resistance training successfully induced muscle hypertrophy and strength gain in older adults (Fiatarone et al., 1990; Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Harridge, Kryger, & Stensgaard, 1999). However, strenuous exercise with large mechanical stress may be associated with a risk of orthopedic injury. Pollock et al. (1991) demonstrated that approximately 20% of older adults (age 70–79 years) showed some symptoms of orthopedic injury after exercise at 1RM. In addition, a marked increase in systolic blood pressure (up to >250 mm Hg) occurred during high-intensity resistance exercise (~8RM) for large muscle groups (Fleck, 1988).

Although the effect of resistance training with low to moderate intensity has been studied for older individuals, the increase in muscle size is limited (Aniansson & Gustafsson, 1981; Moritani & deVries, 1980; Taaffe, Pruitt, Pyka, Guido, & Marcus, 1996) or much smaller than that induced by a high-intensity resistance training (Kalapotharakos et al., 2004). However, recent studies showed that relatively low-intensity (50–60% 1RM) resistance training caused significant increases in muscle size and strength, as did traditional high-intensity (80–90% 1RM) resistance training, in young untrained men (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). The exercise method they used is called low-intensity resistance exercise with slow movement and tonic force generation (LST) that is characterized as slow movement and tonic force generation (sustained contractile force with continuous electromyographic activity of working muscle). Since this type of exercise is not associated with the generation of large accelerating and decelerating force and undesirable elevation of blood pressure (Tanimoto & Ishii, 2006), LST can be a useful intervention, especially for older individuals.

Thus, the current study investigated a chronic effect of LST on muscle size and strength in older men and women. In addition, muscle oxygenation level and blood lactate and hormone concentrations were measured during and after a single bout of LST to see if the LST protocol causes acute physiological responses in older participants similar to those reported for young participants (Goto, Takahashi, Yamamoto, & Takamatsu, 2008; Tanimoto & Ishii, 2006; Tanimoto, Madarame, & Ishii, 2005; Tanimoto et al., 2008).

Methods

Participants

Forty healthy older men and women (59–76 years of age) who were active and did not engage in regular resistance exercise were recruited. They volunteered as participants after a medical screening. None of them had coronary risk factors, symptoms of cardiovascular disease, definite osteoporosis risk for compression fracture, uncontrollable hypertension, or any other medical problems associated with participation in the study. All participants were fully informed about the experiment procedures and the purpose of the study and gave written informed consent before participation. The study was approved by the local ethics committee.

Resistance-Training Procedure

The participants in each training group performed low-intensity (50% 1RM) resistance exercises for knee extension and knee flexion with isotonic resistance-exercise machines (seated knee-extension machine, Galaxy Sport, Germany, and seated knee-flexion machine, Life Fitness, USA). The range of knee-joint motion was 0–90° (0° represents full extension) in knee-extension exercise and 10–100° in knee-flexion exercise. The participants were randomly assigned to two experimental groups. One group ($n = 21$) exercised with the LST method (3-s eccentric, 3-s concentric, and 1-s isometric actions with no rest between repetitions). The other group ($n = 19$) exercised at normal speed (1-s concentric and 1-s eccentric actions with 1-s rests between repetitions, LN group). Participants in both groups repeated the movement at approximately constant speed and frequency with the aid of a metronome. In this study, we matched the intensity of exercise and the work volume (total repetition) to make the LST and LN protocols different only with respect to exercise movement. The exercise session consisted of three sets of eight repetitions with rest periods between sets of 60 s. The participants performed knee-extension exercise and then knee-flexion exercise, with a 5-min rest period between exercises. The exercises were performed twice a week for 12 weeks (2-week preparation and 10-week intervention). The exercise intensity was 50% 1RM, which was tested every 4 weeks. The initial 2 weeks served as a preparation period during which the participants gradually increased exercise intensity and volume (40% 1RM × 2 sets for the first week; 45% 1RM × 2 sets for the second week).

Measurement of Blood Lactate Concentration

Blood lactate concentration was measured before and after a single bout of exercise during 7–9 weeks of the intervention period. Blood samples were collected before, immediately after the knee-extension exercise, and immediately after the knee-flexion exercise. A preexercise blood sample was obtained after a 10-min rest (sitting on a chair). Approximately 5 μl of blood was taken from the fingertip by using a disposable lancet and immediately analyzed for lactate concentration with a lactate analyzer (Lactate Pro, Arkray, Kyoto, Japan).

Measurement of Muscle Thickness

The muscle thickness of both front (knee extensors) and back (knee flexors) portions of the left thigh was measured by B-mode ultrasound imaging, in which the experimenter was not aware of group allocation. The muscle thickness was measured before the 2-week preparation period and after the 10-week intervention. The measurements were made while the participants stood. The measurement position was the midpoint between the lateral epicondyle of the femur and the greater trochanter. Transverse images were obtained using a real-time linear electronic scanner with a 7.5-MHz scanning head (SSD-500, Aloka, Japan). The scanning head was pretreated with water-soluble transmission gel that provided acoustic contact without compressing the skin surface. The measurements were repeated three times for each portion, and the median of the three values used for analysis. The intraclass correlation coefficient and the mean coefficient of variance for the repeated measurements were .998 and 3.7%, respectively.

Measurement of Muscle Strength

Muscle strength was evaluated with a 1RM test and isometric muscle-strength test. The 1RM was defined as the largest weight the participants could lift one time only through a full range motion without noticeable countermovement. Muscle strength was measured before the 2-week preparation period and after the 10-week intervention. 1RM was determined as follows: The participant performed each exercise several times at low to high intensity (approximately 50% 1RM × four to six times and 75–85% 1RM × two to four times) as a familiarization. After familiarization, the participant tried to lift the previously determined 1RM (or the estimated 1RM for the initial test). The weight of trial was then increased by 1.25–5.0 kg in a stepwise manner until the participant could not lift the weight (the determination of 1RM typically required two or three trials). A 2-min recovery period was allowed between trials.

The maximal isometric torque of knee extension and knee flexion was measured with an isokinetic dynamometer (Cybex RZ-450, Cybex, USA), in which the experimenter was not aware of group allocation. After a brief leg-muscle stretching (approximately 15 s), participants sat on a chair with their back upright and with their left leg (nondominant side) firmly attached to the lever of the dynamometer. A pivot point of the lever was accurately aligned with the rotation axis of the knee joint, and the requisite axial alignment of joint and dynamometer axes was maintained during the movement. The isometric peak torque for both knee extension and flexion was measured at a knee angle of 60°. After the participants were familiarized with the test procedure, two trials at maximal effort were made with a 2-min recovery period, and the greater value obtained was used for analysis.

Acute Changes in Muscle Oxygenation and Blood Hormones

Acute physiological responses such as muscle oxygenation level and blood hormone concentrations during and after a single bout of exercises are thought to influence chronic muscle adaptation (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). After the completion of the 10-week intervention period, we thus measured changes in muscle oxygenation level and blood hormone concentrations in response to a single bout of exercises that were assigned to each participant during the intervention. Muscle oxygenation level was measured 1–4 weeks after the intervention period for 16 men and 15 women who completed the 10-week intervention program. Blood hormone concentrations were measured 5–6 weeks after the intervention period for 14 men and 14 women who completed the 10-week intervention. Fourteen men and 13 women participated in both measurements.

Near-infrared continuous-wave spectroscopy (NIRcws) was used to measure the oxygenation level in the left vastus lateralis muscle during and after the knee-extension exercise (BOML1TR, Omegawave Inc., Japan). The wavelengths of emission light were 780, 810, and 830 nm, and the relative concentrations of oxygenated hemoglobin and myoglobin (Oxy-Hb/Mb) in tissues were quantified according to the Beer-Lambert law (Chance, Dait, Zhang, Hamaoka, & Hagerman, 1992). Because the NIRcws signals detected during exercise do not always reflect the absolute levels of oxygenation, the muscle oxygenation level were expressed relative to the overall changes in the signal obtained according to the arterial occlusion method (Chance et al., 1992; Hampson & Piantadosi, 1988). In the current study, the resting level of Oxy-Hb/Mb was defined as 100% (baseline), and the minimum plateau level of Oxy-Hb/Mb after arterial occlusion was defined as 0%. A pressure cuff was placed around the proximal portion of the thigh and manually inflated up to 300 mm Hg until the minimum plateau level of Oxy-Hb/Mb was obtained (Bae et al., 2000). The distance between the incident point and the detector was 30 mm. The laser emitter and detector were fixed with sticky tape after being shielded with a rubber sheet. The NIRcws signals were stored on a personal computer with a data-acquisition system (Mac Laboratory/4S, AD Instruments, USA). In this study, the minimal muscle oxygenation level during exercise and the maximal muscle oxygenation level after exercise were examined as dependent variables.

For the measurement of blood hormone concentration, the participants refrained from ingesting alcohol and caffeine for 24 hr and performing any strenuous exercise for 48 hr before the exercise. Venous blood samples (10 ml for each point of measurement) were taken from the antecubital vein in a seated position. A preexercise blood sample was obtained after 30 min of rest. The exercise session started 15 min after the resting blood sample was taken. After the exercise session, blood samples were obtained 0 min (immediately after the exercise) and 20 min after the exercise and then analyzed for serum growth hormone, plasma noradrenaline, and cortisol. Serum samples were stored at 4 °C and plasma samples were stored at –20 °C until analysis. Serum and plasma samples were obtained by 10-min centrifugation at 3,000 rpm. Concentrations of growth hormone, noradrenaline, and cortisol were determined using immunoradiometric assay, high-performance liquid chromatography, and radioimmunoassay, respectively. Intra-assay coefficients of variance in these measurements were <5.0%.

