Admin Section, Yachiyo City Health Center
3) Ergonomics Section, Faculty of Engineering, Chiba University
4) Department of Physical Therapy, Chiba Prefectural College of Allied Medical Science

Abstract By estimating the deflection velocity from the center of foot pressure (COP), this study aims to prove that the characteristics of the backward stepping reaction in the elderly are related to the strength of the antigravity muscles. The participants in this study were 10 elderly (average age 75.6±7.6 years) and 13 young (average age 22.0±2.6 years) subjects. Using force plate analysis, we measured the shift in the deflection velocity (V-RMS) and the maximum deflection velocity (V-MAX) from the beginning of the COP movement to the onset of the stepping reaction. Furthermore, we measured the strength of the antigravity muscles using a hand-held dynamometer. We correlated the V-RMS, V-MAX, and the rate of change of the deflection velocity (MAX/RMS) with muscular strength. When compared with the young subjects, the elderly showed significantly lower values of V-RMS (p<0.05) and significantly higher values of MAX/RMS (p<0.01). Furthermore, when compared with the young subjects, the elderly showed significantly lower values of muscular strength for all muscles studied (p<0.001). We established a significant correlation between the V-RMS, MAX/RMS, and muscular strength by carrying out a regression analysis (V-RMS: gluteus maximus (r=0.50, p<0.05) and rectus abdominis (r=0.48, p<0.05); MAX/RMS: adductor magnus (r=−0.66, p<0.001) and flexor digitorum longus (r=−0.62, p<0.01)). Differences were observed in the V-RMS and MAX/RMS during the backward stepping reaction; it was proposed that these differences were related to the age and muscular strength of the subjects. Therefore, further investigations should be undertaken in order to understand the effects of aging on the stepping reaction. In other words, the change-in-support strategy, including the preparatory phase of the stepping reaction, and its relationship with muscular strength should be further investigated. J Physiol Anthropol 26(2): 185–189, 2007 http://www.jstage.jst.go.jp/browse/jpa2

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Introduction

Falls are a major concern in the elderly and aging sections of society. One-third to one-half of the population aged 65 years and above falls each year; these falls can result in serious injury and even death. Furthermore, fear of recurrence of the incident can result in a loss of confidence, thus restricting domestic and social activities and leading to isolation and loneliness (Horak et al., 1989; Culhane et al., 2005).

The factors that result in a fall are classified into physical and environmental factors; the decline in the posture-control ability with age is representative of a physical factor. Three discrete patterns of postural movement have been described to correct anterior-posterior sway in normal adults. Of these, the stepping strategy is regarded as the most important posture strategy to prevent falls in the elderly. Horak et al. (1989) reported that the stepping strategy is used in response to very fast or large perturbations when ankle and hip strategies are inadequate. Furthermore, it has been reported that the elderly, especially those with a history of falls, have a greater tendency than youngsters to use the stepping reaction to maintain their balance (Luchies et al., 1994; Hsiao and Robinovitch, 1999). Based on these reports, it appears that the stepping reaction may be a suitable solution for preventing falls in the elderly. Furthermore, it has also been reported that backward falls are common in the elderly and that hip fractures often result from these falls (Sandler and Robinovitch, 2001). However, the mechanism of the backward stepping reaction has not been investigated in detail.
In physiological assessments, balance is evaluated by directly measuring the subject’s sway by calculating the centre of foot pressure (COP) movement. This COP movement has been used to evaluate elderly people that have a history of falls and balance disorders due to aging (Browne et al., 2001). Furthermore, preliminary research has evaluated balance disorders on the basis of the quantity of deflection of the COP. However, Fernie et al. (1982) reported that in the elderly, the deflection velocity provides information that is more characteristic of balance disorders than the absolute quantity of deflection.

With regard to the stepping reaction and muscle strength, there is a report on the relationship of performance with lower extremity strength (Berg and Blasi, 2000). However, there is no report that investigates the relationship between the COP deflection characteristics and muscle strength in the stepping reaction.

