Sensors and Materials, Vol. 28, No. 4 (2016) 379–388
MYU Tokyo

S & M 1188

Vital-Sign Characteristics of an Elderly Person during Walking

Takashi Oyabu,* Yusuke Kajiwara,[1] and Haruhiko Kimura[2]

Kokusai Business Gakuin College, 6-12 Minami-cho, Kanazawa 920-0919, Japan
[1]College of Information Science and Engineering, Ritsumeikan University,
Noji-higashi, Kusatsu, Shiga 525-8577, Japan
[2]Graduate School of Natural Science and Technology, Kanazawa University,
Kakuma, Kanazawa 920-1192, Japan

(Received Novermber 2, 2015; accepted January 25, 2016)

Keywords: elderly, health maintenance, walking, vital sign, pedometer

The needs of older workers are increasing with the advancement of the aging society, and their health consciousness is also rising. Walking is a useful way of maintaining health and wellness in the elderly. Walking is also carried out in tours at tourist sites. It leads to health maintenance and the improvement of the willingness to work as well as satisfying the thirst for knowledge at a visited site. The limit of number of steps should be understood accurately at that time. The number is derived from data measured over one year in this study. The subject was a 65 year-old male. The limit in the number of steps was about 12000 based on this experiment. He plays tennis one or twice a week and is in relatively good health. A walking experiment was carried out in a good viewing location, and data such as vital signs were collected. The experiment was carried out within the limit of step number. It was found that there was a strong correlation between the number of steps and the amount of physical exertion. The mood grade of the subject decreased after over an hour, and he became a bit tired of walking. It is suggested that walking for about 90 min is appropriate for a cheerful older person.

1. Introduction

The aging of the population and declining birthrates are progressing in Japan. The population of Japan peaked in 2006 and is currently decreasing. Therefore, the industrial structure is changing with the progress of the aging society, and the number of aged persons who are willing to work hard is increasing. The number of female workers is also increasing.(1) It is necessary to utilize highly experienced elderly persons and female employees in Japan. However, it is also necessary to improve the work environment for the workers at the same time, particularly with flexible work hours. Policies under which the elderly could work to maintain their health are necessary, especially in local municipalities. An employment form that considers work life balance is required in an aging society.(2) Namely, it is necessary for the elderly to promote travel and fitness without accumulating excessive stress.(3) This will lead to a refreshing change in mood. Walking is essential on trips and satisfies their need for diversion.(4) It is also an aerobic exercise and heightens one's physical strength.(5) The following effects could be expected by walking continuously,

*Corresponding author: e-mail: oyabu24@gmail.com

ISSN 0914-4935

namely brain cell activation, fat burning, and increasing bone density. In particular, it contributes to the health maintenance of the elderly and is effective in an aging society. Walking in a sightseeing spot satisfies one's intellectual curiosity and the person can gently refresh. It has a synergistic effect in addition to the fitness effect. Walking is a basic behavior in a sightseeing spot. Of course, trains and automobiles are often used during trips. Daily exercise (walking) is essential to enjoy one's trip. It is necessary to establish the lifestyle of walking. In recent years, there have been many elderly who travel long distances.

Sightseeing makes the elderly energetic.[6] Some of them have a higher intellectual curiosity than young people, and they are visiting various places all over the world. However, it is necessary to consider the limit of one's physical abilities, namely, understanding the maximum number of steps at all times. It is important to plan an itinerary within the individual's proper number of steps. Namely, it is important to determine one's limiting number of steps (step number). An unreasonable schedule is sometimes planned according to the time restrictions of a trip, and the limit of step number of the aged is often exceeded. Moreover, it affects the future schedule of the trip. The schedule should be matched to the most physically weak person in a tour group.[7] It is particularly important to understand the limits of step number and walking time of the tour participants.