Statistical Analysis

All values are expressed as *M* ± *SD*. Three-way analysis of variance (ANOVA) with a Holm post hoc procedure (Chan et al., 2007) was used to examine main effects of sex, group, and time and their interactions in all variables except muscle oxygenation level. However, none of the interaction terms that included sex was statistically significant. Therefore, for all outcome variables we report the findings from two-way ANOVAs testing the effects of group and time and their interaction. For testing the effects of sex and group and their interaction in muscle oxygenation level, two-way ANOVA with a Holm post hoc procedure (Chan et al., 2007) was used. Differences between two variables in the same group were examined with Student's paired t test. For all statistical tests, in which $p < .05$ was considered significant, the exact p value was reported with an effect size of η_p^2 (ANOVA) and r (t test).

Results

Five participants could not finish the training program, so data from 35 participants (17 men and 18 women) who completed the program were used for the analysis (Table 1). Individuals withdrew from the study for following reasons: injury

Table 1 Physical Characteristics of Participants (*M* ± *SD*)

Variable	Low-intensity resistance exercise with slow movement and tonic force generation (*n* = 18)	Low-intensity resistance exercise with normal speed (*n* = 17)
Age (years)	66.8 ± 3.8	66.8 ± 5.2
Height (cm)	158.3 ± 6.6	158.6 ± 8.5
Body mass (kg)	59.8 ± 6.6	61.0 ± 9.1

unrelated to the training intervention (1 man and 1 woman), illness (2 women), and work (1 man). The exercise adherence rate in this study was 87.5% (35/40). No significant differences between groups were found for physical characteristics, thigh-muscle thickness, or muscle strength (1RM and isometric strengths) before 2-week preparation period.

Blood Lactate Concentration

Figure 1 shows changes in blood lactate concentration measured at rest and immediately after a single bout of exercise with the LST and LN protocols. Two-way ANOVA revealed significant main effects for group, $F(1, 66) = 76.575$, $p < .001$, $\eta_p^2 = .537$, and time, $F(2, 66) = 158.925$, $p < .001$, $\eta_p^2 = .828$, which were superseded by a significant interaction of group by time, $F(2, 66) = 22.006$, $p < .001$, $\eta_p^2 = .400$. In both LST and LN groups, the blood lactate concentration significantly increased after the knee-extension exercise (LST, $p < .001$, $r = .95$; LN, $p < .001$, $r = .89$) and the knee-flexion exercise (LST, $p < .001$, $r = .95$; LN, $p < .001$, $r = .90$) from that at rest. The mean values of blood lactate concentration immediately after the exercise in LST group were significantly higher than after exercise in LN group (knee-extension exercise: $p < .001$, $r = .59$; knee-flexion exercise: $p < .001$, $r = .66$), despite the same intensity and mechanical work in the two groups.

Changes in Muscle Thickness

Table 2 shows the changes in MT of front and back portions of the thigh. In the front muscle thickness, two-way ANOVA revealed no significant main effect for group, $F(1, 33) = 0.024$, $p = .878$, $\eta_p^2 < .001$, and a significant main effect for time, $F(1, 33) = 8.864$, $p = .005$, $\eta_p^2 = .212$, which were superseded by a significant interaction of group by time, $F(1, 33) = 5.898$, $p = .021$, $\eta_p^2 = .152$. The front muscle thickness significantly increased after LST training ($p < .001$, $r = .67$), whereas no such change was observed after LN training ($p = .731$, $r = .09$). The change in the

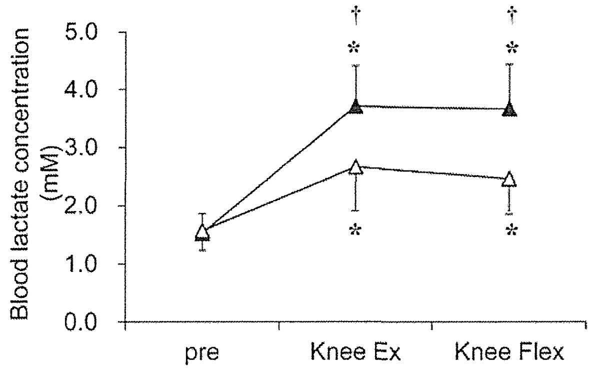

Figure 1 — Changes in blood lactate concentrations before and immediately after exercises with slow movement and tonic force generation (filled, $n = 18$) and normal speed (open, $n = 17$), $M \pm SD$. Ex = extension; flex = flexion. *$p < .05$; significant difference between pre- and postexercise. †$p < .05$; significant difference between groups.

Table 2 Pre- and Posttraining Values for Muscle Thickness, mm ($M \pm SD$)

	LST (n = 18)		LN (n = 17)	
Variable	**Pre**	**Post**	**Pre**	**Post**
Front portion of the thigh	41.3 ± 6.6	43.8 ± 7.0	42.3 ± 4.7	42.6 ± 4.3
Back portion of the thigh	56.8 ± 5.6	60.1 ± 5.0	60.5 ± 6.3	62.6 ± 4.9

Note. LST = low-intensity resistance exercise with slow movement and tonic force generation; LN = low-intensity resistance exercise with normal speed. For details about statistical results, see text.

front muscle thickness was significantly larger in the LST group than in the LN group (p = .038, r = .39).

In the back muscle thickness, two-way ANOVA revealed significant main effects for group, $F(1, 33) = 16.762$, $p < .001$, $\eta_p^2 = .337$, and time, $F(1, 33) = 12.270$, $p = .001$, $\eta_p^2 = .271$, which were superseded by no significant interaction of group by time, $F(1, 33) = 0.636$, $p = .431$, $\eta_p^2 = .019$.

Changes in Muscle Strength

Table 3 shows the changes in 1RM and isometric strength for knee-extension and knee-flexion exercises. In the knee-extension 1RM, two-way ANOVA revealed no significant main effect for group, $F(1, 33) = 0.408$, $p = .527$, $\eta_p^2 = .012$, and a significant main effect for time, $F(1, 33) = 62.809$, $p < .001$, $\eta_p^2 = .656$, which were superseded by no significant interaction of group by time, $F(1, 33) = 0.048$, $p = .829$, $\eta_p^2 = .001$. In the knee-flexion 1RM, two-way ANOVA revealed no significant main effect for group, $F(1, 33) = 0.002$, $p = .964$, $\eta_p^2 < .001$, and a significant main effect for time, $F(1, 33) = 128.495$, $p < .001$, $\eta_p^2 = .796$, which were superseded by no significant interaction of group by time, $F(1, 33) = 1.449$, $p = .237$, $\eta_p^2 = .042$.

In knee-extension isometric strength, two-way ANOVA revealed no significant main effect for group, $F(1, 33) = 2.569$, $p = .119$, $\eta_p^2 = .072$, and a significant main effect for time, $F(1, 33) = 18.909$, $p < .001$, $\eta_p^2 = .364$, which were superseded by no significant interaction of group by time, $F(1, 33) = 1.304$, $p = .262$, $\eta_p^2 = .038$. In knee-flexion isometric strength, two-way ANOVA revealed significant main effects for group, $F(1, 33) = 6.295$, $p = .017$, $\eta_p^2 = .160$, and time, $F(1, 33) = 78.980$, $p < .001$, $\eta_p^2 = .705$, which were superseded by no significant interaction of group by time, $F(1, 33) = .955$, $p = .336$, $\eta_p^2 = .028$.

Muscle Oxygenation Level

Figure 2 shows minimal and maximal oxygenation levels in the left vastus lateralis muscle during and after the knee-extension exercise with the LST and LN protocols. In both groups, the muscle oxygenation level showed a gradual decrease during the exercise and a rapid recovery followed by an overshoot after the exercise. In the minimal oxygenation level during exercise, two-way ANOVA revealed a significant main effect for sex, $F(1, 27) = 10.608$, $p = .003$, $\eta_p^2 = .282$, and no significant main effect for group, $F(1, 27) = 0.545$, $p = .467$, $\eta_p^2 = .020$, which were superseded by

Table 3 Pre- and Posttraining Values for 1RM and Isometric Strength (*M* ± *SD*)

	LST (*n* = 18)		LN (*n* = 17)	
Variable	**Pre**	**Post**	**Pre**	**Post**
1RM (kg)				
knee extension	47.9 ± 11.2	51.7 ± 12.2	47.7 ± 13.5	51.3 ± 14.2
knee flexion	42.9 ± 9.6	51.2 ± 10.9	43.7 ± 11.3	51.2 ± 12.3
Isometric peak torque (N · m)				
knee extension	127.6 ± 43.1	149.7 ± 42.9	138.7 ± 43.5	151.5 ± 49.8
knee flexion	66.3 ± 20.7	78.7 ± 23	64.4 ± 16.4	74.3 ± 18.7

Note. LST = low-intensity resistance exercise with slow movement and tonic force generation; LN = low-intensity resistance exercise with normal speed; 1RM = one-repetition maximum.