By estimating the deflection velocity from the CO% this study aims to prove that the characteristics of the backward stepping reaction in the elderly are related to the strength of their antigravity muscles.

Methods

Subjects

The participants of this study were 10 elderly (average age 75.6±7.6 years, range 64–89 years, height 154.9±8.3 cm, weight 60.2±10.6 kg, and foot length 22.9±1.7 cm) and 13 young (average age 22.0±2.6 years, range 19–26 years, height 172.4±6.6 cm, weight 63.0±8.6 kg, and foot length 24.2±1.0 cm) subjects. Informed consent was obtained from all subjects, both orally and in writing, after a detailed explanation of the experimental purpose and procedure.

Task movement

The subjects were instructed to stand barefoot and upright on a force plate (G-6100, Anima, Tokyo, Japan) in a quiet stance with their feet separated mediolaterally by 10 cm. They maintained this quiet stance for 20 seconds with both upper extremities crossed in front of their chest. After 20 seconds, when signaled by the examiner, they shifted their center of gravity (COG) backward to the maximum possible, and then stepped out from this maximum shift position. The movement strategy and velocity during this task movement were left to the discretion of the subjects.

Experimental measurements and data analysis

The COP signal was acquired at a frequency of 200 Hz and recorded on the force plate with piezoelectric transducers. The stepping reaction was defined by the vertical ground reaction force (GRF) obtained from the force plate data (Fig. 1). The deflection characteristics of the COP were defined by two terms, namely, the value of root mean square at one second of lateral deflection velocity of COP at shift to backward of COG (VRMS; Fig. 1A) and the maximum value of lateral deflection velocity of the pre-period that a foot of step side limb is separated from the force plate (VMAX; Fig 1B). Furthermore, we calculated the rate of change of the deflection velocity (VMAX/VRMS) in order to understand the characteristics of the stepping reaction.

A hand-held dynamometer (MICROFET, Hoggan Health Industry, West Jordan, USA) was used to measure the strength

![Fig. 1](image-url)

**Fig. 1** The define of stepping by a vertical ground reaction force from a force plate

Note) A: A value of root mean square at one second of lateral deflection velocity of COP at shift to backward of COG (VRMS)

B: A maximum value of lateral deflection velocity of the pre-period that a foot of step side is separated from a force plate (VMAX)

C: Initiation point of stepping

VL: Deflection velocity of COP in lateral direction during shifted to backward of COG

GRF-load: Vertical ground reaction force of the load side to be obtained from a force plate

GRF-step: Vertical ground reaction force of the step side to be obtained from a force plate
of the following antigravity muscles: the rectus abdominis (RA), iliopsoas (Psoas), gluteus maximus (GMax), gluteus medius (GMed), adductor magnus (AM), quadriceps femoris (QF), hamstring (Ham), tibialis anterior (TA), triceps surae (TS), peroneus longus (PL), tibialis posterior (TP), and flexor digitorum longus (FDL). The measurement of muscular strength investigated a limb of load side.

Statistical analysis

Welch’s $t$ test was used to compare the difference between the elderly group and the young group with regard to the V-RMS, V-MAX, MAX/RMS, and muscular strength. Regression analysis was performed, and Pearson’s correlation coefficients were calculated to examine the relationship between the V-RMS, V-MAX, MAX/RMS, and strength of the antigravity muscles. The level of statistical significance for all of these analyses was set at $p<0.05$.

Results

COP velocity parameters (V-RMS, V-MAX, and MAX/RMS)

Figure 2 shows the curves of the mean and standard deviation of the COP deflection velocity in the backward stepping. Figures 3 and 4 show the results of the comparison between the elderly group and the young group with regard to the V-RMS (young: 3.6±1.8 cm/s, elderly: 1.8±1.3 cm/s), V-MAX (young: 18.7±8.8%, elderly: 44.6±23.7%), and MAX/RMS (young: 57.1±23.6 cm/s, elderly: 58.8±35.3 cm/s); these were calculated based on the COP deflection velocity. The elderly group showed significantly lower values of V-RMS ($p<0.05$) and significantly higher values of MAX/RMS ($p<0.01$) than the young group. No significant difference was observed between the elderly group and the young group with regard to the V-MAX.

