Original Article

Longitudinal Association Between the Daily Step Count and the Functional Age in Older Adults Participating in a 2.5-year Pedometer-based Walking Program: The YURIN Study

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Abstract

Objective: To investigate the longitudinal association between the daily step count and the functional age (FA) in older adults.

Methods: Twelve males and 15 females (mean age ± standard deviation: 68.9±5.9 years) were recruited from a pedometer-based walking program. At baseline and 0.5, 1.5 and 2.5 years, the Anti-Aging Dock (AAD) system was used to assess the five components of the FA (the muscle age, bone age, vascular age, nervous system age and hormonal age) and various AAD parameters. The number of daily steps (step count) was recorded using an electronic pedometer (HJ-720-IT, Omron, Japan). The subjects were assigned to three groups based on their step count at the four time points. The subjects with step counts in the upper or lower half at all four measurements were defined as the HS and LS groups, respectively. The remaining subjects were assigned to the MS group.

Results: The average step count over the 2.5-year period was 14,892±7,387, 7,954±1,477 and 5,900±1,357 steps/day in the HS, MS and LS groups, respectively. In all subjects, the bone age at 2.5 years (p=0.044) and the hormonal age at 1.5 years (p=0.013) were significantly higher than those measured at baseline. The muscle age, vascular age and nervous system age did not change significantly during the study period.

Conclusions: These results suggest that participating in long-term walking programs can attenuate age-related declines in the muscle and vascular age in older individuals. These results suggest that older individuals should be encouraged to increase and maintain their physical activity levels in order to protect against age-related declines in their physical function.

KEY WORDS: aging, elderly, physical activity, bone mass, skeletal muscle

Introduction

An active lifestyle is associated with numerous health benefits 1). Previous interventional and epidemiological studies have indicated that older individuals can reduce their risk of cardiovascular disease (CVD) by engaging in physical activity (PA) 1). In addition, an active lifestyle among older adults has been shown to be related to higher levels of physical 1,2) and mental well-being 3,4). A prospective cohort study suggested that elderly females can prolong their life span by increasing and maintaining their level of PA 5). Although older individuals tend to have lower levels of PA 6), accumulating daily PA is widely recommended for attenuating age-related changes in the physiological and psychological functions. The World Health Organization recommends that older adults engage in at least 30 minutes of moderate-intensity PA five days a week 7). Older Japanese males and females did not engage in the recommended levels of PA in a previous study 8). However, older individuals can obtain a desirable amount of PA by participating in appropriate interventional programs 9). Therefore, developing and implementing PA programs, especially for elderly subjects, remain an important research issue.

Walking is safe and convenient, and therefore represents an ideal mode of PA for older adults. Hence, establishing a PA regimen involving walking is a practical way to increase the participation in PA. The number of steps has been shown to be a convenient and useful measurement of the level of daily PA. Increasing the number of daily steps is related to improvements in CVD risk factors 10). The beneficial effects of walking have prompted the development of long-term walking programs for older adults. However, although PA interventions targeting older adults have demonstrated increased exercise adherence in the short term, high dropout rates over the long term have been reported 11). Therefore, it is necessary to develop effective exercise programs aimed specifically at promoting walking among older adults. Such programs should assess age-related declines in the physical function using convenient clinical assessment tools.

The functional age (FA), determined according to the Anti-Aging Dock (AAD) system, is a convenient index used to evaluate the degree of aging, not mathematically, but rather functionally 12). The FA can be easily assessed using simple procedures in the clinical setting, and can be used to promote exercise in the outpatient setting. The results of testing provide
Bioelectrical impedance is significantly correlated to that count and the FA in older adults who participated in a 2.5-year investigated the longitudinal association between the daily step increases in the FA among older adults. We herein measuring the daily step count using a pedometer, attenuates maintaining an active lifestyle, as determined objectively by Therefore, the aim of the present study was to assess whether individuals remains unclear, especially over the long term. Therefore, the aim of the present study was to assess whether maintaining an active lifestyle, as determined objectively by measuring the daily step count using a pedometer, attenuates the increases in the FA among older adults. We herein investigated the longitudinal association between the daily step count and the FA in older adults who participated in a 2.5-year pedometer-based walking program.

