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Research article

Utility of a Physical Fitness Score in Screening for Chronic Diseases

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Abstract

We developed a new Physical Score (PS) consisting of comprehensive physical fitness indicators and elucidated the association between the resultant PS and metabolic diseases, i.e., diabetes, hypertension, dyslipidemia, fatty liver, and metabolic syndrome (MetS), among Japanese. Analyzed were 49,850 persons (30,039 men) aged 30 to 69 y who underwent physical fitness tests. Principal component analysis was performed on the correlation matrix of the physical fitness test results (relative grip strength, single-leg balance with eyes closed, and forward bending) according to sex and age. We defined the PS as the first principal component score. A formula was developed for various age groups comprised of men and women from 30 to 69 years of age from which the PS for each age and sex was calculated. The PS for both men and women was normally distributed with a value of 0 ± 1.15-1.16. Multivariate logistic regression analysis showed that the risk of metabolic diseases increased approximately 1.1 - 1.6 times per each 1-point reduction in the PS. The association between PS and MetS was particularly strong in that a 1-point reduction in the PS increased the risk of MetS by 1.54 times (95% confidence interval 1.46 to 1.62) in men and by 1.21 times (1.15 to 1.28) in women. The association between a lower PS and disease risk was stronger in younger men for fatty liver and in older men for MetS. Conversely, in women, the association between a lower PS and disease risk was stronger in older women for fatty liver and in younger women for MetS. For diabetes, hypertension, and dyslipidemia, the change in the impact of PS reductions across age groups was small. The PS is a useful and simple non-invasive tool for screening Japanese people for metabolic diseases.

Key words: Balance, Flexibility, Grip strength, Screening for diseases.

Introduction

Physical fitness is a surrogate measure of many important physical functions and is a good indicator of health status (Erikssen et al., 1998). Although there are various classifications and types of physical fitness, cardiorespiratory fitness (CRF), muscular strength and endurance, balance, flexibility, and body composition are considered to be particularly important components of physical fitness related to health (Riebe et al., 2018). Of those, CRF was found to be associated with the risk of hypertension, all-cause mortality, and cardiovascular death (Blair et al., 1984; Erikssen et al., 1998), results that coincided with those of our own previous study (Kodama et al., 2009). Furthermore, we previously reported that relative grip strength and single-leg balance with eyes closed were associated with the development of type 2 diabetes (Momma et al., 2019), trunk flexibility with hypertension (Gando et al., 2021), and relative grip strength and vertical jump with dyslipidemia (Momma et al., 2021).

As indicated above, several studies have been conducted on individual physical fitness components but since physical fitness has many elements, its components are considered to be intricately interrelated. The U.S. Physical Activity Guidelines for Americans classify exercise as aerobic, anaerobic, muscle-strengthening, bone-strengthening, and balancing, but in reality, most physical activities involve a combination of some of these components (Singh et al., 2020). For example, it is already well established that a combination of aerobic and resistance exercise improves health outcomes (Warburton et al., 2006). Although the results of physical fitness tests do not necessarily accurately reflect health status, it is believed that a comprehensive evaluation of the results of multiple physical fitness tests can provide a reliable estimate of health status.

Due to limitations of time, equipment, and personnel, physical fitness tests are rarely administered in large-scale surveys or epidemiological studies. Therefore, only a limited number of studies have comprehensively assessed physical fitness using the results of physical fitness tests and examined the relationship of those results with a wide range of health outcomes (Merellano-Navarro et al., 2017). However, physical fitness tests are inexpensive, do not require blood sampling, and have the potential to assess health conditions that cannot be measured by laboratory tests. In this study, we calculated a comprehensive physical fitness index for various age groups and each sex using health examination data including results of physical fitness measurements. We then examined the association of these results and the physical fitness index with various metabolic diseases (diabetes, hypertension, dyslipidemia, fatty liver, and metabolic syndrome) in Japanese.

Methods

Participants

Our study focused on data from Japanese individuals who underwent annual health examinations for health screening by the Niigata Association of Occupational Health in Niigata, Japan. Details on health examinations by the Niigata Association of Occupational Health were provided elsewhere (Heianza et al., 2014a; Heianza et al., 2014b). Ini-

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tially included were 115,998 participants (47,255 women, 40.7%) who had an initial health examination from April 2013 through March 2019. Excluded from analysis were individuals with missing values for body mass index (BMI), abdominal circumference, systolic blood pressure (SBP), diastolic blood pressure (DBP), laboratory data such as on HbA1c, and physical fitness test data such as for grip strength. Furthermore, because there were few people examined under age 29 years or over age 70 years, persons in those age categories were excluded. Finally, 49,850 individuals (19,811 women) aged 30 - 69 years were eligible for the analysis. This study was conducted in accordance with the principles of the Declaration of Helsinki and the Japanese Ethical Guidelines with the approval of the Ethics Committee of the National Institute of Biomedical Innovation and the Faculty of Medicine, Niigata University School of Medicine [2015 - 1621]. Written informed consent was obtained from all participants.

Assessment of clinical variables

A questionnaire was used to assess smoking and history of metabolic diseases, i.e., diabetes, hypertension, dyslipidemia, fatty liver, and metabolic syndrome. Height and weight were measured without shoes or heavy clothing, and BMI (weight (kg) divided by height squared[m^2]) was calculated. Abdominal circumference was measured according to the Ministry of Health, Labour and Welfare method recommended by the National Health and Nutrition Survey. Blood pressure was measured in a sitting position. The health examination started early in the morning after ≥ 12 hours of fasting. Examination of blood samples was made using automatic clinical chemistry analyzers (HITACHI 7250, 7600, and 7700; Hitachi, Tokyo, Japan) for triglycerides, low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C). Blood glucose and HbA1c levels were determined using an automated analyzer (JCA-BM9030; JEOL, Tokyo, Japan).

Physical fitness tests

Muscle strength was measured using a grip strength dynamometer (T.K.K. 5401; Takei Scientific Instruments Co., Ltd., Niigata, Japan) with the participant in a standing position. Grip strength was measured once for each hand and values were averaged. Relative grip strength (grip strength [kg]/body weight [kg]) was calculated, as grip strength is influenced by body size (Kawamoto et al., 2016; Ramirez-Velez et al., 2016). Static balance was assessed using a stopwatch to measure the duration (s) of single-leg balance with eyes closed. Participants were asked to stand on a hard surface for 120 s with the hands on the hips. Participants performed the test a maximum of 3 trials, and the best value was used. Trunk flexibility was measured using a standing trunk flexion meter (T.K.K. 5403; Takei Scientific Instruments). Participants were asked to stand on a measurement platform, placing the toes even with the front edge of the platform, and then being asked to bend over and reach down as far as possible without bouncing, while keeping the knees locked. Performance was scored according to the distance (cm) reached by the middle fingers. Participants performed a single trial of the flexibility test. Lower extremity muscle power was assessed using a vertical jump-measuring instrument (T.K.K. 5414; Takei Scientific Instruments) which measured the time that the individual had both feet off the ground. Each individual performed two trials, and the best performance was used. Whole-body reaction time was measured using a pressure-sensing mat (T.K.K. 5408; Takei Scientific Instruments). Participants were asked to stand on the mat's sensor switch and to jump upright as quickly as possible in response to a light sign that was 2 m away from the mat. The time (ms) between the flashing of the light and the disappearance of foot pressure on the mat was measured. Participants underwent three trials, and the average of the three trials was calculated.

