Longer Time Spent in Light Physical Activity Is Associated With Reduced Arterial Stiffness in Older Adults

Yuko Gando, Kenta Yamamoto, Haruka Murakami, Yumi Ohmori, Ryoko Kawakami, Kiyoshi Sanada, Mitsuru Higuchi, Izumi Tabata, Motohiko Miyachi

Abstract—Habitual moderate-to-vigorous-intensity physical activity attenuates arterial stiffening. However, it is unclear whether light physical activity also attenuates arterial stiffening. It is also unclear whether light physical activity has the same effects in fit and unfit individuals. This cross-sectional study was performed to determine the relationships between amount of light physical activity determined with a triaxial accelerometer and arterial stiffness. A total of 538 healthy men and women participated in this study. Subjects in each age category were divided into either high-light or low-light physical activity groups based on daily time spent in light physical activity. Arterial stiffness was measured by carotid-femoral pulse wave velocity. Two-way ANOVA indicated a significant interaction between age and time spent in light physical activity in determining carotid-femoral pulse wave velocity ($P<0.05$). In the older group, carotid femoral pulse wave velocity was higher in the low-light physical activity level group than in the high-light physical activity level group (945±19 versus 882±16 cm/s; $P<0.01$). The difference remained significant after normalizing carotid-femoral pulse wave velocity for amounts of moderate and vigorous physical activity. The carotid-femoral pulse wave velocity ($r=-0.47$; $P<0.01$) was correlated with daily time spent in light physical activity in older unfit subjects. No relationship was observed in older fit subjects. These results suggested that longer time spent in light physical activity is associated with attenuation of arterial stiffening, especially in unfit older people. (Hypertension. 2010;56:540-546.)

Key Words: aging ■ arteriosclerosis ■ triaxial accelerometer ■ physical activity ■ prevention

Age-related arterial stiffening is associated with higher incidences of cardiovascular mortality and cardiovascular events. High levels of cardiorespiratory fitness (CRF) and physical activity (PA) from moderate- and vigorous-intensity (brisk walking, jogging, aerobics, and other sports) activities have been shown to attenuate arterial stiffening. However, it is not clear whether light PA is also effective to attenuate arterial stiffening.

Many previous studies indicated the impact of PA on arterial stiffness. Although PA evaluation in these studies was performed based on self-reported questionnaires, subjective interpretation of questions and perception of PA may lead to misclassification of the magnitude of activity. In addition to the imprecision associated with such measures, it is also difficult to determine the amount of light PA, such as housework (ie, sweeping, mopping, and window washing) and other unstructured activities, by questionnaire.

Recent studies using uniaxial accelerometers indicated the impact of PA on arterial stiffness. Sugawara et al reported that moderate and vigorous PA have favorable effects on arterial stiffness, although light PA had no such effect. However, uniaxial accelerometry does not detect horizontal movements and may, therefore, underestimate the amount of light PA. More recent studies demonstrated a stronger correlation between counts obtained with triaxial accelerometry and energy expenditure measured in a metabolic chamber in comparison with counts from uniaxial accelerometry and validated the predicted energy expenditure in light PA obtained with triaxial accelerometry.

Objective evidence has been reported indicating that light PA has a relatively high energy cost during daily living and is beneficially associated with traditional risk factors. Therefore, we hypothesized that the longer time spent in light PA assessed by triaxial accelerometry may be associated with reduced arterial stiffening. Moreover, it is also unclear whether the effects of light PA are the same in fit and unfit individuals. Evidence of an effect of such differences in fitness level would suggest possibilities for targeted prevention. Therefore, we performed a cross-sectional study to examine the relationships between PA at various intensities obtained with triaxial accelerometry, CRF, and arterial stiffness.
Declaration of Helsinki. Before testing, subjects abstained from coffee and fasted for 4 hours (a 12-hour overnight fast was used).

The study was performed in accordance with the guidelines of the American Heart Association guidelines.20 The mean of right and left brachial BPs was used for analysis.