It is necessary to verify the change in some vital signs when senior citizens are walking, and they should walk reasonably fast on the basis of the measured data. Namely, it is necessary to understand the proper step number matched to each person, and the number depends on an individual's physical fitness.[8] It is also affected by the individual's lifestyle. The personal characteristic of a step number should be measured over a long period. The daily vital signs and step number of a subject were recorded for more than a year in this study. As a result, it was determined that the maximum number of steps for the subject on a trip is about 12000. The vital signs were investigated during walking within the step number. How the subject feels is also important in addition to the vital signs during walking. If the subject feels physical and mental discomfort during walking, it is better to stop the walking for health maintenance. In this study, the subject had discomfort after about one hour. Blood pressure and pulse rate are important for the elderly during exercise. The normal values of both should also be understood.[9]

2. Experimental

In 2015, the number of elderly individuals was about 33 million (it is about 26% of the total population) in Japan, and about 6.5 million (20%) of them are employed. There are many elderly persons who have the desire to work.[10] It is necessary to increase that number when we consider healthy life-extending effects and the aging society. Because of that, a lifestyle that maintains the healthy condition of an elderly person should be considered. Moreover, it has to be matched with the individual's lifestyle. Walking is the simplest moderate exercise to stay in good health for the elderly. Walking while looking at a beautiful scenery and a historical heritage site can satisfy one's intellectual curiosity and is more preferable than a bus tour. The following items may be cited as the effects of walking.[11]

(1) Psychological effect (change of mood, relaxing effect, brain cell activation)
(2) Physical effect (increase of blood flow, decrease in cholesterol levels, fat burning, increase in the amount of muscle, increase in bone density)

A healthy 65-year-old male was the subject of this study and various vital signs were measured while he walked along a place of scenic beauty. Long term measurement was carried out

beforehand to derive the average and maximum step number over 14 months. Strictly speaking, vital signs include blood pressure, pulse rate, breathing rate, and body temperature as numerical values, which show the condition of being alive. However, other signs and factors are adopted as vital signs in this investigation. Those signs are measured using the devices listed below. Some of the measured values are analyzed. Step number was measured using two different pedometers, namely, instruments (3) and (4). The mood (feeling) grade of the subject was indicated on a scale of one to five in the experiment. Five means "fantastic" and one is "the worst". The experiment was carried out on September 14, 2014. The weather was fine at that time.

(1) TANITA: Tn-Link, BC-503
body weight, body fat, basal metabolism, body age, muscle mass, muscle score, visceral fat level, estimated bone mass

(2) TANITA: Tn-Link, BP-301
maximum blood pressure, minimum blood pressure, pulse

(3) TANITA: Tn-Link, FB-723
number of steps

(4) OMRON: CaloriScan HJA-401F
physical activity, total consumption amount, number of steps

(5) Others
weather, maximum temperature, minimum temperature, atmospheric pressure, mood (feeling) grade

The experiment was carried out as follows. The subject walked for 15 min and he took a break for 5 min. This cycle is called one unit. Six units were measured in total in this experiment. The total walking time was 90 min, and the total break time (including measurement time) was 30 min (each break was 5 min). The experiment was finished in 2 h. The subject was feeling slightly refreshed in the early four units (mood grade is 4) and felt "normal" in the latter two units (mood grade is 3). He felt tired of walking and lost interest, and the exhilarated feeling diminished as a result. The mood grade decreased when he walked further. The number of steps was about twelve thousands for the weekend. It is desirable to carry out the experiment within the six units. The experimental process is shown in Fig. 1. The walking course was in Utatsu-yama (a small mountain), which is located in Kanazawa City, Japan. The course is somewhat up and down and the view from the course is superb. Senior citizens are found walking repeatedly on this course. The start and goal are the same point where the elevation is about 110 m. The maximum height is 127 m and the minimum is 22 m on the course. The difference in elevation is 105 m.

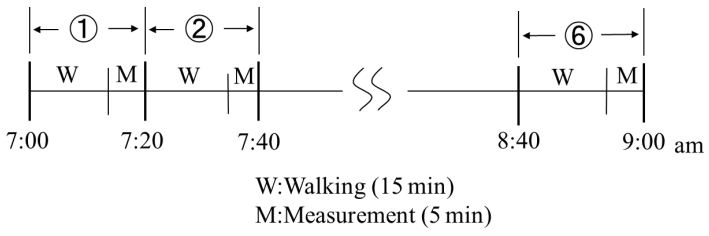

Fig. 1. Experimental process in walking.