Type 2 diabetes mellitus (T2DM)

T2DM was defined by a fasting glucose level of ≥126 mg/dl (7.0 mmol/l), HbA1c ≥6.5%, or a self-reported history of previously diagnosed diabetes or current medication for diabetes (Assoc, 2014).

Hypertension

Hypertension was defined by systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥90 mm Hg, or a self-reported history at the health examination of previously diagnosed hypertension or current use of medication for hypertension (James et al., 2014; Umemura et al., 2019).

Dyslipidemia

Dyslipidemia was defined by hyper-LDL-cholesterolemia (≧3.6mmol/l or ≥140 mg/dl), hypertriglyceridemia (≥ 1.7 mmol/l or ≥150 mg/dl), hypo-HDL-cholesterolemia (<1.03 mmol/l or <40 mg/dl), or a self-reported history of a previous diagnosis of dyslipidemia or currently taking medication for dyslipidemia (Teramoto et al., 2013).

Fatty liver

Fatty liver was diagnosed by abdominal ultrasonography based on the following four common criteria according to guidelines for the Asia-Pacific region : bright liver (high level echoes from the hepatic parenchyma), greater echogenicity in the liver than the kidneys (sonographic contrast between the liver and right kidney), deep attenuation (attenuation of the echo penetration into deep portion of the right hepatic lobe), and vascular blurring (blurring of the hepatic vein trunk) (Chitturi et al., 2018). An ultrasound technician certified by the Japan Society of Ultrasonics in Medicine performed the examination.

Metabolic syndrome

Metabolic syndrome was diagnosed based on the International Diabetes Federation criteria for Asians. Individuals must have central obesity (waist circumference for men ≥ 90 cm, women ≥ 80 cm) plus any two of the following four additional factors: raised TG level ≥ 1.7 mmol/l (150 mg/dl); reduced HDL-C <1.03 mmol/l (40 mg/dl) in males and < 1.29 mmol/l (50 mg/dl) in females or specific treatment for these lipid abnormalities; elevated blood pressure (systolic BP ≥ 130 or diastolic BP ≥ 85 mmHg) or treatment of previously diagnosed hypertension); and elevated fasting plasma glucose (FPG ≥ 5.6 mmol/l (100 mg/dl) or previously diagnosed T2DM (Alberti et al., 2006).

Statistical analysis

First, we examined the relationship between the numerical values of each physical fitness item and each metabolic disease. The results of logistic regression analysis of the change in the prevalence of each metabolic disease for each 1-SD decrease in the numerical value of each physical fitness item are shown in Supplemental Table 1. The prevalence of diabetes mellitus, dyslipidemia, fatty liver, and metabolic syndrome increased significantly as the relative grip strength, single-leg balance with eyes closed, and forward bending decreased. Hypertension was significantly associated only with single-leg balance with eyes closed among these three items, and the prevalence of hypertension increased with decreasing values for single-leg balance with eyes closed. Reaction time was weakly associated with each metabolic disease. Results of the vertical jump were inconsistent: the prevalence of diabetes and hypertension increased with decreasing values, but the prevalence of dyslipidemia, fatty liver, and metabolic syndrome decreased with decreasing values. Based on these results, we decided to calculate a comprehensive physical fitness index using relative grip strength, single-leg balance with eyes closed, and forward bending.

Principal component analysis is a method for reducing the dimensionality of data and facilitating interpretation while minimizing the loss of information by considering the interrelationships among multiple data (Jolliffe and Cadima, 2016). It is considered to be useful in deriving a one-dimensional index from multiple physical fitness test items, as in the present study, and is often used in research evaluating physical fitness (Lee et al., 1993; Nakagaichi et al., 2018; Nishijima et al., 2006).

Principal component analysis was applied to the correlation matrices of relative grip strength, single-leg balance with eyes closed, and forward bending for each age group and sex. The first principal component score was calculated and defined as the Physical Score (PS).

As an example, the process of deriving formulas for a 50-year-old man and a 50-year-old woman is shown as follows. Principal component analysis was applied to the correlation matrices of relative grip strength, single-leg balance with eyes closed, and forward bending for a 50-year-old man. The mean ± SD and first principal component score coefficients were relative grip strength (0.63 ± 0.10, 0.631), single-leg balance with eyes closed (44.2 ± 44.5, 0.538), and forward bending (2.3 ± 8.5, 0.558), respectively. The eigenvalue of the first principal component was 1.345, explaining 44.8% of the total variance. The first principal component score is the sum of the product of the first principal component score coefficient and the standard score for each test item, and the PS for the 50-year-old man is calculated as follows.

*Physical Score (50-year-old man****)*** *= 6.392 × Relative grip strength + 0.0121 × Single-leg balance + 0.0654 × Forward bend - 4.682*

Similarly, the mean ± SD and first principal component scoring coefficients for a 50-year-old woman were relative grip strength (0.48 ± 0.08, 0.664), single-leg balance with eyes closed (49.1± 48.4, 0.562), and forward bending (8.2 ± 7.6, 0.493), respectively. The eigenvalue of the first principal component was 1.305, explaining 43.5% of the total variance.The PS for the 50-year-old woman was calculated as follows.

Physical Score (50-year-old woman) = 8.001 × Relative grip strength + 0.0116×Single-leg balance + 0.0645×Forward bend - 4.974

Individual formulas were developed for various age groups among men and women, respectively,from 30 to 69 years of age, and the PS for each age and sex was calculated. Each fomula is shown in Supplemental Table 2 and Table 3. A histogram of the calculated PS is shown in Supplemental Figure 1. The PS for both men and women was normally distributed with a value of 0 ± 1.15-1.16.

The association between the prevalence of five metabolic diseases (diabetes mellitus, hypertension, dyslipidemia, fatty liver, and metabolic syndrome) and the PS was examined using logistic regression analysis. Other covariates used were sex, age, BMI, and current smoking status. The ability of the PS to predict metabolic syndrome was examined by receiver operation characteristic (ROC) curve analyses. Analyses were performed using SPSS (version 21.0, Chicago, IL, USA) and SAS Version 9.4 (SAS Inst., Cary, NC, USA). Statistical significance was considered for $P < 0.05$.