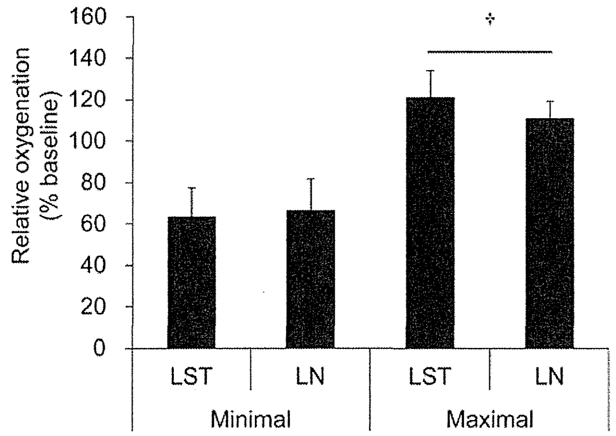

Figure 2 — Minimal and maximal oxygenation levels in the vastus lateralis muscle during and after knee-extension exercise, $M \pm SD$ (LST = low-intensity resistance exercise with slow movement and tonic force generation, $n = 16$; LN = low-intenstiy resistance exercise with normal speed, $n = 15$). †$p < .05$; significant difference between groups.

no significant interaction of sex by group, $F(1, 27) = 0.730$, $p = .400$, $\eta_p^2 = .026$. No significant difference was observed in the minimal oxygenation level between LST and LN groups.

In the maximal oxygenation level after exercise, two-way ANOVA revealed no significant main effect for sex, $F(1, 27) = 1.644$, $p = .211$, $\eta_p^2 = .045$, and a significant main effect for group, $F(1, 27) = 6.479$, $p = .017$, $\eta_p^2 = .156$, which were superseded by no significant interaction of sex by group, $F(1, 27) = 0.004$, $p = .952$, $\eta_p^2 < .001$. The maximal oxygenation level was significantly higher in LST than in LN ($p = .018$, $r = .42$; Figure 2).

Blood Hormone Concentrations

Figure 3 shows changes in concentrations of serum growth hormone, plasma noradrenaline, and plasma cortisol measured at rest and after exercise in the LST and LN protocols. In the concentrations of serum growth hormone, two-way ANOVA revealed significant main effects for group, $F(1, 52) = 16.745, p < .001, \eta_p^2 = .244$, and time, $F(2, 52) = 4.472, p = .016, \eta_p^2 = .147$, which were superseded by no significant interaction of group by time, $F(2, 52) = 0.472, p = .627, \eta_p^2 = .018$. In the concentrations of plasma noradrenaline, two-way ANOVA revealed significant

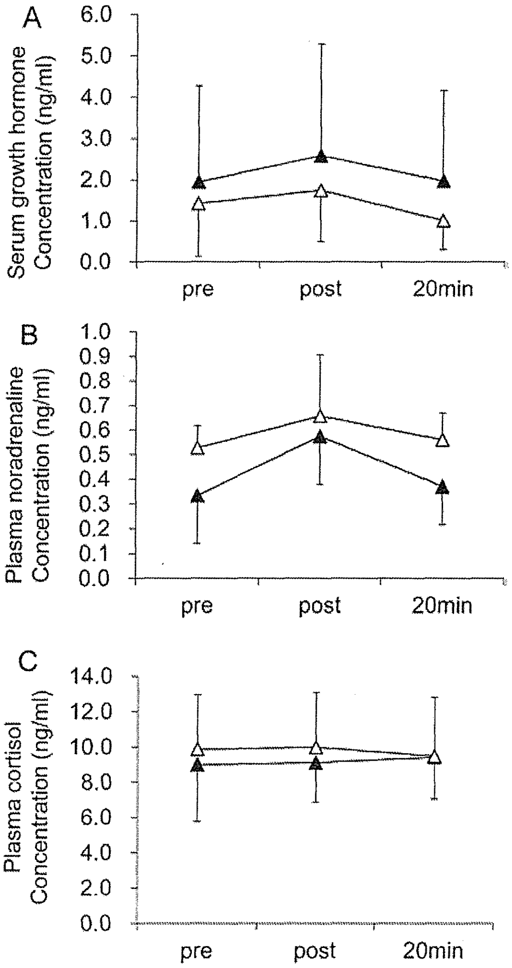

Figure 3 — Changes in concentrations of serum growth hormone, plasma noradrenaline, and cortisol before and after exercises with slow movement and tonic force generation (filled, $n = 15$) and normal speed (open, $n = 13$), $M \pm SD$. pre = preexercise; post = immediately after exercise; 20 min = 20 min after exercise.

main effects for group, $F(1, 52) = 50.220$, $p < .001$, $\eta_p^2 = .491$, and time, $F(2, 52) = 28.278$, $p < .001$, $\eta_p^2 = .521$, which were superseded by no significant interaction of group by time, $F(2, 52) = 2.720$, $p = .075$, $\eta_p^2 = .095$. In the concentrations of plasma cortisol, two-way ANOVA revealed no significant main effects for group, $F(1, 52) = 2.134$, $p = .156$, $\eta_p^2 = .039$, and time, $F(2, 52) = 0.027$, $p = .973$, $\eta_p^2 = .010$, which were superseded by no significant interaction of group by time, $F(2, 52) = 0.418$, $p = .661$, $\eta_p^2 = .016$. These results indicate no significant differences in the changes in blood hormone concentrations between the LST and LN groups.

Discussion

This study demonstrates three important findings for participants age 59–76 years: (a) Muscle thickness and strength of the knee extensors and flexors increased after 12 weeks (2-week preparation and 10-week intervention) of low-intensity (50% 1RM) resistance training with slow movement and tonic force generation (LST), (b) strength of the knee extensors and flexors but not muscle thickness of the knee extensors increased after a 12 weeks (2-week preparation and 10-week intervention) of low-intensity (50% 1RM) resistance-exercise training with normal speed (LN), and (c) there were no differences in acute physiological responses to a single bout of exercises, such as changes in blood hormone concentrations and the minimal muscle oxygenation level, between the LST and LN groups.

Kalapotharakos et al. (2004) compared the hypertrophic effect of high-intensity resistance training with that of moderate intensity. They concluded that muscle strength and mass can be improved in older participants with both high- and moderate-intensity resistance training, but high-intensity resistance training can cause greater increases in muscle size and strength. According to their report, moderate-intensity resistance training (60% 1RM) caused a 7.1% increase in the cross-sectional area (CSA) of quadriceps and a 7.9% increase in the CSA of hamstrings, as well as 6.3–13.4% increases in isokinetic knee-extension and -flexion strength, in older individuals (Kalapotharakos et al., 2004). In the current study, the LST intervention caused a 6.5% increase in front muscle thickness, a 6.1% increase in back muscle thickness, and 20.5% increases in both isometric knee-extension and isometric knee-flexion strength. It should be noted that in this study, we measured muscle thickness, the increase in which is theoretically proportional to the square root of the increase in muscle CSA. Thus, the muscle CSA might increase by as much as 10%. Previous studies showed that LST caused significant increases in muscle size and strength, as did traditional high-intensity (80–90% 1RM) resistance training, in young untrained men (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). Therefore, it is possible that the effect of LST is as large as that of traditional high-intensity resistance training, even for older adults.

The current study showed significant increases in all strength measures after both LST and LN training (Table 3). Thus, it can be interpreted that the LN protocol effectively caused an increase in strength, as did LST, while its hypertrophic effect was smaller than that of LST. This is probably because muscle strength is primarily related to neural factors—that is, the ability to recruit motor units—in addition to muscle CSA (Ikai & Fukunaga, 1970). In particular, 1RM strength is influenced by the "learning effect" of repeated exercise bouts (Rutherford & Jones, 1986). Because of the absence of a sedentary control group in this study, an additional study is needed to examine the contribution of learning effect to strength gain. Taaffe et al. (1996) reported that low-intensity resistance training (40% 1RM) caused a 41.5% gain in 1RM strength in leg exercise. Vincent et al. (2002) also reported that low-intensity resistance training (50% 1RM) increased 1RM strength of knee extension and flexion by 10.8% and 25.3%, respectively. In the current study, an intervention of low-intensity resistance training (LST or LN) caused 7.8–20.1% increases in knee extension and flexion, which is lower than previous reports (Taaffe et al., 1996; Vincent et al., 2002). The variability in strength gain might be attributable to the differences in age of participants, their initial physical activity levels, and exercise regimens. However, to prevent sarcopenia, LST, with its higher possibility to induce muscle hypertrophy, would be more desirable than LN.