3. Results and Discussion

There is a limit in the amount of exercise for every individual, and it is necessary to consider that the number of steps (or step number, henceforth) does not exceed over the limit. In particular, it is necessary to ensure that the person does not exceed the step number.[12] Each individual should understand the usual step number and avoid exceeding the limit. For a year and two months, the vital signs of the subject were recorded before going to bed. It was confirmed that the subject felt considerably tired following a day when he walked over 15000 steps. Over-exercise is a source of muscle pain, and lactic acid is produced in the muscle. The elderly require care for the pain. The experiment was carried out within 12000 steps in consideration of his physical strength, and the total step number was 10746 in the experiment, which was measured using a commercially available pedometer (TANITA Tn-Link). The average number of steps per unit is 1791 (about 120 steps/min). The step size is 0.74 to 0.79 m and becomes longer when he walks quickly.

3.1 Long-term vital signs and characteristics of the step number

The average (*av*) and standard deviation (σ) of the primary vital signs for 14 months (July 2013 to August 2014) are indicated in Table 1. The step number in September 2014 is shown in Fig. 2. This experiment was carried out on September 14, 2014. The *av* for the month is 9866 and σ is 3212.7. The coefficient of variation (σ/av) is 0.3256. This value is relatively small; the total step number (10746) in this experiment is scientifically correct.

Table 1
Average and standard deviation of weight, fat, basal metabolism, muscle mass, and steps of the subject for 14 months.

	Weight (kg)	Fat (%)	Metabolism (kcal)	Muscle mass (kg)	Steps
av	66.5	20.0	1439.4	50.4	8431.1
σ	0.6	0.8	19.4	0.7	3043.4

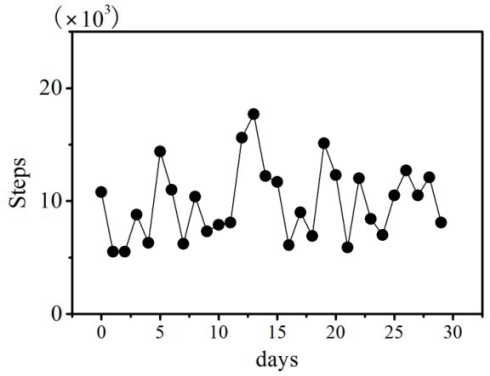

Fig. 2. Step numbers in September 2014.

3.2 Muscle mass for long-term measurement

The muscle mass of the subject increased gradually by walking every day. Muscle is heavier than fat. The average basal metabolism and muscle amount for 14 months are indicated in Fig. 3. Both characteristics have a similar tendency and the correlation coefficient (r) is 0.99. It is considered that the algorithms of the measurement apparatuses interact mutually and affect the characteristics strongly in deriving each value. The average step number is shown similarly in Fig. 4. There is no correlation between the step number and the muscle mass (r = 0.2). It cannot be considered that the muscle mass increases immediately as the step number increases. It is considered that the step number affects the muscle mass after one or two months. Therefore, the correlation between both characteristics is derived when the step characteristic is shifted toward "future". The result is shown in Fig. 5. The step characteristic affects the muscle characteristic after two months. The maximum correlation coefficient is 0.6. It can be said that there is a correlation between both characteristics when the step characteristic is shifted, namely, the increase and decrease in muscle mass due to walking is delayed by about two months.

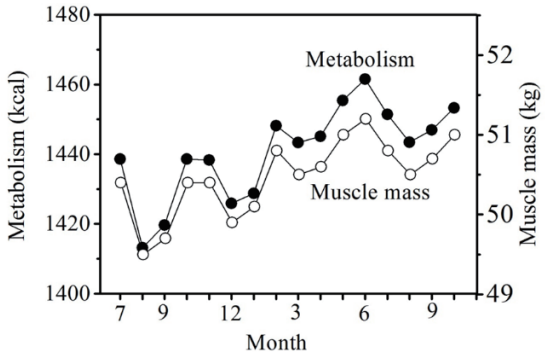

Fig. 3. Averages of metabolism and muscle mass for each month.