Results

Table 1 shows the baseline characteristics of the study participants. Of the participants, 60.3% were male and the mean age was 49.8 years for men and 49.5 years for women. The prevalence of metabolic diseases (men, women) were diabetes mellitus (7.5%, 3.0%), hypertension (25.2%, 11.7%), dyslipidemia (51.2%, 32.4%), fatty liver (23.2%, 8.4%), and metabolic syndrome (11.1%, 10.9%). Compared to the results of the National Health and Nutrition Examination Survey and other surveys, the prevalence of the diseases targeted in this study was lower for diabetes, hypertension, fatty liver, and metabolic syndrome, and higher for dyslipidemia (Ministry of Health, Labour and Welfare, Japan The National Health and Nutrition Survey in Japan,2013; Eguchi et al., 2012).

Table 2 shows the association between the prevalence of each metabolic disease and the PS. The PS was used as continuous variable. In the analysis of all age groups, for every reduction of 1 in the PS, men were 1.40 times more likely to have diabetes, 1.08 times more likely to have hypertension, 1.17 times more likely to have dyslipidemia, 1.32 times more likely to have fatty liver, and 1.57 times more likely to have metabolic syndrome. For women, the same lower score resulted in a 1.10 times higher likelihood of diabetes, 1.08 times higher likelihood of hypertension, 1.10 times higher likelihood of dyslipidema, 1.16 times higher likelihood of fatty liver, and 1.21 times higher likelihood of metabolic syndrome. The associations between PS and diabetes, fatty liver, and metabolic syndrome were found to be particularly strong in men.

Table 1. Baseline characteristics of study participants.

Parameters	Men (n=30039)	Women (n=19811)
Age (years)	49.8 ± 9.7	49.5 ± 9.6
Height (cm)	170.9 ± 6.1	158.0 ± 5.6
Weight (kg)	68.2 ± 10.3	53.5 ± 8.4
BMI (kg/m^2)	23.3 ± 3.1	21.4 ± 3.2
WC (cm)	83.1 ± 8.4	77.6 ± 8.6
SBP (mmHg)	120 ± 14	112 ± 14
DBP (mmHg)	77 ± 10	70 ± 10
Hypertension,n (%)	7575(25.2)	2315(11.7)
HbA1c (%)	5.6 ± 0.6	5.5 ± 0.4
Blood glucose (mmol/l)	5.5 ± 0.9	5.1 ± 0.6
Diabetes mellitus, n (%)	2257(7.5)	599(3.0)
TG (mmol/l)	1.1(0.8-1.7)	0.8(0.6-1.1)
LDL-C (mmol/l)	3.2 ± 0.8	3.1 ± 0.8
HDL-C (mmol/l)	1.5 ± 0.4	1.8 ± 0.4
Dyslipidemia,n (%)	15382(51.2)	6409(32.4)
Fatty liver, n(%)	6983(23.2)	1659(8.4)
Metabolic syndrome, n (%)	3332(11.1)	2163(10.9)
Current smoking, n (%)	19835(66.0)	3707(18.7)
Relative grip strength mean (kg/kg)	0.62 ± 0.10	0.48 ± 0.08
median(kg/kg)	0.62(0.56-0.69)	0.48(0.43-0.54)
Single-leg balance mean (s)	40.4 ± 34.4	43.2 ± 35.9
median(s)	29.0(13.0-58.0)	31.0(15.0-62.0)
Forward bend,mean (cm)	2.0 ± 8.6	8.1 ± 8.1
median(cm)	3.0(-4.0-8.0)	9.0(3.0-14.0)
Physical score	0.0 ± 1.15	0.0 ± 1.16

BMI, body mass index, calculated as weight in kilograms divided by height in meters squared; WC, Waist circumference; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglycerides. Data are presented as mean (standard deviation) or median (interquartile range) and n(%).

Table 2. **Odds ratios of the prevalence of each** disease **according to a 1-increment reduction in the Physical Score (PS)**

	Age (years)	Men	Women
Diabetes mellitus	All Ages	1.40(1.33-1.46)	1.32(1.21-1.44)
	30-39	1.43(1.15-1.79)	1.34(0.85-2.10)
	40-49	1.50(1.35-1.67)	1.28(1.02-1.61)
	50-59	1.35(1.25-1.46)	1.35(1.17-1.55)
	60-69	1.40(1.31-1.51)	1.30(1.14-1.49)
Hypertension	All Ages	1.08(1.06-1.12)	1.08(1.04-1.14)
	30-39	1.12(1.00-1.24)	1.09(0.86-1.39)
	40-49	1.06(1.00-1.12)	1.16(1.04-1.29)
	50-59	1.07(1.02-1.12)	1.09(1.02-1.18)
	60-69	1.13(1.07-1.19)	1.04(0.97-1.12)
Dyslipidemia	All Ages	1.16(1.13-1.19)	1.09(1.06-1.23)
	30-39	1.22(1.15-1.30)	1.10(0.98-1.22)
	40-49	1.19(1.15-1.24)	1.11(1.04-1.19)
	50-59	1.14(1.09-1.19)	1.13(1.07-1.19)
	60-69	1.11(1.06-1.17)	1.02(0.96-1.09)
Fatty liver	All Ages	1.30(1.26-1.34)	1.15(1.08-1.23)
	30-39	1.35(1.25-1.47)	1.09(0.87-1.36)
	40-49	1.32(1.25-1.39)	0.99(0.87-1.12)
	50-59	1.31(1.23-1.38)	1.24(1.12-1.37)
	60-69	1.24(1.16-1.33)	1.21(1.08-1.35)
Metabolic syndrome	All Ages	1.54(1.46-1.62)	1.21(1.15-1.28)
	30-39	1.37(1.18-1.58)	1.44(1.13-1.83)
	40-49	1.53(1.40-1.68)	1.36(1.19-1.54)
	50-59	1.54(1.41-1.68)	1.16(1.06-1.27)
	60-69	1.65(1.48-1.82)	1.15(1.05-1.26)

Adjusted for age (All Ages category), BMI, smoking status (current smoking or not). Data in boldface are statistically significant

Figure 1 shows the difference in prevalence of each disease among the groups divided by age (30-39, 40 - 49, 50-59, and 60-69 years) and PS tertiles (High PS group, Middle PS group, and Low PS group).

The prevalence of each disease increased with lower PS in both men and women, but the association between lower PS and higher prevalence was particularly strong for fatty liver and metabolic syndrome in each age group. Fatty liver was more strongly affected by a lower PS in younger men and in older women. In older women, we observed an increased prevalence of fatty liver and dyslipidemia, which may be due to menopause, but among older women, a lower PS had an effect on prevalence. For hypertension and dyslipidemia, we found an association between a lower PS and higher prevalence, but the effect was not as large. The area under the curve (AUC) of the receiver operating characteristic (ROC) curve for metabolic syndrome in this study was 0.78 for men and 0.70 for women.