### Methods

#### Subjects

A total of 538 adults (172 men and 366 women), under the age of 40 years (young), 40 to 59 years of age (middle-aged), and over the age of 60 years (older) participated in this study (Table 1). None of the subjects smoked or were on medication for hypertension, hyperlipidemia, or diabetes mellitus. Subjects with a history of stroke, cancer, or chronic renal failure, as well as those regularly engaging in weight training, were excluded from the study.19 None of the female subjects were taking oral contraceptives or hormone replacement therapy. Subjects who were regularly engaged in swimming or cycle training were also excluded because the PA of swimming could not be measured and that of cycling may not be measured accurately by triaxial accelerometry. The purpose, procedures, and risks of the study were explained to each participant, and all of the subjects gave their written informed consent before participating in the study, which was approved by the human research committee of the National Institute of Health and Nutrition. The study was performed in accordance with the guidelines of the Declaration of Helsinki. Before testing, subjects abstained from caffeine and fasted for ≥4 hours (a 12-hour overnight fast was used to determine arterial stiffness and blood pressure).

#### Arterial Stiffness and Blood Pressure

Subjects were studied under quiet resting conditions in the supine position. Carotid-femoral pulse wave velocity (cPWV), which is an index of arterial stiffness, and blood pressure (BP) were measured with a vascular testing device (form PWV/ABI, Omron Colin). Recordings were made in triplicate, with subjects in the supine position, and conformed strictly to American Heart Association guidelines.20 The mean of right and left brachial BPs was used for analysis.

The metabolic equivalent (MET) intensity levels of PA were with 1.1 to 2.9 METs (light), 3.0 to 5.9 METs (moderate), and ≥6.0 METs (heavy).

#### Physical Activity

The duration and intensity of PA were evaluated by triaxial accelerometer (Actimarker EW4800, Panasonic Electric Works). All of the subjects were asked to wear a triaxial accelerometer for 20 days; we used the data for 14 days, during which the accelerometer was worn continuously on waking until going to bed. Acceleration in the anterior-posterior (x), mediolateral (y), and vertical (z) axes were calculated using a sensor with a sample rate of 20 Hz over a range from 0 to 2×g. The apparatus stores the SD of the vector norm of the composite acceleration (Km) in 3 dimensions each minute as follows:

$$K_m = \sqrt{\frac{1}{n-1} \left( \sum_{i=1}^{n} k_x^2 + \sum_{i=1}^{n} k_y^2 + \sum_{i=1}^{n} k_z^2 \right) - \frac{1}{n} \left( \sum_{i=1}^{n} k_x \right)^2 - \left( \sum_{i=1}^{n} k_y \right)^2 - \left( \sum_{i=1}^{n} k_z \right)^2}$$

where n is the number of data for 1 minute (n=1200), and Σx, Σy, and Σz are the sums of the accelerations in each axis for 1 minute.

The metabolic equivalent (MET) intensity levels of PA were calculated by simple linear regression of Km. A previous validation study investigated the relationship between oxygen uptake (VO2) during 7 types of housework and 7 levels of walking/running speed and triaxial acceleration and confirmed that PA and VO2 were highly correlated (r=0.93).21 We obtained daily PA duration corresponding with 1.1 to 2.9 METs (light), 3.0 to 5.9 METs (moderate), and ≥6.0 METs (heavy).