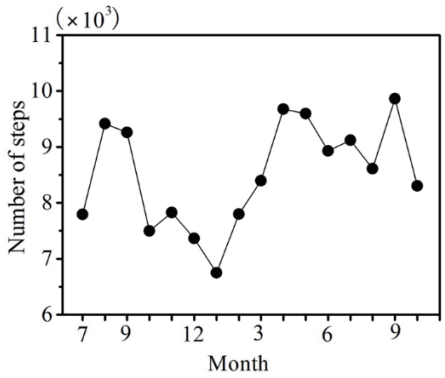

Fig. 4. Average step numbers for each month.

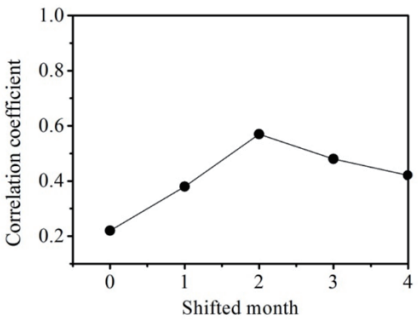

Fig. 5. Correlation coefficient of muscle mass and step number when the step characteristic is shifted rightward in Fig. 4.

3.3 Step number characteristic

Moderate physical activity is important for maintaining health, and the range (especially limit) of the exercise should be understood. When the exercise limit is passed, a physical disability may be induced and the person may die. There is a possibility that the average lifespan of professional sports players is generally short owing to excessive movement. A suitable amount of exercise corresponding to age and individual differences should be understood, and it is said that light exercise is good for elderly health, for example, jogging and walking.[13] The maximum step number (msn) was about 15000 in the long term experiment covering 14 months. It was determined that the maximum step number was 12000 (0.8 × msn) in this study, and the experiment was carried out within the step number. The msn varies according to individuals. It is desirable to have a heart rate meter (maximum heart beat is about 120) while walking. The experimental walking course had some ups and downs. The total step number was 10746 and total walking time was 90 min (about 120 steps/min). The step number for each unit is indicated in Fig. 6. The steps for each unit are nearly constant, and they fluctuate according to the landscape and course slope. The cumulated distribution is shown in Fig. 7. It is understood that the subject walked at a uniform speed as the characteristic linearly changes.

3.4 Vital signs during walking

Each vital sign fluctuates depending on the psychological and physical conditions of the subject. It is important that these values are grasped from everyday life, and the abnormal condition as well as the overloaded state should be detected. Walking contributes to health maintenance, but excessive walking causes physical fatigue and physical damage. The estimated average step number during the experimental period was adopted in this investigation, and it was carried out to prevent overloading of the subject's physical or mental capacity.

The maximum and minimum blood pressures are also measured for every experimental unit. The blood pressure is affected by mental condition and physical exercise. These pressures were measured around the end of the break (the period was 5 min). The characteristics are shown

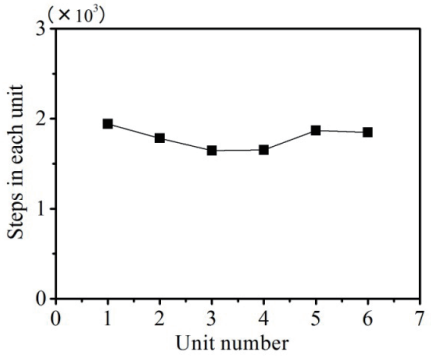

Fig. 6. Step number in each experimental unit.

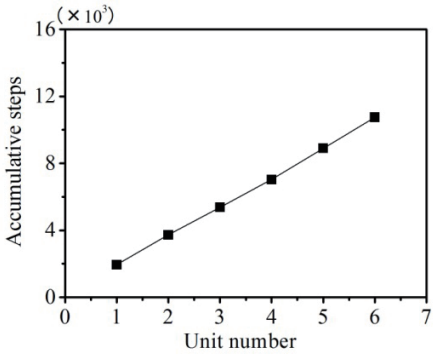

Fig. 7. Cumulative step number as a function of unit number.

in Fig. 8. Both pressure characteristics increased at the early stage (in the morning), decreased temporarily, and increased again. The characteristics are similar. The subject walked toward to a higher elevation for the first time and went toward a low-altitude point. It is considered that his physical loading increased and the pressure increased. The temperature during the experiment was 18 to 22.2 °C and humidity was 65 to 90% RH (near a river in a wooded area, the temperature was 19 °C).