Figure 2 shows the number of people in each group, divided from 0 to 5 according to the number of metabolic diseases (no metabolic disease, or diabetes, hypertension, dyslipidemia, fatty liver, and metabolic syndrome). In the group with a high PS, about 70% had no metabolic disease, and less than 10% had two or more metabolic diseases. In contrast, in the group with a low PS, about 70% had one or more metabolic diseases, and nearly half had two or more metabolic diseases.

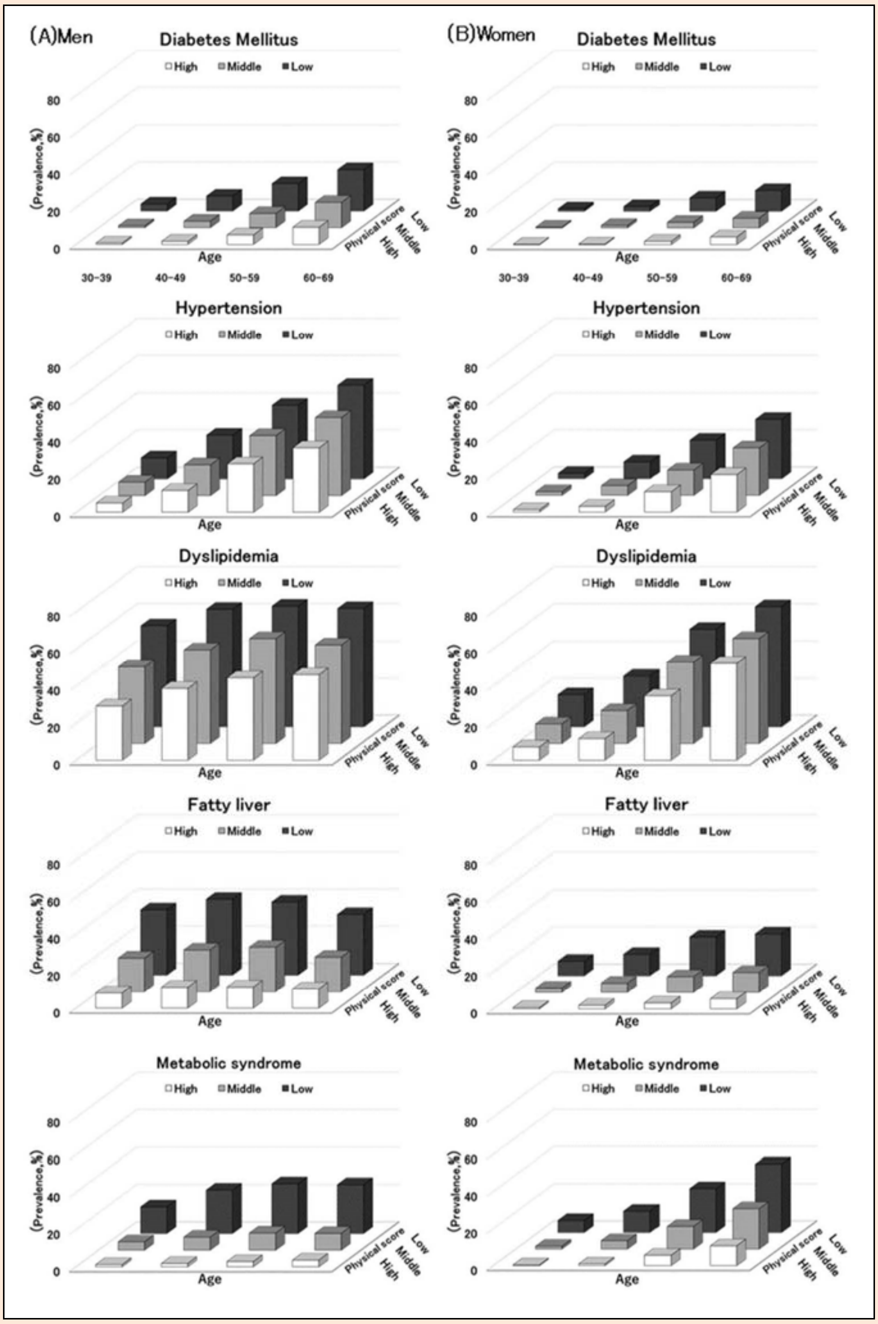

Figure 1. **Patients were divided into groups according to age (30-39, 40-49, 50-59, 60-69) and tertiles of Physical Score (High, Middle, Low). Prevalence of each disease (diabetes mellitus, hypertension, dyslipidemia, fatty liver, metabolic syndrome) is shown.**

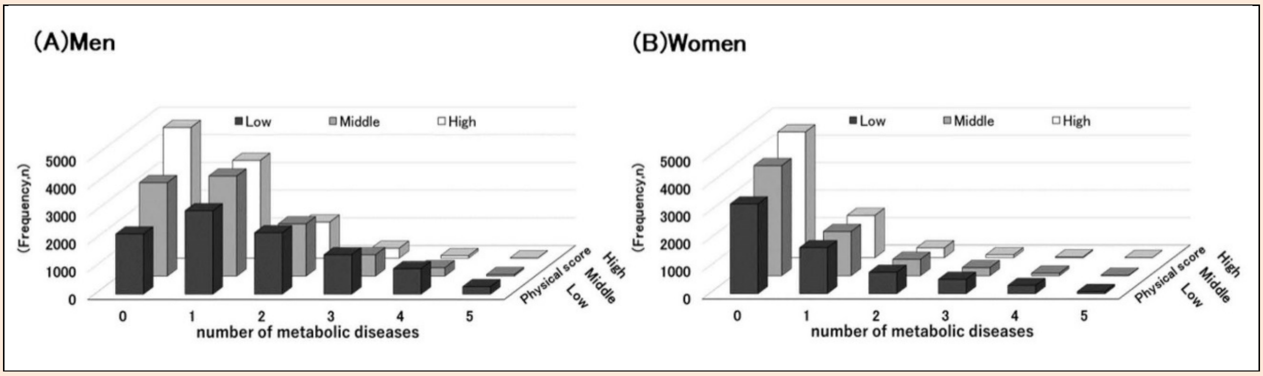

Figure 2. Patients were divided into groups according to the number of affected metabolic diseases (0-5: metabolic diseases are diabetes mellitus, hypertension, dyslipidemia, fatty liver, and metabolic syndrome) and tertiles of Physical Score (High, Middle, Low). Frequency of each groups is shown.

