J. Phys. Ther. Sci. 31: 482–487, 2019

The Journal of Physical Therapy Science

Original Article

Relationship between muscle-strengthening activities recommended by physical activity guidelines and knee extensor strength in the elderly

Naofumi Yamamoto, PhD[1)*], Takenori Kawakami, MA[2)], Nobuko Hongu, PhD[3)], Hidenori Asai, PhD[1)], Yumiko Hagi, PhD[4)]

[1)] *Faculty of Collaborative Regional Innovation, Ehime University: 3 Bunkyo-cho, Matsuyama, Ehime 790-8577, Japan*
[2)] *TAKE foot works, Japan*
[3)] *University of Arizona, USA*
[4)] *School of Physical Education, Tokai University, Japan*

Abstract. [Purpose] This study aimed to cross-sectionally examine the relationship between the practice of muscle-strengthening activities assessed according to Japanese and foreign physical activity guidelines and knee extensor strength in the elderly. [Participants and Methods] Overall, 223 (66 males and 157 females) participants aged ≥60 years were included. The questionnaire included four items on muscle-strengthening activities: undergoing strength training, performing vigorous farming and gardening, carrying heavy loads, and climbing stairs and hills. Thereafter, participant performance was classified as "sufficient" or "insufficient" based on whether they practiced each muscle-strengthening activity for ≥2 or <2 days a week, respectively. [Results] After the adjustment for age, gender, body mass index, physical activity level, and the practice of other muscle-strengthening activities, knee extensor strength was significantly higher in the elderly participants who sufficiently practiced strength training than in those who did not. Furthermore, those who sufficiently practiced farming and gardening had significantly higher knee extensor strength than those who did not. [Conclusion] Our findings suggest that the non-exercise muscle-strengthening activity of sufficient farming and gardening practiced according to physical activity guidelines is positively associated with knee extensor strength independent of other muscle-strengthening activities or the amount of physical activity in healthy elderly individuals.
Key words: Physical activity, Muscle-strengthening activity, The physical activity guideline

(This article was submitted Dec. 28, 2018, and was accepted Mar. 2, 2019)

INTRODUCTION

Muscle strength, particularly of the lower extremities, is closely associated with the walking ability and the physical function among the elderly[1)]. Weak lower extremity muscle strength is reported to be a strong predictor of poor outcomes, such as falls[2)], disability[3)], and the overall risk of mortality[4)]. Considering the accelerated speed of aging in the populations of developed countries, preventing the decline of lower extremity muscle strength associated with aging in the elderly and promoting its maintenance and improvement are some important public health priorities.

Regular muscle-strengthening activity (MSA) is promoted in Japanese and foreign physical activity guidelines to improve and maintain muscle strength[5–7)]. These physical activity guidelines define MSA as the "physical activity that involves

*Corresponding author. Naofumi Yamamoto (E-mail: yamamoto.naofumi.mk@ehime-u.ac.jp)

moderate and higher intensity loading on the main muscle groups" that can be practiced through strength training exercises; moreover, it includes the activities of daily living, in other words, non-exercise activities[5)], and gives specific examples, such as gardening, carrying and transporting groceries and other goods, and climbing up and down the stairs[5, 6)]. In particular, the Japanese physical activity guidelines recognize that strength training can be hard to practice and maintain; therefore, it proposes daily activities such as climbing stairs or hills as alternatives[7)]. Numerous previous studies have reported on the effectiveness of strength training among the elderly[8)]. However, to the best of our knowledge, no study has investigated how well non-exercise MSA, such as those promoted in the guidelines, affects lower extremity muscle strength independently from other forms of physical activity. Because their evidence level is low and simply a recommendation of authorities and experts, it requires further evidence to support the relationship between non-exercise MSA and lower extremity muscle strength toward promoting health based on the scientific evidence[9)].

Knee-extensor strength is applied in several studies as a surrogate marker of lower extremity muscle strength[4)] and also used in algorithms to assess dynapenia[10)]. Therefore, we conducted a cross-sectional study to investigate the relationship between practice of MSA as assessed according to the physical activity guidelines and knee-extensor strength among the elderly.

PARTICIPANTS AND METHODS

Participants comprised individuals aged ≥60 years who attended in a health promoting event jointly organized by several elderly social activity groups and organizations in Matsuyama City. Among the 259 elderly (77 males and 182 females) who responded to an invitation to participate in taking measures of lower extremity muscle strength, 223 (66 males and 157 females) were included as they had no missing values for the measured parameters used in this study. Measurements were taken after obtaining a written consent from the study participants after explaining them the purpose of the study, the voluntary nature of cooperation in the study, and the possible risks involved in taking the measurements. This study was approved by the ethics committee of the Faculty of Collaborative Regional Innovation of Ehime University (approval number 01).