In the current study, muscle hypertrophy of both knee extensors and knee flexors was induced only by LST. The primary factors responsible for LST's effect would be the continuous muscle action (3-s eccentric, 3-s concentric, and 1-s isometric force generation), because the relative intensity and the amount of mechanical work for LST were the same as those for LN. Although the precise mechanisms underlying LST's chronic effect remain unclear, the suppression of both blood inflow to and outflow within the working muscle due to continuous force generation at >40% maximum voluntary contraction (Bonde-Petersen, Mork, & Nielsen, 1975; Koba et al., 2004) is considered important (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). The acute physiological responses to continuous force generation throughout exercise movement might be related to the effect of the LST intervention (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). Previous studies (Goto et al., 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2005; Tanimoto et al., 2008) reported that the acute responses to LST in young men have the following characteristics: much lowered peripheral muscle oxygenation level during exercise, elevated peripheral muscle oxygenation level immediately after exercise, increased blood lactate concentration after exercise, and increased circulating anabolic hormones such as growth hormone after exercise, and the magnitude of changes in LST has been shown to be much larger than in LN for all of these factors. However, in the current study, the acute responses to LST in older participants were different from those in young men (Figures 1–3). A possible reason for the discrepancy in the acute responses to LST between old and young participants is that the current LST protocol would not cause a sufficient restriction of muscle blood flow. Muscle atrophy with aging may attenuate contraction-associated increases in intramuscular pressure, thereby causing an insufficient restriction of muscle blood flow during LST. It has been also reported that arterial stiffness increases with aging (Vaitkevicius et al., 1993), and this may be a factor for the attenuation of contraction-induced reduction in muscle blood flow. The attenuated restriction of muscle blood flow during contraction may account for the lack of a significant difference in the minimal oxygenation level between LST and LN (Figure 2). It is also possible that the smaller decrease in muscle oxygenation level during LST causes smaller accumulation of metabolic subproducts such as lactate and proton, which has been shown to be related to the hypophyseal secretion of growth hormone (Kraemer & Ratamess, 2005; Takarada et al., 2000). In addition, preferential atrophy of Type II muscle fibers with aging (Lexell, 1995; Lexell, Taylor, & Sjostrom, 1988) may influence lower blood lactate concentration during LST in older participants, because lactate is mainly produced in Type II muscle fibers (Brooks, 2000). However, the interpretations of acute physiological responses to a single bout of exercise are associated with several limitations in this study. One limitation is that blood lactate concentration was measured shortly before the end of the intervention (at 7–9 weeks). Although adaptations to exercise might occur, there was a significant difference between LST and LN. Another limitation is that muscle oxygenation level and blood hormone concentrations were measured 1–6 weeks after the intervention period. Thus, they might have been subject to the effect of detraining.

This study demonstrated that the LST intervention effectively increased muscle size and strength in older participants without the acute responses that have been observed in young participants (Goto et al., 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2005; Tanimoto et al., 2008). Although the exact mechanism remains unclear, a long contraction time and thus large mechanical impulse (force–time integral) may be related to the muscle hypertrophy and strength gain. In this study, we matched the intensity of exercise (50% 1RM) and the work volume (8 repetitions × 3 sets) to make the LST and LN protocols different only with respect to exercise movement. However, total contraction time in LST was much longer than that in LN (7 s × 8 repetitions × 3 sets = 168 s for LST, and 2 s × 8 repetitions × 3 sets = 48 s for LN). Therefore, it is possible that LN is also effective in increasing muscle size if the total contraction time is the same as that for LST. In fact, low-intensity resistance training with a long total contraction time has been reported to significantly increase muscle size and strength (Holm et al., 2008; Westcott et al., 2001). However, increasing the total contraction time in LN is necessarily associated with an increase in work volume and resulting metabolic and cardiovascular stress. Therefore, we believe that LST is more desirable for older adults, in particular when their physical strength is exceptionally low. Research is needed comparing both acute and chronic effects between LST and LN with the same intensity and total contraction time.

In conclusion, LST is effective in increasing muscle size and strength, even for older individuals. Since LST exercise is low intensity and bears lower risk for orthopedic injury and cardiac events (Tanimoto & Ishii, 2006), this should be useful as a countermeasure against sarcopenia. However, the exact mechanisms underlying the muscle-hypertrophic effect of LST in older participants still remain unclear and need further elucidation.

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References

Aniansson, A., & Gustafsson, E. (1981). Physical training in elderly men with special reference to quadriceps muscle strength and morphology. *Clinical Physiology (Oxford, England), 1*(1), 87–98. doi:10.1111/j.1475-097X.1981.tb00876.x

Bae, S.Y., Hamaoka, T., Katsumura, T., Shiga, T., Ohno, H., & Haga, S. (2000). Comparison of muscle oxygen consumption measured by near infrared continuous wave spectroscopy during supramaximal and intermittent pedalling exercise. *International Journal of Sports Medicine, 21*(3), 168–174. PubMed doi:10.1055/s-2000-8880

Bonde-Petersen, F., Mork, A.L., & Nielsen, E. (1975). Local muscle blood flow and sustained contractions of human arm and back muscles. *European Journal of Applied Physiology and Occupational Physiology, 34*(1), 43–50 10.1007/BF00999914. PubMed doi:10.1007/BF00999914

Brooks, G.A. (2000). Intra- and extra-cellular lactate shuttles. *Medicine and Science in Sports and Exercise, 32*(4), 790–799. PubMed doi:10.1097/00005768-200004000-00011

Chan, A.O., Jim, M.H., Lam, K.F., Morris, J.S., Siu, D.C., Tong, T., . . . Lam, S.K. (2007). Prevalence of colorectal neoplasm among patients with newly diagnosed coronary artery disease. *Journal of the American Medical Association, 298*(12), 1412–1419. doi:10.1001/jama.298.12.1412

Chance, B., Dait, M.T., Zhang, C., Hamaoka, T., & Hagerman, F. (1992). Recovery from exercise-induced desaturation in the quadriceps muscles of elite competitive rowers. *The American Journal of Physiology, 262,* C766–C775. PubMed

Evans, W. J. (1995). What is sarcopenia? *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 50*(Spec. Iss.), 5–8. doi:10.1093/gerona/50A.Special_Issue.5

Fiatarone, M.A., Marks, E.C., Ryan, N.D., Meredith, C.N., Lipsitz, L.A., & Evans, W.J. (1990). High-intensity strength training in nonagenarians. Effects on skeletal muscle. *Journal of the American Medical Association, 263*(22), 3029–3034. PubMed doi:10.1001/jama.1990.03440220053029

Fleck, S.J. (1988). Cardiovascular adaptations to resistance training. *Medicine and Science in Sports and Exercise, 20*(5, Suppl) S146–S151. PubMed

Frontera, W.R., Meredith, C.N., O'Reilly, K.P., Knuttgen, H.G., & Evans, W.J. (1988). Strength conditioning in older men: Skeletal muscle hypertrophy and improved function. *Journal of Applied Physiology, 64*(3), 1038–1044. PubMed

Goto, K., Takahashi, K., Yamamoto, M., & Takamatsu, K. (2008). Hormone and recovery responses to resistance exercise with slow movement. *Journal of Physiological Sciences, 58*(1), 7–14. doi:physiolsci/RP003107

Hampson, N.B., & Piantadosi, C.A. (1988). Near infrared monitoring of human skeletal muscle oxygenation during forearm ischemia. *Journal of Applied Physiology, 64*(6), 2449–2457. PubMed

Harridge, S.D., Kryger, A., & Stensgaard, A. (1999). Knee extensor strength, activation, and size in very elderly people following strength training. *Muscle & Nerve, 22*(7), 831–839. PubMed doi:10.1002/(SICI)1097-4598(199907)22:7<831::AID-MUS4>3.0.CO;2-3

Holm, L., Reitelseder, S., Pedersen, T. G., Doessing, S., Petersen, S. G., Flyvbjerg, A., . . . Kjaer, M. (2008). Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity. *Journal of Applied Physiology, 105*(5), 1454–1461. doi:10.1152/japplphysiol.90538.2008

Ikai, M., & Fukunaga, T. (1970). A study on training effect on strength per unit cross-sectional area of muscle by means of ultrasonic measurement. *Internationale Zeitschrift für angewandte Physiologie, einschliesslich Arbeitsphysiologie, 28*(3), 173–180. PubMed

Kalapotharakos, V.I., Michalopoulou, M., Godolias, G., Tokmakidis, S.P., Malliou, P.V., & Gourgoulis, V. (2004). The effects of high- and moderate-resistance training on muscle function in the elderly. *Journal of Aging and Physical Activity, 12*(2), 131–143. PubMed

Koba, S., Hayashi, N., Miura, A., Endo, M., Fukuba, Y., & Yoshida, T. (2004). Pressor response to static and dynamic knee extensions at equivalent workload in humans. *Japanese Journal of Physiology, 54*(5), 471–481 10.2170/jjphysiol.54.471. PubMed doi:10.2170/jjphysiol.54.471

Kraemer, W.J., & Ratamess, N.A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine, 35*(4), 339361.