Pulse pressure (= maximum pressure − minimum pressure) is also an important factor. It is said that the upper limit is about 60 mmHg. The risk for cardiac infarction and apoplexy increases when the pressure exceeds this limit. The pulse pressure in the experiment is shown in Fig. 9. The value was 63 mmHg at the end of the experiment. There was a risk of heart failure. The pressure was low (31 mmHg) when the altitude was low in this experiment, and conditions were low temperature and high humidity (19 °C and 90% RH) at that point. In addition, it is necessary to determine the mean blood pressure (arteriosclerosis degree index of peripheral blood vessel; it should preferably be 100 mmHg or lower). The value becomes higher during walking. It is said that pulse pressure is related to thick blood vessels which causes arteriosclerosis and that the mean blood pressure is related to thin blood vessels. It is important to consider one's chronic diseases when designing a walking course.

3.5 Amount of body fat and muscle

There are two types of body fat, namely, offal fat (most common in men) and subcutaneous fat (most common in women). Walking is an aerobic exercise and the amount of offal fat decreases depending on the amount of exercise. It is necessary to decrease the amount of fat, which is strongly correlated to lifestyle diseases. Muscle is important to promote fat combustion; consequently, the elderly should develop muscle mass and lower the amount of offal body fat by walking. The amount of body fat decreases and muscle mass increases after two months of walking. There is a fluctuating mass of several grams per day depending on the exercise, and the tendency is shown in the measurement data. The tendency depends on deriving the algorithm of

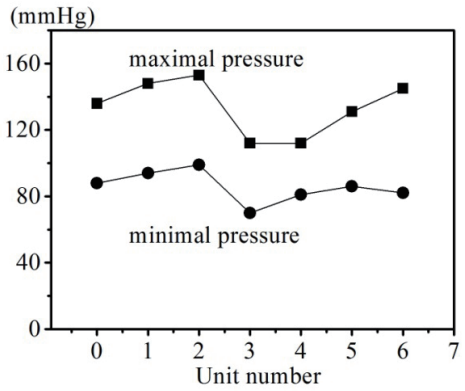

Fig. 8. Maximum and minimum pressures during walking.

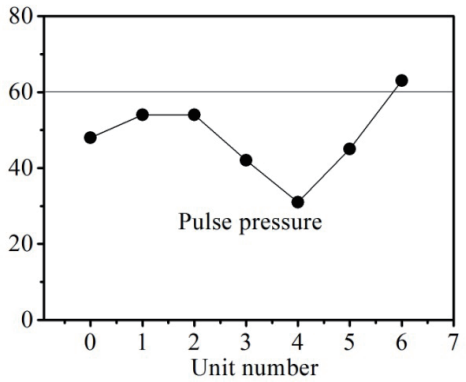

Fig. 9. Pulse pressure during walking.

the measuring apparatus and it is also affected by the subject's sweat and blood flows. The body fat characteristic is shown in Fig. 10. Body age is also indicated in the figure. The age is introduced statistically according to each body composition of the subject by the measuring apparatus. The age that was indicated by the measuring apparatus was 44 when he woke up, but the apparatus showed 39 years old at the end of the experiment. The apparatus indicates a younger age after walking.

Muscle mass is indicated in Fig. 11. It increases as a function of unit number in the experiment. This characteristic tends to increase; however, it is not considered that muscle mass increases in a short time. Bone quantity is also measured and the result is shown in Fig. 12. The value does not fluctuate considerably and is 2.7 or 2.8.

The values (body fat, biological age, muscle mass, and bone quantity) were also measured as a control experiment when the subject was just sitting and not doing anything after rising. Those values were almost constant.

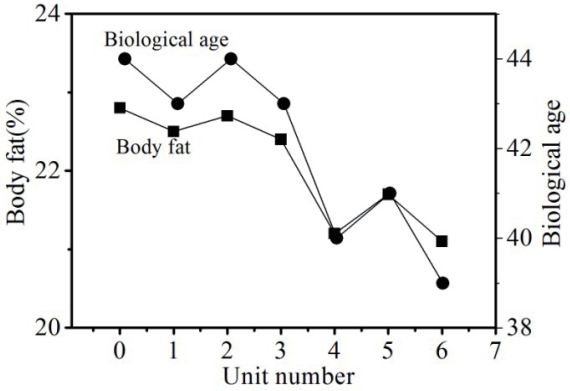

Fig. 10. Body fat and biological age determined by the adopted apparatus.