Discussion

The primary objective of this study was to calculate a comprehensive index of physical fitness in adults and to evaluate its association with metabolic diseases. To our knowledge, only a few large-scale studies have examined the relationship between objectively assessed overall physical fitness indices and lifestyle-related diseases (Momma et al., 2019; 2021).

The International Fitness Scale (IFIS), a five-point self-report measure of CRF, muscle strength, agility, flexibility, and overall fitness using a questionnaire, has been shown to be associated with obesity and cardiovascular metabolic risk scores (Sanchez-Lopez et al., 2015). Although the IFIS is said to correlate with actual physical fitness test results, it is not an index that is formulated using physical fitness test results.

A study in China used the sum of the Z-scores of six physical fitness components (lung capacity, standing long jump, seated body bending, muscular strength, 50 m run, and endurance run) in youths aged 7-18 years as a physical fitness indicator (PFI) to calculate an index to assess physical fitness, and its relationship with blood pressure was described (Dong et al., 2020). However, the present study is the first that we are aware of that has calculated a large-scale, comprehensive index of physical fitness in adults and examined its relationship with health outcomes.

The three items used to calculate the physical fitness score in this study, relative grip strength, single-leg balance with eyes closed, and forward bending, are items that have been described in previous studies as being associated with metabolic diseases. In our study, we also found that the risk of metabolic diseases increased with decreasing results of these physical fitness tests, so we adopted these items. We did not adopt the whole body reaction time because we could not find any mention of its association with metabolic diseases in previous studies, and its association with diseases was weak in the present study. As for vertical jump, the results were difficult to interpret in this study, as better results decreased the risk of diabetes and hypertension but increased the risk of dyslipidemia, fatty liver, and metabolic syndrome. This is contrary to previous studies, which stated that the better the vertical jump results, the lower was the future incidence of dyslipidemia (Momma et al., 2021) and that older women with metabolic syndrome have poorer vertical jump results (Vieira et al., 2013). The same result was obtained when the analysis was performed using the vertical jump weight ratio. In summary, we did not find a consistent association with the prevalence of lifestyle-related diseases and therefore did not adopt it for the calculation of the physical fitness score in this study.

The second objective of this study was to accurately assess the fitness of participants in consideration of how much their fitness deviated from the average of those in the same age and sex group. According to a 2015 report by the Sports Agency of the Ministry of Education, Culture, Sports, Science and Technology, the peak grip strength of Japanese people is in their 40s, but the peak body forward flexion is in their 10s (2021). It is difficult to accurately and comprehensively evaluate the physical fitness of people of different ages and sex, because the peak scores for different measurement items differ. In this study, we attempted to comprehensively evaluate physical fitness by principal component analysis using data from an age group for which a certain number of people of the same age can be secured so that it can be compared with the average of the same age and sex. The PS calculated in this way showed that the prevalence of each metabolic disease increased as the PS decreased, although the magnitude of the effect varied by age and sex. It is thought that even the same degree of decline in physical fitness has a different impact on the prevalence of disease depending on age and sex, and this should be taken into account when counseling patients. A healthy lifestyle, including exercise, is important for the prevention and improvement of metabolic diseases, but it can be difficult to get patients to adhere to such regimens (Sallis et al., 2015). The PS will make it easier to communicate to patients the results of an overall physical fitness assessment and disease risk according to their current status. The PS is calculated by non-invasive physical fitness measurements that do not require any special tools and can be expected to identify people who are at high risk of metabolic diseases and lead to more extensive health examinations.

Regarding the calculation of the PS it should be mentioned that the original data from the health examinations by the Niigata Association of Occupational Health used 240 seconds as the upper limit for single-leg balance with eyes closed. In this study, we calculated the physical fitness score using 120 seconds as the upper limit for single-leg balance with eyes closed for the convenience of conducting physical fitness tests in actual settings (Supple mental Table 4). The results of calculating the PS using 240 seconds as the upper limit was similar to those using 120 seconds, suggesting that using 120 seconds as the upper limit for single-leg balance with eyes closed was reasonable in clinical settings.

In terms of individual diseases, it has been reported that low scores for relative grip strength and single-leg balance with eyes closed were associated with the onset of diabetes (Momma et al., 2019). Sarcopenia, a loss of muscle mass, was shown to be an independent risk factor for diabetes (Kim et al., 2010), and it is easy to imagine a relationship between relative grip strength, which is thought to represent upper limb muscle strength, and diabetes. The diagnostic criteria for sarcopenia include decreased walking speed (Chen et al., 2020), and it has been reported that there is a correlation between decreased balance and decreased walking speed (Sugiura et al., 1998). The PS, which includes relative grip strength and single-leg balance with eyes closed, can be used to evaluate individuals who are at high risk for such problems.

As for hypertension, decreased flexibility was reported to be associated with its onset (Gando et al., 2021). It was also reported that people with hypertension have decreased static and dynamic balance function and decreased ability to perform single-leg balance with eyes closed (Ozaldemir et al., 2020). It has been speculated that the cause of this result is decreased motor processing speed in the lower limbs and an increase in heart rate. The PS included single-leg balance with eyes closed as a calculated factor, and although the association was weak, the prevalence of hypertension decreased when the PS decreased.

Decreased relative grip strength and vertical jump were associated with the onset of dyslipidemia (Momma et al., 2021). Resistance training lowers triglycerides, total cholesterol, and LDL-C and increases HDL-C (Costa et al., 2019). Also, in Americans, the higher the relative grip strength, the lower the triglycerides and the higher the HDL-C (Lawman et al., 2016). Relative grip strength was included as a calculated factor, and the prevalence of dyslipidemia increased when the PS decreased.

We found no reports on the association between fatty liver and metabolic syndrome with specific physical fitness measures such as those used in this study. However, the association between a lower PS and a higher prevalence of fatty liver and metabolic syndrome was found to be stronger than in other diseases. It has been reported that the longer one sits, the greater the risk of fatty liver and metabolic syndrome (Davies et al., 2019), and that reducing sitting time reduces the risk of fatty liver (Hallsworth et al., 2015) and metabolic syndrome (Healy et al., 2008). A high PS may suggest a high level of physical activity.

We compared previous indexes to our results regarding metabolic syndrome since we found the strongest relationship between metabolic syndrome and the Physical Score among the chronic diseases in this study. The AUCs for metabolic syndrome were reported to be approximately 0.60 to 0.76 for the body shape index (ABSI), body roundness index (BRI), and Clínica Universidad de Navarra-Body Adiposity Estimator (CUN-BAE), which are relatively well-known previously described indexes (Suliga et al., 2019). The AUCs for metabolic syndrome in this study were 0.78 for men and 0.70 for women indicating that the Physical Score may have similar predictive ability to those of the previous index. In addition, the results of physical fitness tests can be presented to patients in an easy-to-understand manner, which may be expect ed to encourage patients to modify their exercise habits.