Methods

Subjects

The subjects evaluated in the present study included 27 older adults (mean age ± standard deviation [SD]: 68.9±5.9 years; M/F=12/15). This subject number was equivalent to that in previous studies that examined the long-term effects of PA among adults. The subjects were recruited from the Senior Club of the Yurin School District, a school district in the Shimogyo district of Kyoto, Japan using fliers placed on bulletin boards in the district. All subjects were free from diagnosed severe cardiovascular diseases and cancer at the time of entry. All subjects provided their written informed consent for participation. The study was approved by the Ethics Committee of Doshisha University.

The Anti-Aging Dock (AAD) system and calculation of the functional age (FA)

At baseline and at 0.5, 1.5 and 2.5 years, the functional age (FA) of each subject was determined based on the Anti-Aging Dock (AAD) system. The FA is composed of five indices (the muscle age, bone age, vascular age, nervous system age and hormonal age). After each AAD examination, the parameters were entered into the database of the Age Management Check System (Ginga Kobo, Naka-ku, Nagoya, Aichi, Japan). The database is comprised of thousands of subjects’ data. First, using the age and raw data in the database, a standard aging curve was determined. Second, the FA was calculated using the curve and the functional equation. The algorithms used to calculate the FAs are confidential, and were developed by the manufacturer. The details of the AAD system have been documented in a number of previous studies. The muscle age was determined using a bioelectrical impedance analyzer (Physion MD, Physion Inc. Shimogyo-ku, Kyoto, Japan), as described in a previous study. The muscle volume measured by this bioelectrical impedance is significantly correlated to that measured by magnetic resonance imaging, with a value of \( r = 0.902–0.976 \). The bone age was determined based on the bone mineral density of the calcaneus calculated using a quantitative ultrasound measurement device (A-1000; GE Yokogawa Medical Systems, Ltd., Hino, Tokyo, Japan) and was assessed based on the stiffness index. The coefficients of variation of the device were reported to be within 1.0% in the previous publication. The vascular age was determined using an acceleration plethysmograph (Dynaarise SDP-100, Fukuda Denshi Co., Ltd., Bunkyo-ku, Tokyo, Japan). This method was validated to assess vascular aging and to screen subjects for atherosclerosis. The nervous system age was determined using the Wisconsin card sorting test (WCST). The WCST is used to measure the brain potential. The hormonal age was determined according to the levels of insulin-like growth factor 1 (IGF-1) and stress indicators (dehydroepiandrosterone sulfate [DHEA-s] and cortisol). In order to assess the levels of IGF-1, DHEA-s and cortisol, blood samples were obtained at the time of the other examinations. All measurements described above were obtained between 9 and 10 a.m. after an overnight fast. Vigorous physical activity was prohibited for one day prior to the examinations.

Anthropometric measurements

Anthropometric measurements were obtained at every AAD examination. The body weight was measured to the nearest 0.1 kg and the height was measured to the nearest 0.1 cm using standard scales and a stadiometer with the subject wearing light clothes and no shoes. The body mass index (BMI) was calculated as the weight in kilograms divided by the height in meters squared.

Pedometer-based walking program

The study comprised a pedometer-based walking program that lasted for 2.5 years. Age-related physical dysfunctions occur within a short period for older people. Two-year PA interventions have previously been shown to protect against physical dysfunctions in older people. The procedures used for this program were described in a previous study. Briefly, each subject was instructed to wear a pedometer (HJ-720IT, Omron Health Care Corporation, Ukyo-ku, Kyoto, Japan) at the waist for the entire day, every day throughout the study period, except when sleeping, swimming or bathing. Each subject was given a step goal report every month that informed them of their average number of steps/day achieved for the current month and the goal for the number of steps/day for the subsequent months. The step goals were determined based on the individual’s average steps/day in the current month based on the following criteria: 1) an increase of 1,000 steps/day for subjects currently below 5,000 steps/day; 2) an increase to 7,500 steps/day for subjects currently at 7,500-10,000 steps/day; and 3) an increase to 10,000 steps/day for subjects currently over 10,000 steps/day. The medical significance of these step count categories were well documented in a number of previous studies.

