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ORIGINAL ARTICLE

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Mechanical power during maximal treadmill walking and running in young and elderly men

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Abstract This study determined mechanical power during movements specific to maximal walking and running using a non-motorized treadmill in 38 elderly [69.4 (5.0) years] and 50 young [24.3 (3.4) years] men. The mean mechanical power over a period of time covering six steps, during which the belt velocity peaked and then kept almost plateau, was determined as a performance score in each of maximal walking (WP) and running (RP). In terms of the value relative to body mass, the relative difference between the two age groups was greater for RP (61.7%) than for WP (21.4%) or isometric knee extension (34.1%) and flexion torque (43.8%). In the two groups, WP was significantly ($P < 0.05$) correlated to knee extension ($r = 0.582$ for the elderly and $r = 0.392$ for the young) and flexion torque ($r = 0.524$ for the elderly and $r = 0.574$ for the young). Similarly, RP was also significantly ($P < 0.05$) correlated to knee extension ($r = 0.627$ for the elderly and $r = 0.478$ for the young) and flexion torque ($r = 0.500$ for the elderly and $r = 0.281$ for the young). In these relationships, the WP adjusted statistically by thigh muscle torque was similar in the two age groups. However, the corresponding value for RP was significantly higher in the young than in the elderly. The findings here indicate that: (1) the difference between the young and elderly men in mechanical power is greater during maximal running than maximal walking, and (2) although the thigh muscle torque contributes to the power production during the two maximal exercise modes in the two age groups, the RP is greater in the young than in the elderly regardless of the difference in the thigh muscle torque.

Keywords Ageing · Non-motorized treadmill · Mechanical power · Isometric torque

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Introduction

Most daily activities require the generation of velocity as well as force, and their performances depend on the product of the two variables, i.e., power (Bonnefoy et al.1998). It has been documented that the influence of ageing on mechanical power during instantaneous or maximal repetitive muscle contractions is greater than that on maximal muscle strength (Bassey et al. 1992; Metter et al.1997; Skelton et al.1994; Young and Skelton 1994). In addition, the explosive power of the lower limbs in elderly populations is closely associated with the loss of functional ability to walk, to rise from a chair, or to climb stairs (Bassey et al. 1992). Therefore, combining analyses of power and muscle strength in elderly populations provides useful information on the age-associated loss of functional performance during daily activities (Metter et al. 1997).

In the previous studies cited above, two exercise modes, i.e., an explosive single leg extension on an ergometer or force platform (Bassey et al. 1992; De Vito et al. 1998; Izquierdo et al.1999; Rantanen and Avela 1997; Skelton et al. 1994) and short-lasting sprints on a cycle ergometer (Bonnefoy et al. 1998; Chamari et al. 1995; Metter et al. 1997), have mainly been adopted for power determination. Although Margaria et al. (1966) developed the Running Upstairs Test for assessing anaerobic power, no study has tried to investigate age-related differences in the mechanical power needed for walking as well as running using ergometry. Walking and running are most fundamental forms of human movement, and at the same time integral components of the many tasks required for independent living. Hence, the power determinations of these forms may be representative scales of functional capabilities in many routine activities of daily living.

Recently, we developed a non-motorized treadmill to determine the mechanical power developed during movements specific to either walking or running (Funato et al. 2001). While subjects walk or run on the treadmill, they grip a handlebar in a horizontal position in front of them, keeping both arms straight and horizontal. Using this ergometer, therefore, the exercise task lacks arm movements. However, this system has the advantage that the subjects can easily maintain their posture during the exercise on the treadmill, and so safely perform walking and/or running with maximal effort, regardless of age and physical level.

In the present study, we determined the mechanical power during the movement forms of maximal walking and running in elderly and young populations using the non-motorized treadmill. In addition, the isometric strength of knee extensors and flexors was also measured. The main purpose of this study was to investigate age-related differences in mechanical power developed in the two maximal exercise modes, with relation to the strength capabilities of knee extensors and flexors.

