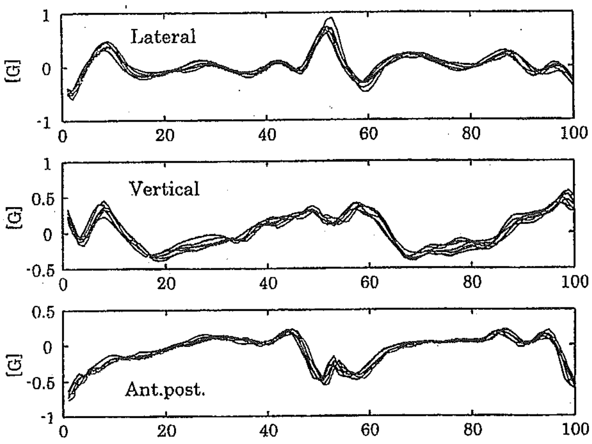

Fig. 3 Example of trunk acceleration during six strides (12 steps) walking in a young subject

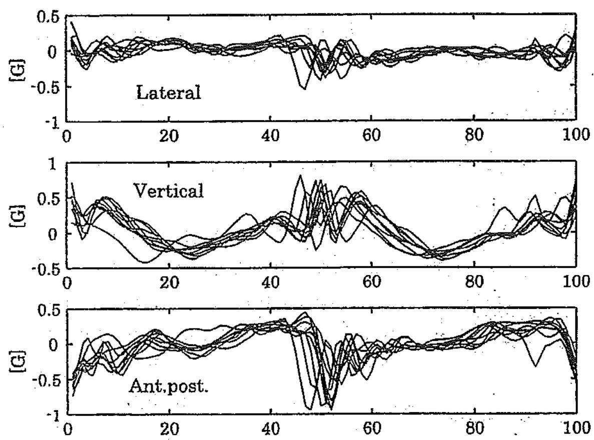

Fig. 4 Example of the trunk acceleration during six strides (12 steps) walking in an elderly subject

lateral, vertical, and anterior posterior directions. Figure 4 shows the same elderly subject before intervention. That subject illustrated more variability than young subjects had in all directions. Table 1 shows results of analyses with comparison between young and elderly subjects. Significant differences were found in the step number, cadence, and walking speeds ($p < 0.05$). Elderly subjects walked significantly more slowly than young subjects. The Lyapunov exponents of elderly subjects were slightly higher than those of young subjects, indicating less local dynamic stability, but no statistical significance was observed ($p = 0.05$). It is noteworthy that elderly persons demonstrated almost identical instability at much slower walking speeds than did young subjects. Results suggested that aging diminished the local dynamic stability of walking, consequently decreasing elderly subjects' walking speed to improve stability to compensate for variations of gait.

Table 2 shows results of male elderly subjects with comparison between groups before and after the exercise intervention. Mean values of the right and the left side records were calculated for the ROM, the hip abductors muscle strength, the lower leg extensor power, and the functional reach. For male subjects, significant improvements were found in the hip abductors muscle strength and the lateral functional reach ($p < 0.05$). The Lyapunov exponents after the exercise intervention indicated significantly lower values in the lateral and the anteroposterior direction, which indicated improvement of local dynamic stability. Table 3 shows that female elderly subjects also presented significant improvements in the muscle strength of hip abductors and the lateral functional reach. Additionally, a significant increase of the forward functional reach and decrease of the step number were also observed. The Lyapunov exponents of the group after exercise intervention were significantly lower than those of the before group in all directions. No remarkable differences in SD and CV values were found between the groups before and after, in either male or female elderly subjects.

Table 2 Comparison of a male elderly subject before and after the exercise intervention. The standard deviation is shown in parentheses. Significant differences ($p <$ 0.05) ate marked with asterisks

	Before	After
N	28	
Age	75.9 (4.2)	75.9 (4.2)
Height [cm]	162.4 (7.0)	162.4 (7.0)
Weight [kg]	65.6 (12.0)	66.3 (12.1)
ROM Ankle [deg]	15.5 (5.2)	17.6 (5.6)
ROM Knee [deg]	137.1 (10.8)	138.3 (7.9)
Hip Abductors Strength [kg/BW]	1.22 (0.24)*	1.45 (0.31)*
Leg Extension Power [watts]	683.5 (179.5)	686.2 (212.8)
Functional Reach		
– Forward [cm]	26.4 (4.8)	27.1 (5.0)
– Lateral [cm]	15.9 (2.4)*	19.7 (2.3)*
Step Number	17.5 (1.4)	17.2 (1.2)
Cadence [step/min]	116.5 (11.1)	118.7 (7.9)
Walking Speed [m/s]	1.27 (0.16)	1.31 (0.17)
CV Gait Cycle	0.067 (0.067)	0.068 (0.042)
SD Lateral	0.076 (0.036)	0.072 (0.019)
SD Vertical	0.089 (0.049)	0.081 (0.026)
SD Ant. post.	0.068 (0.032)	0.083 (0.032)
LyEp Lateral	0.065 (0.026)*	0.048 (0.018)*
LyEp Vertical	0.057 (0.026)	0.046 (0.020)
LyEp Ant. post.	0.051 (0.023)*	0.038 (0.018)*

According to those results, we hypothesized that strengths of hip abductors contributed to improvement of the local dynamic stability while walking. Figures 5 and 6 show relationships between the strength of hip abductors and the Lyapunov exponents in the group of after exercise

Table 3 Comparison of a female elderly subject before and after the exercise intervention. Significant differences ($p < 0.05$) ate marked with asterisks

	Before	After
N	24	
Age	77.0 (4.5)	77.0 (4.5)
Height [cm]	146.0 (5.2)	146.0 (5.2)
Weight [kg]	51.9 (9.8)	51.6 (8.8)
ROM Ankle [deg]	19.9 (7.5)	18.0 (5.5)
ROM Knee [deg]	141.6 (15.4)	141.4 (15.2)
Hip Abductors Strength [kg/BW]	0.89 (0.25)*	1.07 (0.28)*
Leg Extension Power [watts]	252.8 (111.0)	264.4 (100.2)
Functional Reach		
– Forward [cm]	23.4 (5.2)*	24.7 (4.7)*
– Lateral [cm]	15.1 (2.5)*	18.0 (3.3)*
Step Number	20.04 (2.27)*	19.67 (2.24)*
Cadence [step/min]	118.64 (8.56)	117.98 (8.42)
Walking Speed [m/s]	1.14 (0.18)	1.16 (0.16)
CV Step	0.061 (0.032)	0.074 (0.038)
SD Lateral	0.071 (0.018)	0.076 (0.023)
SD Vertical	0.084 (0.025)	0.085 (0.031)
SD Ant. post.	0.061 (0.017)	0.077 (0.021)
LyEp Lateral	0.075 (0.032)*	0.056 (0.019)*
LyEp Vertical	0.073 (0.038)*	0.048 (0.019)*
LyEp Ant. post.	0.062 (0.029)*	0.043 (0.014)*

intervention, respectively, for the male and female elderly subjects. Remarkable correlations were observed in the female elderly subjects ($p < 0.05$), but not in the male elderly subjects. Hip abductors are known to contribute to stabilizing the pelvis in biped locomotion. Further investigation is required to ascertain specific effects of muscle building or balance training on improvement of walking stability.

Results of the traditional variability index used in this study did not reveal significant differences between subjects before and the after the intervention. Elderly persons' walking patterns reflect not only the direct effects of aging, but also some adaptive mechanisms developed to compensate for their diminished physical performance. They acquired their own gait pattern, engendering variability in the acceleration waveform. However, standard deviations merely provided a picture of the overall level of variability in the gait patterns. Although they provided a general picture of the level of variability, no information is apparent about any temporal structure of the variations involving with time[(13)]. In contrast, the technique used to analyze nonlinear dynamic systems illustrates both spatial and temporal aspects of the data.

In the experimental study, a short walking distance was chosen to avoid effects of fatigue from elderly persons' walking. According to a pre-experiment, 16 m was

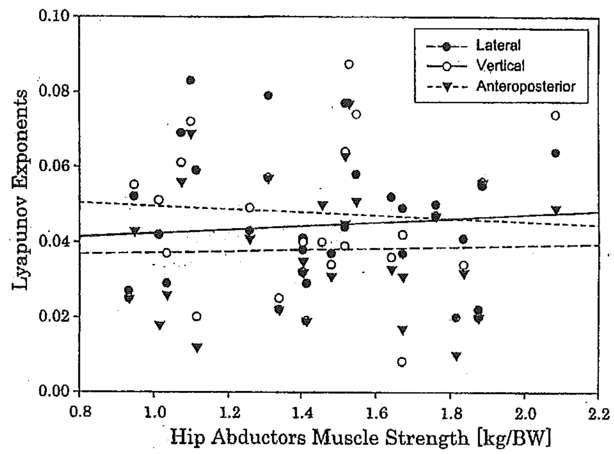

Fig. 5 Relationships between the strength of hip abductors and Lyapunov exponents in male elderly subjects after the exercise intervention

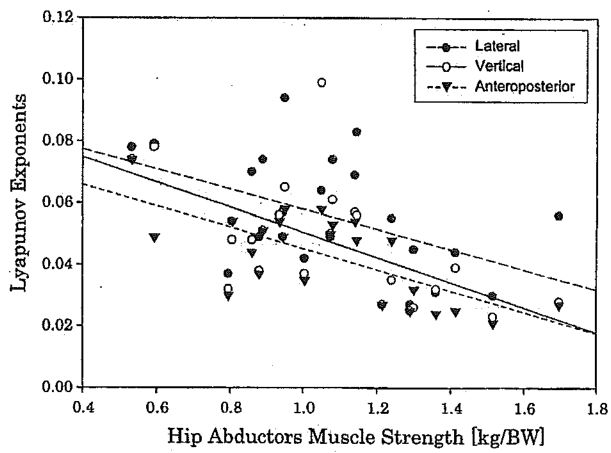

Fig. 6 Relationships between the strength of hip abductors and Lyapunov exponents in female elderly subjects after the exercise intervention

a feasible and proper condition to assess stable continuous walking. It is important to mention that estimation of Lyapunov exponents is sensitive to the data size and the observation time[(17)]. Therefore, estimation accuracy of Lyapunov exponents was rather low in this study. However, we quantified the exponential rate of divergence of trajectories, which followed trends of Lyapunov exponents. Consequently, we assumed that our indices were reliable for this inter-subjective study to assess relative improvement of walking performance.

The proposed method was adequate to quantify the nature of the dynamic system, which changes the states continuously while walking. It should also be emphasized that the method analyzes the dynamic stability of walking using a light-weight portable instrument that is easy to wear and convenient to use. A quantitative measure of walking stability might provide a promising method to assess personal risk of falls. It might also contribute to designing of proper training strategies and monitoring of their progress.

5. Conclusion

This study described a technique for assessing dynamic stability of walking using nonlinear time-series analyses with a portable instrument. The proposed method was concluded to be feasible for revealing effects and efficacies of exercise interventions for elderly persons. The method might be useful for scoring the degree of improvement in terms of walking stability. This method is readily applicable in the clinical field. Further application of the present technique might help to predict personal risks of falls.