Lexell, J. (1995). Human aging, muscle mass, and fiber type composition. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 50*(Spec. Iss.), 11–16. doi:10.1093/gerona/50A.Special_Issue.11

Lexell, J., Taylor, C.C., & Sjostrom, M. (1988). What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *Journal of the Neurological Sciences, 84*(2-3), 275–294. PubMed doi:10.1016/0022-510X(88)90132-3

McDonagh, M.J., & Davies, C.T. (1984). Adaptive response of mammalian skeletal muscle to exercise with high loads. *European Journal of Applied Physiology and Occupational Physiology, 52*(2), 139–155 10.1007/BF00433384. PubMed doi:10.1007/BF00433384

Moritani, T., & deVries, H.A. (1980). Potential for gross muscle hypertrophy in older men. *Journal of Gerontology, 35*(5), 672–682. PubMed

Pollock, M.L., Carroll, J.F., Graves, J.E., Leggett, S.H., Braith, R.W., Limacher, M., & Hagberg, J.M. (1991). Injuries and adherence to walk/jog and resistance training programs in the elderly. *Medicine and Science in Sports and Exercise, 23*(10), 1194–1200. PubMed

Rutherford, O.M., & Jones, D.A. (1986). The role of learning and coordination in strength training. *European Journal of Applied Physiology and Occupational Physiology, 55*(1), 100–105. PubMed doi:10.1007/BF00422902

Taaffe, D.R., Pruitt, L., Pyka, G., Guido, D., & Marcus, R. (1996). Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clinical Physiology (Oxford, England), 16*(4), 381–392. PubMed doi:10.1111/j.1475-097X.1996.tb00727.x

Takarada, Y., Nakamura, Y., Aruga, S., Onda, T., Miyazaki, S., & Ishii, N. (2000). Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *Journal of Applied Physiology, 88*(1), 61–65. PubMed

Tanimoto, M., & Ishii, N. (2006). Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. *Journal of Applied Physiology, 100*(4), 1150–1157.

Tanimoto, M., Madarame, H., & Ishii, N. (2005). Muscle oxygenation and plasma growth hormone concentration during and after resistance exercise: comparison between "Kaatsu" and other types of regimen. *International Journal of KAATSU Training Research, 2,* 53–58.

Tanimoto, M., Sanada, K., Yamamoto, K., Kawano, H., Gando, Y., Tabata, I., . . . Miyachi, M. (2008). Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *Journal of Strength and Conditioning Research, 22*(6), 1926–1938. PubMed doi:10.1519/JSC.0b013e318185f2b0

Vaitkevicius, P.V., Fleg, J.L., Engel, J.H., O'Connor, F.C., Wright, J.G., Lakatta, L.E., . . . Lakatta, E.G. (1993). Effects of age and aerobic capacity on arterial stiffness in healthy adults. *Circulation, 88,* 1456–1462. PubMed doi:10.1161/01.CIR.88.4.1456

Vincent, K.R., Braith, R.W., Feldman, R.A., Magyari, P.M., Cutler, R.B., Persin, S.A., . . . Lowenthal, D.T. (2002). Resistance exercise and physical performance in adults aged 60 to 83. *Journal of the American Geriatrics Society, 50*(6), 1100–1107.

Westcott, W.L., Winett, R.A., Anderson, E.S., Wojcik, J.R., Loud, R.L., Cleggett, E., & Glover, S. (2001). Effects of regular and slow speed resistance training on muscle strength. *The Journal of Sports Medicine and Physical Fitness, 41*(2), 154–158. PubMed

Wolfson, L., Judge, J., Whipple, R., & King, M. (1995). Strength is a major factor in balance, gait, and the occurrence of falls. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 50*(Spec. Iss.), 64–67. doi:10.1093/gerona/50A.Special_Issue.64

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原　著

健康づくりのための運動基準2006における身体活動量の基準値週23メッツ・時と1日あたりの歩数との関連

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Translating from 23METs-h/wk as physical activity reference value for Japanese to daily step counts

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Abstract A physical activity reference value for health promotion, 23 METs-h/week was established by the Ministry of Health, Welfare, and Labour in Japan in 2006. The purpose of this study was to determine the daily step counts (steps/day) that classify adults as meeting the 23 METs-h/week reference value by using objective measurements. Objectively measured physical activity levels of 1837 Japanese adults aged from 23 - 69 yrs from both urban and rural Japanese cohorts were provided. Amount of physical activity and daily step counts were assessed using a triaxial accelerometer (Actimarker EW4800; Panasonic Electric Works). Receiver operating characteristics (ROC) curve analysis determined the optimal daily step counts (steps/day) that discriminated adults who met the reference value from those who did not. Approximately 48 % of Japanese adults met the 23 METs-h/week of physical activity reference value. ROC curve analysis found that 9341 steps/day produced 77.1 % of sensitivity and 79.5 % of specificity in all subject. When the analysis was performed in each cohort, 9980 steps/day and 8640 steps/day were indicated as the optimal daily step counts for them to meet 23 METs-h/week in urban and rural cohort, respectively. These data suggest that Japanese adults are likely to meet 23 METs-h/week of physical activity reference value if they accumulate between 8500 and 10,000 steps/day of daily step counts.

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Keywords : Physical activity, Reference value, Health promotion, ROC curve

緒　言

身体活動・運動習慣や食習慣などの生活習慣は，肥満や生活習慣病の発症に関わっており，多くの研究において，身体活動・運動を増大させることは，それらの発症を予防すると報告している[1-4]．さらに，それらを予防・改善するための身体活動・運動に関するガイドラインが，多くの国や機関から出されており[5-7]，日本においても，2006年に厚生労働省から「健康づくりのための運動基準2006」（以下，運動基準）が発表され，健康づくりのための身体活動量の基準値として週23メッツ・時が提唱された[8,9]．

日本における運動基準では，各運動強度の単位メッツと時間（時）の積であるメッツ・時を用いて身体活動量の基準値を示しているが，専門家には受け入れやすいものの，一般国民には理解が困難な場合が多い．身体活動量の増大をめざしたポピュレーションアプローチにおいては，身体活動量の基準値である週23メッツ・時をより平易な語句に変換し，一般国民が理解しやすい言葉で普及・啓発させることが必要である．近年では，歩数計を用いた介入研究の生活習慣病予防の有効性も示されており[10,11]，また身体活動ガイドラインを歩数で示すことの

重要性が提唱されている[12]．

欧米においても各国のガイドラインにおいて提唱されている「中強度の身体活動を少なくとも１日30分」を，歩数で示す試みが行われてきた[13-18]．Macfarlaneらは，15～55歳の男女49名を対象に，歩数計と加速度計を用い，中強度の身体活動30分は，歩数にすると１日8000歩に相当することを示した[14]．また，Adamsらは，子供を対象に，推奨量である「中強度の身体活動を60分」に相当する歩数を，ROC曲線を用いて算出すると１日9930歩であることを報告している[13]．日本においても，Tanakaらにより，４～６歳の子供157名を対象に，中強度の身体活動60分に対する歩数として１日9934歩であることが示された[16]．歩数計は，質問紙法による身体活動量評価よりも主観が入りにくく客観性が高い．歩数計とともに最近では加速度計も使用されるが，これら２つの機器のうち，歩数計はより安価であり，使用法が簡便である[19,20]．また，歩数計からの歩数データは，加速度計の身体活動量データとよく相関している[21]．加えて，歩数計を用いた認知行動的介入が身体活動の増加に有効であることが示されている[11]．したがって，運動基準で示されている身体活動量の基準値である週23メッツ・時を歩数に変換することは，国民がこの基準を活用する上で有用であると思われる．

運動基準を国民に広く普及させるための「健康づくりのための運動指針2006＜エクササイズガイド2006＞」(以下，エクササイズガイド）では，週23メッツ・時を歩数に換算し，１日あたりおよそ8000～10,000歩と推定している[9]．しかしながら，これは，週23メッツ・時＝１日3.3メッツ・時が３～４メッツの強度の歩行もしくはそれと同等の身体活動を１日あたり１時間程度行うのに相当（10分あたり1000歩とすると，約6000歩に相当）し，これに加えて日常生活で意識されない間欠的な低強度の歩行による歩数が2000～4000歩であるという推定から示されたものであり，科学的根拠が不十分であると言わざるをえない．そこで本研究は，運動基準で示された身体活動の基準値週23メッツ・時をより平易な指標である歩数に変換し，運動基準ならびにエクササイズガイドのさらなる普及･啓発を促す手だてとすることを目的に行う．また，地域差や，肥満者と非肥満者，若齢者と高齢者といった集団特性の差が，これらメッツ・時と歩数との関連に違いをもたらすかについても検討することを目的とした．

研究方法

対象　本研究の対象者は，東京都を中心としたコホートであるNutrition and Exercise Intervention Study（NEXIS）（ClinicalTrials.gov Identifier：NCT00926744）に登録されている909名，および，長野県佐久市を中心としたコホートであるSaku Control Obesity Program（SCOP）に登録されている2175名のうち，下記の基準を満たす1837名を対象とした．NEXISコホートでは，地域住民への広告や企業等での募集により研究への参加を募り，その参加基準としては運動が禁忌でないものとした．SCOPコホートにおいては，総合病院の人間ドック受診者を対象に研究参加を募った．両コホート登録者3084名のうち，加速度計データが欠損している530名（17.2%）を除外した．また自記式の問診票により，現病歴等を聞き取り，脳血管疾患，腎臓病等の重篤な疾患を有する者（n ＝ 219名，7.1%），高血圧症，糖尿病，脂質異常症の服薬を行っている者（n ＝ 826名，26.8%）も除外した．最終的に23歳から69歳までの男女1837名（NEXIS 773名，SCOP 1064名，男性848名，女性989名）を本研究の対象とした．

本研究を始めるにあたり，独立行政法人国立健康・栄養研究所における研究倫理審査委員会の承認を受けた．また，全ての被験者には，本研究の目的や意義，危険性について口頭および文章にて説明を行い，研究参加への同意を得た．