Strength of antigravity muscles

Table 1 shows the muscular strength of each of the muscles studied in the elderly group and the young group, and the differences between the two groups. The results revealed that the elderly group had significantly lower values than the young group with regard to the muscular strength of all the investigated muscles.

Relationship between the COP velocity parameters and muscular strength

Table 2 shows the correlation coefficients between the V-
RMS, MAX/RMS, and muscular strength. The V-RMS was observed to be significantly related to the muscular strengths of rectus abdominis ($r=0.48$, $p<0.05$), gluteus maximus ($r=0.51$, $p<0.05$), adductor magnus ($r=0.42$, $p<0.05$), and flexor digitorum longus ($r=0.42$, $p<0.05$). The MAX/RMS was observed to be significantly related to the strength of all measured muscles (Table 2), particularly adductor magnus ($r=-0.66$, $p<0.01$) and flexor digitorum longus ($r=-0.62$, $p<0.01$).

Discussion

This study revealed that the elderly and young groups significantly differed with regard to the V-RMS and MAX/RMS. Fernie et al. (1982) examined the length and COP deflection velocity in an elderly group and reported that the COP deflection velocity is a more accurate index of balance problems than the length of the COP. In addition, Fujiwara et al. (1982) reported that the extent of shift in the COP reduces with age and concluded that, in particular, the backward shift of the COP is more affected by age than the shift in other directions. This study revealed that the COP deflection velocity is a more accurate index for evaluation of posture control in the elderly and that the backward shift in the COP reflects the effects of aging.

The elderly group showed significantly lower values of V-RMS than the young group. In comparison with elderly people, young people are able to bring about a rapid shift in the position of the COP and assimilate more information from the sensory system in situations where their balance is unstable (Shumway-Cook and Woollacott, 1995). In addition, the COP position varies around the COG and has a higher frequency than the motion of the COG (Benda et al., 1994). In other words, COP displacement functions to control drifting of the COG. Our results suggested that the young group were able to assimilate more information from the sensory system, bring about a rapid shift in the COP, and control the position of the COG skillfully. These abilities were observed to be decreased in the elderly group.

The stepping reaction is an unstable movement in which the base of support decreases suddenly in order to shift from double leg support to single leg support. It was hypothesized that the increase in the V-MAX at the time of stepping is one of the factors responsible for falls in the elderly. However, our study revealed no significant difference between the two groups with regard to the V-MAX. On the other hand, a significant difference was observed between the two groups with regard to the MAX/RMS at V-MAX in the pre-period of the stepping and the V-RMS during the preparation phase of the stepping. Therefore, we suggest that further investigations should be performed in order to understand the effects of aging on the stepping reaction, i.e., the change-in-support strategy (Maki and Mcllroy, 1997), including the preparatory phase of stepping reaction.

The rectus abdominis, gluteus maximus, and adductor magnus muscles, which is the group of muscles that contributes to trunk and pelvic stability, showed a significant positive correlation in their V-RMS values (Neumann, 2002). A previous study has reported that lateral postural stability is mainly controlled by the hip joint and trunk (Kapteyn, 1973; Horak and Moore, 1989; Day et al., 1993). Therefore, it is thought that the COG is controlled by a rapid shift in the COP in the lateral direction by stabilizing the trunk and pelvis using the rectus abdominis, gluteus maximus, and adductor magnus muscles. Similarly, the flexor digitorum longus muscle exhibited a positive correlation with the V-RMS and functions to grasp the floor by flexion of the toes. This suggested that the COP velocity is controlled by providing stability to the foot, which is the only contact point with the floor.