Limitation

Several limitations should be considered. First, we did not take into account the effect of CRF because it was not included in the health examination data used in this study. CRF is an indicator that assesses cardiopulmonary function and has a significant impact on health outcomes, and that not being able to measure it in this study is a major limitation. We think that the present results must be validated with data that include CRF.

Second, from the perspective of a pure physical fitness assessment, the role of PS seems to be limited. Even with the same exercise, the degree of physical fitness varies greatly from person to person, and environmental factors such as exercise history and genetic factors are thought to have a significant impact on trainability (Bouchard et al., 1998). In addition, in this study, the physical fitness test items used to calculate the PS were selected from the viewpoint of the strength of the association with the risk of each metabolic disease. However, from the viewpoint of a pure assessment of physical fitness, the physical fitness test items that were not used in this study may also be important. It should be taken into account that PS does not always fully reflect the status of physical activity and fitness.

Third, there is a question of whether the population in this study reflects the general population. Among these data, there were fewer than 100 persons in each age group below 29 years. The PS is in the characteristic of an assessment of an individual's fitness status compared to the average for the same age and gender. Thus, we excluded persons under 29 years of age. Compared to the results of the National Health and Nutrition Examination Survey and other surveys, the prevalence of each disease in this study was lower for diabetes, hypertension, fatty liver, and metabolic syndrome, and higher for dyslipidemia. This study included persons between the ages of 30 and 69 years old, and the National Health and Nutrition Survey included persons older than 20 years old as well as the elderly. Exclusion of the elderly in this study may have contributed to the lower prevalence of some diseases analyzed. Also,since the data used in this study are health examination data, the participants could be expected to be highly health conscious. The reason for the higher prevalence of dyslipidemia in this study may be that high triglyceride levels are not reflected in the diagnosis of dyslipidemia in the National Health and Nutrition Examination Survey due to the difficulty of fasting blood sampling.Therefore, it is necessary to be cautious when applying the PS calculated here to a more general population.

Conclusion

In conclusion, the PS, which is a comprehensive assessment index of physical fitness, was significantly associated with the prevalence of each metabolic disease under consideration (diabetes, hypertension, dyslipidemia, fatty liver, and metabolic syndrome). It can be expected to be a useful tool for encouraging people to undergo health examinations and engage in exercise.

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Key points

- We developed a comprehensive physical fitness score (Physical Score) that takes into account the effects of age and sex.
- The Physical Score may be a useful and simple non-invasive tool for screening Japanese people for metabolic diseases.
- The Physical Score will make it easier to communicate to patients the results of an overall physical fitness assessment and disease risk according to their current status.

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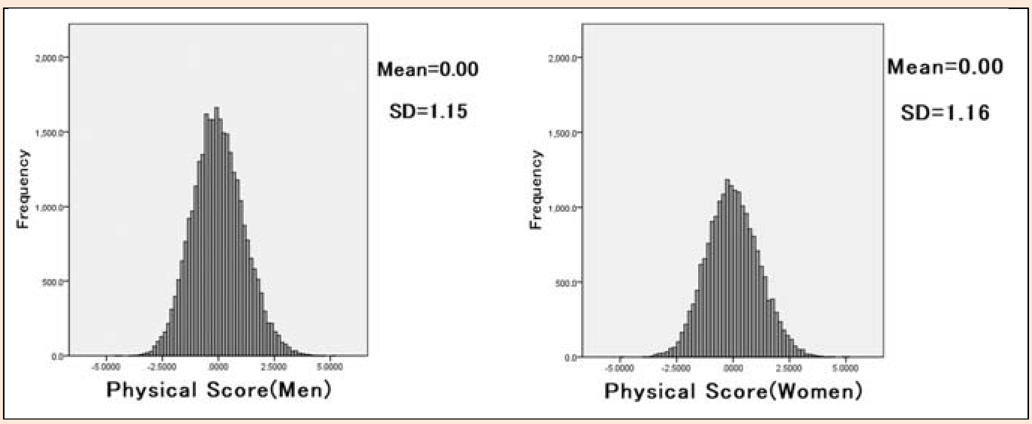
Supplementary Figures and Tables



Supplemental Figure 1. Histogram of Physical Scores for men and women.

Supplemental Table 1. **Odds ratios for the prevalence of each disease per 1 SD decrease in the value of the results of the physical fitness test.**

	Diabetes mellitus	Hypertension	Dyslipidemia	Fatty Liver	Metabolic syndrome
Relative grip strength	1.28(1.20-1.35)	1.00(0.97-1.04)	1.13(1.10-1.17)	1.33(1.28-1.39)	1.81(1.70-1.93)
Single-leg balance	1.27(1.19-1.34)	1.15(1.11-1.18)	1.10(1.07-1.12)	1.18(1.14-1.22)	1.24(1.18-1.31)
Forward bend	1.10(1.05-1.14)	1.00(0.97-1.02)	1.08(1.05-1.10)	1.16(1.13-1.19)	1.13(1.09-1.17)
Reaction time	0.99(0.95-1.04)	1.03(1.01-1.06)	1.04(1.02-1.06)	1.04(1.01-1.07)	0.99(0.95-1.02)
Vertical jump	1.11(1.05-1.17)	1.09(1.05-1.12)	0.92(0.90-0.94)	0.77(0.75-0.80)	0.85(0.81-0.89)

Adjusted for sex, age, BMI, smoking status (current smoking or not). Data in boldface are statistically significant.

Supplemental Table 2. **Mean, standard deviation, and first principal component of each physical fitness measurement item and formula for calculating physical score using them for men.**