Acknowledgment

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References

(1) Tinetti, E.M., Speechley, M. and Ginter, F.S., Risk Factors for Falls among Elderly Persons Living in the Community, New England Journal of Medicine, Vol.319 (1988), pp.1701–1707.

(2) Maki, B.E., Holliday, P.J. and Topper, A.K., Fear of Falling and Postural Performance in the Elderly, Journal of Gerontology: Medical Sciences, Vol.46 (1991), pp.123–131.

(3) Fujita, K., Nagatomi, R., Hozawa, A., Ohkubo, T., Sato, K., Anzai, Y., Sauvaget, C., Watanabe, Y., Tamagawa, A. and Tsuji, I., Effects of Exercise Training on Physical Activity in Older People: A Randomized Control Trial, Journal of Epidemiology, Vol.13, No.2 (2003), pp.120–125.

(4) Rogers, M.E., Fernandez, J.D. and Bohlken, R.M., Training to Reduce Postural Sway and Increase Functional Reach in the Elderly, Journal of Occupational Rehabilitation, Vol.11, No.4 (2002), pp.291–297.

(5) Bloem, R.B., Haan, J., Lagaay, A.M., Beek, W., Wintzen, A.R. and Roos, R.A.C., Investigation of Gait in Elderly Subjects over 88 Years of Age, Journal of Geriatric Psychiatry and Neurology, Vol.5 (1992), pp.78–84.

(6) Morris, J.R.W., Accelerometry—A Technique for the Measurement of Human Body Movements, Journal of Biomechanics, Vol.6 (1973), pp.729–736.

(7) Hurmuzlu, Y. and Basdogan, C., On the Measurement of Dynamic Stability of Human Locomotion, Journal of Biomechanical Engineering, Vol.116 (1994), pp.30–36.

(8) Arif, M., Ohtaki, Y., Ishihara, T. and Inooka, H., Analysis of Aging Effect on Human Walking Gait Using Detrended Fluctuation Analysis Technique, International Journal of HWRS, Vol.3, No.4 (2002).

(9) Arif, M., Ohtaki, Y., Nagatomi, R. and Inooka, H., Estimation of the Effect of Cadence on Gait Stability in Young and Elderly People Using Approximate Entropy Technique, Measurement Science Review, Vol.4 (2004), pp.29–40.

(10) Ohtaki, Y., Iijima, Y., Arif, M., Suzuki, A., Nagatomi, R. and Inooka, H., Assessment of Walking Stability by Lyapunov Exponent Estimation, Proceedings of the Second EMBS/BMES Conference, (2002), pp.2475–2476.

(11) Dingwell, J.B., Cusumano, J.P., Sternad, D. and Cavanagh, P.R., Slower Speeds in Patients with Diabetic Neuropathy Lead to Improved Local Dynamic Stability of Continuous Overground Walking, Journal of Biomechanics, Vol.33 (2000), pp.1269–1277.

(12) Dingwell, J.B.D. and Cavanagh, P.R., Increased Variability of Continuous Overground Walking in Neuropathic Patients Is Only Indirectly Related to Sensory Loss, Gait and Posture, Vol.14 (2001), pp.1–10.

(13) Buzzi, U.H., Stergiou, N., Kurz, M.J., Hageman, P.A. and Heidel, J., Nonlinear Dynamics Indicates Aging Affects Variability during Gait, Clinical Biomechanics, Vol.18 (2003), pp.435–443.

(14) Awata, S., Seki, T., Koizumi, Y., Sato, S., Hozawa, A., Omori, K., Kuriyama, S., Arai, H., Nagatomi, R., Matsuoka, H. and Tsuji, I., Factors Associated with Suicidal Ideation in an Elderly Urban Japanese Population: A Community-Based, Cross-Sectional Study, Psychiatry and Clinical Neurosciences, Vol.59 (2005), pp.327–336.

(15) Hozawa, A., Ohmori, K., Kuriyama, S., Shimazu, T., Niu, K., Watando, A., Ebihara, S., Matsui, T., Ichiki, M., Nagatomi, R., Sasaki, H. and Tsuji, I., C-Reactive Protein and Peripheral Artery Disease among Japanese Elderly: The Tsurugaya Project, Hypertension Research, Vol.27 (2004), pp.955–961.

(16) Newton, R.A., Validity of the Multi-Directional Reach Test: A Practical Measure for Limits of Stability in Older Adults, Journal of Gerontology: Medical Sciences, Vol.56A, No.4 (2001), pp.248–252.

(17) Cao, L., Practical Method for Determining the Minimum Embedding Dimension of a Scalar Time Series, Physica D, Vol.110 (1997), pp.43–50.

(18) Kantz, H., A Robust Method to Estimate the Lyapunov Exponent of a Time Series, Physics Letters A, Vol.185 (1994), pp.77–87.

Original Article

Influence of Leisure-Time Physical Activity on the Relationship between C-Reactive Protein and Hypertension in a Community-Based Elderly Population of Japan: The Tsurugaya Project

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There are several studies indicating an association between C-reactive protein (CRP) and blood pressure (BP) in the Japanese population, but the influence of physical activity has not been considered. Therefore, we designed a cross-sectional survey to determine whether leisure-time physical activity (LTPA) modifies the relation between CRP and hypertension among Japanese elderly. Our study population comprised 643 subjects aged 70 years and over in whom CRP, home BP, and self-reported LTPA were measured. LPTA was categorized into three levels of intensity—walking, brisk walking, and sports—and a questionnaire was used to estimate the level in each patient. Hypertension was defined as a home systolic BP of 135 mmHg or over and/or home diastolic BP of 85 mmHg or over or current use of antihypertensive agents. LTPA levels were associated with both CRP and hypertension. After adjustment for factors affecting CRP and hypertension, and additional adjustment for LTPA levels, the odds ratio (95% confidence interval) of hypertension by CRP was 2.21 (range: 1.33–3.72), 1.99 (1.17–3.42), and 2.38 (1.36–4.21) times higher in subjects in the second, third, and fourth quartiles of CRP, as compared to subjects in the first quartile, respectively. A multiple regression model showed a positive and significant relation between log-transformed CRP and systolic BP after adjustment for potential confounding factors when participants taking antihypertensive medication were excluded. This is the first study to clarify that the positive significant relation between CRP and hypertension was independent of LTPA levels among Japanese elderly. (*Hypertens Res* 2005; 28: 747–754)

Key Words: **C-reactive protein, leisure-time physical activity, hypertension, Japanese, community-dwelling population**

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Introduction

C-reactive protein (CRP) is a classical acute-phase marker and a member of the pentraxin family of innate immune response proteins (*1*, *2*). The concentration of CRP in serum is generally less than 2 μg/ml but increases by as much as 1,000-fold in response to stimuli such as tissue injury or inflammation (*3*). Following removal of the inflammatory stimulus, CRP levels decline rapidly. These features have made CRP useful as a clinical marker of an inflammatory process. Over the last several years, increasing evidence has suggested that inflammation mechanisms are important in the pathophysiology of hypertension (*4–7*). Furthermore, several studies have shown that serum CRP levels are associated with the development of hypertension (*8*, *9*).

At the same time, numerous studies have indicated that physical activity (PA), including leisure-time physical activity (LTPA), is inversely related to the prevalence of hypertension (*10*, *11*) or serum concentration of CRP (*12–19*). A more recent study has also demonstrated that inflammatory markers including CRP were lower in older adults with higher levels of exercise and non-exercise PA (*12*). Considering these studies together, it is natural to assume that PA would be a potent modifier of the relationship between CRP and hypertension. But to our knowledge, there are only three reports that have investigated the relationship between CRP and hypertension adjusted for the effect of PA (*20–22*), and their results are inconsistent. Furthermore, although there have been several studies that indicated an association between serum CRP level and blood pressure (BP) in Japanese, the influence of PA on this relationship has not been considered (*23–27*). Therefore, we considered that it would be worthwhile to examine whether the relation between CRP and hypertension is dependent of LTPA, and designed the present cross-sectional analysis in Japanese community-dwelling elderly individuals for this purpose.

Methods

Study Participants

Our study population was comprised of subjects aged 70 years and older who were living in the Tsurugaya area of Sendai, one of the major cities in the Tohoku area of Japan. At the time of the study in 2002, there were 2,730 individuals aged 70 years and older living in Tsurugaya. We invited all of these individuals to participate in a comprehensive geriatric assessment, which included medical status, physical function, cognitive function and dental status, and 1,178 of them did so, giving their informed consent for analysis of the data. The protocol of this study was approved by the Institutional Review Board of Tohoku University Graduate School of Medicine.

We excluded subjects whose high-sensitivity CRP had not been measured ($n=29$). Since we assessed hypertension using self-measured BP at home (home blood pressure [HBP]) data, subjects who did not measure HBP data more than 3 days during the 4-week study period were also excluded ($n=182$). This criterion was based on our previous observation that average BP values for the first 3 days did not differ significantly from those obtained during the entire study period (*28*, *29*). We also excluded those subjects whose serum CRP concentrations were higher than 10.0 mg/l ($n=24$), because those with acute inflammatory conditions were frequently found to have serum CRP levels ≥10.0 mg/l (*30*). Furthermore, we excluded subjects who did not complete the questionnaire items on LTPA ($n=109$). Finally, we excluded all potential subjects with notable comorbidity factors that might influence the frequency and degree of PA by a self-reported decline of physical function using the Medical Outcome Study (*31*) (physical functioning score ≤1; $n=77$) or arthritis ($n=114$). As a result of these exclusions, the final study population comprised 643 subjects (mean age, 75.5±4.4 years; men: 48.5%).

Measurements

Anthropometric measures (height, body weight) were recorded by a standardized protocol. HBP was measured with an HEM747IC device (Omron Life Science Co., Ltd., Tokyo, Japan), which uses the cuff-oscillometric method to generate a digital display of systolic and diastolic blood pressures (SBP and DBP). This device has been validated previously, and satisfies the criteria of the Association for the Advancement of Medical Instrumentation (*32*). We used the following procedure to ascertain the accuracy of the HBP measurement. First, physicians informed the population about HBP recording and taught them how to measure their own BP. The daily measurement was made within 1 h of awakening and before breakfast, with the subject seated and having rested for at least 2 min. In subjects receiving antihypertensive drugs, HBP was measured before taking the drugs. The HBP of an individual was defined as the mean of all measurements obtained for that person. The mean (±SD) number of HBP measurements was 15.9±10.5 (range, 3–49).

Blood samples were drawn from the antecubital vein of the seated subject with minimal tourniquet use. Specimens were collected in siliconized vacuum glass tubes containing sodium fluoride for blood glucose, and no additives for lipids and CRP analyses.