A questionnaire form was used to survey how the participants practiced MSA. The questionnaire included four items on MSA: strength training, heavy farming and gardening work, carrying heavy loads, and climbing stairs and hills, as per the Japanese and foreign physical activity guidelines[5–7)]. Strength training was defined as "all exercises for muscular training using equipment such as machines, dumbbells and tubes as well as training that uses own bodyweight, such as sit-ups/crunches and push-ups." The respondents were instructed that they should only count activities that involved moderate intensity and effort levels and to answer how many days they practiced it in an average week. The participants were then classified as "sufficient" or "insufficient" based on whether they practiced for each MSA for ≥2 days or <2 day a week, respectively, as per the Japanese and foreign physical activity guidelines[5–7)].

A leg strength measurement unit (T.K.K 5715 and T.K.K. 5710e; Takei Scientific Instruments Co., Ltd., Niigata, Japan) was used to measure the knee extensor strength in the seated position in a chair. With the belt linked to the tension meter attached to the ankle, the participant was asked to extend the knee from the 90° knee position to the anterior direction at the maximum effort to measure the isometric knee-extensor strength (kg). The right and left legs were alternatively measured, and the highest value was treated as the individuals' representative value.

Data pertaining to the participants' age, gender, height, and weight were self-reported in the questionnaire, and the values for height and weight were used to calculate the body mass index (BMI). The Japanese version of the International Physical Activity Questionnaire-Short Version[11)] was used to measure the levels of physical activity in the activities of daily living. The reliability and criterion-related validity of this scale had been confirmed in previous studies[12)]. Total metabolic equivalent of tasks (METs)•min of 1 week was calculated from the obtained data and used as an indicator of physical activity.

Unpaired t-test was used for comparison of the difference of the mean values, and χ^2 test was used to compare the difference in the proportions between the two groups. The analysis of covariance was used to compare the knee-extensor strength by the MSA activity levels. The levels of practice of each MSA was entered as an independent variable, the knee-extensor strength as a dependent variable, and gender (male/female), age (continuous variable), BMI (continuous variable), total METs•min (continuous variable), and the practice of MSA other than that as independent variables were entered as covariates. The analysis of covariance was also used to examine the relationship between the confounders (gender, age, BMI, and total METs•min) and knee-extensor strength. Each confounder was entered as an independent variable, the knee-extensor strength as a dependent variable, and the confounders other than that as independent variables and four items on MSA were entered as covariates. All statistical analysis was performed using IBM SPSS Statistics Version 25 (IBM Corp, Armonk, NY, USA), and $p<0.05$ was considered to be statistically significant.

RESULTS

Participants' characteristics are summarized in Table 1. Females had lower knee extensor strength than males, and a smaller proportion of them practiced strength training and heavy gardening and farming work.

Table 2 summarizes participants' characteristics according to differences in MSA practiced. When participants were classified according to strength training, those who insufficiently did practice strength training had significantly lower knee

Table 1. Characteristics of participants

	All (n=223)		Male (n=66)		Female (n=157)		p[a]
Age (yrs)	71.8	5.7	70.6	5.0	72.3	5.9	0.052
Height (cm)	156.1	8.3	165.8	5.7	152.0	5.2	**<0.001**
Weight (kg)	55.0	9.1	63.0	7.4	51.6	7.6	**<0.001**
BMI (kg/m^2)	22.5	2.9	22.9	2.5	22.3	3.0	0.156
PA (METs•min/week)	1,349.4	2,221.7	1,484.2	1,583.1	1,292.8	2,443.2	0.558
Knee extensor strength (kg)	33.0	11.1	44.4	10.0	28.2	7.4	**<0.001**
Strength training							**0.021**
Insufficient	150	(67.3)	37	(56.1)	113	(72.0)	
Sufficient	73	(32.7)	29	(43.9)	44	(28.0)	
Heavy gardening and farming work							**0.018**
Insufficient	184	(82.5)	46	(69.7)	138	(87.9)	
Sufficient	39	(17.5)	20	(30.3)	19	(12.1)	
Carrying heavy loads							0.443
Insufficient	160	(71.7)	45	(68.2)	115	(73.2)	
Sufficient	63	(28.3)	21	(31.8)	42	(28.3)	
Climbing stairs and hills							0.849
Insufficient	90	(40.4)	26	(39.4)	64	(40.8)	
Sufficient	133	(59.6)	40	(60.6)	93	(59.6)	