### Table 1. Physical Characteristics of Subjects Divided by Age and Light PA Level

<table>
<thead>
<tr>
<th>Variables</th>
<th>Young High</th>
<th>Young Low</th>
<th>Middle-Aged High</th>
<th>Middle-Aged Low</th>
<th>Older High</th>
<th>Older Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>67</td>
<td>68</td>
<td>146</td>
<td>148</td>
<td>54</td>
<td>55</td>
</tr>
<tr>
<td>Men, n/ %</td>
<td>40/60</td>
<td>41/60</td>
<td>37/25</td>
<td>38/26</td>
<td>8/15</td>
<td>8/15</td>
</tr>
<tr>
<td>Postmenopausal women, n/ %</td>
<td>0/0</td>
<td>0/0</td>
<td>53/49</td>
<td>44/40</td>
<td>46/100</td>
<td>47/100</td>
</tr>
<tr>
<td>Age, y</td>
<td>34±0.4</td>
<td>34±0.5</td>
<td>50±0.5*</td>
<td>49±0.4*</td>
<td>63±0.3*†</td>
<td>64±0.4*†</td>
</tr>
<tr>
<td>Height, cm</td>
<td>167.3±1.0</td>
<td>167.3±0.6</td>
<td>159.8±0.6*</td>
<td>160.6±0.6*</td>
<td>157.7±0.8*</td>
<td>156.4±1.1†</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>62.2±1.4</td>
<td>62.7±1.3</td>
<td>57.9±0.8*</td>
<td>60.0±0.7*†</td>
<td>55.3±1.2*</td>
<td>56.0±1.0†</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>22.1±0.4</td>
<td>22.3±0.4</td>
<td>22.6±0.2</td>
<td>23.3±0.3*</td>
<td>22.2±0.4</td>
<td>22.9±0.4</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>20.7±0.8</td>
<td>22.8±0.71</td>
<td>26.6±0.5*</td>
<td>28.0±0.6*</td>
<td>27.9±0.7*</td>
<td>30.2±0.8†‡</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>115±1</td>
<td>112±1</td>
<td>117±1</td>
<td>118±1*</td>
<td>118±2</td>
<td>125±2*†‡</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>69±1</td>
<td>67±8</td>
<td>73±1*</td>
<td>72±1*</td>
<td>70±1</td>
<td>75±2*†‡</td>
</tr>
<tr>
<td>MAP, mm Hg</td>
<td>86±1</td>
<td>84±1</td>
<td>90±1*</td>
<td>90±1*</td>
<td>90±1</td>
<td>96±2*†‡</td>
</tr>
<tr>
<td>PP, mm Hg</td>
<td>46±1</td>
<td>46±1</td>
<td>45±1</td>
<td>45±1</td>
<td>49±1*†</td>
<td>50±2*†‡</td>
</tr>
<tr>
<td>Plasma glucose, mmol/L</td>
<td>4.8±0.1</td>
<td>4.8±0.1</td>
<td>5.0±0.1*</td>
<td>5.0±0.1*</td>
<td>5.1±0.1*</td>
<td>5.4±0.1*†‡</td>
</tr>
<tr>
<td>Plasma insulin, µU/mL</td>
<td>3.9±0.2</td>
<td>4.0±0.2</td>
<td>3.9±0.2</td>
<td>4.6±0.2†</td>
<td>3.9±0.3</td>
<td>4.7±0.4</td>
</tr>
<tr>
<td>Total cholesterol, mmol/L</td>
<td>4.75±0.10</td>
<td>4.72±0.09</td>
<td>5.44±0.07</td>
<td>5.46±0.08</td>
<td>5.90±0.11†</td>
<td>5.87±0.12†</td>
</tr>
<tr>
<td>HDL cholesterol, mmol/L</td>
<td>1.59±0.05</td>
<td>1.45±0.04§</td>
<td>1.74±0.03*</td>
<td>1.63±0.03*†</td>
<td>1.72±0.05</td>
<td>1.59±0.05</td>
</tr>
<tr>
<td>Triglycerides, mmol/L</td>
<td>0.88±0.06</td>
<td>0.87±0.05</td>
<td>0.98±0.05</td>
<td>1.05±0.05*</td>
<td>0.97±0.06</td>
<td>1.09±0.08*</td>
</tr>
<tr>
<td>ÑV O2peak, mL/kg per min</td>
<td>38.8±1.0</td>
<td>34.6±0.8†</td>
<td>30.5±0.5*</td>
<td>29.8±0.6*</td>
<td>27.0±0.6†</td>
<td>28.2±0.8*</td>
</tr>
</tbody>
</table>

Data are mean±SE. High and low indicate high-light PA level groups and low-light PA level groups; PP, pulse pressure.

*P<0.05 vs young.
†P<0.05 vs middle-aged.
‡P<0.05 vs high in the same age group.

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METs (vigorous).22 Time spent in inactivity was defined as the sum of sedentary (<1.1 METs) and nonwearing periods, which was calculated as 1440−(daily time spent in light PA+moderate PA+vigorous PA).