Total cholesterol (T-C), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C) levels and blood glucose levels were measured by enzymatic methods (T-C, Denka Seiken, Tokyo, Japan; TG, Kyowa Medex, Tokyo, Japan; HDL-C, Daiichi Pure Chemicals, Tokyo, Japan; blood glucose, Shino-Test, Tokyo, Japan). Serum uric acid levels were determined according to a uricase method (*33*) with the Olympus autoanalyzer AU-5000 (Olympus Corp., Tokyo, Japan).

Table 1. Definition of Physical Activity Level

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
N	147	131	148	71	80	66
Walking	None	Low	High	Any	Any	Any
Brisk walking	None	None	None	Low	High	Any
Sports	None	None	None	None	None	Low and High
Walking (*N*)						
None	147	0	0	25	49	30
Low	0	131	0	21	2	19
High	0	0	148	25	29	17
Brisk walking (*N*)						
None	147	131	148	0	0	41
Low	0	0	0	71	0	12
High	0	0	0	0	80	13
Sports (*N*)						
None	147	131	148	71	80	0
Low	0	0	0	0	0	58
High	0	0	0	0	0	8

High: at least 3–4 times per week for at least 30 min each time; Low: reporting some activity in the past year, but not enough to meet high levels; None: no leisure-time physical activity. *N*: number of subjects.

CRP levels were determined using an immunotechnique on a Behring BN II analyzer (Dade Behring, Tokyo, Japan). The BN II high-sensitivity assay utilizes a monoclonal antibody coated on polystyrene particles and fixed-time kinetic nephelometric measurements (*34*). The BN II nephelometer uses a 1:400 dilution to measure CRP concentrations between 3.5 and 210 mg/l. The assay has been approved by the US Food and Drug Administration for use in assessing the risk of cardiovascular and peripheral vascular disease.

Questionnaire of LTPA

LTPA was measured through a self-reported single-item question and corresponding response sets. The question asked whether the subject had performed any activities from the following categories in the previous 12 months: walking, brisk walking, or sports (*e.g.*, aerobics, tennis, swimming, jogging, *etc.*). If they had participated in a given activity, the frequency and duration spent in the activity were ascertained using the following categories: for frequency, 1) 1–2 times per month, 2) 1–2 times per week, 3) 3–4 times per week, or 4) almost every day; and for duration (per walk or workout), 1) 0–30 min, 2) 0.5–1 h, 3) 1–2 h, 4) 2–3 h, 5) 3–4 h, or 6) 4 h or more.

Statistical Analysis

Hypertension was defined as a home SBP of 135 mmHg or over and/or a home DBP of 85 mmHg or over or using antihypertensive agents (*35*, *36*). Based on the recently proposed cutoff point for CRP, we also categorized the study participants as having a low (less than 1.0 mg/l) or high level (at least 1.0 mg/l) of CRP (*37*, *38*). The high-sensitivity CRP value (ng/ml) was used for calculating the log-transformed CRP.

Among the levels of exercise intensity, sports were considered the highest, followed in order by brisk walking and walking. Each of the three types was further classified into three subcategories according to the frequency and duration of the walks or workouts as follows (*11*, *39*): 1) High, at least 3–4 times per week for at least 30 min each time; 2) Low, some activity in the past year, but not enough to meet the criteria for the high group; and 3) None, no LTPA. Finally, we used these categories and subcategories to define the following six levels of LTPA (Table 1): 1) Level 1, no sports, no brisk walking, no walking; 2) Level 2, no sports, no brisk walking, low amount of walking; 3) Level 3, no sports, no brisk walking, high amount of walking; 4) Level 4, no sports, low amount of brisk walking, any amount of walking; 5) Level 5, no sports, high amount of brisk walking, any amount of walking; 6) Level 6, any amount of sports, any amount of brisk walking, any amount of walking. Since only 8 subjects reported participating in a high amount of sports activity, we combined high- and low-level sports activity into a single category. Table 1 also shows the number of participants according to the LTPA levels.

Diabetes was defined as a free blood glucose level of 200 mg/dl or over or current use of antidiabetic medication. Hypercholesterolemia was defined as a level of total cholesterol of 220 mg/dl or over, or current use of non-statin lipid-lowering agents. Gout was defined as a serum uric acid level of 7.0 mg/dl or over or current use of antihyperuricemic medication. Information on smoking status, drinking status and histories of prior cardiovascular diseases (CVD) were obtained from the questionnaire survey. Current drinkers

Table 2. Association between High Sensitive C-Reactive Protein Levels and Cardiovascular Disease Risk Factors

	C-reactive protein (mg/l)				*p* value
	0.05–0.27	0.28–0.54	0.55–1.16	1.17–9.96	
No. of participants	160	161	161	161	
Age (years)	75.2±4.4	75.6±4.1	75.8±4.8	75.2±4.5	0.51
Sex (male %)	41.9	49.1	51.6	51.6	0.26
BMI (kg/m^2)	22.0±3.1	23.5±2.9	24.3±3.0	25.0±3.3	<0.01
Hypertension (%)	54.4	75.2	75.8	79.5	<0.01
SBP (mmHg)	132.7±18.4	139.2±17.2	141.6±18.8	144.6±19.1	<0.01
DBP (mmHg)	74.7±9.0	76.3±10.0	77.9±9.4	79.1±9.8	<0.01
Hypercholesterolemia (%)	30.0	33.5	36.7	38.5	0.40
HDL-C (mg/dl)	60.8±14.5	55.9±13.5	53.8±13.3	52.2±14.3	<0.01
Diabetes (%)	3.1	8.7	11.8	13.7	<0.01
Gout (%)	10.0	16.8	17.4	25.5	<0.01
Smoker					
Current smoker (%)	11.3	14.3	12.4	18.0	0.32
Ex-smoker (%)	22.5	32.3	37.2	37.3	0.01
Non-smoker (%)	63.1	52.8	48.5	44.7	<0.01
Alcohol consumption (g)	11.8±29.3	12.7±32.7	13.5±28.7	11.9±24.2	0.95
Use of statin drugs (%)	13.8	16.8	21.1	17.4	0.38
Use of aspirin drugs (%)	5.0	10.6	10.6	13.7	0.07
History of CVD (%)	11.9	14.9	14.3	19.3	0.02

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein-cholesterol; CVD, cardiovascular diseases. Variables are pressented as mean±SD. Hypertension: home SBP 135 mmHg or over and/or home DBP 85 mmHg or over or using antihypertensive agents.

Table 3. Correlation between Physical Activity and Blood Pressure or C-Reactive Protein

	Physical activity						*p* for trend
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	
Walking	None	Low	High	Any	Any	Any	
Brisk walking	None	None	None	Low	High	Any	
Sports	None	None	None	None	None	Low and High	
N (total: 643)	147	131	148	71	80	66	
Hypertension (%)	75.5	77.9	74.3	69.0	57.5	60.6	<0.01
SBP (mmHg)	142.6±1.5	142.1±1.6	139.3±1.5	136.6±2.2	137.0±2.1	134.4±2.3	0.13
DBP (mmHg)	78.1±0.8	77.9±0.8	76.4±0.8	76.9±1.1	75.7±1.1	75.8±1.2	0.12
log-hsCRP (ng/ml)	6.5±0.1	6.5±0.1	6.3±0.1	6.3±0.1	6.2±0.1	6.2±0.1	0.14
High-CRP (%)	36.1	30.5	27.0	28.2	22.5	21.2	<0.01
Odds ratio (95% CI)							
Hypertension*	1.00	1.09 (0.61–1.96)	0.97 (0.56–1.67)	0.89 (0.47–1.73)	0.53 (0.29–0.97)	0.62 (0.33–1.19)	0.02
High-CRP*	1.00	0.70 (0.41–1.20)	0.64 (0.38–1.08)	0.70 (0.36–1.34)	0.57 (0.29–1.10)	0.49 (0.24–0.98)	0.04

N: number of subjects. SBP, systolic blood pressure; DBP, diastolic blood pressure; log-hsCRP, log-transformed high sensitivity C-reactive protein (CRP); CI, confidence interval. Variables are pressented as mean±SD. High-CRP: CRP≥1.0 mg/l. *Adjusted for age, sex, body mass index, and smoking status. High: at least 3–4 times per week for at least 30 min each time; Low: reporting some activity in the past year, but not enough to meet high levels; None: no leisure-time physical activity.

were further asked about drinking frequency, beverage types usually consumed, and amount consumed on a single occasion. From these responses, we calculated the average daily alcohol consumption in g. We also treated statin agents as independent confounding factors because they have been reported to lower CRP levels (*40, 41*). The drug information was confirmed by a well-trained pharmacist.

The clinical and biochemical data of the subjects are presented as the means±SD, or as the median and interquartile range for variables with a skewed distribution or percentages.

Table 4. Adjusted Relationships of High Sensitive C-Reactive Protein Levels (Quartile) to Hypertension

	Level of C-reactive protein (mg/l)				*p* for trend
	0.05–0.27	0.28–0.54	0.55–1.16	1.17–9.96	
All					
N (total: 643)	160	161	161	161	—
N of hypertensives	87	121	122	128	—
Odds ratio (95% CI)					
Age- and sex-adjusted	1.00	2.57 (1.60–4.18)	2.67 (1.66–4.35)	3.41 (2.08–5.67)	<0.01
Multiple adjusted*	1.00	2.26 (1.36–3.78)	2.05 (1.21–3.50)	2.45 (1.41–4.31)	0.03
Multiple* and PA levels adjusted	1.00	2.21 (1.33–3.72)	1.99 (1.17–3.42)	2.38 (1.36–4.21)	0.04
	Level of C-reactive protein (mg/l)				*p* for trend
	0.05–0.29	0.30–0.57	0.58–1.34	1.35–9.96	
Participants without brisk walking or sports activity					
N (total: 426)	106	107	106	107	—
N of hypertensives	64	86	84	89	—
Odds ratio (95% CI)					
Age- and sex-adjusted	1.00	2.81 (1.52–5.32)	2.60 (1.42–4.89)	3.38 (1.80–6.55)	<0.01
Multiple adjusted*	1.00	2.46 (1.28–4.86)	1.98 (1.00–3.96)	2.48 (1.21–5.19)	0.11
	Level of C-reactive protein (mg/l)				*p* for trend
	0.05–0.23	0.24–0.51	0.52–0.93	0.94–9.25	
Participants with sports or brisk walking activity					
N (total: 217)	53	55	54	55	—
N of hypertensives	25	31	38	41	—
Odds ratio (95% CI)					
Age- and sex-adjusted	1.00	1.52 (0.71–3.33)	2.85 (1.28–6.51)	3.52 (1.56–8.27)	<0.01
Multiple adjusted*	1.00	1.30 (0.57–2.98)	2.00 (0.81–5.00)	2.67 (1.06–6.94)	0.04

N: number of subjects. PA, physical activity; CI, confidence interval. *Adjusted for age, sex, body mass index, hypercholesterolemia, high-density lipoprotein-cholesterol, gout, history of cardiovascular diseases, diabetes, smoking, alcohol consumption, use of aspirin,

Differences in variables among the CRP groups were examined by analysis of variance (ANOVA) for continuous variables, or by the χ^2 test for variables of proportion. Multiple logistic regression analysis and analysis of covariance (ANCOVA) were used to examine the relation of LTPA with hypertension, SBP, DBP, log-transformed CRP and high-CRP (≥1.0 mg/l) after adjustment for age, gender, body mass index (BMI), and smoking status. *p* values for linear trends were calculated using the level of LTPA as a continuous variable. The odds ratio (OR) and 95% confidence interval (CI) of hypertension for increasing CRP levels with the lowest level as the reference was also calculated using multiple logistic regression analysis. When we calculated the OR, we used an age-sex adjusted model and a multivariate model adjusted for age, sex, BMI, hypercholesterolemia, HDL-C, gout, history of CVD, diabetes, smoking habits/history, alcohol consumption, use of aspirin, and use of statin drugs; the final multivariable model was further adjusted for LTPA levels. *p* values for linear trends were calculated using the median (mg/l) of CRP levels. Multiple linear regression analysis was used to establish the relationship between BP and CRP after adjustment for age, gender, BMI, hypercholesterolemia, HDL-C, gout, history of CVD, diabetes, smoking, alcohol consumption, and LTPA levels in the subjects who were not using antihypertensive agents, aspirin, and statin drugs. Values of $p<0.05$ were considered to indicate statistical significance. All statistical analyses were performed using the Statistical Analysis System (version 9.1 for Windows; SAS Institute Inc., Cary, USA).