A significant negative correlation was observed among all the measured muscles in terms of the MAX/RMS. In other words, MAX/RMS exhibited a high value while muscular

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**Table 1** Results of Welch’s $t$ test performed on the muscular strength of the elderly and young groups (mean±SD, %)

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>Psoas</th>
<th>GMax</th>
<th>GMed</th>
<th>HA</th>
<th>QF</th>
<th>Ham</th>
<th>TA</th>
<th>TS</th>
<th>PL</th>
<th>TP</th>
<th>FDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td>19.7±6.0</td>
<td>22.0±4.9</td>
<td>18.0±5.0</td>
<td>25.0±6.3</td>
<td>16.6±4.0</td>
<td>24.5±5.6</td>
<td>17.4±5.2</td>
<td>23.6±10.0</td>
<td>28.1±7.8</td>
<td>17.4±5.2</td>
<td>15.2±2.1</td>
<td>3.1±3.3</td>
</tr>
<tr>
<td>Young</td>
<td>32.8±4.2</td>
<td>39.3±4.2</td>
<td>33.3±10.8</td>
<td>41.4±5.1</td>
<td>31.2±4.1</td>
<td>44.5±4.7</td>
<td>34.9±6.4</td>
<td>36.3±6.1</td>
<td>53.2±7.1</td>
<td>31.4±5.0</td>
<td>30.9±4.7</td>
<td>23.2±4.3</td>
</tr>
</tbody>
</table>


*: $p<0.01$, **: $p<0.001$ indicates significant difference between elderly and young group.

**Table 2** Correlation coefficients between the values of the V-RMS, MAX/RMS and muscular strength

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>Psoas</th>
<th>GMax</th>
<th>GMed</th>
<th>AM</th>
<th>QF</th>
<th>Ham</th>
<th>TA</th>
<th>TS</th>
<th>PL</th>
<th>TP</th>
<th>FDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-RMS</td>
<td>0.483*</td>
<td>0.403</td>
<td>0.505*</td>
<td>0.283</td>
<td>0.423*</td>
<td>0.366</td>
<td>0.362</td>
<td>0.106</td>
<td>0.390</td>
<td>0.280</td>
<td>0.349</td>
<td>0.423*</td>
</tr>
<tr>
<td>MAX/RMS</td>
<td>-0.564**</td>
<td>-0.595**</td>
<td>-0.541**</td>
<td>-0.498*</td>
<td>-0.659**</td>
<td>-0.51*</td>
<td>-0.516*</td>
<td>-0.438*</td>
<td>-0.574**</td>
<td>-0.612**</td>
<td>-0.574**</td>
<td>-0.619**</td>
</tr>
</tbody>
</table>


*: $p<0.05$, **: $p<0.01$
strength exhibited a low value. The results of the regression analysis used in this study revealed that MAX/RMS is an index by which the muscular strength of the antigravity muscles can be predicted. An earlier study confirmed that muscular strength decreases with age (Lee et al., 2006). Further, the ability to successfully recover from a slip, thus preventing a fall, is believed to be affected by the decline in the muscle strength of the lower extremities and sensory degradation in the elderly (Lockhart et al., 2005). This suggests that the MAX/RMS is a useful index of the effects of aging on the stepping reaction. The rectus abdominis and flexor digitorum longus muscles showed a particularly high correlation in their MAX/RMS values. The rectus abdominis is the hip adductor and contributes to the stability of the pelvis and hip joint (Neumann, 2002); flexor digitorum longus is a toe flexor muscle, the function of which is to fix the foot by grasping the floor. Future investigations can be undertaken to determine the effect that the functioning of these muscles has on the rate of change of the COP deflection velocity; electromyogram analysis can be included in these studies.

In conclusion, based on the results of our study, further investigations should be performed in order to understand the effects of aging on the stepping reaction. In other words, the change-in-support strategy, including the preparatory phase of the stepping reaction, and its relationship with the muscular strength of the antigravity muscles (e.g., hip adductors, hip extensors, and toe flexor muscles) should be further investigated.

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Correspondence to: Yahiyo Takeuchi, 111 Hanawa, Chuo-ku, Chiba 260–8702, Japan
Phone: +81–043–266–9002
Fax: +81–043–209–6831
e-mail: takeuchi@igidai.ac.jp