To assess the effects of age and light PA on arterial stiffness, subjects in each age category were categorized into high-light PA and low-light PA groups based on the median value of the daily time spent in light PA in each age and sex category. To determine sample size of each group, we performed power calculations using nQuery Adviser version 4.0 (Statistical Solutions) before starting the study.

Cardiorespiratory Fitness

CRF, assessed from peak oxygen uptake (\(\dot{V}O_2\)peak), was measured by an incremental cycle exercise test using a cycle ergometer (Ergomedic 828E Test Cycle, Monark).2 The incremental cycle exercise began at a work rate of 30 or 60 W for women and 60, 90, or 120 W for men, and power output was increased by 15 W·min⁻¹ until the subjects could not maintain the fixed pedaling frequency (60 rpm). The subjects were encouraged during the ergometer test to exercise at the level of maximum intensity. The heart rate and rating of perceived exertion23 were monitored on a minute-by-minute basis. The \(\dot{V}O_2\) was measured by the Douglas bag method during the last 30 seconds of each increase in work rate. The highest value of \(\dot{V}O_2\) during the exercise test was designated as \(\dot{V}O_2\)peak. Because the test required incremental cycle exercise to exhaustion, subjects were allowed to determine whether they were willing to participate in the test; 504 of the pooled population participated in the test.

To examine whether the effects of light PA on arterial stiffness are the same in fit and unfit individuals, the subjects were categorized into high (fit) or low (unfit) CRF groups based on \(\dot{V}O_2\)peak. The \(\dot{V}O_2\)peak reference values are provided for sex and age groups, as described by the Japanese Ministry of Health, Labor, and Welfare to prevent lifestyle-related diseases.24

Blood Samples

Blood samples were taken after an overnight fast of \(\geq 10\) hours to determine fasting glucose and insulin levels. In the same session, serum samples were obtained to determine fasting total cholesterol, high-density lipoprotein cholesterol, and triglyceride levels.

Body Composition

Body composition was determined by dual-energy X-ray absorptiometry (Hologic QDR-4500, Hologic) with subjects in the supine position.

Statistical Analyses

The data were analyzed by 2-way ANOVA (age×light PA level) and ANCOVA with sex as a covariate. In cases with a significant \(F\) value, post hoc test with the Scheffe method was used to identify significant differences among mean values. To investigate the effects of age, the groups were compared by 1-way ANOVA and Tukey post hoc test for multiple comparisons. Univariate regression and correlation analyses were used to examine the relationships between variables of interest. Spearman correlation coefficients were also used to examine the associations between the time spent in vigorous PA and cfPWV. Independent relations among the dependent variables were determined by partial correlation analysis. Stepwise multiple regression analysis was used to determine the influence of daily time spent in light, moderate, and vigorous PA on cfPWV. Collinearity was detected between daily time spent in light PA and inactivity (\(r=0.97; P<0.001\)), and the former was included in the stepwise multiple regression analysis. In all of the analyses, \(P<0.05\) was considered statistically significant. Data are presented as mean±SE.

Results

Table 1 shows the physical characteristics. In young and older subjects, percentage of body fat values were higher in the low-light PA level group than in the high-light PA level group. In older subjects, SBP, DBP, and MAP were higher in the low-light PA level group than in the high-light PA level group. In older subjects, plasma glucose was higher in the low-light PA level group than in the high-light PA level group.

Figure 1 shows the effects of age and the amount of light PA on cfPWV. Two-way ANOVA indicated a significant interaction (\(P<0.05\)). In both light PA level groups, cfPWV was higher in middle-aged and older groups compared with the young group. In the older group, cfPWV was higher in the low-light PA level group than in the high-light PA level group (\(P<0.01\)). The differences remained significant after normalizing cfPWV for sex when analyzed by ANCOVA. In addition, there were no significant differences in amounts of moderate and vigorous PA between high-light PA and low-light PA in older groups (moderate: 61±3 versus 57±3 minutes/day, \(P>0.05\); vigorous: 0.9±0.5 versus 1.7±0.6 minutes/day, \(P>0.05\)). The differences in cfPWV between the high-light PA group and low-light PA group remained significant after normalizing for amounts of moderate and vigorous PA.