Results

Association between High-Sensitivity CRP Levels and Cardiovascular Disease Risk Factors

Table 2 shows the association between high-sensitivity CRP levels (quartile) and CVD risk factors. Both SBP and DBP were significantly higher in the highest CRP quartiles. BMI was also significantly higher in the highest CRP quartile and the mean HDL-C was lower in the highest CRP quartile. Mean age and alcohol consumption did not significantly differ among the CRP groups. The proportion of subjects with hypertension, diabetes, gout, history of smoking (*i.e.*, ex-smokers), and subjects with a history of CVD was larger in the highest CRP quartile. The proportion of subjects with no history of smoking was significantly smaller in the lowest

Table 5. Results of Multivariate Modelling for log-Transformed C-Reactive Protein

	log-CRP (ng/ml) (n=318)	
	β coefficient (SEM)	p value
SBP	0.008 (0.003)	<0.01
Age	0.013 (0.014)	0.34
Sex	−0.086 (0.183)	0.64
BMI	0.090 (0.020)	<0.01
Hypercholesterolemia	0.275 (0.126)	0.03
HDL-C	−0.009 (0.005)	0.06
Gout	0.242 (0.170)	0.16
History of CVD	−0.114 (0.218)	0.60
Diabetes	0.241 (0.207)	0.25
Current smoker	0.492 (0.200)	0.01
Ex-smoker	0.291 (0.183)	0.11
Alcohol consumption	−0.003 (0.002)	0.20
PA Level 2	−0.038 (0.180)	0.83
PA Level 3	−0.237 (0.169)	0.16
PA Level 4	−0.287 (0.202)	0.16
PA Level 5	−0.096 (0.186)	0.61
PA Level 6	−0.073 (0.206)	0.72

log-CRP, log-transformed C-reactive protein; SBP, systolic blood pressure; BMI, body mass index; HDL-C, high-density lipoprotein-cholesterol; CVD, cardiovascular diseases; PA, physical activity.

CRP quartile. The gender ratio, the number of current smokers, and the rates of hypercholesterolemia, statin user, and aspirin use did not differ significantly among the CRP groups.

Correlation between LTPA Levels and BP or CRP

Table 3 shows the relationship between LTPA levels and the prevalence of hypertension, SBP, DBP, log-transformed high sensitivity CRP, or high-CRP after adjustment for age, gender, BMI and smoking status. In the crude model, increasing PA levels showed a significant inverse relationship with both the prevalence of hypertension (p for trend <0.01) and high-CRP (p for trend <0.01). Even after the adjustment for sex, age, BMI and smoking status, the significant inverse relation between PA levels and hypertension or high-CRP was unchanged (p for trend =0.02 and 0.04, respectively).

Relationships between High-Sensitivity CRP Levels (Quartile) and Hypertension

Adjusted relationships between CRP levels (quartile) and the prevalence of hypertension are shown in Table 4. The age- and sex-adjusted OR of hypertension increased from the lowest (reference) to the highest CRP quartiles in all subjects. These results were somewhat attenuated when we adjusted for other potential confounders: the ORs for hypertension of the second, third, and fourth CRP quartiles were 2.26 (95% CI: 1.36–3.78, p<0.01), 2.05 (95% CI: 1.21–3.50, p<0.01), and 2.45 (95% CI: 1.41–4.31, p<0.01), compared with the first group as a reference, and the frequency of hypertension was significantly higher in the high CRP group. When we additionally adjusted for the LTPA levels, which are potential confounding factors, the significantly positive association was unchanged: the ORs for hypertension of the second, third, and fourth CRP quartiles were 2.21 (1.33–3.72), 1.99 (1.17–3.42), and 2.38 (1.36–4.21), respectively. We also analyzed the relation between the CRP quartiles adjusted for hypertension and the subgroups, *i.e.*, participants who participated in sports or brisk walking (LTPA levels 4–6) and those who did not (LTPA levels 1–3). The relations between CRP and hypertension were mostly identical among these subgroups (p for interaction =0.95).

Multiple Regression Model Analysis of the Relationship between log-Transformed CRP and BP

To confirm the relationship between CRP and SBP values, we performed a multiple regression analysis among subjects who did not use antihypertensive medication, aspirin, or statin drugs. The multiple regression model showed a positive and significant relationship between log-transformed CRP and SBP after adjustment for potential confounding factors, including LTPA levels (Table 5). The SBP distinctly showed a significant relationship with log-transformed CRP (p<0.01). BMI, hypercholesterolemia, and current smoking were also positively related to log-transformed CRP. There was no significant interaction between LTPA levels and SBP for log-transformed CRP values (p for interaction =0.63).

Discussion

Hypertension is one of the most important modifiable risk factors for CVD in Western and Asian populations (*42*, *43*). It is well known that lifestyle changes (*e.g.*, diet, weight loss, exercise and smoking cessation, *etc.*) can reduce cardiovascular risk; in particular, regular PA reduces coronary and cardiovascular morbidity and mortality, independently from the other risk factors (*44*, *45*). PA is one of the most important independent contributors to the prevalence of hypertension (*10*, *11*). In this cross-sectional survey of Japanese community-dwelling elderly individuals, we found LTPA levels in daily life were inversely correlated with both serum CRP and the prevalence of hypertension.

Since the LTPA level was inversely related with both CRP and the prevalence of hypertension, we tested our hypothesis that the relation between CRP and hypertension would be dependent of LTPA levels. However, the positive significant relation between CRP and hypertension remained even after adjustment for the LTPA levels. Furthermore, there was a strong relation between the CRP and SBP values that was independent of the LTPA level among participants not taking antihypertensive or statin drugs or aspirin. Thus, we were able to conclude for the first time that the relation between CRP and hypertension was independent of LTPA levels in a Japanese elderly population.

Several prospective studies have employed the amount of subjects' PA as one of the confounding factors in their multivariate analysis of the causal relationship between serum CRP and the development of hypertension and/or metabolic syndrome (*20–22*). In two of these studies (*21, 22*), the amount of exercise did not attenuate the relationship between CRP and BP. The third prospective cohort study (*20*) also considered the influence of PA on the relation between CRP and BP, but in contrast to the other two studies, the results indicated that CRP was not a significant predictor of the development of hypertension or other metabolic syndromes. Although the reason for these discrepancies remains unclear, our data are similar to the first two studies, which indicated that CRP may be related to hypertension independent of PA levels.

In this study, we used HBP measurement. HBP makes it possible to obtain multiple measurements over a long observation period under relatively controlled conditions (*46, 47*). It has been reported that multiple measurements eliminate observer bias and regression dilution bias; therefore, HBP measurements are more reliable than conventional BP measurements taken in medical settings (office BP) (*46–48*). We also adjusted for a considerable number of confounding factors. In this way, we were able to confirm the positive and significant relation between log-transformed CRP and SBP in subjects who were not using antihypertensive agents.

This study had several limitations. First, most of the participants were sufficiently active to participate in the survey. Therefore, we lacked the participation of those who were physically dependent or disabled due to metabolic syndromes or hypertension, leading to underestimation of the relation between CRP and hypertension. Second, since this study was a cross-sectional study, we could not conclude that CRP causes hypertension or that hypertension leads to increased CRP among subjects aged 70 years and over. Third, we did not directly measure the exercise intensities of walking, brisk walking and sports. Still, one may easily discriminate one's own "brisk walking" from ordinary walking. We therefore believe that the categorization of relative walking intensity based on the subjects' own perceptions was reliable. It is well known that ratings of perceived exertion correspond well to exercise intensity as measured by oxygen uptake (*49*).

In conclusion, we have demonstrated that among elderly subjects 70 years and older the higher LTPA levels were associated with reductions of serum CRP levels and hypertension prevalence, but that the positive significant relation between CRP and hypertension was independent of LTPA levels.