	Average			Standard deviation			First principal component			Physical score calculation formula
Age	GWR	Balance	Flexibility	GWR	Balance	Flexibility	GWR	Balance	Flexibility	
30	0.63	85.1	1.5	0.1	70.4	8.2	0.386	0.741	0.549	3.743a+0.0105b+0.0672c-3.337
31	0.63	77	1.2	0.12	66.6	8.7	0.701	0.707	-0.097	6.075a+0.0106b-0.0111c-4.638
32	0.61	58.1	-0.5	0.11	48.2	10	0.696	0.454	0.557	6.418a+0.0094b+0.0555c-4.437
33	0.64	64.3	-0.4	0.1	62.7	8.6	0.575	0.618	-0.537	5.664a+0.0099b-0.0626c-4.276
34	0.62	64.3	0.3	0.1	57.2	9.3	0.722	0.54	0.432	6.897a+0.0094b+0.0466c-4.924
35	0.63	70.5	1.5	0.1	61.6	8.9	0.659	0.592	0.463	6.489a+0.0096b+0.0523c-4.849
36	0.63	69.1	1.4	0.11	60.4	9.2	0.672	0.445	0.592	6.341a+0.0074b+0.0643c-4.569
37	0.63	63.3	2.2	0.11	56.4	8.4	0.668	0.503	0.549	6.122a+0.0089b+0.0652c-4.589
38	0.62	62.1	2.1	0.1	54.1	8.4	0.675	0.42	0.607	6.726a+0.0078b+0.0722c-4.813
39	0.63	59	2	0.11	54.6	8.9	0.654	0.551	0.519	6.152a+0.0101b+0.0582c-4.559
40	0.63	59.5	2	0.1	55	8.5	0.628	0.565	0.535	6.028a+0.0103b+0.0626c-4.523
41	0.62	55.6	1.7	0.1	51.8	8.7	0.646	0.547	0.532	6.555a+0.0106b+0.0611c-4.774
42	0.62	55.6	1.2	0.1	51.3	8.9	0.634	0.576	0.516	6.135a+0.0112b+0.058c-4.513
43	0.62	56.5	1.6	0.1	54	8.6	0.659	0.559	0.503	6.633a+0.0104b+0.0586c-4.796
44	0.63	52.2	1.4	0.1	48.6	8.6	0.639	0.55	0.538	6.326a+0.0113b+0.0622c-4.641
45	0.62	48.2	1.5	0.1	48.3	8.6	0.648	0.549	0.529	6.447a+0.0114b+0.0613c-4.634
46	0.62	51.1	2	0.1	50.1	8.7	0.656	0.529	0.538	6.526a+0.0106b+0.0615c-4.691
47	0.62	50.3	1.8	0.1	50.4	8.7	0.633	0.568	0.526	6.174a+0.0113b+0.0603c-4.477
48	0.62	52.3	2.7	0.1	53.9	8.5	0.657	0.545	0.521	6.915a+0.0101b+0.0612c-5.006
49	0.63	46.4	1.9	0.1	48.4	8.7	0.65	0.564	0.509	6.691a+0.0117b+0.0587c-4.864
50	0.63	44.2	2.3	0.1	44.5	8.5	0.631	0.538	0.558	6.392a+0.0121b+0.0654c-4.682
51	0.63	45.9	2.3	0.09	46.2	8.4	0.619	0.586	0.523	6.659a+0.0127b+0.0624c-4.929
52	0.62	42.3	2.4	0.1	43.1	8.6	0.61	0.588	0.53	6.236a+0.0136b+0.0614c-4.589
53	0.62	41.9	2.5	0.1	42.6	8.6	0.628	0.568	0.531	6.444a+0.0133b+0.0615c-4.736
54	0.63	40.2	2.2	0.09	42.3	8.7	0.625	0.542	0.561	6.609a+0.0128b+0.0648c-4.793
55	0.63	35.9	2.2	0.09	37.4	8.3	0.648	0.527	0.551	6.843a+0.0141b+0.0663c-4.929
56	0.62	38.2	1.5	0.09	40.7	8.4	0.604	0.555	0.572	6.56a+0.0136b+0.0677c-4.717
57	0.62	35.9	2.6	0.09	37.6	8.5	0.622	0.476	0.622	6.611a+0.0126b+0.0733c-4.762
58	0.62	34.1	2.3	0.09	38.5	8.2	0.658	0.524	0.54	7.208a+0.0136b+0.0658c-5.102
59	0.62	28.4	2.4	0.09	32.5	8.5	0.619	0.57	0.54	7.001a+0.0176b+0.0636c-4.981
60	0.61	30.4	2.1	0.09	35.5	8.5	0.65	0.583	0.486	7.439a+0.0164b+0.0571c-5.165
61	0.61	25.7	2.2	0.09	26.8	8.1	0.635	0.501	0.589	6.832a+0.0187b+0.0731c-4.825
62	0.61	25.2	2.4	0.09	27	8.5	0.595	0.555	0.581	6.596a+0.0206b+0.0685c-4.723
63	0.61	23.7	2.3	0.09	27.1	8.5	0.634	0.524	0.568	6.937a+0.0193b+0.0672c-4.841
64	0.61	22.7	2	0.09	27.9	8.3	0.622	0.567	0.541	6.695a+0.0203b+0.0654c-4.694
65	0.61	20.6	3.1	0.09	24.7	8.3	0.624	0.512	0.591	7.028a+0.0207b+0.0715c-4.905
66	0.6	19	2.8	0.09	20	8.4	0.656	0.557	0.509	7.3a+0.0279b+0.0603c-5.104
67	0.6	17.8	3	0.09	19.8	8.4	0.603	0.554	0.574	6.631a+0.0279b+0.0681c-4.66
68	0.6	17.1	1.7	0.09	19.9	8.7	0.664	0.515	0.542	7.152a+0.0259b+0.062c-4.823
69	0.6	17.3	3.1	0.09	19.1	8	0.704	0.16	0.692	7.584a+0.0084b+0.0861c-4.993

GWR(Grip weight ratio):Relative grip strength, Balance: Single-leg balance, Flexibility: Forward bend

a, b, and c are the measured values of Relative grip strength, Single-leg balance, and Forward bend, respectively.

a: Relative grip strength,b: Single-leg balance,c: Forward bend.

Supplemental Table 3. **Mean, standard deviation, and first principal component of each physical fitness measurement item and formula for calculating physical score using them for women.**