Methods

Subjects

Fifty young (20–29 years) and 38 elderly (63–80 years) men voluntarily participated in this study. The means and standard deviations (SD) in age, height, and body mass were 24.3 (3.4) years, 172.7 (5.4) cm, and 67.2 (9.9) kg, respectively, for the young, and 69.4 (5.0) years, 162.2 (5.8) cm, and 61.7 (7.3) kg, respectively, for the elderly group. The height and body mass of each subject were within the normal range of the corresponding age group in Japanese men. None of the subjects was or had been an athlete. Moreover, none were using sticks or other walking aids and all were functionally independent in daily life. Again, each subject was required to obtain medical clearance prior to testing and therefore could be characterized as healthy and free from any condition that might affect the test results. This study was approved by the Office of the Department of Sports Sciences, University of Tokyo and was consistent with their requirements for human experimentation. The subjects were fully informed about the procedures to be used as well as the purpose of the study. Written informed consent was obtained from all the subjects.

Test procedures

The subjects performed both the torque and power tests on the same day. Firstly, the torque test was executed. After the completion of the torque test and a rest (more than 60 min), the subjects performed the walking and running power tests.

Measurements of knee extension and flexion torque

The torque output during maximal voluntary isometric knee extension and flexion were determined using an isometric torque measurement system (KND-005, Vine, Japan). To standardize the measurements and localize the action to the appropriate muscle group, the subject sat on an adjustable chair with support for the hips and back. The right ankle of the subject was fixed to the lever of the dynamometer with a knee joint angle of 90 deg (full extension = 0 deg). The rotation axis of the knee joints was aligned with that of the lever arm of the dynamometer. During torque measurements, the hips and back of the subject were held tightly in the seat using adjustable lap belts.

Before maximal testing the subjects were asked to exert submaximal force isometrically at the test position to familiarize them with the test procedure. After a warm-up, the subjects were encouraged to perform maximal knee extensions. After completion of the knee extension task and a 3-min rest, the subjects performed maximal knee flexions. In each of the two tasks, the subjects were asked to exert maximal force two times with a rest period of 30 s between trials. The torque produced was recorded continuously, and the peak value of the torque curve was accepted as torque in a given trial. The subject who produced a higher torque in the second trial than in the first trial was asked to perform the third maximal contraction. For each of the knee extension and flexion tasks, the highest value among these trials was used for the subsequent analysis.

Measurements of walking and running power

A non-motorized treadmill ergometry (Funato et al 2001) was used to measure mechanical power developed during maximal walking and running. A schematic description of the apparatus and data acquisition system has been given in a prior study (Funato et al 2001). The ergometer was equipped with two force transducers (TR2001, Kyowa, Japan), mounted on the handlebar in order to detect the horizontal pushing force developed by the subject's hands during locomotion on the belt, and a pulse generator attached to the flywheel to detect the revolution speed of the flywheel. During the test, the subject gripped the handlebar in front keeping both arms straight and horizontal. The height of the handlebar was adjusted to the height of the horizontally straightened arms when each subject performed on the belt. Electrical signals from the force transducers and pulse generator were amplified and fed into a personal computer (Macintosh PowerBook G3/233, Apple) via an A/D converter (MacLab/16sp, AD Instruments, Australia) at a rate of 200 Hz. The pulses produced by the pulse generator were converted to the displacement of the belt by multiplying by a predetermined conversion factor. The instantaneous velocity of the belt was determined by differentiating the horizontal displacement of the belt. The horizontal pushing force and belt velocity were considered to represent the propulsive force and velocity, respectively (Funato et al. 2001). Multiplying the instantaneous velocity and propulsive force gave the instantaneous mechanical power in every step (Fig. 1). In this study, the mean values of mechanical power in a period of time covering six steps, in which the belt velocity peaked and remained almost at a plateau during maximal walking and running, were calculated as representative scores of performances in the two maximal exercises, and defined as walking power and running power, respectively. The validity of the power measurements by this ergometer was certified in a prior study (Funato et al. 2001). Further, walking power and running power were negatively correlated to the time taken to walk 10 m ($r = -0.820$, $P < 0.05$) and run 50 m ($r = -0.683$, $P < 0.05$) with maximal effort, respectively, as the results of a preliminary study in which ten young men were examined.