Data represent mean SD or n (%).
[a] Differences between male and female by an independent t-test or χ^2 test.

extensor strength than those who sufficiently did, and a significantly lower proportion of them had opportunities to climb stairs and hills. When participants were classified according to heavy gardening and farming work, those who insufficiently did practice this type of MSA had significantly lower physical activity levels and knee extensor strength than those who sufficiently did, and the lower proportion of them had opportunities to carry heavy loads or climb stairs and hills. When participants were classified according to heavy load carrying, those who insufficiently practiced this work had a lower physical activity levels than those who sufficiently, and a significantly lower proportion of them had opportunities carry heavy loads and climb stairs and hills. When participants were classified according to stair and hill climbing, those who insufficiently did practice this work had significantly lower physical activity levels than those who sufficiently did, and had a significantly lower proportion of them had opportunities practicing all MSA.

Table 3 summarizes the relationship between known or latent confounding factors and knee extensor strength. Males had higher values than females. Participants aged <75 years had higher levels than those aged ≥75 years, and those with higher BMI tended to have higher knee extensor strength than those with lower BMI. Participants in the third tertile of physical activity had significantly higher knee extensor strength than did those in the second tertile.

A comparison of knee extensor strength according to each MSA after adjusting for age, gender, BMI, physical activity level, and practice of other MSA revealed that those who sufficiently practiced strength training had significantly higher values than those who insufficiently did (Table 4). Furthermore, in terms of non-exercise MSA, those who sufficiently practiced heavy gardening and farming work had significantly higher knee extensor strength than those who insufficiently did. No significant differences in knee extensor strength were noted between those who sufficiently practiced other MSA in activities of daily living and those who insufficiently did.

DISCUSSION

This study investigated the relationship between MSA practiced and knee extensor strength in elderly individuals. The results demonstrated that sufficient strength training and heavy gardening and farming work activities according to physical activity guidelines had a positive association with knee extensor strength, which was independent of confounding factors such as other MSA and physical activity.

Among the non-exercise MSA, no significant association was noted between heavy load carrying or stair and hill climbing and knee extensor strength. As it has been suggested that muscle activity levels of lower limb achieved while walking on an inclined slope exceeds the levels required for improving muscle strength in elderly individuals[13)], the authors predicted a significant association between knee extensor strength and stair and hill climbing; however, no such association was observed. This study aimed to investigate the relationship between the recommended levels in the physical activity guidelines

Table 2. Characteristics of participants, according to differences in sufficiency muscle-strengthening activities

	Strength training					Heavy gardening and farming work					Carrying heavy loads					Climbing stairs and hills				
	Insufficient (n=150)		Sufficient (n=73)		p	Insufficient (n=184)		Sufficient (n=39)		p	Insufficient (n=160)		Sufficient (n=63)		p	Insufficient (n=90)		Sufficient (n=133)		p
Gender (no. of female participants)	113	(75.3)	44	(60.3)	**0.021**	138	(75.0)	19	(48.7)	**0.001**	115	(71.9)	42	(66.7)	0.443	64	(71.1)	93	(69.9)	0.849
Age (yrs)	71.8	6.0	71.6	5.1	0.804	71.6	5.9	72.3	5.1	0.408	71.2	5.9	72.0	5.0	0.404	72.4	5.9	71.4	5.5	0.208
Height (cm)	155.4	8.0	157.5	8.7	0.793	156.0	8.5	156.4	7.8	0.769	155.5	7.9	155.7	8.0	0.905	156.4	8.0	156.0	8.5	0.716
Weight (kg)	54.7	9.1	55.7	9.2	0.463	54.5	8.6	56.4	10.3	0.156	54.1	8.1	55.9	10.4	0.239	55.7	9.5	54.5	8.9	0.326
BMI (kg/m^2)	22.6	3.0	22.3	2.7	0.569	22.3	2.7	23.0	3.4	0.112	22.3	2.7	23.0	3.4	0.202	22.7	3.1	22.4	2.7	0.336
PA (METs•min/week)	1,247.0	2,032.2	1,559.8	2,570.3	0.325	1,216.3	2,052.2	1,687.4	2,590.7	0.154	1,241.9	2,234.1	1,797.5	2,795.1	0.164	763.5	1,083.2	1,745.9	2,668.0	**0.001**
Knee extensor strength (kg)	31.3	10.3	36.4	11.8	**0.001**	33.0	10.6	32.8	12.2	0.905	32.9	10.6	31.8	12.1	0.574	32.7	11.6	33.2	10.7	0.736
Strength training (Sufficient)			-			57	(31.0)	16	(41.0)	0.225	51	(31.9)	22	(34.9)	0.663	19	(21.1)	54	(40.6)	**0.002**
Heavy gardening and farming work (Sufficient)	23	(15.3)	16	(21.9)	0.225			-			15	(9.4)	24	(38.1)	**<0.001**	9	(10.0)	30	(22.6)	**0.015**
Carrying heavy loads (Sufficient)	41	(27.3)	22	(30.1)	0.663	39	(21.2)	24	(61.5)	**<0.001**			-			14	(15.6)	49	(36.8)	**0.001**
Climbing stairs and hills (Sufficient)	79	(52.7)	54	(74.0)	**0.002**	103	(56.0)	30	(76.9)	**0.015**	84	(52.5)	49	(77.8)	**<0.001**			-		