References

1. Gewurz H, Zhang XH, Lint TF: Structure and function of the pentraxins. *Curr Opin Immunol* 1995; **7**: 54–64.
2. Volanakis JE: Human C-reactive protein: expression, structure, and function. *Mol Immunol* 2001; **38**: 189–197.
3. Claus DR, Osmand AP, Gewurz H: Radioimmunoassay of human C-reactive protein and levels in normal sera. *J Lab Clin Med* 1976; **87**: 120–128.
4. Yudkin JS, Stehouwer CD, Emeis JJ, Coppack SW: C-reactive protein in healthy subjects: associations with obesity, insulin resistance, and endothelial dysfunction: a potential role for cytokines originating from adipose tissue? *Arterioscler Thromb Vasc Biol* 1999; **19**: 972–978.
5. Rodriguez-Iturbe B, Vaziri ND, Herrera-Acosta J, Johnson RJ: Oxidative stress, renal infiltration of immune cells, and salt-sensitive hypertension: all for one and one for all. *Am J Physiol Renal Physiol* 2004; **286**: F606–F616.
6. Brasier AR, Recinos A 3rd, Eledrisi MS: Vascular inflammation and the renin-angiotensin system. *Arterioscler Thromb Vasc Biol* 2002; **22**: 1257–1266.
7. Virdis A, Schiffrin EL: Vascular inflammation: a role in vascular disease in hypertension? *Curr Opin Nephrol Hypertens* 2003; **12**: 181–187.
8. Ridker PM, Wilson PW, Grundy SM: Should C-reactive protein be added to metabolic syndrome and to assessment of global cardiovascular risk? *Circulation* 2004; **109**: 2818–2825.
9. Das UN: Metabolic syndrome X: an inflammatory condition? *Curr Hypertens Rep* 2004; **6**: 66–73.
10. Chiriac S, Dima-Cozma C, Georgescu T, Turcanu D, Pandele GI: The beneficial effect of physical training in hypertension. *Rev Med Chir Soc Med Nat Iasi* 2002; **107**: 258–263.
11. Bassuk SS, Manson JE: Physical activity and the prevention of cardiovascular disease. *Curr Atheroscler Rep* 2003; **5**: 299–307.
12. Colbert LH, Visser M, Simonsick EM, *et al*: Physical activity, exercise, and inflammatory markers in older adults: findings from the health, aging and body composition study. *J Am Geriatr Soc* 2004; **52**: 1098–1104.
13. Wannamethee SG, Lowe GD, Whincup PH, Rumley A, Walker M, Lennon L: Physical activity and hemostatic and inflammatory variables in elderly men. *Circulation* 2002; **105**: 1785–1790.
14. Ford ES: Does exercise reduce inflammation? Physical activity and C-reactive protein among U.S. adults. *Epidemiology* 2002; **13**: 561–568.
15. Abramson JL, Vaccarino V: Relationship between physical activity and inflammation among apparently healthy middle-aged and older US adults. *Arch Intern Med* 2002; **162**: 1286–1292.
16. Geffken DF, Cushman M, Burke GL, Polak JF, Sakkinen PA, Tracy RP: Association between physical activity and markers of inflammation in a healthy elderly population. *Am J Epidemiol* 2001; **153**: 242–250.
17. Pischon T, Hankinson SE, Hotamisligil GS, Rifai N, Rimm EB: Leisure-time physical activity and reduced plasma levels of obesity-related inflammatory markers. *Obes Res* 2003; **11**: 1055–1064.
18. Reuben DB, Judd-Hamilton L, Harris TB, Seeman TE: The associations between physical activity and inflammatory markers in high-functioning older persons: MacArthur Studies of Successful Aging. *J Am Geriatr Soc* 2003; **51**: 1125–1130.

19. Albert MA, Glynn RJ, Ridker PM: Effect of physical activity on serum C-reactive protein. *Am J Cardiol* 2004; **93**: 221–225.
20. Han TS, Sattar N, Williams K, Gonzalez-Villalpando C, Lean ME, Haffner SM: Prospective study of C-reactive protein in relation to the development of diabetes and metabolic syndrome in the Mexico City Diabetes Study. *Diabetes Care* 2002; **25**: 2016–2021.
21. Sesso HD, Buring JE, Rifai N, Blake GJ, Gaziano JM, Ridker PM: C-reactive protein and the risk of developing hypertension. *JAMA* 2003; **290**: 2945–2951.
22. Niskanen L, Laaksonen DE, Nyyssonen K, *et al*: Inflammation, abdominal obesity, and smoking as predictors of hypertension. *Hypertension* 2004; **44**: 859–865.
23. Tomiyama H, Koji Y, Yambe M, *et al*: Elevated C-reactive protein augments increased arterial stiffness in subjects with the metabolic syndrome. *Hypertension* 2005; **45**: 997–1003.
24. Tsunoda K, Arita M, Yukawa M, *et al*: Retinopathy and hypertension affect serum high-sensitivity C-reactive protein levels in type 2 diabetic patients. *J Diabetes Complications* 2005; **19**: 123–127.
25. Saijo Y, Kiyota N, Kawasaki Y, *et al*: Relationship between C-reactive protein and visceral adipose tissue in healthy Japanese subjects. *Diabetes Obes Metab* 2004; **6**: 249–258.
26. Tamakoshi K, Yatsuya H, Kondo T, *et al*: The metabolic syndrome is associated with elevated circulating C-reactive protein in healthy reference range, a systemic low-grade inflammatory state. *Int J Obes Relat Metab Disord* 2003; **27**: 443–449.
27. Yamada S, Gotoh T, Nakashima Y, *et al*: Distribution of serum C-reactive protein and its association with atherosclerotic risk factors in a Japanese population: Jichi Medical School Cohort Study. *Am J Epidemiol* 2001; **153**: 1183–1190.
28. Hozawa A, Ebihara S, Ohmori K, *et al*: Increased plasma 8-isoprostane levels in hypertensive subjects: the Tsurugaya Project. *Hypertens Res* 2004; **27**: 557–561.
29. Imai Y, Satoh H, Nagai K, *et al*: Characteristics of a community based distribution of home blood pressure in Ohasma, a northern part of Japan. *J Hypertens* 1993; **11**: 1441–1449.
30. Pepys MB, Hirschfield GM: C-reactive protein: a critical update. *J Clin Invest* 2003; **111**: 1805–1812.
31. Tarlov AR, Ware JE Jr, Greenfield S, Nelson EC, Perrin E, Zubkoff M: The Medical Outcomes Study. An application of methods for monitoring the results of medical care. *JAMA* 1989; **262**: 925–930.
32. Chonan K, Kikuya M, Araki T, *et al*: Device for the self-measurement of blood pressure that can monitor blood pressure during sleep. *Blood Press Monit* 2001; **6**: 203–205.
33. Kabasakalian P, Kalliney S, Westcott A: Determination of uric acid in serum, with use of uricase and a tribromophenol-aminoantipyrine chromogen. *Clin Chem* 1973; **19**: 522–524.
34. Ledue TB, Weiner DL, Sipe JD, Poulin SE, Collins MF, Rifai N: Analytical evaluation of particle-enhanced immunonephelometric assays for C-reactive protein, serum amyloid A and mannose-binding protein in human serum. *Ann Clin Biochem* 1998; **35**: 745–753.
35. Chobanian A, Bakris G, Black H, *et al*: The seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 Report. *JAMA* 2003; **289**: 2560–2571.
36. European Society of Hypertension–European Society of Cardiology Guidelines Committee: 2003 European Society of Hypertension–European Society of Cardiology Guidelines for the manangement of arterial hypertension. *J Hypertens* 2003; **21**: 1011–1053.
37. Pearson TA, Mensah GA, Alexander RW, *et al*: Markers of inflammation and cardiovascular disease: application to clinical and public health practice: a statement for healthcare professionals from the Centers for Disease Control and Prevention and the American Heart Association. *Circulation* 2003; **107**: 499–511.
38. Hozawa A, Ohmori K, Kuriyama S, *et al*: C-reacitve protein related to the peripheral artery disease among Japanese elderly: the Tsurugaya Project. *Hypertens Res* 2004; **27**: 955–961.
39. Pate RR, Pratt M, Blair SN, *et al*: Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995; **273**: 402–407.
40. Albert MA, Danielson E, Rifai N, Ridker PM: Effect of statin therapy on C-reactive protein levels: the pravastatin inflammation/CRP evaluation (PRINCE): a randomized trial and cohort study. *JAMA* 2001; **286**: 64–70.
41. Ridker PM, Rifai N, Lowenthal SP: Rapid reduction in C-reactive protein with cerivastatin among 785 patients with primary hypercholesterolemia. *Circulation* 2001; **103**: 1191–1193.
42. Making a difference. The World Health Report 1999. *Health Millions* 1999; **25**: 3–5.
43. Roccella EJ, Bowler AE: Hypertension as a risk factor. *Cardiovasc Clin* 1990; **20**: 49–63.
44. Leon AS, Connett J, Jacobs DR Jr, Rauramaa R: Leisure-time physical activity levels and risk of coronary heart disease and death. The Multiple Risk Factor Intervention Trial. *JAMA* 1987; **258**: 2388–2395.
45. Gibbons LW, Clark SM: Exercise in the reduction of cardiovascular events. Lessons from epidemiologic trials. *Cardiol Clin* 2001; **19**: 347–355.
46. Bobrie G, Chatellier G, Genes N, *et al*: Cardiovascular prognosis of "masked hypertension" detected by blood pressure self-measurement in elderly treated hypertensive patients. *JAMA* 2004; **291**: 1342–1349.
47. Ohkubo T, Imai Y, Tsuji I, *et al*: Home blood pressure measurement has a stronger predictive power for mortality than does screening blood pressure measurement: a population-based observation in Ohasama, Japan. *J Hypertens* 1998; **16**: 971–975.
48. Tachibana R, Tabara Y, Kondo I, Miki T, Kohara K: Home blood pressure is a better predictor of carotid atherosclerosis than office blood pressure in community-dwelling subjects. *Hypertens Res* 2004; **27**: 633–639.
49. Noble BJ: Clinical applications of perceived exertion. *Med Sci Sports Exerc* 1982; **14**: 406–411.

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TECHNICAL PAPER

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Automatic classification of ambulatory movements and evaluation of energy consumptions utilizing accelerometers and a barometer

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Abstract This paper describes a method to evaluate daily physical activity by means of a portable device that determines the type of physical activity based on accelerometers and a barometer. Energy consumption of a given type of physical activity was calculated according to relative metabolic ratio (RMR) of each physical activity type that reflects exercise intensity of activities. Special attention was paid to classification algorithms for activity typing that identify detailed ambulatory movements considering vertical movements, such as stair/slope climbing or use of elevators. A portable measurement device with accelerometers and a barometer, and a Kalman filter was designed to detect the features of vertical movements. Furthermore, walking speed was calculated by an equation which estimates the walking speed as a function of signal energy of vertical body acceleration during walking. To confirm the usefulness of the method, preliminary experiments were performed with healthy young and elderly subjects. The portable device was attached to the waist. A standard accelerometer based calorie counter was also attached for comparison. Experimental results showed that the proposed method feasibly classified the type of ambulatory physical activities; level walking, stair going up and down and elevator use. It was suggested that the consideration of vertical movements made a significant improvement in the estimation of energy consumptions, and the proposed method provides better estimation of physical activity compared to the conventional calorie counter.

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1 Introduction

Physical activity is a determining factor of quality of life. A practical and reliable method to investigate individual's daily physical activity allows better assessment such as of outcomes of medical interventions. Currently, the amount of energy consumption due to daily physical activity is widely accepted as an important factor in the prevention of obesity, diabetes, hyperlipidemia, cardiovascular disease, and muscle wasting in the aged people. Information such as intensity of exercise, types of activities is also necessary to appropriately formulate safe and beneficial exercise program on individual basis. Ambulatory movement is the most accessible type of exercise easy to perform that does not require any special equipments. Therefore, a reliable assessment of ambulatory movements in daily life, such as walking, climbing stairs or slopes up and down, is essential for exercise prescription in the clinics as well as in health promotion programs.

Conventionally, clinicians simply recorded patients' recall of daily exercise to evaluate energy expenditure of patients. A variety of methods have also been used to quantify daily energy expenditure in a more precise manner, by means of heart rate monitoring, oxygen uptake measurement or doubly labeled water. However, these methods are either unreliable, cumbersome or impractical in recording daily energy expenditure of free living people. In order to overcome these problems, various advanced small calorie counters have been developed utilizing an accelerometer or an angular velocity sensor attached on the waist, wrist or ankle.