Prior to the test, the subjects had a warm-up session of about 5 min, which consisted of several stretching exercises, and walking at a comfortable speed and running with submaximal effort on the ergometer to familiarize themselves with the apparatus. After the completion of the warm-up exercise and a rest (more than 5 min), the subjects performed firstly the walking test and secondly the running test for about 7 s, two times each. In each task, the subject started to walk or run from a standing position and accelerated as fast as possible. During the test, the subjects could monitor the belt velocity shown on a digital counter set in front of them. First, the walking sessions were completed. A rest period of 5 min was taken

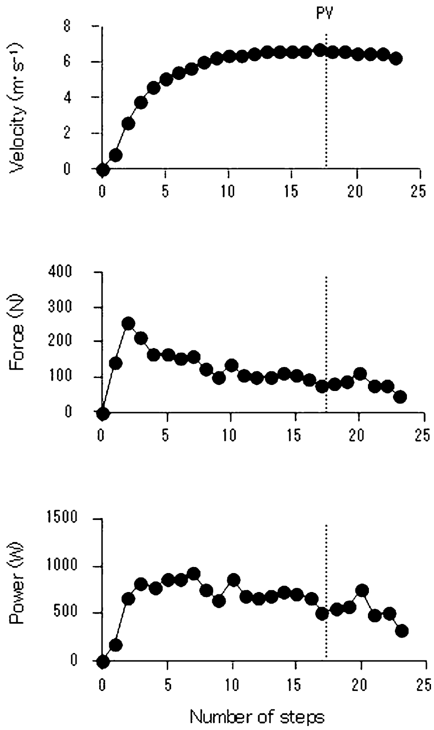

Fig. 1 Typical example of the belt velocity of the ergometer (*upper panel*), the horizontal pushing force on the handlebar (*middle panel*), and the mechanical power (*lower panel*) developed at every step during 7 s maximal sprint running. *PV* The step where the belt velocity peaked

between the two trials in each of the exercise tasks and between the walking and running sessions. The higher value in the two trials was taken as a representative score in both walking power and running power.

Repeatability of torque and power measurements

The repeatability of each of the torque and power measurements was tested on 2 separate days in a pilot study examining eight women and seven men. The intraclass correlation coefficient for the test–retest was $r=0.926$ for knee extension torque, $r=0.961$ for knee flexion torque, $r=0.941$ for running power, and $r=0.872$ for walking power. The mean value of the coefficient of variation of the two measurements for each score was 6.6% for knee extension torque, 6.4% for knee flexion torque, 6.8% for running power, and 6.8% for walking power. There was no significant difference between the mean values of the two tests in each of the four scores.

Table 1 Descriptive data on the measured variables. Values are means (SD). *KET* Knee extension torque relative to body mass, *KFT* knee flexion torque relative to body mass, *WP* walking power relative to body mass, *RP* running power relative to body mass. *Relative difference (%)* The percentage of the difference between the two age groups relative to the mean value for the young

Variables	Young $n=50$	Elderly $n=38$	Relative difference (%)
KET (Nm kg^{-1})	2.5 (0.5)	1.7 (0.5)	32.0*
KFT (Nm kg^{-1})	1.6 (0.4)	0.9 (0.3)	43.8*
WP (W kg^{-1})	1.4 (0.3)	1.1 (0.3)	21.4*
RP (W kg^{-1})	4.7 (1.5)	1.8 (0.7)	61.7*

*$P<0.05$

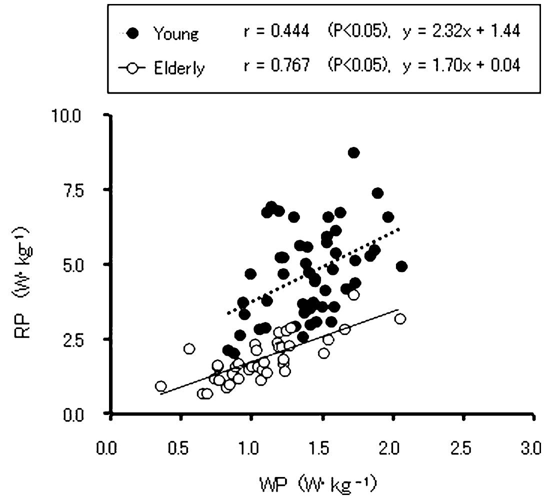

Fig. 2 Relationship between walking power (*WP*) and running power (*RP*). WP and RP are expressed relative to body mass