Data represent mean SD or n (%).

Table 3. Relationship between known or latent confounding factors and knee extensor strength

	n	Estimate value[a]	95%CI	p
Gender				**<0.001**
Male	66	40.5	38.4–42.5	
Female	157	29.4	28.0–30.8	
Age				**0.005**
<75 yrs	153	34.1	32.7–35.6	
≥75 yrs	70	30.4	28.3–32.5	
BMI				**0.011**
First tertile <21.2 kg/m^2	73	30.4	28.4–32.5	
Second tertile 21.3–23.3 kg/m^2	74	33.9	31.9–35.9	
Third tertile >23.3 kg/m^2	76	34.5	32.5–36.5	
Physical activity				**0.043**
First tertile <480 Mets•min/week	74	32.3	30.2–34.3	
Second tertile 481–1,198 Mets•min/week	75	31.5	29.5–33.6	
Third tertile >1,198 Mets•min/week	74	35.1	33.1–37.2	

[a]Adjusted for the other confounders, strength training, heavy gardening and farming work, carrying heavy loads, and climbing stairs and hills.

Table 4. Estimate value of knee-extensor strength, according to differences in muscle-strengthening activity practiced

	Insufficient			Sufficient			p
	n	Estimate value[a]	95%CI	n	Estimate value[a]	95%CI	
Strength training	150	31.5	30.1–33.0	73	35.9	33.8–38.0	**0.001**
Heavy gardening and farming work	184	32.2	30.9–33.5	39	36.5	33.5–39.6	**0.012**
Carrying heavy loads	160	33.3	31.8–34.7	63	32.3	29.9–34.6	0.484
Climbing stairs and hills	90	33.8	31.8–35.7	133	32.4	30.8–34.0	0.288

[a]Adjusted for gender, age, BMI, PA, and the practice of other muscle-strengthening activities.

and knee extensor strength by examining the parameters of MSA according to the physical activity guidelines and prepared questions about MSA. The American physical activity guidelines[5)] define MSA as "physical activity that involves moderate to highly intensive effort and moves main muscle groups of the body." However, because no additional details are provided, it is difficult to determine the level of intensity described as "moderate to highly intensive effort." Furthermore, although the guidelines recommend a frequency of twice a week or more, there are no specific descriptions of quantity, such as the duration, of physical activity. This lack of specific descriptions of intensity or duration of physical activity is common across guidelines[5–7)]. Questions pertaining to MSA similarly lacked details related to the intensity or duration of physical activity in this study. Therefore, participants may have lacked a uniform understanding of intensity or duration of physical activity when answering questions about each MSA. Previous studies[14)] have reported that individuals tend to overestimate the intensity of physical activity that they perform. Similarly, the duration is also overestimated in the self-assessment of physical activity of relatively high intensity[15)]. In addition, physical activity that individuals perform intermittently may be difficult to recall[16)]. In this study, the estimates of knee extensor strength in the analysis of covariate were lower in participants who sufficiently practiced heavy load carrying and stair and hill climbing, indicating that relative strain caused by the physical activity of same intensities is higher in individuals with lower physical strength; therefore, individuals with lower strength may tend to remember—or overestimate—how frequently they performed heavy load carrying or stair and hill climbing in their daily lives. The abovementioned recall bias and overassessment of the duration of physical activity may have distorted the relationship between heavy load carrying or stair and hill climbing and knee extensor strength.

In this study, a significant association was noted between strength training and knee extensor strength. Exercises such as strength training are practiced with planning and intention for maintaining or improving physical fitness[17)]; therefore, they were expected to be comparatively less affected than daily activities by recall bias. The efficacy of strength training in the maintenance and improvement of muscular strength in elderly individuals has been reported in many studies[8)], thereby supporting the results of the present study.