Accelerometers are preferable to detect frequency and intensity of vibrational human motion (Morris et al. 1973; Bouten et al. 1997). Many studies have demonstrated the usefulness of accelerometry for the evaluation of physical activity, mostly focusing on the detection of level walking or active/rest discrimination (Tamura et al. 1997; Nakahara et al. 1999; Aminian et al. 1999; Mathie et al. 2002). However, with regard to vertical movements such as stair climbing, evaluation of energy consumption has been still insufficient even though stair climbing requires more than twice the energy of level walking. This is because of difficulties in the detection of vertical movement. As for the detection of vertical position shift, DGPS as an infrastructure-dependent positioning technology made better measurement of vertical positioning. However, it has serious problems of coarse time resolution and limited availability of the satellite service. Walking speed also contributes to energy consumption, though it is still difficult to estimate accurately under unconstrained ambulatory conditions from acceleration data. New methods have been proposed utilizing a neural network or a mechanical biped model that needs tuning each time (Aminian et al. 1995, 2002; Miyazaki et al. 1997). Uses of multiple wearable vital sensors still involves some restrictions and discomfort that may interfere with natural and spontaneous daily physical activity.

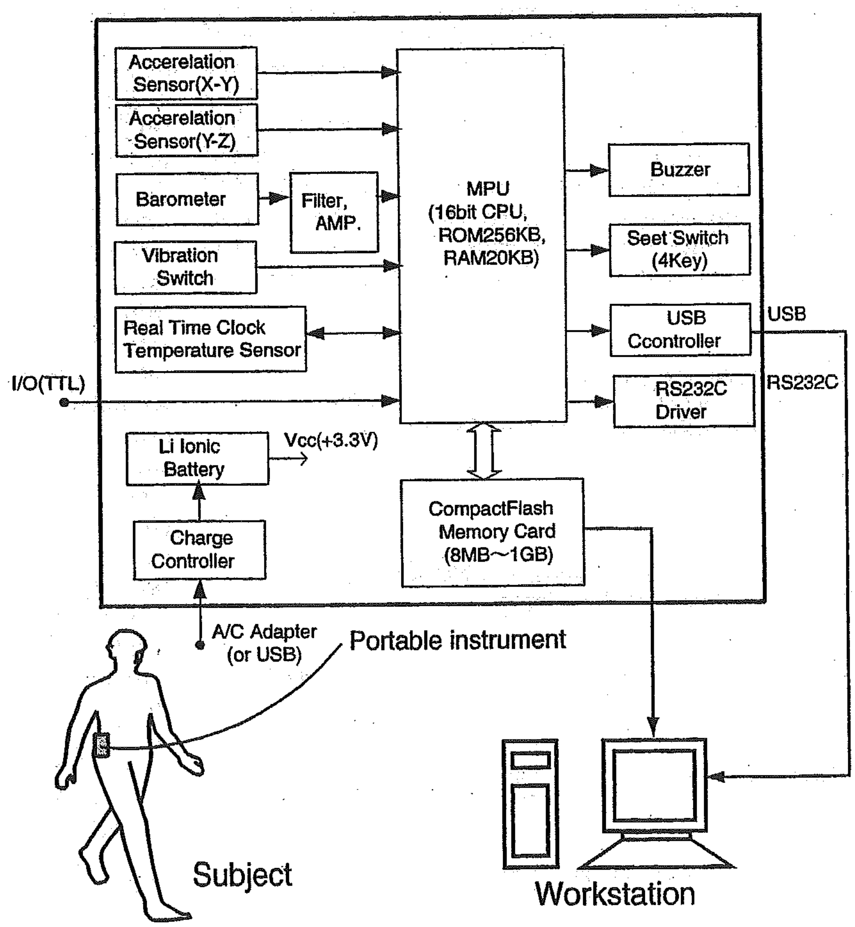
Main objective of this study was to present a method to quantify energy consumption of detailed ambulatory movements, both indoors and outdoors in daily life, by use of a portable measurement device employing accelerometers and a barometer. Special attention was paid to advanced classification algorithms and walking speed estimation, which was robust to measurement conditions, individual differences, and aging effect. Potential usefulness of the proposed method was investigated by comparing the new method with the conventional accelerometer based calorie counter in the experimental study.

2 Method

2.1 Portable measurement device

We developed a portable device consisted of monolithic IC accelerometers (AnalogDevices, ADXL202E, ±2 [G]) with 16-bit duty cycle converter, a packaged silicon piezoresistive pressure sensor (Fujikura, X3AM-115KPASR), Li-Ionic batteries, micro processor units and CompactFlash card, as shown in Figure 1. This equipment (Instruments Technology Research, Intelli-

Fig. 1 Architecture of the portable measurement device



gent Calorie Counter: ICC) was small (100×55×18.5 [mm]) and light enough to carry without any restriction. Sampling frequency was selectable from 10, 33.3, 100 [Hz]. Data was downloaded via USB, and processed offline by a workstation. The equipment was designed to be attached on the waist as shown in Figure 2. Although the equipment provided three-dimensional acceleration, vertical acceleration and air pressure data were applied to the classification method of ambulatory movement typing.

2.2 Estimation of energy expenditure

Energy expenditure is calculated as shown in Equation 1. Total energy consumption E is the summation of energy consumed by exercise E_w and individual's basic metabolism E_b. The relative metabolic rate (RMR) represents the ratio of energy expenditure that is required for the exercise and one's basal metabolism. The basal metabolic rate (BMR) is the number of calories burned in a day while lying down, which depends on one's age or gender. The notation t and w represent the exercise time length and the body weight respectively. It should be noted that the type of exercise and intensity are determinant factors of RMR, as shown in Table 1 ("Guidelines for graded exercise testing and exercise prescription" published by American College of Sports Medicine. 1986; Ainsworth et al. 1993). Therefore, a precise evaluation of energy expenditure in daily life with the new device requires detailed classification of ambulatory movements with stair/slope-climbing activity taken into consideration.

$$E = E_w + E_b$$
$$E_w = RMR \times BMR \times t \times w \quad (1)$$

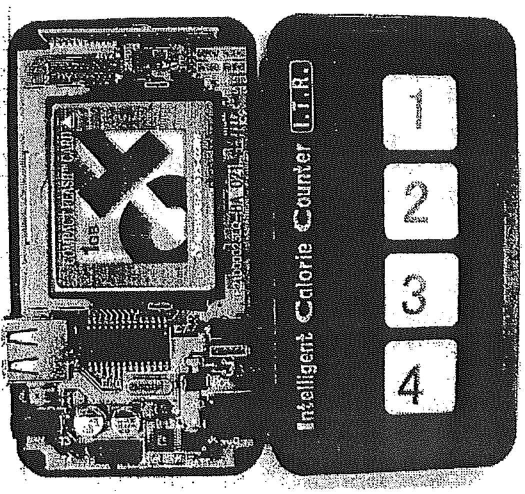


Fig. 2 Photo of the portable measurement device: Intelligent Calorie Counter (ICC)

Table 1 RMR (Relative Metabolic Rate)

Type of Motion	RMR
Rest(Standing)	0.4
Rest(Sitting)	0.0~0.2
Rest(Lie Down)	0.0
-Walking Speed-	
50 m/min	1.5
60 m/min	1.9
70 m/min	2.4
80 m/min	3.2
90 m/min	4.0
100 m/min	5.0
110 m/min	6.4
120 m/min	8.5
-Slope Walking-	
-9 %	1.3
-5 %	1.7
5 %	3.8
10 %	5.4
15 %	7.2
20 %	9.4
-Stair-	
Up	10.0
Down	2.5

2.3 Detection of walking phase

The body acceleration reflects characteristics of the biped locomotion. The walking periodicity appears as a frequency peek f_p in a spectrum, and the intensity of movement corresponds to amplitudes and the signal energy of acceleration, as shown in Figure 3. Therefore,

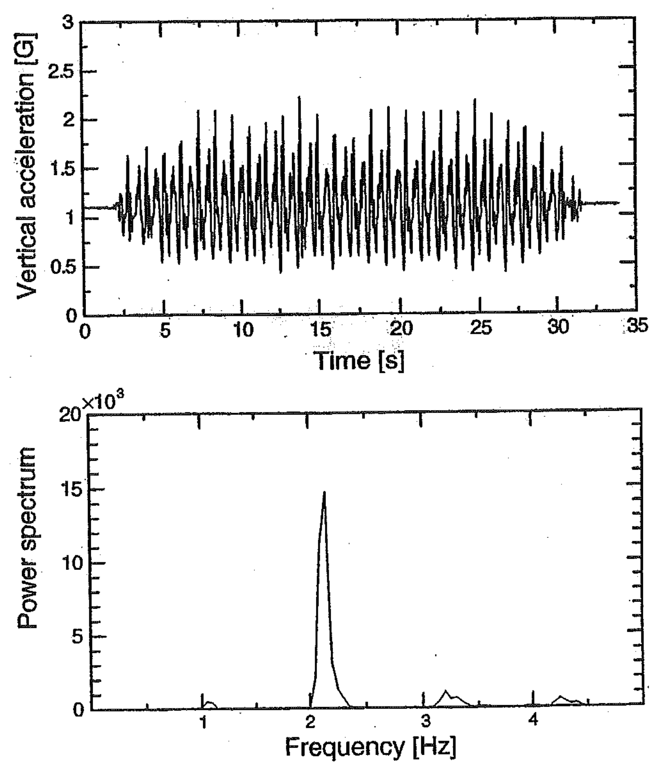


Fig. 3 Vertical acceleration and power spectrum during walking

walking phases were defined by the acceleration as a condition with a variance S over 0.02 [G] and frequency peak inside f_p 1–3 [Hz] in the spectrum.