Daily step count

For the step data collection, the subjects were asked to
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bring their pedometers to an evaluation site at least once a month, at which time, the step data were entered into a personal computer by a researcher using a software program (Bi-Link Professional Edition 2.0, Omron Health Care Corporation, Ukyo-ku, Kyoto, Japan). The validity of the pedometer has been described elsewhere. The device provides mean walking distance values within 1.5-4% of the walking speed (80 m/min)\(^2\). The step count data for a particular day were excluded from the analysis if the pedometer was worn for less than 12 hours on that day\(^3\). All eligible days (days on which the pedometer was worn for over 12 hours) were included in the analysis.

The average number of steps/day over two consecutive weeks was analyzed at each AAD examination (baseline and 0.5, 1.5 and 2.5 years). The multiple two-week measurements using pedometers have been applied to examine year-long PA levels in previous publications\(^4\). Subjects whose step counts were always categorized in the upper or lower half of all four measurements were assigned to the high step (HS) (n=8) or low step (LS) (n=8) group, respectively. The remaining subjects were assigned to the middle step (MS) (n=11) group (Fig. 1).

**Statistical analysis**

The percentage of valid days was calculated as follows: the number of days on which the pedometer was worn for \(\geq\) 12 hours divided by the total number of study days (874 days) multiplied by 100. The differences in the parameters between the baseline values and those obtained at 0.5, 1.5 and 2.5 years were assessed using a repeated measures analysis of variance (ANOVA). A two-way ANOVA with repeated measurements which was covariate-adjusted for age, sex or baseline PA levels, was used to determine the significance of longitudinal changes (at 0.5, 1.5 and 2.5 years) in the daily step count and FA in each group. Pairwise comparisons of the within-subject factors were made using the Bonferroni adjustment for multiple comparisons to discriminate means when the ANOVA yielded significant results. All data were expressed as the means ± SD, and \(p<0.05\) was considered to be statistically significant. The statistical tests were performed using the SPSS for Windows Ver. 19.0 software program (SPSS Inc., Chicago, IL, USA).

![Fig. 1](image-url). The study design.

FA: functional age, HS: high step group, MS: middle step group, LS: low step group.
**Results**

**Subjects**

The clinical characteristics of the subjects are described in Table 1. None of the clinical variables differed significantly between the groups, except for the step count, confirming the homogeneity of and comparability between the groups.

**Adherence to the study protocol**

During the duration of the study (874 days), the mean number of valid measurements (days on which the pedometer was worn for ≥ 12 hours) was 818.0 ± 67.0 days (93.6%, 512-871 days). The number of invalid measurements totaled 55.8 ± 67.1 days (6.4%, 3-362 days). At baseline, the number of subjects in each step count category was two (below 5,000 steps/day), 14 (5000-7,500 steps/day), six (7,500-10,000 steps/day) and five (over 10,000 steps/day). During the study (27 months), the percent of step goal achievers for each month averaged 39.6±7.3% (Fig. 2).

**Table 1 Characteristics of subjects at baseline**

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<tr>
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<th>HS(n=8)</th>
<th>MS(n=11)</th>
<th>LS(n=8)</th>
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<td>SD</td>
<td>Mean</td>
<td>SD</td>
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<td>M/F</td>
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<td>6096.9</td>
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</table>

Data are the means ± standard deviation (SD).

**Fig. 2.** The number of individuals who achieved the monthly step goals.
**Daily step counts**

The baseline step counts in each group are shown in Table 1. The average step counts over the 2.5-year period were 14,892±7,387, 7,954±1,477 and 6,061±784 steps/day in the HS, MS and LS groups, respectively (Fig. 3). A two-way ANOVA with repeated measurements showed a significant difference in the longitudinal changes in the daily step count ($F=5.839$, $p=0.004$), with a significant difference between the groups ($F=10.366$, $p<0.0001$); however, there were no significant time × group interactions ($F=1.874$, $p=0.120$). The post-hoc test showed that the step count at 0.5 years was significantly higher than that observed at baseline ($p=0.002$), with significant differences observed in the LS ($p=0.001$) and MS ($p=0.005$) groups compared to the HS group (Fig. 3).

**FA**

Among all subjects, the one-way repeated ANOVA found significant effects of time on the hormonal age ($F=3.661$, $p=0.016$) and bone age ($F=5.433$, $p=0.007$). The hormonal age at 1.5 years ($p=0.013$) and the bone age at 2.5 years ($p=0.008$) were significantly higher than those observed at baseline (Fig. 4b and e). However, a two-way ANOVA (time*group) found no interactions between any of the parameters (Table 2).