生活習慣病危険因子の測定　10時間の絶食を行った後，早朝に身長および体重を測定し，BMI（kg/m^2）を算出した．仰臥位において十分な安静の時間を取った後，form ABI/PWV（オムロンコーリン社製，日本）により上腕血圧を測定した．また，肘正中皮静脈から採血を行った．採取した血液を3000 rpmで20分間の遠心分離を行い，血清を得た．得られた血清から，血糖値，中性脂肪，HDL-コレステロールを測定した．

身体活動量の評価　日常生活における身体活動量（メッツ・時）および歩数は，３次元加速度計（Actimarker EW4800;パナソニック社製，日本）を用いて評価した．この加速度計には３軸方向（x：上下，y：左右，z：前後）の加速度センサーが内蔵されており，各軸方向の加速度を合成した加速度値が算出された[22]．活動強度は，３軸の合成加速度の標準偏差によって算出され，１分毎の加速度値（Km）は以下の式で算出された．

$$Km=\sqrt{\frac{1}{n-1}\left[\left(\sum_{k=1}^{n}x_i^2+\sum_{k=1}^{n}y_i^2+\sum_{k=1}^{n}z_i^2\right)-\frac{1}{n}\left\{\left(\sum_{k=1}^{n}x_i\right)^2+\left(\sum_{k=1}^{n}y_i\right)^2+\left(\sum_{k=1}^{n}z_i\right)^2\right\}\right]}$$

xi，yi，ziは１分毎における各軸方向の加速度を示しており，nは１分間にサンプリングされる個数である．加速度値のサンプリング周波数は20Hzであり，算出された加速度値は内蔵されたアルゴリズムによってメッツに変換され，１分毎に平均した値が時刻暦とともに内蔵メモリに蓄積された．この３次元加速度計は，それにより得られた身体活動量が，７種類の家事作業と７水準の

歩行におけるダグラスバックを用いて得られた酸素摂取量との間に高い相関（r=0.93）が認められており，また，二重標識水法によって測定された総消費エネルギーとの間にも高い相関（r=0.84）が認められており，妥当性が検証されたものである[23]．

被験者は，起床から就寝までの間，水泳や入浴のような水中での活動以外において，３次元加速度計を腰部に装着した．また，同時に身体活動の簡易な１日毎の欄を設けた記録用紙にて，その日が非日常的活動を伴ったか否か，また非装着時間の有無について記録した．非日常的活動を伴ったか否かについては，“装着期間中に，非日常的な出来事（怪我をした，風邪を引いて寝込んだ，旅行に行った）があれば特記事項の欄にご記入下さい．毎月旅行に行くなど，定期的な事柄については記入頂かなくても結構です”とし，非装着時間の有無については，“機器の着け忘れや諸事情により，活動をしていたにもかかわらず，機器を装着しなかった時間がありましたら，その時刻を記入してください”とした．この身体活動記録を元に，非日常的活動を伴った日および非装着時間があった日を除外した．さらに，３次元加速度計に記録された1.1METs以上の加速度データが６時間以上認められる日を採用し，６時間に到達しない日を除外した．この基準を用いることで，加速度計の有効日として先行研究において多く採用されている基準である装着時間10時間以上[24]を満たしている日数は93.5%に達することを本研究の被験者から抽出した24名のデータにおいて確認した．

本研究において装着した28日間のうち，上記基準を満たす日を全て有効日とし，平日および休日を含む14日以上28日以下の日数において，３メッツ以上の強度における身体活動量（メッツ·時）（以下，中高強度身体活動量）および歩数の１日あたりの平均値を算出した．有効日が14日未満の場合には，有効日が14日を超えるよう再度装着を依頼した．７日以上の歩数のデータが１ヶ月間の身体活動量を評価することが可能であると報告されているため[25]，14日以上の装着期間は，１ヶ月間の身体活動を評価していると考えられる．また，１日における３メッツ以上の中高強度身体活動に費やした時間についても算出した．中高強度身体活動量については，運動基準の週23メッツ・時と比較するため，得られた１日あたりの中高強度身体活動量（メッツ・時）から週あたりの中高強度身体活動量（メッツ・時/週）を求めた．この週あたりの中高強度身体活動量が23メッツ・時以上の者を運動基準達成者，23メッツ・時未満の者を運動基準未達成者とした．

統計解析　性別や地域における年齢や体組成，生活習慣病危険因子，身体活動量の比較には，対応のないt-testを用いた．またコホートにおける男女の度数を比較するために，χ^2検定を行った．中強度身体活動量と１日あたりの歩数との相関関係は，Pearsonの相関係数の検定により行い，週あたりのメッツ・時と１日あたりの歩数との関係については直線回帰分析により検討した．運動基準である週23メッツ・時に相当する１日あたりの歩数を検出するため，受診者動作特異性曲線（Receiver Operating Characteristic curve: 以下ROC曲線）を用いて検討した．連続的な任意の歩数における週23メッツ・時に対する感度および特異度を求め，ROC曲線を作成し，AUC（area under curve）を獲得した．ROC曲線の左肩ポイント（感度 = 1, 1 − 特異度 = 0）に最も近い距離にある値を求め，これをカットオフ歩数とした．左肩に最も近い距離は，$(1 - 感度)^2 + (1 - 特異度)^2$の最小値とした．得られたカットオフ歩数における週23メッツ・時に対する感度と特異度，陽性および陰性反応適中度を求め，そのカットオフ歩数の妥当性を検討した．

結果は，平均値±標準偏差で示し，有意水準は危険率５%未満とした．解析にはSPSS 16.0（SPSS Japan社，日本）を用いて行った．

研究結果

被験者特性　対象者の性年代別の構成を表１に示した．平均年齢は53.0±9.9歳であった．男性の平均年齢は52.6±10.2歳で，女性は53.2±9.7歳であり，男女において年齢に差は認められなかった．また対象者の勤務形態について，NEXISに関しては不明であるが，SCOPに関して常勤・自営業が63.9%と半数以上を占め，臨時・パートが7.1%，農業が7.1%，主婦・無職が21.8%だった．また，農業への従事の有無について聞いたところ37.1%の対象者が従事していた．本研究における被験者特性を表２に示した．生活習慣病危険因子においては，BMI，血糖値，中性脂肪，血圧が男性において有意に高い値であり，HDLコレステロールが女性において有意に高い値を示

Table 1.　Numbers of participants by gender and age groups

	age					
	20-29	30-39	40-49	50-59	60-69	Total
Male	5	107	183	309	244	848
	0.6%	12.6%	21.6%	36.4%	28.8%	100%
Female	5	109	195	375	305	989
	0.5%	11.0%	19.7%	37.9%	30.8%	100%

Table 2. The subjects characteristics according to the sex and the cohort

	Total	Male	Female	NEXIS	SCOP
N	1837	848	989	773 (246/527)	1064 (602/462)
age	53.0 ± 9.9	52.6 ± 10.2	53.2 ± 9.7	48.8 ± 10.4	55.9 ± 8.4 #
Hight (cm)	162.7 ± 8.4	169.4 ± 5.9	157.0 ± 5.6 *	161.3 ± 8.3	163.7 ± 8.4 #
Weight (kg)	60.2 ± 11.0	67.3 ± 9.8	54.1 ± 7.8 *	59.0 ± 10.9	61.1 ± 10.9 #
Waist circumstance (cm)	81.5 ± 8.6	83.8 ± 7.8	79.6 ± 8.9 *	80.8 ± 9.2	82.0 ± 8.2 #
BMI	22.6 ± 3.0	23.4 ± 2.9	22.0 ± 3.0 *	22.6 ± 3.2	22.7 ± 2.9
Fasting blood glucose (mg/dL)	95.4 ± 12.8	98.4 ± 13.6	93.0 ± 11.5 *	90.3 ± 10.8	99.2 ± 12.9 #
HDL choresterol (mg/dL)	62.4 ± 15.2	56.7 ± 14.1	66.9 ± 14.6 *	64.2 ± 15.6	60.6 ± 14.7 #
Trigricerol (mg/dL)	100.0 ± 65.8	118.2 ± 78.4	84.3 ± 47.2 *	89.3 ± 55.4	107.7 ± 71.4 #
SBP (mmHg)	116.7 ± 14.7	119.8 ± 13.7	114.1 ± 14.9 *	117.2 ± 14.6	116.4 ± 14.7
DBP (mmHg)	71.1 ± 10.4	74.6 ± 9.9	68.0 ± 9.8 *	71.2 ± 10.1	71.0 ± 10.6
Daily step counts (steps/day)	9564 ± 3540	9594 ± 3630	9537 ± 3463	10517 ± 3691	8871 ± 3257 #
Amount of MVPA (METs-h/week)	25.0 ± 14.7	24.8 ± 16.4	25.2 ± 13.1	26.7 ± 14.5	23.8 ± 14.7 #

MVPA: moderate and vigrous physical activity
*: P<0.05, Male vs Female
#: P<0.05, NEXIS vs SCOP