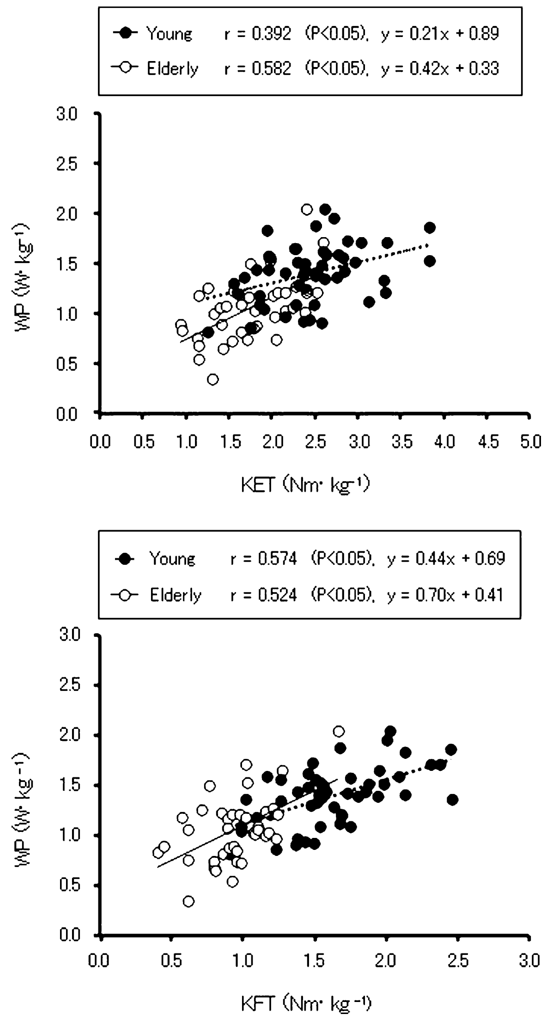

Fig. 3 Relationships between knee extension (*KET*, *upper panel*) and flexion (*KFT*, *lower panel*) torques and WP. The torque and power are expressed relative to body mass

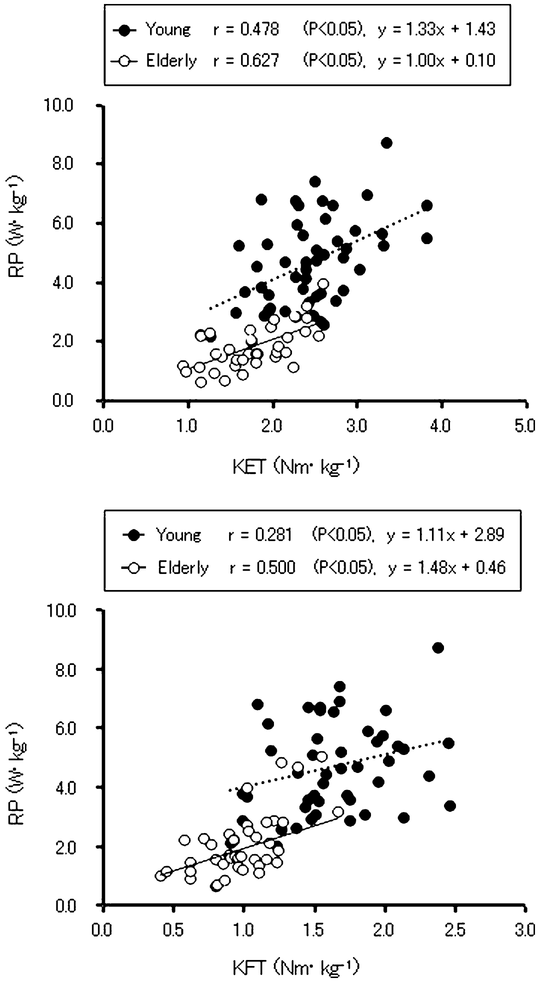

Fig. 4 Relationships between KET (*upper panel*) and KFT (*lower panel*) torques and RP. The torque and power are expressed relative to body mass

Statistical analyses

Descriptive data are presented as the mean and SD for each age group. The knee extension torque, knee flexion torque, walking power, and running power are expressed as values relative to body mass and referred to as KET, KFT, WP, and RP, respectively. The difference between the mean values of the two age groups was expressed as a percentage of the mean value for the young. Student's *t*-test was used to test the significance between the means of the two age groups. A simple linear regression analysis was used to calculate the correlation coefficients between WP and RP, and between KET or KFT and both WP and RP. In addition, when a significant correlation was found between the variables mentioned above in the young and elderly, an analysis of covariance (ANCOVA) was applied to test the difference between the two age groups in the dependent variable adjusted by the independent variable. Statistical significance was set at $P < 0.05$.