	Average			Standard deviation			First principal component			Physical score calculation formula
Age	GWR	Balance	Flexibility	GWR	Balance	Flexibility	GWR	Balance	Flexibility	
31	0.5	62.7	5.7	0.08	51.2	7.9	0.711	0.043	0.701	9.03a+0.0008b+0.0891c-5.096
32	0.52	77.7	5.7	0.09	65.3	9.9	0.67	0.539	0.511	7.333a+0.0082b+0.0519c-4.726
33	0.5	65.5	5.4	0.08	64.9	9	0.714	0.599	0.362	9.332a+0.0092b+0.0401c-5.45
34	0.49	66.4	5.5	0.09	61.7	8.9	0.694	0.153	0.703	8.123a+0.0025b+0.079c-4.604
35	0.49	68.2	6.3	0.09	62.4	8.8	0.665	0.502	0.554	7.687a+0.008b+0.0629c-4.722
36	0.49	64.4	6	0.09	59.5	8.7	0.614	0.534	0.581	6.988a+0.009b+0.0667c-4.426
37	0.5	67.7	6.8	0.09	59.2	8.9	0.634	0.585	0.506	7.323a+0.0099b+0.0568c-4.698
38	0.5	67.1	6.1	0.08	61.9	8.8	0.709	0.488	0.51	8.664a+0.0079b+0.0581c-5.215
39	0.49	62.2	6.2	0.09	56	8.7	0.641	0.548	0.537	7.473a+0.0098b+0.0619c-4.69
40	0.49	58.1	5.9	0.08	55.8	8.5	0.688	0.489	0.536	8.304a+0.0088b+0.0631c-4.964
41	0.5	61.5	6.7	0.09	59	8.2	0.612	0.576	0.543	7.108a+0.0097b+0.0662c-4.611
42	0.5	64.1	7.1	0.08	58.1	9.2	0.616	0.63	0.474	7.307a+0.0108b+0.0517c-4.725
43	0.49	57.1	6.9	0.09	51.9	8.2	0.658	0.509	0.555	7.558a+0.0098b+0.0677c-4.752
44	0.5	58.1	7.3	0.09	55	7.9	0.697	0.604	0.387	7.996a+0.011b+0.0493c-5
45	0.49	58.5	7.2	0.09	55.1	8.5	0.616	0.583	0.53	6.919a+0.0106b+0.0626c-4.49
46	0.49	58.6	7.1	0.09	57.3	7.7	0.659	0.543	0.52	7.744a+0.0095b+0.0673c-4.858
47	0.49	54.8	7	0.09	51.9	7.7	0.663	0.476	0.577	7.672a+0.0092b+0.0747c-4.795
48	0.49	55.1	7.3	0.09	55.3	8.1	0.665	0.552	0.502	7.794a+0.01b+0.0618c-4.842
49	0.48	47.8	7.3	0.08	48.8	8.5	0.648	0.516	0.56	7.645a+0.0106b+0.0658c-4.675
50	0.48	49.1	8.2	0.08	48.4	7.6	0.664	0.562	0.493	8.001a+0.0116b+0.0645c-4.974
51	0.48	49.8	8.2	0.08	50.5	8.1	0.658	0.599	0.457	8.054a+0.0119b+0.0567c-4.934
52	0.48	51	8.1	0.08	54.4	7.7	0.674	0.55	0.493	8.315a+0.0101b+0.0645c-5.031
53	0.48	47.4	8.4	0.08	50	7.3	0.612	0.579	0.538	7.329a+0.0116b+0.0733c-4.66
54	0.48	40.7	8.6	0.08	40.4	7.8	0.678	0.538	0.501	8.146a+0.0133b+0.0639c-4.961
55	0.47	40	8.9	0.09	41.4	7.8	0.65	0.51	0.563	7.58a+0.0123b+0.0724c-4.729
56	0.48	42.3	10.1	0.08	45	6.9	0.636	0.549	0.542	7.776a+0.0122b+0.0789c-5.062
57	0.48	36	9.6	0.08	43.5	7	0.629	0.527	0.572	7.748a+0.0121b+0.0812c-4.965
58	0.48	37.9	9.7	0.08	42.2	7	0.643	0.544	0.539	7.922a+0.0129b+0.0771c-5.049
59	0.48	31.6	10.4	0.08	35.4	6.9	0.639	0.658	0.399	7.981a+0.0186b+0.0576c-4.994
60	0.47	35.4	10.3	0.08	41.4	7.1	0.643	0.517	0.566	7.867a+0.0125b+0.0802c-4.953
61	0.47	31.8	10.5	0.08	37.4	7.4	0.632	0.519	0.575	8.202a+0.0139b+0.0775c-5.147
62	0.47	27.6	10.5	0.08	28.9	7.4	0.65	0.502	0.57	7.764a+0.0174b+0.0772c-4.955
63	0.47	28.4	10.6	0.08	34.9	7	0.616	0.567	0.547	7.612a+0.0162b+0.0784c-4.848
64	0.47	25.7	11.3	0.08	29.3	7	0.674	0.588	0.447	8.252a+0.0201b+0.0641c-5.085
65	0.48	26	11.7	0.08	33.6	6.9	0.66	0.521	0.541	7.831a+0.0155b+0.0779c-5.042
66	0.46	21.9	10.7	0.08	22.7	7	0.693	0.326	0.643	8.467a+0.0144b+0.0919c-5.2
67	0.46	19.2	12	0.08	26.5	6.9	0.639	0.403	0.655	7.987a+0.0152b+0.0951c-5.09
68	0.46	17.1	10.3	0.08	14.7	7.4	0.675	0.63	0.384	8.896a+0.0428b+0.052c-5.331
69	0.46	18.6	12.3	0.08	21.4	7.1	0.644	0.616	0.454	7.934a+0.0288b+0.0638c-4.996

GWR(Grip weight ratio):Relative grip strength, Balance: Single-leg balance, Flexibility: Forward bend

a, b, and c are the measured values of Relative grip strength, Single-leg balance, and Forward bend, respectively.

a: Relative grip strength,b: Single-leg balance,c: Forward bend.

Supplemental Table 4. Odds ratios for the prevalence of each disease according to decrease of 1 in the Physical Score (PS). (Physical score was calculated using the upper limit of 240 seconds for the single-leg balance.)

	Age(years)	Men	Women
Diabetes mellitus	All Ages	1.40(1.34-1.47)	1.30(1.19-1.43)
	30-39	1.47(1.16-1.86)	1.29(0.81-2.05)
	40-49	1.50(1.34-1.68)	1.31(1.04-1.67)
	50-59	1.37(1.26-1.48)	1.36(1.17-1.57)
	60-69	1.40(1.30-1.51)	1.27(1.11-1.45)
Hypertension	All Ages	1.08(1.08-1.09)	1.08(1.03-1.13)
	30-39	1.10(0.99-1.23)	1.11(0.87-1.42)
	40-49	1.05(0.99-1.11)	1.13(1.02-1.27)
	50-59	1.06(1.01-1.11)	1.08(1.01-1.17)
	60-69	1.04(1.02-1.06)	1.04(0.97-1.12)
Dyslipidemia	All Ages	1.17(1.14-1.19)	1.10(1.10-1.10)
	30-39	1.23(1.16-1.31)	1.11(1.00-1.24)
	40-49	1.20(1.15-1.25)	1.11(1.04-1.19)
	50-59	1.14(1.09-1.19)	1.13(1.08-1.19)
	60-69	1.12(1.06-1.18)	1.02(0.96-1.09)
Fatty liver	All Ages	1.32(1.28-1.36)	1.16(1.09-1.23)
	30-39	1.38(1.27-1.51)	1.09(0.86-1.38)
	40-49	1.34(1.27-1.42)	0.99(0.87-1.12)
	50-59	1.32(1.24-1.40)	1.24(1.12-1.38)
	60-69	1.25(1.16-1.34)	1.21(1.08-1.36)
Metabolic syndrome	All Ages	1.57(1.49-1.65)	1.21(1.14-1.28)
	30-39	1.40(1.20-1.64)	1.44(1.12-1.86)
	40-49	1.58(1.43-1.74)	1.36(1.19-1.56)
	50-59	1.57(1.44-1.72)	1.16(1.06-1.27)
	60-69	1.67(1.50-1.86)	1.15(1.05-1.26)