した．いずれの生活習慣病危険因子においても，全被験者の平均値は基準値の範囲内にあった．

日常生活における身体活動量 本研究における全被験者の平均歩数は１日あたり9564±3540歩（男性9594±3630歩，女性9537±3463歩）であり，中高強度身体活動量は週25.0±14.7 メッツ・時（男性24.8±16.4 メッツ・時，女性25.2±13.1 メッツ・時）であった（表２）．これは，平成21年に発表された国民健康・栄養調査の平均歩数を（男性7214歩，女性6352歩）大きく上回っており，本研究の被験者は身体活動量の高い集団であると考えられる．また，NEXISとSCOPにおいて，歩数および中高強度身体活動量を比較すると，歩数は，それぞれ10517±3691歩と8871±3257歩であり（p<0.01），中高強度身体活動量においては，週26.7±14.5 メッツ・時と週23.8±14.7 メッツ・時で，両指標ともNEXISの被験者の方が有意に高い値であった（p<0.01）（表２）．

週あたりの中高強度身体活動量と１日あたりの歩数との間には，有意な正の相関が認められた（r=0.743, p<0.01）．中高強度身体活動量の基準値である週23メッツ・時を達成している被験者の割合は，47.8%（男性42.8%，女性52.2%，男性vs女性：p<0.01）であった．

週23メッツ・時と歩数との関係 本研究では，週23メッツ・時に相当する１日あたりの歩数を決定するため，ROC曲線を用いてカットオフ歩数を求め，その歩数を用いた際の週23メッツ・時に対する感度および特異度，陽性および陰性反応適中度から妥当性を考慮した．全被験者におけるROC曲線を図１に示した．AUCは0.862（95%信頼区間：0.845 − 0.878）であり（p<0.01），カットオフ値として9341歩が決定された．この9341歩における感度は77.1%，特異度79.5%，陽性反応適中度77.6%，陰性反応適中度79.1%であった（表３）．さらに，運動基準の週23メッツ・時は，１日において３メッツ以上の中高強度身体活動量をどのくらいの時間行うことに相当するかを検討するため，全被験者を対象にROC曲線により求めたところ，１日あたり54分というカットオフポイントが得られた．

また，地域差や集団の特性の差が，週23メッツ・時に相当する歩数に違いをもたらすかを検討した．コホート別に，週23メッツ・時に相当する歩数をROC曲線により求めたところ，NEXISで9980歩（感度76.2%，特異度80.9%），SCOPで8640歩（感度79.2%，特異度76.5%）であった．男女別では，男性で9414歩（感度80.2%，特異度80.0%），女性で9188歩（感度77.3%，特異度77.4%）であった．さらに，本被験者を年齢により３分位（49歳以下，50−58歳，59歳以上）に分類し，カットオフ歩数を求めた．3分位に分ける際，同年齢が多く存在しており

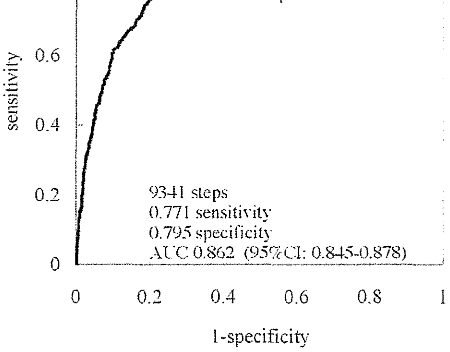

Fig 1. Receiver operating characteristic (ROC) curves showing the optimal daily step counts cutoff point for 23 METs-h/week of amount of moderate and vigorous physical activity

Table 3. Daily step counts cutoff points to identify 23METs-h/week of amount of physical acvitivy by ROC analysis.

Category	n	Cutoff point	AUC (95%CI)	Se (%)	Sp (%)	+PV (%)	-PV (%)
All subjects	1837	9341	0.862 (0.845-0.878)	77.1	79.5	77.6	79.1
Cohorts							
NEXIS	773	9980	0.860 (0.834-0.887)	76.2	80.9	83.5	72.8
SCOP	1064	8640	0.855 (0.833-0.877)	79.2	76.5	70.9	83.5
sex							
male	848	9414	0.879 (0.856-0.902)	80.2	80.0	75.0	84.3
female	989	9188	0.851 (0.828-0.875)	77.3	77.4	78.9	75.8
age							
~49	604	9434	0.879 (0.852-0.906)	81.4	79.9	79.5	81.8
50-58	603	9187	0.854 (0.824-0.884)	78.0	77.7	71.7	82.9
59~	630	9296	0.855 (0.825-0.884)	75.2	81.7	81.8	74.9
BMI							
<18.5	101	8865	0.826 (0.745-0.906)	80.8	77.6	79.2	79.2
18.5-25	1391	9341	0.861 (0.841-0.880)	78.4	79.0	78.4	79.0
25=<	345	9004	0.873 (0.837-0.909)	77.5	78.3	71.4	83.2

AUC, area under the ROC curve; Se, Sensitivity; Sp, Specificity; +PV, positive Predictive value; −PV, negative predictive value

均等に人数を分類することが出来なかったため，人数が最も3分位に近似する年齢により分類した．49歳以下の群で9434歩（感度81.4%，特異度79.9%），50-58歳の群で9187歩（感度78.0%，特異度77.7%），59歳以上の群で9296歩（感度75.2%，特異度81.7%）であった．BMIでは，BMIが18.5未満においては8865歩（感度80.8 %，特異度77.6 %），18.5以上かつ25未満では9341歩（感度78.4%，特異度79.0%），25以上においては，9004歩（感度77.5%，特異度78.3%）であった．

また，週あたりのメッツ・時と1日あたりの歩数との回帰分析から週23メッツ・時に相当する歩数を求めた．独立変数に中高強度身体活動量（メッツ・時/週），従属変数に歩数（歩/日）を取り，回帰直線を引いたところ，全被験者において$y=179x-5090$の式が得られ（図2）（$p<0.05$）．週23メッツ・時に相当する歩数は9206歩であった．ROC曲線の検討と同様，コホート別，性別，年齢別，BMI別にも検討を行った（表4）．コホート別に見ると，NEXISでは9809歩，SCOPでは8746歩だった．

さらに欧米において身体活動量の基準となっている「中強度以上の身体活動を1日30分以上」について，中強度の身体活動を3メッツ以上と定義し，ROC曲線により歩数を算出したところ，7709歩（感度76.9%，特異度59.0%）であった．

考　察

本研究において，23歳から69歳までの健康な男女1837名を対象に，運動基準で提唱された身体活動量の基準値である週23メッツ・時に相当する歩数を検討したところ9341歩であることが推計された．コホート別に見ると東京都を中心とするコホートであるNEXISにおいては9980歩であり，長野県佐久市を中心とするコホートであるSCOPにおいては8640歩であった．東京都と長野県と

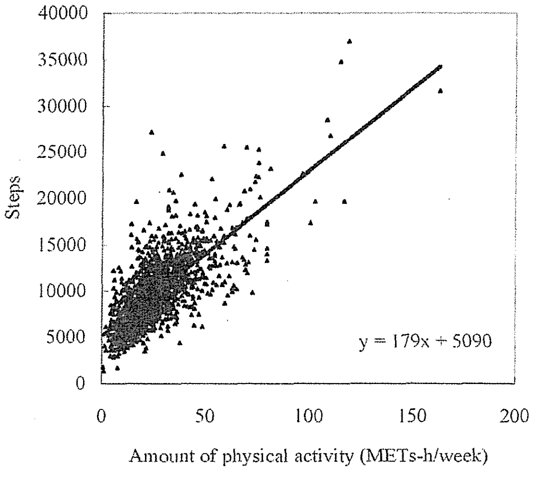

Fig 2. Relationship between amount of moderate and vigorous physical activity (METs-h/week) and daily step counts

Table 4. The regression analysis for daily step counts corresponding to 23 METs-h/week of amount of physical activity

Category	n	Equation	Steps
All subjects	1837	y = 179 x + 5090	9206
Cohort			
NEXIS	773	y = 191 x + 5406	9809
SCOP	1064	y = 164 x + 4982	8746
sex			
male	848	y = 160 x + 5623	9308
female	989	y = 204 x + 4399	9092
age			
~50	604	y = 170 x + 5455	9361
51-60	603	y = 180 x + 5104	9253
61~	630	y = 191 x + 4616	9013
BMI			
<18.5	101	y = 167 x + 5343	9194
18.5-25	1391	y = 181 x + 5048	9216
25=<	345	y = 174 x + 5150	9158

いう地域の差により，週23メッツ・時を達成するための歩数に1340歩の差が認められた．また，性別や年齢，BMIによる分類において，週23メッツ・時に相当する歩数には差が認められたものの，その差は約220～480歩であり，地域による差より小さかった．ROC曲線によって求めた歩数のカットオフポイントは，回帰直線により算出した歩数と同様の傾向を示した．本研究では，地域別，集団属性別で見た場合，そのカットオフ歩数は1日8640歩～9980歩の範囲に分布した．したがって，週23メッツ・時に相当する歩数は，おおよそ1日8500～10,000歩と表現するのが妥当であると考えられる．この知見は，エクササイズガイドにおいて推奨されている歩数である1日8000歩～10,000歩とほぼ一致しており，その妥当性を支持するものであった．