Table 2 shows the PA, inactivity, and CRF of the subjects divided by age group. There were no significant differences in the number of steps among the 3 groups. \(\dot{V}O_2\)peak decreased with age. The daily time spent in light PA was longer and the time spent in inactivity was shorter in middle-aged and older groups compared with the young group. The time spent in light PA was strongly correlated with the time spent in inactivity in all of the age groups (\(r=0.97; P<0.001\)). There were no significant differences in the daily time spent in moderate PA among the 3 groups. The daily time spent in vigorous PA was shorter in middle-aged and older groups than in the young group. The coefficients of variation in times spent in inactivity and light, moderate, and vigorous PA for 14 consecutive days were 12±1%, 17±1%, 48±3%, and 287±27%, respectively.

In the overall study population, cfPWV was weakly correlated with time spent in moderate (\(r=-0.14; P<0.01\)) or vigorous PA (Pearson \(r=-0.09; \)Spearman \(r=0.17; P<0.05\))
but was not significantly related to time spent in light PA or inactivity. Thus, correlations between the daily time spent in light (A), moderate (B), and vigorous (C) PA or inactivity (D) and cfPWV in each age category were analyzed (Figure 2), because cfPWV increases progressively with advancing age. In the young group, there was no relationship between daily time spent in PA and cfPWV. In the middle-aged group, cfPWV was significantly related to the daily time spent in moderate (r = −0.21; P < 0.01) and vigorous (r = −0.12; P < 0.05; Spearman r = −0.19, P < 0.01) PA. In the older group, cfPWV was significantly related to the daily time spent in light (r = −0.39; P < 0.01) and moderate (r = −0.31; P < 0.01) PA and inactivity (r = −0.44; P < 0.01) but not in vigorous PA (r = 0.09, P = 0.37; Spearman r = −0.05, P = 0.50). The relations remained significant after normalizing for sex in partial correlation analysis (light: r = −0.30; moderate: r = −0.29). The above results were confirmed in stepwise multiple regression analysis. In the middle-aged subjects, cfPWV was independently predicted by the daily time spent in moderate PA (β = −0.22). In the older subjects, cfPWV was independently predicted by the daily time spent in light (β = −0.39) and moderate (β = −0.30) PA. In general, qualitatively similar results (although inverse in direction) were obtained using time spent in inactivity in place of light PA.

Figure 3 shows the relationships between the daily time spent in light PA and cfPWV or MAP in unfit (n = 56) and fit (n = 32) older subjects. The cfPWV (r = −0.47; P < 0.01) and MAP (r = −0.30; P < 0.05) were correlated with the daily time spent in light PA in unfit subjects. No such relationships were observed in older fit subjects.

### Discussion

The key new findings of the present study were as follows. First, in older subjects, arterial stiffness was higher in the low-light PA level group as compared with the high-light PA level group. The differences remained significant after normalizing cfPWV for amounts of moderate and vigorous PA. Second, a negative relationship between the daily time spent in light PA and arterial stiffness was observed in the older group. Third, although the daily time spent in light PA was inversely related with the arterial stiffness in unfit subjects, no such relationship was observed in fit subjects. These results suggest that the longer time spent in light PA <3 METs, such as housework or other unstructured activities, is associated with attenuation of arterial stiffening, especially in unfit older people. Our findings have important implications, because increasing light PA may be easier to achieve in the older population than increasing structured exercise training at vigorous or moderate intensities.

Little information is available regarding the relationships between light PA and arterial stiffness. Therefore, we determined the relationships between the daily times spent in inactivity and light, moderate, and vigorous PA and arterial stiffness. The strength of the present study was that daily PA levels of subjects were evaluated by triaxial accelerometry, because self-reported PA may be subject to bias and misclassification,19 and this method allows for better determination of light PA.16 Similar to previous findings, the present study also showed that arterial stiffness was significantly related to the daily time spent in moderate PA in middle-aged and older groups. More importantly, the present study first demonstrated that the daily time spent in light PA was inversely related with arterial stiffness in the older group, independent of the daily time spent in moderate and vigorous PA. Moreover, qualitatively similar results (although inverse in direction) were obtained using time spent in inactivity in place of light PA. The present findings suggest that replacing inactivity with light PA may be one factor associated with reduced arterial stiffening in older people.

