Effects of aging on gait patterns in the healthy elderly

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Abstract The free gait of 52 healthy elderly persons was examined. All the subjects were volunteers, aged 65 years or older, and lived in the community in the Kaga area, Ishikawa Prefecture, Japan. They were healthy and active enough to attend the study location by themselves. The comparison group of young adults consisted of 20 volunteer students. The percentages of females and males were similar in the two groups. The healthy elderly walked more slowly than the young adults. Their slower speed was largely caused by their shorter stride length. Differences were still observed between the young and elderly groups when gait parameters were presented in the form of dimensionless numbers. The elderly were weaker in grip strength and had shorter single-leg balance with eyes open than the young adults. The number of steps per day correlated negatively with age within the elderly group. Negative correlations between age and walking speed, as measured directly or in terms of dimensionless numbers, and between age and stride length were also observed within the elderly group. The relative stance phase duration correlated positively with age within the elderly group. Slow speed may be related to low daily activity, reduced muscle power, and diminished balance ability. Long stance phase duration and slow speed in the elderly could be an adaptive characteristic in response to impaired balance.

Key words: aged walking, dimensionless speed, stride length, steps per day, stance phase duration

Introduction

The rapidly increasing number of aged people in developed countries raises problems of maintenance of quality of life in the aged. Walking ability is an important parameter of healthy and independent living. Since the classic work of Murray (1969), walking in the elderly, as compared with that in young adults, has not been the subject of extensive research; however, growing interest in this subject has recently seen the publication of a number of studies (e.g. Kaneko et al., 1991; Hirasaki et al., 1993; Nishizawa et al., 2000; Sadeghi et al., 2001). These recent studies—with some exceptions (Himann et al., 1988; Bendall et al., 1989; Ferrandez et al., 1990)—have not studied in detail the gait characteristics within the elderly. No longitudinal study with repeated trials has been reported.

This study was planned to gather information on the walking characteristics of healthy elderly dwellers in the community. The long-term goal of the study is to gather longitudinal information on walking in the elderly and to clarify the relationship between their walking patterns and quality of life. Because the study is still in its initial stages, the present paper reports only preliminary results on walking characteristics in relation to aging among the elderly and in comparison with young students. Future aspects of this study will include longitudinal analysis.

Participants

The subjects included in the study were 52 healthy elderly people living in the community, 27 women and 25 men, all of whom were 65 years of age or older. They were recruited from the Kaga area, near the Ishikawa Prefectural Nursing University (IPNU). The members of the elderly group were all healthy and active enough to visit the university by themselves, in order to take part in the program. Twenty young adult students, 10 women and 10 men, in their twenties or younger, were recruited from the IPNU. All participants were volunteers, were informed of the purpose of the study, and signed a participation agreement form. Almost all the data presented here were obtained during the summers of 2004 and 2005.

Methods

The basic physical parameters of the participants were measured: height, body mass, body mass index, fat proportion, bone density, grip strength, and single-leg balance with eyes open. Fat proportion was obtained using a body fat analyzer (TBF-410, Tanita), which measures impedance via electrodes fitted to the soles of the feet. Bone density was measured at the calcaneus using ultrasound (CM-100, elk). Grip strength in each hand was measured with the subject in
a standing position and the average value was recorded. Force delivered was divided by body weight in order to eliminate the influence of body size. Stance side for single-leg balance was chosen by the participant. The test lasted 60 s. For gait analysis, participants were asked to walk freely to and fro at their ordinary speed on a level wooden walkway 7 m long, in a gymnasium. They were barefoot and wore dark clothing with white ball markers 30 mm in diameter attached at points as follows: vertex, acromion, radiale, trochanterion, merion laterale, supratarsale fibulare (Martin and Knussmann, 1988), dorsal center of the interphalangeal joint of the big toe, and the posterior center of the accelerometer which was attached near the lower lumbar vertebrae. The data from the accelerometer are not discussed here. A CCD video camera (MotionMeter 250, Redlake) with a field rate of 60 Hz and a shutter speed of 1/300th of a second was situated 6 m from the walkway. Kinematics while walking the middle 3 m on the walkway were recorded. The video signal was stored on a digital video recorder (GV-D1000, Sony) and analyzed using motion analysis software (FrameDIAS II, DKH).