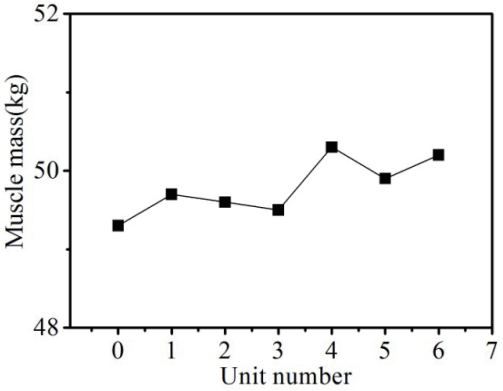

Fig. 11. Muscle mass.

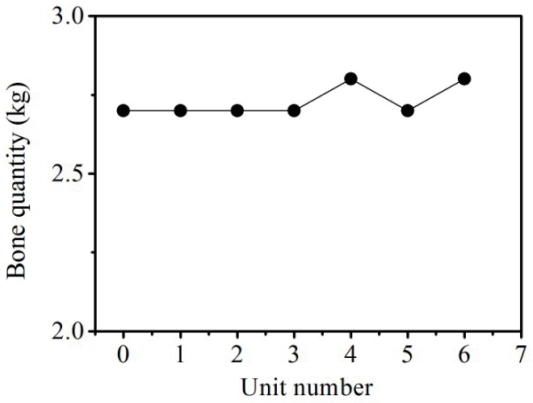

Fig. 12. Fluctuation of bone quantity during walking.

3.6 Mood grade

The mood grade of the subject is also recorded for every experimental unit on a scale of one to five (five means "refreshing").[14] The result is shown in Fig. 13. It was third grade ("average") at the start of this experiment (immediately on rising) and was "slightly refreshing" at unit numbers 1 to 4, namely, he felt better for 60 min after starting to walk. Most people feel good when they look at beautiful scenery but lose the interest after 1 h. It was grade "3" at units 5 and 6. The subject felt slightly bad (mood grade = 2) after walking further and was not able to enjoy the scenery. The subject walked 7028 steps (117 steps/min) in units 1 to 4. The interval is good for the subject. The total number of steps was 3,718 in units 5 and 6 (124 steps/min). The speed was somewhat fast because the goal was near. Walking is good for our health but it is not necessary to perform it forcibly. It is generally better for the cheerful elderly to walk about 6000 to 8000 steps per day.

There is a possibility for the grade to differ for every individual at morning and night. The mood grade was recorded at both hours of rising and bedtime in September 2015. Both grades differed by only one day. It is considered that the elderly's mood does not change frequently. Mood grade "3" at both rising and bedtime was observed for 27 d. Both grades were "2" in only one day and those were "4" also in only one day. In this study, the grade changed after 1 h despite the above result. It is considered that 1 h is a limit for walking continuously and comfortably.

3.7 Amount of physical exertion and total Calorie consumption

Another apparatus (OMRON: CaloriScan HJA-401F) was also used in this experiment for measuring the amount of physical exertion (kcal) and total Calories consumed (kcal) in addition to the number of steps. The amount of physical exertion is estimated as the consumption of Calories by walking and deskwork. Total Calories consumed is determined by adding the amount of physical exertion and the basal metabolic rate. The former is increased by exercising, for example, walking. Walking is fundamental in all movements. The correlation between the number of steps and the amount is shown in Fig. 14. The correlation coefficient (R) is 0.86. It is very high, namely, the amount of physical exertion could be estimated on the basis of the step number. The figure is introduced using the data obtained for 45 d including the experimental month.