One possible reason for the negative association between light PA and arterial stiffness is that light PA may be relatively harder for older subjects than for young and middle-aged subjects, because CRF in the older group was significantly lower than those in the young and middle-aged groups. Indeed, relative intensities (%V\text{O}2peak) at 3 METs in young, middle-aged, and older groups corresponded with 29%, 35%, and 38% of V\text{O}2peak, respectively. The relative intensity of PA may be an important factor in considering physiological adaptation of arterial stiffness, because it is strongly related with heart rate and BP responses during PA. In the present study, we found that plasma glucose was higher in the low-light PA level group than in the high-light PA level group among older subjects. Several recent studies indicated that objective measured light-intensity PA is beneficially associated with blood glucose and other metabolic risk factors,18,25–27 Taken together, these findings suggested that the favorable effect of light PA on arterial stiffness is mediated by metabolic profile improvement. Other mechanisms by which daily light PA may influence arterial stiffness in older people are still speculative and include the effects of PA on the bioavailability of NO, vascular smooth muscle tone, connective tissue cross-linking, and gene expression.28–30

Our findings have a number of important practical implications. Increasing light PA may be easier to achieve in older people, especially in the unfit older population. In fact, the CRF and time spent in vigorous PA in the older group were markedly lower than those in middle-aged and young groups (Table 2). Moreover, subjects spent only a small proportion of time in moderate (59.0 minutes/day) and vigorous (1.3 minutes/day) PA. Most time spent can be categorized broadly...
into 2 distinct modes: light PA and inactivity (mostly sedentary and sleeping time). Those who spent more time in light PA must, therefore, spend less time in sedentary behaviors. A recent prospective study suggested that increased time spent in sedentary activities is associated with elevated fasting insulin levels regardless of the amount of time spent in moderate-vigorous PA. Substituting light PA for sedentary behavior may be a practical and achievable preventive strategy in older people. Light PA can be achieved through household tasks and other nonexercise activities, which need not be fitness-enhancing activities. The modes of PA that are common at the population level are primarily unstructured forms, and our data indicated that elevated energy expenditure through less-defined modes of PA is likely to be important in the primary prevention of arterial stiffening. On the other hand, we should emphasize that structured exercise training from moderate to vigorous intensity is an important way in which arterial stiffening may be prevented.

Figure 2. Relationships between daily time spent in each PA intensity and cPWV. In the older group, cPWV was significantly related to the daily time spent in light PA ($r = 0.39; P < 0.01$), moderate PA ($r = 0.31; P < 0.01$), and inactivity ($r = 0.44; P < 0.01$).
As the initial approach to determine the relationships between the PA at various intensities or CRF and arterial stiffness, we used a cross-sectional study design. Because of the limitations associated with this design, we attempted to isolate the influence of light PA level as much as possible. To do so, low-light and high-light PA groups were carefully matched for age, number of males, and menopausal status. In addition, to isolate the effects of light PA, per se, we performed 2-way ANCOVA (age × light PA level) with these covariates. However, because of the design of this study, we could not evaluate individual changes in age-related arterial stiffness. A prospective study is needed to determine the cause-and-effect relationships between PA at various intensities and arterial stiffness. Moreover, in the present study, the time spent in light PA included all of the activities under 3 METs, for example, intermittent unstructured activities and continuous slow walking, and also included daily variations attributed mainly to changes in work-leisure balance. Although we will be able to clarify the type, duration, frequency, and daily variation of activity by analyzing the data accumulated with the accelerometer, the analysis will be very difficult. Therefore, further studies are required to make definitive conclusions regarding which pattern of activity is the most beneficial.

**Perspectives**
The present study indicated that time spent in light PA is negatively associated with arterial stiffness in older people. The association was especially evident in unfit subjects. Moreover, qualitatively similar results (although inverse in direction) were obtained using time spent in inactivity. These findings suggested that replacing inactivity with light PA, such as household tasks and other unstructured activities, may be an effective means of preventing age-related arterial stiffening. The underlying mechanisms and practical implications of these findings warrant further investigation.

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**Disclosures**
None.

**References**


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