**AAD parameters**

The one-way repeated ANOVA showed that the weight-bearing index at 2.5 years was significantly higher than that observed at baseline ($p<0.001$), 0.5 year ($p=0.015$) and 1.5 years ($p=0.001$) and that the IGF-1 level at 1.5 years ($p=0.020$) was significantly higher than that observed at baseline. However, a two-way ANOVA (time*group) found no interactions between any of the parameters (Table 2).

![Graph showing the changes in daily step count](image)

**Fig. 3.** The changes in the daily step count.

The time, group and interactions between the time and group were tested using a two-way ANOVA, followed by Bonferroni’s post-hoc test. *: significant difference between the groups or time points, with a value of $p<0.05$. The error bars indicate the standard deviation (SD).
**Fig. 4.** The changes in the functional age (FA).

The time, group and interactions between the time and group were tested using a two-way ANOVA, followed by Bonferroni’s post-hoc test. Note that the values are not adjusted. Adding the age, sex or baseline PA levels as a covariate did not significantly affect the results. *: significant difference between the groups or time points, with a value of $p<0.05$. The error bars indicate the standard deviation (SD).
Table 2  The Anti-Aging Dock parameters at baseline, and at 0.5, 1.5 and 2.5 years

<table>
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<td>160.3</td>
<td>85.2</td>
<td>141.6</td>
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</table>

Data are the means ± standard deviation (SD).
A: p<0.05 vs. baseline. B: p<0.05 vs. 0.5 years. C: p<0.05 vs. 1.5 years. Note that values are not adjusted. Adding age, sex or the baseline PA levels as a covariate did not significantly affect the results.

WBI: weight bearing index; CA: categories achieved; NUCA: numbers of response cards used until the first category achieved; TE, total errors; PEM, perseverative; PEN, perseverative errors of the Nelson errors of Milner; UE, unique errors; BR, bizarre errors.
Discussion

The present study investigated the longitudinal relationships between the step count and the FA in older adults participating in a 2.5-year walking program. We found that the muscle age, vascular age and nervous system age did not change significantly after the 2.5-year intervention compared to the values observed at baseline. However, contrary to our hypothesis, we found significant increases in the bone and hormonal ages. In addition, there were no significant differences in the FA between the groups categorized based on the number of steps. These results suggest that older individuals can attenuate age-related declines in the muscle age, vascular age and nervous system age by participating in long-term walking programs. Furthermore, we did not detect any significant effects of the number of steps on the longitudinal changes in the FA, and both the LS and HS groups maintained their FA values for 2.5 years. In the present study, all subjects were instructed to walk for exercise. In addition, the PA levels among our subjects were higher than those of general Japanese older people. Thus, these results suggested that not habitual PA, but long-term walking programs, can independently prevent physical dysfunctions in older adults. In addition, even a small increase in the daily step count was associated with parameters reflecting a better health status, such as the insulin sensitivity and blood pressure. These results suggest that older individuals should be encouraged to increase and maintain their level of PA in order to protect against age-related declines in the physical function.

The present investigation is the first to show the relationship between the changes in walking behavior and the FA over a 2.5-year period. The results demonstrated that the muscle age, vascular age and nervous system age did not change during the 2.5-year intervention period. It is well known that the muscle mass decreases in elderly individuals by 1-2% per year. Similarly, the vascular and cognitive functions have been shown to exhibit age-associated declines in previous studies. The physical functions and cognitive functions declined 7.4-9.6 % in 10 years in one study. Therefore, the results of the present investigation indicate that long-term walking programs have protective effects against age-related changes in the FA. In support of this, previous studies of long-term walking programs prevented age-related physical dysfunctions, such as lower body disability. Furthermore, one of the primary findings of the present study is that older individuals can maintain their physical function by maintaining their PA level, regardless of the absolute number of steps. Previous studies have demonstrated that the PA levels significantly decrease in association with increases in age; therefore, it is likely that older individuals can obtain desirable effects simply by maintaining their current PA level.