2.4 Estimation of walking speed

Furthermore, a method of walking speed estimation was developed. It is known that natural human gait has a clear relationship between step length and cadence. These factors reflect frequency and intensity of the vertical trunk vibration during walking (McMahon 1984). Therefore, we focused on the relationship between signal energy and natural walking speed. The signal energy in the frequency bandwidth 1–3 [Hz] was considered as a determinant of one's natural walking speed. The relationship between signal energy and natural walking speed was formulated from walking test results of 199 young (Age: 25.0 ± 1.63) and elderly (Age: 75.2 ± 7.83) subjects. From the result of the experiment, an approximate expression as a clear logarithmic relationship was found among the signal energy and the walking speed, as shown in Figure 4. Estimation equation of walking speed was thus formulated as Equation 2. The notation x represents the signal energy of 1–3 [Hz] frequency bandwidth of vertical acceleration. The notation y represent the walking speed standardized by subject's height. This method does not require any personal template of biped model, pre-investigation of step length, but applicable to walking speed estimation of elderly people.

$$y = 0.1722\ln(x) - 0.3346 \tag{2}$$

2.5 Detection of vertical movement

In order to classify ambulatory including vertical position shift, a practical methods was developed to detect slight altitude changes by use of a barometer. Direct measure-

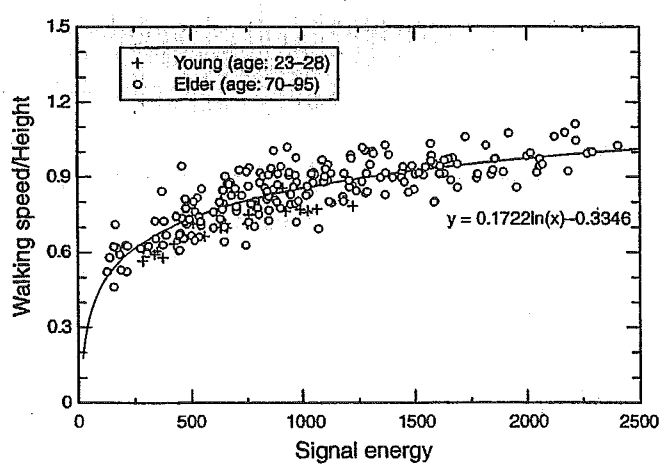


Fig. 4 Relationship between walking speeds standardized with height and the signal energy of acceleration

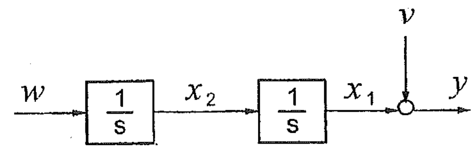


Fig. 5 The model of air pressure measurement

ment of the air pressure or its differential hardly gives precise altitudes change, because of the effect of weather conditions, artifacts, and high frequency measurement noise. Weather conditions sometimes cause larger air pressure changes than that of the vertical altitude change caused by one's motion. However, the change in the atmospheric pressure due to weather changes appears to be much slower than that caused by one's motion. On the other hand, air pressure differentials practically indicate vertical position shifts. It is also beneficial that the measurement of air pressure differentials provides wider dynamic measurement range as compared to absolute air pressure measurement. Considering the above points, a Kalman filter with following characteristics was designed to eliminate effects of such disturbances and to get optimal estimation of the air pressure differential.

To construct the filter, a model of the air pressure measurement system was proposed as shown in Figure 5 (Sagawa et al. 1998). The notation x_1 and x_2 represent an air pressure and its differential of the state variable **x** respectively. The notation v is the sensor noise and y is the output of the barometer. The notation w represents a virtual signal that corresponds to a dynamic error between a signal generation model and the actual air pressure. An optimal filter to estimate a state variable $\mathbf{x} = [x_1\ x_2]^T$ using the sensor output y will be written by a Kalman filter as follow.

$$\dot{\hat{\mathbf{x}}} = \mathbf{A}\hat{\mathbf{x}} + \mathbf{K}(\mathbf{y} - \mathbf{C}\hat{\mathbf{x}}) \tag{3}$$

The equation provides a transfer function $G_k(s)$ from the sensor output y to the optimal estimation of the air pressure differential $\hat{x}_2$.

$$G_k(s) = \frac{{\omega_k}^2 s}{s^2 + 2\zeta_k\omega_k s + \omega_k^2} \tag{4}$$

where w_k and ζ_k are natural frequency and damping ratio, respectively. Moreover, an amplifier and an low pass filter with a cut-off frequency of 10 [Hz] is applied to the output signal. The bode diagram of the constructed filter is shown in Figure 6. The filter works as differentiation in the frequency range lower than 0.3 [Hz].

A value of air pressure differential corresponds to a direction and speed of the vertical movements. Therefore, types of vertical motion or kinds of transporter can be identified according to the value of air pressure differential combined with the result of walking phase detection.

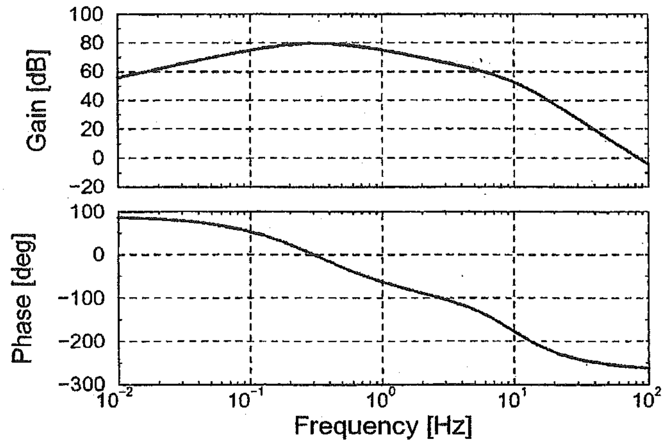


Fig. 6 Bode diagram of the filter

2.6 Classification algorithm

There were four steps in the classification algorithm. The first step was the separation of ambulatory and resting states. The second step was the detection of vertical position shift and detailed identification of up/down movements. The third step was the estimation of walking speeds and slope inclination to evaluate the intensity of the movement. Threshold and clustering approach provided classification of level walking, climbing up/down the stair/slope, going up/down in an elevator, and rest (Static). The threshold value and the classification condition were described as Equation 5 – Equation 10. The value of air pressure differentials $dA_p = 1$ [Pa] correspond to vertical position shift of 8.49 [cm]. The threshold values were determined considering reported characteristics of human walking and the Japanese guideline of elevator design. The threshold values were experimentally adjusted and verified by the preliminary investigation of six kinds of elevators (Lifting speed: 58.9 - 101.5 [m/min]) and four kinds of stairs (Inclination pitch: 3.5 - 30.0 [deg.]). In the classification algorithm, short term movements less than 3 second was negligible to assess main series of ambulatory movements.

$$\left\{ \text{Level walking} \left| \begin{array}{l} S^2 \geq 0.02\ [G],\ 1 < f_p < 3\ [Hz] \\ -1.86 < dA_p < 1.86\ [Pa/s] \end{array} \right. \right\} \quad (5)$$

$$\left\{ \begin{array}{l} \text{Stair Slope} \\ \text{Going Up} \end{array} \left| \begin{array}{l} S^2 \geq 0.02\ [G],\ 1 < f_p < 3\ [Hz] \\ dA_p > 1.86\ [Pa/s] \end{array} \right. \right\} \quad (6)$$

$$\left\{ \begin{array}{l} \text{Stair/Slope} \\ \text{Going Down} \end{array} \left| \begin{array}{l} S^2 \geq 0.02\ [G],\ 1 < f_p < 3\ [Hz] \\ dA_p < -1.86\ [Pa/s] \end{array} \right. \right\} \quad (7)$$

$$\left\{ \begin{array}{l} \text{Elevator} \\ \text{Going Up} \end{array} \left| \begin{array}{l} 0 \leq S^2 \leq 0.02\ [G] \\ dA_p > 8.64\ [Pa/s] \end{array} \right. \right\} \quad (8)$$

$$\left\{ \begin{array}{l} \text{Elevator} \\ \text{Going Down} \end{array} \left| \begin{array}{l} 0 \leq S^2 \leq 0.02\ [G] \\ dA_p < -8.64\ [Pa/s] \end{array} \right. \right\} \quad (9)$$

$$\left\{ \text{Rest (Static)} \left| \begin{array}{l} 0 \leq S^2 \leq 0.02\ [G] \\ -8.64 < dA_p < 8.64\ [Pa/s] \end{array} \right. \right\} \quad (10)$$

3 Experiment

Two kinds of preliminary experiments were performed with healthy young subjects. All subjects gave signed informed consent. Subjects wore their own shoes. The measurement data was processed offline by the proposed classification algorithm.

First experiment (Experiment 1) was demonstrated to show the usefulness of the method to identify and classify details of ambulatory movements. Subjects were thirteen young volunteers (Age: 23.9 ± 2.02). The portable device ICC was attached on the waist of subject. Sampling frequency was 100 [Hz]. Subjects were instructed to move in the sequence of "static standing, going down in an elevator, walking through level corridor, climbing up stairs, walking climbing down stairs walking, and going up in an elevator".

The second experiment (Experiment 2) was performed to investigate whether the detailed classification provides significant differences in the evaluation of energy consumption as compared with conventional accelerometry. Subjects were five young volunteers (Age: 23.2 ± 2.39). In addition to ICC, accelerometer based calorie counter (Kenz, Lifecorder) as a standard of conventional method was attached on the other side of the waist. Sampling frequency was 100 [Hz]. The accelerometer based calorie counter provides data of exercise intensity every four seconds. Subjects were instructed to walk along a course three times in the sequence of "level walking, climbing down stairs, walking, climbing up stairs, and walking". Walking speed was changed every round in the order of "normal, slow, and fast" on their own decision.

The third experiment (Experiment 3) was performed to assess the validity of the method in a community environment. Two elderly subjects (Age: 71 and 82) volunteered for a two day monitoring of physical activity in their personal lives. They carried ICC for 16 hours each day. To enable long-term recordings, sampling frequency was reduced to 33.3 [Hz]. Types of ambulatory movement in their daily life were investigated.

4 Result

Typical result of Experiment 1 was shown in Figure 7 illustrating vertical accelerations (top), air pressure differentials (middle) and classification results of the movements (bottom). The value of air pressure differential changed according to the direction and the speed of vertical movements. All types of ambulatory movements were successfully classified. Indeed, a few steps in and out of the elevator cage was detectable just before and after the use of elevator. Such short walking less than three second were neglected in the classification process. The series of ambulatory movements could be accurately classified in all the subjects and the trials. The algorithm made about 1.5 second delay for classification, which is negligible in the evaluation of energy expenditure. On the other hand, large ripples were observed in the air pressure differential, probably caused by the pre-amp of the barometer. This ripple made a limitation in the classification method. When climbing up/down stairs/slopes less than 10 [deg] angle, frequent miss classification was observed because of less variation of air pressure differential than that of the ripple.