Results

Descriptive data on KET, KFT, WP, and RP are shown in Table 1. The young group showed significantly higher values than the elderly group for all variables. The relative difference was greater for RP than the other variables.

In each of the young and elderly groups, a significant correlation was found between WP and RP (Fig. 2). In this relationship, most of the RP values for the young group distributed above the regression line between WP and RP for the elderly group. An analysis on the regression line showed that, although the slope was similar in the two groups, RP adjusted by WP was significantly higher in the young (4.4 W kg^{-1}) than in the elderly group (2.5 W kg^{-1}).

In the two groups, WP was significantly ($P < 0.05$) correlated to KET ($r = 0.582$ for the elderly and $r = 0.392$ for the young) and KFT ($r = 0.524$ for the elderly and $r = 0.574$ for the young) (Fig. 3). Similarly, RP was also significantly ($P < 0.05$) correlated to KET ($r = 0.627$ for the elderly and $r = 0.478$ for the young) and KFT ($r = 0.500$ for the elderly and $r = 0.281$ for the young) (Fig. 4). There were no significant differences between the two groups in the slopes of the regression lines for the relationships between torque and both WP and RP. In the results of ANCOVA, no significant differences were found between the age groups in the WP adjusted by KET (1.3 W kg^{-1} for the young and 1.2 W kg^{-1} for the elderly) and KFT (1.3 W kg^{-1} for the young and 1.3 W kg^{-1} for the elderly). However, significant age-related differences still remained in the RP adjusted by KET (4.4 W kg^{-1} for the young and 2.2 W kg^{-1} for the elderly) and KFT (4.4 W kg^{-1} for the young and 2.3 W kg^{-1} for the elderly).

Discussion

This study is the first to assess ergometrically the age-related differences in mechanical power during the movement forms of maximal walking and running. The major results here were that: (1) the age-related difference in mechanical power during running movement (RP) was greater than that in walking movement (WP) and that in the isometric torque of the thigh muscles, (2) WP and RP were significantly correlated to the thigh muscle torques in both the young and elderly, and (3) RP was significantly greater in the young than in the elderly even if the thigh muscle torque was the same regardless of age.

Before interpreting the findings, we should comment on the mechanical power determined here. The mean RP for the young group (4.7 W kg^{-1}) was considerably lower than the values reported in prior studies in which the mechanical power during short-term maximal running on a non-motorized treadmill was determined by detecting the pulling force exerted by subjects (Brooks et al.1988; Cheetham et al. 1986; Falk et al.1996; Gaitanos et al. 1991; Greenhaff et al. 1994). For example, Greenhaff et al. (1994) reported a peak power and a mean power relative to body mass of 12.4 W kg^{-1} and 7.7 W kg^{-1}, respectively, for young men, during maximal running on a non-motorized treadmill. The exercise task used in the present study lacked arm movements, because both arms were straightened in a horizontal position to push the handlebar. This may partially explain the lower mechanical power determined here as compared to previous reports. In addition, the difference in the calculation of mechanical power between the present study and previous studies should be considered to explain the lower value determined here for maximal running. The studies cited above accepted either a peak value in the first few steps or a mean value during the acceleration phase as a representative value during maximal running. On the other hand, we defined mechanical power as that during a phase in which the belt velocity peaked and more or less maintained a plateau during maximal walking or running. As shown in Fig. 1, the mechanical power in each step was greater up until the velocity reached a maximum, i.e., in the acceleration phase, than in the latter phase in which RP was calculated in this study. However, the variations in the force and velocity components were greater in the acceleration phase than the latter phase. Moreover, we desired to assess the power generation capability corresponding to that in which the maximum velocities of either walking or running on the ground were developed. Therefore, the phase of the maximal velocity in which the belt velocity peaked and then kept almost the plateau was selected to calculate the mechanical power as representative of the ergometric performance.