We found that our program maintained the muscle age, vascular age and nervous system age for 2.5 years, regardless of the absolute number of steps. These results suggested that long-term walking programs prevented the declines in muscle mass, vascular and cognitive functions. This is important, because these functions obviously decline with advancing age. Maki et al. showed that a long-term walking program for older people maintained their cognitive functions, but they reported significant declines in the function of the control groups. Taken together, our findings suggest that older people should maintain their PA levels to sustain their current physical functions such as their muscle mass and vascular and cognitive functions.

Unexpectedly, we observed significant increases in the bone and hormonal ages of our subjects. These results suggest that long-term walking programs did not prevent age-related declines in bone mass and circulating hormone levels. A previous study reported that aerobic PA did not affect the bone mass in older adults, furthermore, previous studies have demonstrated that strength training is more suitable for maintaining the bone health compared with habitual PA, including horizontal walking. In addition, with regard to the hormonal age, the present investigation assessed the age according to the circulating IGF-1 and DHEA-s levels. Previous studies have shown that one-year aerobic training did not change the IGF-1 levels in adults. Based on these findings, it is not surprising that the bone and hormonal ages declined in spite of the participation in the walking program.

One of the strengths of the present investigation is the duration of the study intervention (2.5 years). As previously mentioned, the physical function generally exhibits notable declines over long-term periods in older adults living typical lifestyles. Therefore, the study period employed in the present investigation (2.5 years) appears to be sufficiently long to demonstrate age-associated changes in the FA. Subsequently, the present study showed that long-term walking programs can attenuate diverse age-related abnormalities.

Our results are supported by previous findings. For example, an eight-year study of older females demonstrated that the amount of weight gain was significantly lower in the subjects who increased or maintained their level of PA compared to that observed in the inactive subjects. In another study, over a two-year period, the subjects who maintained their level of PA exhibited a 45% lower mortality rate compared with the sedentary subjects. Furthermore, a longitudinal study demonstrated a similar risk of mortality in older adults who remained active and maintained a moderate level of PA. Based on these findings, maintaining the PA level over the long term is considered to be beneficial for reducing the risk of CVD, and ultimately contributes to reducing the mortality among older individuals. Therefore, the present findings suggest that middle-aged to older adults can obtain several health benefits simply by maintaining their PA level, and additional benefits can be expected if the PA level is increased.

In contrast to the present investigation, several previous studies have demonstrated that long-term walking programs successfully improved numerous health outcomes in middle-aged to older adults. Yates et al. reported that the improvements in glucose regulation observed following a pedometer-based walking program were maintained at 24 months. In addition, year-long walking programs have been shown to improve inflammation and lipid parameters in older individuals. These findings indicate that, regardless of the length of the intervention period, pedometer-based walking programs are an appropriate method for obtaining health benefits. A previous eight-week moderate-intensity walking program that used heart rate monitors showed significant reductions in the systolic blood pressure. The lack of significant effects on blood pressure observed in the present study can be attributed to several factors, including the healthy baseline profiles of the subjects and the program instructions (maximum 10,000 steps).

Several limitations are associated with the present study. First, the lack of effects can be attributed to the baseline PA levels of our subjects. The baseline PA level in the LS group was comparable to that observed in older individuals of similar age in the general population (males and females in their 60s: 7,162 and 6,559 steps, respectively).
Therefore, the LS group may not be representative of physically inactive older adults. Second, we advised the active subjects (those taking >10,000 steps/day) to maintain their current PA levels. Therefore, the present investigation could not be used to examine dose-response relationships between the number of steps and the FA. Third, our sample size was relatively small. A larger sample size would lead to greater confidence in the results. Finally, diet is a confounding factor that would influence the results. Dietary factors (i.e., energy intake and the levels of consumption of protein, calcium, magnesium, zinc and vitamin C) have been shown to be related to the bone mass, and were not examined in the present study.

Conclusions

The present investigation examined the long-term (2.5-year) effects of a walking program on the FA among older adults. The results suggest that participating in long-term walking programs can attenuate age-related declines in the muscle and vascular age in older individuals. We did not detect any significant effects of the number of steps on the longitudinal changes in the FA, and both the LS and HS groups maintained their FA over the 2.5-year period. These results suggest that older individuals should be encouraged to increase and maintain their level of PA in order to protect against age-related declines in the physical function. Additional studies are warranted to assess the dose-response relationships between the step count and FAs in a larger number of subjects under more controlled conditions.

Conflicts of Interest

The authors declare no financial or other conflicts of interest with regard to this paper.

References