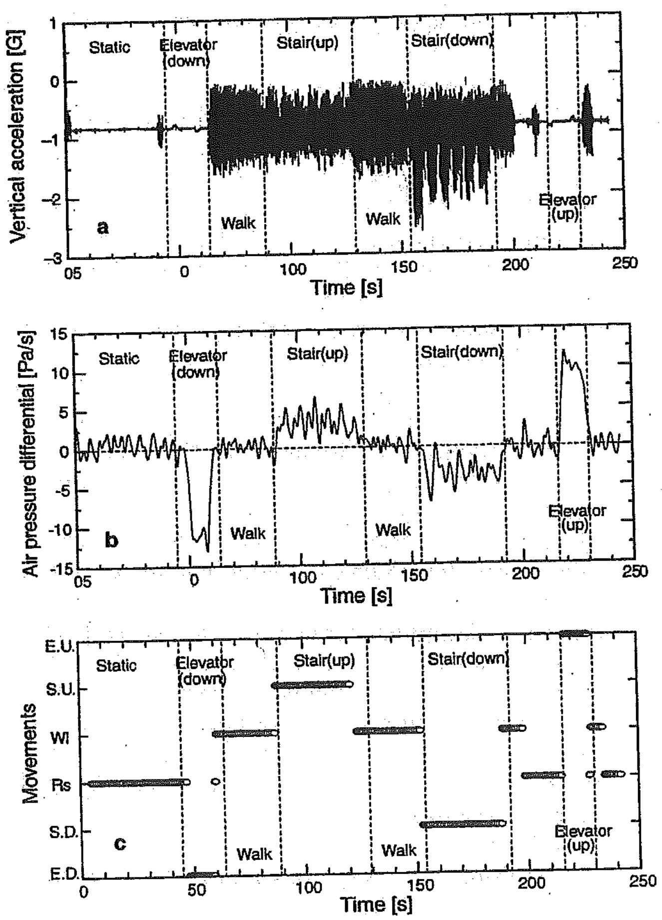


Fig. 7 Typical waveform of vertical accelerations (top), air pressure differentials (middle) as measured, and classification results of the ambulatory movements (bottom). The notation E.U., S.U., Wl, Rs, S.D., E.D. indicate 'Elevator going up', 'Stair going up', 'Level walking', 'Rest(static)', 'Stair going down', 'Elevator going down' respectively

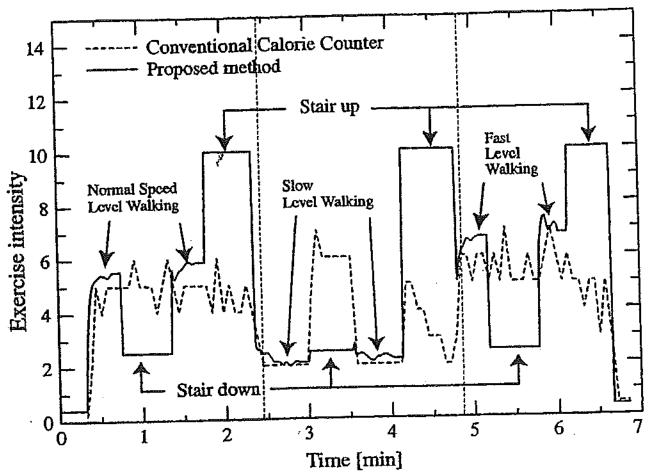


Fig. 8 Exercise intensities estimated by the proposed method during level walking in various speed and stair up/down, comparing with the results of conventional accelerometer based calorie counter

The result of Experiment 2 was shown in Figure 8 illustrating exercise intensity estimated by ICC compared with the result of standard calorie counter. ICC provided the exercise intensity as RMR. Note that ICC successfully evaluated exercise intensity of the vertical movements whereas the conventional accelerometer based calorie counter ignored them. This result suggested that the conventional evaluation of stair climbing upwards was underestimated, and stair climbing downwards was overestimated. As illustrated in Figure 8, during the second round when subjects moved slower, the conventional accelerometer overestimated stair climbing downwards. This can be explained by the fact that conventional accelerometer calculates energy consumption simply according to the intensity of acceleration. Speed

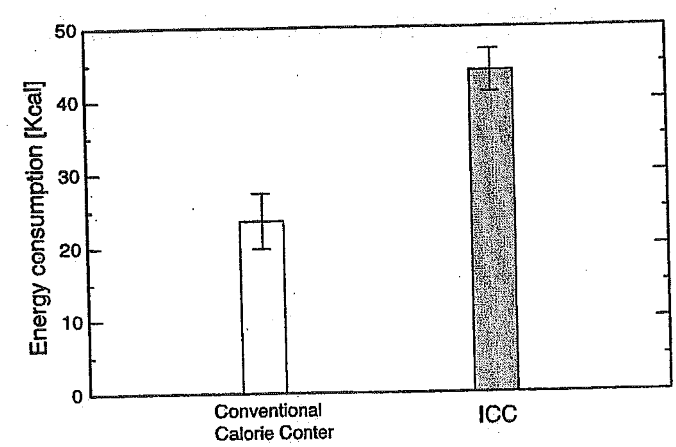


Fig. 9 Comparison of estimated total energy consumption by the proposed method and the conventioanal accelerometer based calorie counter

Table 2 Distribution of daylong physical activity

Subject No.		Level walk [min] (RMR < 7)	Stair up/down [min]
1	1st day	101.95	9.15
	2nd day	88.68	7.12
2	1st day	55.42	1.67
	2nd day	53.27	0.98

of level waking was also evaluated correctly in a good agreement with the result of the conventional method. Figure 9 shows the comparison of the total amount of expenditure during the trial. The energy consumption estimated by ICC was larger than the conventional method. It was suggested that the consideration of vertical ambulatory movements may provide a significant improvement in the evaluation of energy expenditure in daily activities. However, the reliability of the estimated values is still uncertain. The measurement of the oxygen uptake should be performed to confirm the reliability of the estimation. The stepping speed of stair climbing was not addressed in our method. This is because RMR table has not addressed the intensity of stair climbing speed sufficiently, even though the calculation of stair walking speed would not be difficult.

The result of Experiment 3 was shown in Table 2. The proposed method successfully illustrates the classification of ambulatory movements in daily lives. This information may be helpful in formulating more appropriate and safer exercise program on individual basis. This method should be extended to cover other types of movements in order to realize wider application and a more precise assessment of daily physical activity. Further clinical and community-based studies with a larger number of subjects are our future studies.

5 Conclusion

In this article, an alternative method to evaluate energy expenditure of ambulatory movements was described. A small portable device utilizing accelerometers and a barometer was developed, which detects features of ambulatory movements including vertical position shifts. The classification method based on a frequency analysis of body acceleration and data processing of air pressure variation provided identification and classification of one's ambulatory movements without significant limitations and restrictions. Furthermore, walking speed was estimated from the signal energy of the acceleration. Experimental results have shown that the proposed method is able to effectively classify and evaluate level walking, stair/slope climbing, elevator use, and walking speed. The proposed method provides better estimation of energy expenditure and exercise intensity as compared to conventional accelerometer based calorie counters.

This device is feasible for community-based studies. Further application of the present technique may be helpful in the health promotion of both young and elderly, and in the management of obese, diabetic, hyperlipidemic and cardiac patients. Efforts are being directed to make the device smaller and allow data collection for longer time periods. Implementation of real-time processing firmware and encapsulation of the hardware are our future studies.

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References

Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, Paffenbarger RS Jr (1993) Compedium of physical activities: classification of energy cost of human physical activities. Medicine and Science in Sports and Exercise 25(1):71–80

American College of Sports Medicine (1986) Guidelines for graded exercise testing and exercise prescription, 3rd edn. Lea and Febiger, Philadelphia

Aminian K, Robert Ph, Jequier E, Schutz Y (1995) Estimation of speed and incline of walking using newral network. Transaction of Instrumentation and Measurement 44(3):743–746

Aminian K, Robert P, Buchser EE, Rutschmann B, Hayoz D, Depairon M (1999) Physical activity monitoring based on accelerometry. Medical and Biological Engineering and Computing 37:304–308

Aminian K, Najafi B, Bula C, Leyvraz PF, Robert Ph (2002) Spatio-temporal parameters of gait measured by an ambulatory system using miniature gyroscopes. Journal of Biomechanics 35(5):689–699

Bouten CVC, Koekkoek KTM, Verduin M, Kodde R, Janssen JD (1997) A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity. IEEE Transactions on Biomedical Engineering 44(3):136–147

Mathie MJ, Lovell NH, Coster CF, Celler BG (2002) Determining activity using a triaxial accelerometer. In: Proceedings of the second joint EMBS/BMES conference, 2481–2482

McMahon TA (1984) Mechanics of Locomotion. The International Journal of Robotics Research 3(2):4–28

Miyazaki S (1997) Long-term unrestrained measurement of stride length and walking velocity utilizing a piezoelectric gyroscope. IEEE Transactions on Biomedical Engineering 44(8):1701–1707

Morris JRW (1973) Accelerometry–a technique for the measurement of human body movements. Journal of Biomechanics 6:729–736

Nakahara AK, Sabelman EE, Jaffe DL (1999) Development of a second generation wearable accelerometric motion analysis system. Proceedings of the first joint EMBS/BMES conference, 630

Sagawa K, Ina A, Ishihara T, Inooka H (1998) Classification of human moving patterns using air pressure and acceleration. In: Proceedings of the 24th Annual Conference of the IEEE Industrial Electronics Society (IECON'98) 2:1214–1219

Tamura T, Fujimoto T, Sakaki H, Higashi Y, Yoshida T, Togawa T (1997) A Solid-State Ambulatory Physical Activity Monitor and Its Application to Measuring Daily Activity of the Elderly C. Journal of Medical Engineering and Technology 21:96–105

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地域虚弱高齢者に対する体力レベル別運動指導の効果

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<要約>目的:地域虚弱高齢者を体力レベル別に運動を指導する体力別運動クラスを介入群、体力レベルの異なるものが混在する体力混在型運動クラスを対照群とし無作為に割付け、それらの有効性の差異を検証することを目的とした。**方法**：仙台市宮城野区鶴ヶ谷地区に居住する70歳～84歳の高齢者2,582名に質問紙調査を実施し、motor fitness scale (MFS) 8点以下で、1）強度の聴力、視力、起居および移動能力障害者、2）要介護2以上の介護認定者を除外した574名に対し案内を送付し124名が本研究に参加した。Timed up & go test (TUGT) の下位4分の1を重度体力低下者、その他を軽度体力低下者と定義し、それぞれをA,B,C の3グループに無作為に割り付けた。3つの運動クラスに対して、すべて週1回3ヶ月間の運動介入を実施した。ただし、体力別運動クラスAおよびBでは、軽度体力低下者と重度体力低下者を分け別々の教室で運動指導を行い、体力混在型運動クラスCでは、軽度および重度体力低下者を合わせて運動指導を実施した。**結果**：ベースラインにおいて3群間には男女比、年齢、TUGT には差異を認めなかった。ドロップアウト者数は、運動クラス間で有意差を認めなかった。3つの運動クラスの Group×Time 交互作用は、TUGT、Lateral Reach (LR)、脚伸展パワー体重比、MFS のすべてで有意ではなかった。群内前後比較では、体力別運動クラスAは、TUGT、LR、脚伸展パワー体重比すべてで有意な変化がなく、BではLRのみに有意な低下を認めた。一方、体力混在型運動クラスCでは、脚伸展パワー体重比では変化がなかったが、TUGT、LRともに有意な低下を示した。MFS はすべての運動クラスで有意な向上を示した。**結論**：無作為割り付け対照試験において、運動機能前後比較では、体力混在型運動クラスと比較して体力レベル別運動クラスで維持項目が多かったが統計学的に有意な交互作用を認めるには至らなかった。

Key Words：地域虚弱高齢者、体力レベル、無作為化対照試験

緒　言

75歳以上の地域在住高齢者の約30%以上が1年間に転倒を経験し、転倒者のうち24%が重大な傷害を受傷する[1]と報告されている。そして、前向き研究により、運動機能の低下が転倒リスクの一要因である[1,2]と指摘されている。そのため、高齢者の運動機能維持改善を目的とした運動教室[3,4]や家庭で実施する運動指導[5]や訪問運動指導[6]が各地で実施され、その介入効果も多く報告されている。さらに、その効果を高めるためにバランス機器の利用[7]、機能的課題運動の導入[8]、機動性課題に特化した速いスピードでの運動遂