Although there was a difference in the procedure of the power determination as mentioned above, the present result that the relative difference between the two groups was greater for RP than KET or KFT is consistent with the findings of previous studies, which compared age-related changes of isometric muscle strength and mechanical power developed during explosive single and/or short-term maximal exercises (Bassey et al. 1992; Metter et al.1997; Skelton et al.1994; Young and Skelton 1994). Further, the observed relative difference between the young and elderly groups in RP (61.7%) is comparable to that in reported previous studies in which mechanical power during running up stairs (Margaria et al. 1966) or maximal jumping (Bosco and Komi 1980) was determined in the male subjects of similar ages to those in this study. For example, Margaria et al. (1966), who developed a power test in which the subjects run up stairs at maximal speed, reported that the mechanical power relative to body mass for the subjects of 70 years of age was less than half that for young subjects aged 20–30 years. In addition, Bosco and Komi (1980) indicated that the relative difference between subjects of 24 and 73 years of age in mechanical power relative to body mass during maximal squatting jump on a force platform was about 70%. Considering these findings, therefore, it is reasonable to assume that the relative difference observed between the young and elderly in RP represents the age-related reduction in the power generation capability during a short-term maximal exercise using the whole body, even if its absolute value is lower than those reported in previous studies using a non-motorized treadmill.

WP was significantly correlated to KET and KFT in not only the elderly group but also young group, without significant differences between the two groups in the slopes of the regression lines. For elderly individuals, it is well documented that there is a positive association between the ability of the lower limb muscles to generate force or power and maximal walking speed (Bassey et al. 1992; Kwon et al. 2001; Ploutz-Snyder et al. 2002; Rantenen and Avela 1997; Rantenen et al. 1998). However, the relationship between muscle strength and maximal walking speed is not linear, in which beyond a certain threshold level an increase in strength does not improve maximal walking speed (Kwon et al. 2001; Rantanen et al. 1998). Therefore, it was expected that a positive correlation between torque and WP would be found in the elderly group only, especially only in the persons with a lower torque. However, the present result differs from this. In addition to the similarity in the slopes of the regression lines, no significant differences between the young and elderly in the WP adjusted by either KET or KFT suggest that the torque generation capability of the thigh muscles influences WP in both the age groups in almost the same manner.

There are two possible reasons for why the torque generation capability of the thigh muscles was associated with WP in both the young and elderly groups. The first is that, in the exercise modes used in this study, the lack of arm movements would increase the contribution of the thigh muscle force to mechanical power during maximal walking regardless of age. The second is that, because power consists of the two components of force and speed, WP might be more closely associated with the thigh muscle torque beyond the expectation from previous findings on the relationship between muscle strength and maximal walking speed. Even if these points are valid, however, the reason for the observed similarity between the two groups in the regression lines for the relationships between torque and WP remains a question. In the present results, the relative difference between the two age groups in WP (21.4%) was lower than that in torque (32% for KET and 43.7% for KFT). It is known that, although resistance training improves maximal walking speed in the elderly, the magnitude of the effect is generally lower than that in muscle strength (Fiatarone et al. 1990; Judge et al. 1993; Schlicht et al. 2001; Sipilä et al.1996), suggesting that the change in maximal walking speed with strength increase is not so sensitive. Taking this point into account together with the relative difference in each of the measured variables, therefore, it seems that the age-related difference in torque would be sufficiently great to explain that in WP.

Significant correlation was found between WP and RP in each of the young and elderly groups. Further, RP was also significantly correlated to KET and KFT in both the two groups, without significant age-related differences in the slopes of the regression lines. In these relationships, however, most of the RP values for the young individuals distributed above the regression line for the elderly group and so RP adjusted by either WP or the thigh muscle torque were significantly greater in the young than in the elderly. As an explanation for the greater age-related loss in power during explosive and/or rapid movements, changes in muscle fiber composition and neuromuscular function, which are associated with the reduction in the rate of force development, have been considered (Bassey et al. 1992; Bonnefoy et al. 1998; Bosco and Komi 1980; Izquierdo et al. 1999). This explanation may be applicable to the observed greater age-related difference in RP, being independent of the differences in the thigh muscle torques. In addition, although the elderly subject of this study were considered as healthy and free from any condition that affect the test results, we cannot exclude that they have been more cautious during maximal running what might have produced different patterns and/or levels of the activities of the exercising muscles in them from those in the young group, and consequently contributed to the age-related difference in RP. Unfortunately, we have no data to certify the points mentioned above. Further study needs to clarify factors explaining the greater age-related reduction in RP than in torque as well as WP.

In summary, the findings here indicate that: (1) the age-related difference in mechanical power is greater during maximal running than maximal walking, and (2) although the thigh muscle torque contributes to the power production during the two maximal exercise modes in the two age groups, the maximal RP is greater in the young than in the elderly regardless of the difference in the thigh muscle torque.

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