我々の研究以前に，ガイドラインで提示されている身体活動の推奨量を歩数で示すことを試みた研究がいくつか行われてきている．100歩/分のペースでの歩行が，おおよそ3メッツでの強度の通常歩行であることがよく知られており[26]，中強度以上の身体活動30分は，3000歩～4000歩に直接的に歩数に変換可能なことが示唆されている[18,26-28]．米国の身体活動ガイドラインでは，「中強度以上の身体活動を少なくとも1日あたり30分」といった推奨量が提唱されているが，Macfarlaneら[14]は，中強度以上の身体活動1日30分は1日8000歩に相当することを報告している．本研究において，中高強度身体活動30分に相当する歩数を算出したところ，1日7709歩という結果が得られた．これはMacfarlaneら[14]と比較して若干低い値であった．その理由として，歩数や活動量算出の感度やアルゴリズムの違いや研究対象の民族ならびに生活環境の違いなどが推察される．また，本研究において「中強度以上の身体活動30分」を算出する際，米国の「10分以上の継続する活動のみを30分に含める」という概念は考慮されていない．したがって，「中強度以上の身体活動30分」の基準達成の判断が緩くなり，カットオフ歩数を求めた際，その歩数が低くなっている可能性が考えられる．

Bassett et al.[29]によると，米国における成人の歩数は男性が5340歩，女性が4912歩であると報告されている．米国の「中強度以上の身体活動を少なくとも1日あたり30分」といった身体活動の推奨量は約8000歩に相当し[14,17]，米国の歩数の現状より約2500歩～3000歩ほど多い．一方，我が国の国民健康・栄養調査の結果では男性が7321歩，女性が6267歩であり[30]，米国と比較して歩数が多いことが報告されている．運動基準である週23メッツ・時は，本研究において8500歩～10,000歩に相当し，我が国の歩数の現状よりも2500歩～3500歩ほど多い．米国も我が国も，各国民の身体活動の現状より同程度多い基準を設定していることは興味深い．このことと，身体活動と生活習慣病リスクの低減との間に量反応関係がある[1]ことを考え併せると，本研究により得られた週23メッツ・時に相当する1日当たりの歩数8500歩～10,000歩は，日本国民が生活習慣病予防の目的に目指すべき歩数として妥当であると思われる．

都心部と農村部において歩数や身体活動量を比較した研究では，都市部において歩数が多く[31]，また身体活動ガイドラインの基準値に達しているものが多い[32]ことが報告されている．一方で，これまで一歩あたりの強度といった“身体活動の質”に関して地域による差があるかを検討した研究は行われていない．本研究では，コホートや性，年齢，BMIによる集団特性の差が，カットオフ歩数に違いをもたらすかを検証した．その結果，性，年齢，BMIにおいては大きな差は見られなかったが，2つのコホートの間に約1340歩の差が認められた．週あたりの中高強度身体活動量および歩数を比較すると，東京を中心としたNEXISで有意に高いものの，カットオフ歩数は高値を示している．これらカットオフ歩数における地域差は，通勤形態の違いや農業従事の有無などの“身体活動の質”の差が影響を及ぼしている可能性が考えられる．さらにPark et al[33]によると，本研究において使用した3次元加速度計は，55m／分＝3.3km／時程度の遅い歩行速度において歩数を有意に過小評価することが報告された．したがって，歩行速度の遅い集団を含む場合，週23メッツ・時に相当する歩数が低く見積もられるかもしれない．一方，男女や若齢者と高齢者，非肥満者と肥満者において，週23メッツ・時に相当する歩数には地域差のような差が認められなかった．本研究において週23メッツ・時に相当する歩数に差が生じなかった理由については，脳血管疾患，腎臓病等の重篤な疾患を有する者や高血圧症，糖尿病，脂質異常症の服薬を行っている者が除外され，比較的健康な被験者であることが考えられる．

本研究において，59歳以上を対象とした場合の週23メッツ・時に相当する歩数は9296歩であることが推計された．平成21年度の国民健康・栄養調査における歩数は，60-69歳において男性で6949歩，女性で6381歩であり，70歳以上において男性で4707歩，女性で3797歩である．本研究の60-69歳の対象者における歩数は，男性において平均9741±3434歩であり，女性で9224±3393歩であり，国民健康・栄養調査と比較して歩数が多い集団である．したがって，本研究で示された59歳以上を対象とした際の週23メッツ・時に相当する歩数9296歩は日本国民における59歳以上の集団で達成可能か否かを十分考慮する必要があると思われる．

週23メッツ・時が，3メッツ以上の中高強度身体活動量を1日あたりどのくらいの時間行うことに相当するかを検討した結果，1日あたり54分というカットオフポイ

ントが得られた．米国の身体活動ガイドライン「中強度以上の身体活動30分」と比較して，長い時間が示されたが，これには上述したカットオフ歩数と同様，「10分以上の継続」が考慮されていないことや，基準値策定のための論文の採択基準が異なることなどが考えられ，日本において示されている週23メッツ・時という基準と単純に比較することはできず，慎重な解釈が必要である．しかしながら，Masurier et al.[34]は1日10,000歩以上を達成しているグループの1日あたりの中強度身体活動の時間を算出したところ，「10分以上の継続」が考慮されていない場合においては62.1±27.7分，「10分以上の継続」を考慮した場合には30.1±21.0分であったことを報告している．本研究における週23メッツ·時は9341歩であり，「10分以上の継続」を考慮しない中高強度身体活動時間の54分は概ね妥当な数値であると思われる．

本研究には，いくつかの限界が存在する．まず1点目は，本研究において使用した3次元加速度計の歩数の正確性についてである．先に述べたようにPark et al.[33]は，本研究において使用した3次元加速度計は，55m／分＝3.3km／時程度のゆっくりとした歩行速度において歩数を有意に過小評価することを報告している．したがって，ゆっくりとした活動が多い集団においては，活動が歩行として認識されておらず，週23メッツ・時に相当する歩数を少なく見積もる可能性が考えられる．2点目は使用する加速度計の違いに関してである．加速度計を使用して身体活動量の基準値に相当する歩数を求めようとする際，各加速度計における歩数への変換における感受性や身体活動量評価のアルゴリズムに器差があるため[35]，これらがカットオフ歩数に影響を及ぼす可能性が考えられる．最後に，集団における差異についても考慮する必要があると思われる．本研究では，NEXISおよびSCOPにおいて2つの集団を対象としたが，それら対象によりカットオフ歩数には1340歩の差が認められ，異なる集団を対象にした際には，これらカットオフ歩数に差異が生じる可能性がある．Tudor-Lockeら[36]は，推奨値や基準値に対する歩数は，地域や属性で異なっており，それらを含む範囲で提唱することが良いとしている．本研究の3つの限界を考慮すると，週23メッツ・時に相当する歩数は，おおよそ1日8500～10,000歩に相当するというように範囲を持って表現するのが妥当であろう．

我が国は歩数計が古くから普及しており，1960年代以降の万歩計という言葉に象徴されるとおり1日あたり10,000歩を基準に歩くことが“経験的に”推奨されてきた[36]．また，「すこやか生活習慣国民運動」のような厚生労働省の最近の健康づくりのためのポピュレーションアプローチにおいて，「まず1000歩増やしてみよう」といった歩数に焦点を当てたスローガンが掲げられている[37]．さらに，最近では普及率が93％となった携帯電話に[38]，加速度センサーを活用した歩数計機能が搭載され，多くの国民が歩数を知ることが出来る環境が整ってきている．このような歴史的，社会的背景から，学問的にはメッツ・時などの単位で表現される身体活動量の概念をより平易で日本人になじみの深い歩数に換言することは，身体活動に関する認知を高めること，エクササイズガイドの普及・啓発，ひいては日本人の身体活動量増大のために，有効であると思われる．

結　論

本研究では，「健康づくりのための運動基準2006」で示された身体活動量の基準値である週23メッツ・時に相当する歩数を，23歳から69歳までの健康な男女1837名において検証した．その結果，全被験者における週23メッツ・時に相当する歩数は，1日9341歩であった．また地域別や集団の特性別に検討した結果，週23メッツ・時に相当する歩数は1日8640歩～9980歩の範囲に分布した．以上の結果から，週23メッツ・時の中強度以上の身体活動量に相当する歩数は，おおよそ1日8500～10,000歩に相当することが示唆された．

引用文献

1) Helmrich SP, Ragland DR, Leung RW, and Paffenbarger RS, Jr. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med* 325: 147-152, 1991.

2) Okada K, Hayashi T, Tsumura K, Suematsu C, Endo G, and Fujii S. Leisure-time physical activity at weekends and the risk of Type 2 diabetes mellitus in Japanese men: the Osaka Health Survey. *Diabet Med* 17: 53-58, 2000.

3) Hu G, Barengo NC, Tuomilehto J, Lakka TA, Nissinen A, and Jousilahti P. Relationship of physical activity and body mass index to the risk of hypertension: a prospective study in Finland. *Hypertension* 43: 25-30, 2004.

4) Zheng H, Orsini N, Amin J, Wolk A, Nguyen VT, and Ehrlich F. Quantifying the dose-response of walking in reducing coronary heart disease risk: meta-analysis. *Eur J Epidemiol* 24: 181-192, 2009.

5) Organization WH. Global recommendations on physical activity for health. http://www.who.int/dietphysicalactivity/factsheet_recommendations/en/index.html. 2010.

6) Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, Macera CA, Heath GW, Thompson PD, and Bauman A. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 39: 1423-1434, 2007.

7) Nelson ME, Rejeski WJ, Blair SN, Duncan PW, Judge JO, King AC, Macera CA, and Castaneda-Sceppa C. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Med*