The elderly participants were asked to wear a pedometer (Lifeencoder Ex, Kenz) for a week beginning on the day following the test. The average number of steps taken per day was calculated from the data obtained from the pedometer.

Height differed significantly between the elderly and the young groups for both males and females, and so to eliminate the effect of size differences, a dimensionless value was calculated for the length of stride and speed of walking. Lower limb length was determined from trochanteric height (Kimura et al., 2005), and stride length was standardized by lower limb length (Table 1). Cycle duration was standardized by the square root of the lower limb length. Stance phase duration, i.e. stance phase duration/cycle duration, was then standardized by dividing by the square root of gravitational acceleration and the square root of the lower limb length.

The statistical significance of differences was tested using Student’s t-test or Welch’s t-test. Percentage figures were natural log transformed for statistical evaluation (Sokal and Rohlf, 1995). Table 1 shows the relative calculations.

### Results

As the numbers of females and males in each group were nearly equal, it was legitimate to compare many parameters with the sexes combined.

Walking posture differed between the elderly and the young adult groups. Examples of stick pictures are shown in Figure 1 for an elderly male and a young male of about the same height. The figure shows that the elderly male walked with a shorter stride length than the young male (1.26 m vs. 1.36 m), and with his head bent forward.

The means and standard deviations (SD) of the various parameters are shown in Table 2. Stride length in the elderly was significantly shorter ($p < 0.01$) than in the young, and the elderly group also walked at a significantly slower speed ($p < 0.05$). The same results were observed for dimensionless speed ($p < 0.05$), and dimensionless stride length ($p < 0.01$). There was no significant difference between the two groups in cycle durations either as measured directly or in dimensionless form.

Within the elderly group, speed and stride length were negatively correlated with age (Figure 2), with the least-square linear regressions for both measures being significant (both $p < 0.05$). The regression coefficients were $-0.016$ m/s and $-0.009$ m per year of age, respectively. Dimensionless speed was also negatively correlated with age (Figure 2). The regression coefficient ($p < 0.05$) was $-0.005$ per year of age.

Relative stance phase duration, i.e. stance phase duration divided by cycle duration (Table 1), was not significantly different in the elderly and young adult groups, but was positively correlated with age in the elderly group (Figure 3).

![Figure 1. Stick pictures showing walking in an elderly male (left) and a young male (right) of about the same height (elderly male 1.690 m; young male 1.702 m). Images shown are from left heel contact to the next left heel contact at intervals of 1/30th of a second.](image-url)
Table 2. Physical and gait parameters

<table>
<thead>
<tr>
<th></th>
<th>Elderly</th>
<th>Young adults</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Females, $n = 27$</td>
<td>Males, $n = 25$</td>
</tr>
<tr>
<td></td>
<td>Average ± SD</td>
<td>Average ± SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>69.2 *** 2.71</td>
<td>71.7 *** 3.73</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.510** 0.045</td>
<td>1.635** 0.069</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>55.4 8.0</td>
<td>64.6 10.0</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>24.2 ** 2.7</td>
<td>24.1 2.8</td>
</tr>
<tr>
<td>Fat proportion (%)</td>
<td>29.0 5.8</td>
<td>21.0 4.2</td>
</tr>
<tr>
<td>Bone density (m/s)</td>
<td>1508 19</td>
<td>1513* 23</td>
</tr>
<tr>
<td>Relative grip strength</td>
<td>0.447 0.081</td>
<td>0.595** 0.095</td>
</tr>
<tr>
<td>Single-leg balance (s)$^1$</td>
<td>42.5 *** 22.4</td>
<td>37.0 21.7</td>
</tr>
<tr>
<td>Cycle duration (s)</td>
<td>0.996 0.082</td>
<td>1.037 0.097</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.213 0.105</td>
<td>1.220* 0.127</td>
</tr>
<tr>
<td>Speed (m/s)</td>
<td>1.230 0.159</td>
<td>1.187* 0.167</td>
</tr>
<tr>
<td>Dimensionless stride length</td>
<td>1.489* 0.109</td>
<td>1.452* 0.152</td>
</tr>
<tr>
<td>Dimensionless speed</td>
<td>0.435 0.051</td>
<td>0.413* 0.580</td>
</tr>
<tr>
<td>Relative stance phase</td>
<td>0.601 0.016</td>
<td>0.609 0.019</td>
</tr>
<tr>
<td>Steps per day</td>
<td>8152 2597</td>
<td>8149 3762</td>
</tr>
</tbody>
</table>

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ significantly different from young adults.