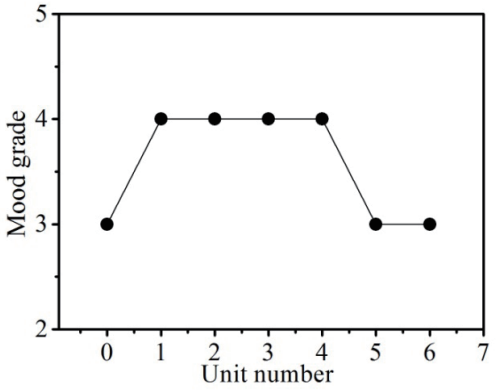

Fig. 13. Fluctuation of mood grade.

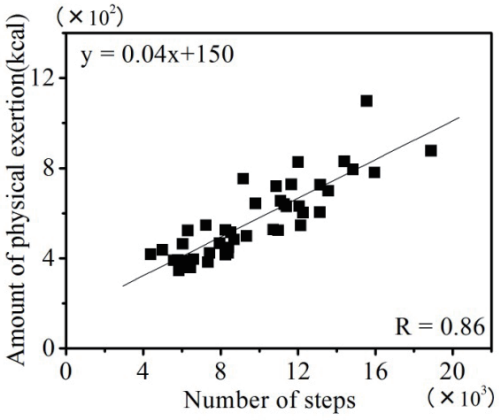

Fig. 14. Correlation among steps and amount of physical exertion.

4. Conclusions

Walking is an effective exercise for the elderly to maintain their health. They are willing to work hard and sometimes go on a journey if they are cheerful. However, it is necessary to understand the limit of each individual to engage in work. Continuous walking maintains one's muscle mass. The subjective limit of step number was derived on the basis of measurements obtained over one year in this experiment, and a walking experiment was carried out within the limit. Measurements were performed every 15 min.

It became obvious that the limit of the subject was about 12000 steps per day, which is derived from the data obtained over one year. Body fat and body age decreased by walking continuously. The period that the subject could walk comfortably was about 1 h. The number of steps and the amount of physical exertion are related. The amount can be estimated on the basis of the step number. Muscle mass is affected by walking characteristics. The effect on muscle mass appears after about two months.

It is necessary to verify the accuracy of the apparatuses that can measure vital signs. The elderly prefer an apparatus that is inexpensive and almost correct rather than one that has high accuracy but is expensive. Of course, it should be user-friendly and easy to manipulate.

Acknowledgements

The authors are grateful to Mr. Shinzo Ishigami (Mitene Internet Co., Ltd.) and Mr. Go Hishinuma (TANITA Health Link Inc.) for their helpful discussion and support.

References

1 Cabinet Office of Japan: White paper on aging society 2014 (Nikkei-insatsu, Tokyo, 2015).
2 Ministry of Health, Labour and Welfare: Annual Health, Labour and Welfare Report 2014 (Nikkei-insatsu, Tokyo, 2015).
3 R. Yoshida: Life Skills and Fitness (Iwanami-shoten, Tokyo, 2013).
4 S. Mori and N. Mori: Walking Res. **17** (2013) 43 (in Japanese).
5 M. Miura, K. Inn, and T. Miura: Walking Res. **16** (2012) 53 (in Japanese).
6 Santho-sya: Spare time and Leisure & General Sightseeing Statistics 2014–2015 (Santho-sya, Tokyo, 2013).
7 Y. Tanaka: Support guidebook on going out of the elderly (Chuohoki Publishing, Tokyo, 2007).
8 T. Izumi: Walking method recommending by a doctor (Syueisya, Tokyo, 2005).
9 T. Oyabu, S. Ishigami, G. Hishinuma, and H. Kimura: Technical Meeting on Chemical Sensor, IEEE Japan, **CHS-14-015-20** (2014) 1.
10 F. Miura: Zusetsu White paper on elderly 2006 (Japan National Council of Social Welfare, Tokyo, 2007).
11 T. Oyabu, Y. Kajiwara, and H. Kimura: Stud. Sci. Technol. **4** (Dec. 2015) 197.
12 Japan Walking association: Perfect manual on healthy walking (Jitsugyo no Nihon Sha, Tokyo, 2003).
13 John J. Ratey and E. Hagerman: SPARK: The Revolutionary New Science of Exercise and the Brain (Baror International Inc., New York, 2008).
14 Y. Kajiwara, M. Nakamura, H. Kimura, and T. Oyabu: IEE Japan Transaction on Electronics, Information and Systems **135** (2015) 570.