$^1$ Statistical evaluation was undertaken as a percentage of 60 s and natural log transformed.
The average number of steps taken per day in the elderly correlated negatively with age (Figure 3). The regression coefficient \( p < 0.05 \) was \(-295\) steps/day per year of age.

The elderly participants had lower relative grip strength than the young adults \( p < 0.05 \) (Table 2). The duration of single-leg balance with eyes open was shorter in the aged subjects than in the young adults (Table 2). Almost all of the student group could stand on one leg for the full 60 s of the test.

The elderly group was significantly shorter and had a higher body mass index than the young adults \( p < 0.01 \), but the groups did not differ significantly with respect to body mass or fat proportion (Table 2). Bone density was significantly lower in the elderly males than in the young males \( p < 0.05 \), and although there was a difference between elderly females and young females, this was not significant.

**Discussion**

When the subjects of research on walking are volunteers, they are usually members of a healthy ‘elite’ (Imms and Edholm, 1981), and are able to visit the study venue independently. By contrast, an elderly population will have high percentages of bed-rest patients and patients with a wide
variety of severe gait difficulties that make it difficult to include them in research on walking. The focus of the present study was on walking in healthy elderly people living in the community. Volunteers from hospitals or healthcare centers were not included. Almost all volunteers, 45 out of the 50 who answered the question about sports, enjoyed a sport named ‘ground golf’, which is very popular in the community, and 24 (12 women and 12 men) were members of a community sports club devoted to ground golf. However, almost no significant differences were observed between club members and non-members. In the present analysis, all the elderly participants in our study who lived in the community were combined to provide a healthy group numbering 52 volunteers. All participants lived in the community, were healthy, able to walk independently, and sufficiently active to visit the IPNU by themselves.

Slow walking speed in the elderly has been reported in many previous papers (Murray et al., 1969; Hageman and Blanke, 1986; Himann et al., 1988; Kaneko et al., 1991), and this slowness has been found to be mainly caused by short stride length (Imms and Edholm, 1981; Ferrandez et al., 1990; Nishizawa et al., 2000). Over the last century, differences in height have been observed between cohorts in developed countries (Kouchi, 1996). Height is directly related to stride length and speed (Bendall et al., 1989). In the present study, height differed between the elderly and young adult groups. We found that the elderly walked more slowly and with a shorter stride length, even when parameters were presented in the form of dimensionless numbers. Hirasaki et al. (1993) reported a difference in relative step length (step length divided by height) between young and elderly subjects, but did not discuss relative speed. A negative regression of speed on age in the elderly was observed by Bendall et al. (1989), but they did not calculate dimensionless speed. In the present study, within the elderly group, older subjects walked more slowly in terms of both direct measurement and dimensionless speed.

Single-leg balance is reported to be related to walking speed (Nagasaki et al., 1995), and the elderly people in the present study had difficulty maintaining single-leg balance with eyes open for a duration that the students achieved easily. One of the reasons for slowness in walking in older subjects may be diminished balance ability. Relative stance phase duration correlated with age within the elderly group. This parameter is known to be negatively correlated with speed in young adults (Kimura and Kamiya, 1982). Long stance phase duration equates to a long double support phase. Long double support duration aids balance in bipedal walking (Ferrandez et al., 1990; Kimura et al., 2005), and can be an adaptive characteristic of the older people in response to impaired balance. The relative stance phase duration was longer in the elderly than in the young adults, but the difference was not significant. The slow walking speed of the elderly is partly caused by the increased duration of double support.

The number of steps taken per day correlated negatively with age in the elderly. Although the elderly participants in this study were very active, their daily activity appeared to reduce with age. Slow speed in the older elderly can be related to daily activity.

Long stride length and high speed may be related to muscle power (Bendall et al., 1989; Judge et al., 1993; Sadeghi et al., 2001). Grip strength is a muscle parameter that can easily be measured with great accuracy, and grip strength has been reported to be related to walking speed (Nagasaki et al., 1995). In the present study, no significant correlation was observed between relative grip strength and speed in the elderly group, but both were lower in the elderly group than in the young adult group.

Acknowledgments

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References