Heavy gardening and farming work with the purpose of cultivating plants may also be considered as planned and intentional activities; therefore, this activity may also be slightly affected by recall bias similar to that in strength training. In addition, the results of this study are supported by previous studies that have reported the intensity of physical activity involved in farming and gardening work[18)] and by studies that have reported that elderly farmers have higher physical strength than elderly individuals living in urban areas[19)].

The results of this study suggest that strength training and farming and gardening work maintain or increase lower extremity muscle strength, which is independent of other physical activities. Furthermore, the results of this study also suggest that individuals who made self-assessments as practicing MSA according to physical activity guidelines do not necessarily have higher muscle strength than those who did not make such self-assessments. Therefore, efforts to determine the sufficiency of MSA by self-assessments should be undertaken with caution. To determine whether elderly individuals practice MSA sufficiently from the perspective of lower extremity muscle strength, it is important to understand which MSA are practiced by them. In particular, individuals who insufficiently do practice strength training but meet their physical activity guidelines/recommended needs according to non-exercise MSA (e.g., carrying heavy loads and climbing stair and hill) may not have high level of lower extremity muscle strength. This study may provide important practical information for those promoting MSA.

This study has several limitations. First, this is a cross-sectional study; therefore, causal relationships cannot be determined with certainty. Second, the participants were recruited from individuals who were participating or had interest in social activities such as working and volunteering; therefore, the participants were not a representative sample of the general elderly population, suggesting that the results of this study are not generalizable to all elderly individuals and are limited to healthy elderly individuals. Third, the sample size of this study may not be large enough to allow for an assessment of the relationship between gender and MSA and knee extensor strength. Future studies should include a larger sample size to investigate gender-based differences. The final limitation is related to the aim of this study, which was to investigate the relationship between the recommendations in physical activity guidelines and knee extensor strength. Therefore, simple questions related to MSA were written with reference to physical activity guidelines. However, future investigations may use other methods (e.g., behavioral observation) for more detailed assessments of MSA type, intensity, and amount. These improvements to the study design can help identify specific MSA in activities of daily living that are related to muscle strength, including knee extensor strength.

Funding

This study was supported by JSPS KAKENHI with a research grant provided to N.Y (16K21206).

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1) Marsh AP, Miller ME, Saikin AM, et al.: Lower extremity strength and power are associated with 400-meter walk time in older adults: The InCHIANTI study. J Gerontol A Biol Sci Med Sci, 2006, 61: 1186–1193. [Medline] [CrossRef]
2) Pijnappels M, van der Burg PJ, Reeves ND, et al.: Identification of elderly fallers by muscle strength measures. Eur J Appl Physiol, 2008, 102: 585–592. [Medline] [CrossRef]
3) Manini TM, Visser M, Won-Park S, et al.: Knee extension strength cutpoints for maintaining mobility. J Am Geriatr Soc, 2007, 55: 451–457. [Medline] [CrossRef]
4) García-Hermoso A, Cavero-Redondo I, Ramírez-Vélez R, et al.: Muscular strength as a predictor of all-cause mortality in apparently healthy population: a systematic review and meta-analysis of data from approximately 2 million men and women. Arch Phys Med Rehabil, 2018, 99: 2100–2113.e5. [Medline] [CrossRef]
5) US Department of Health and Human Services: 2018. Physical Activity Guidelines for Americans, 2nd ed. https://health.gov/paguidelines/second-edition/pdf/Physical_Activity_Guidelines_2nd_edition.pdf (Accessed Dec. 26, 2018)
6) Canadian Society for Exercise Physiology: Canadian Physical Activity Guidelines for older adults. http://www.csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_older-adults_en.pdf (Accessed Dec. 26, 2018)
7) Ministry of Health, Labour and Welfare of Japan: 2006. Exercise and physical activity guide for health promotion 2006—to prevent lifestyle-related diseases—(Tabata, I., Trans.). http://www.nih.go.jp/eiken/programs/pdf/exercise_guide.pdf. (Accessed Dec. 26, 2018)
8) Csapo R, Alegre LM: Effects of resistance training with moderate vs heavy loads on muscle mass and strength in the elderly: a meta-analysis. Scand J Med Sci Sports, 2016, 26: 995–1006. [Medline] [CrossRef]
9) Harada K, Shibata A, Oka K, et al.: Suggestion of “kinryoku-kojo-katsudo” as a Japanese translation of “muscle-strengthening activity”. Undo Ekigaku Kenkyu (Research in Exercise Epidemiology), 2011, 13: 146–150 (in Japanese).
10) Manini TM, Clark BC: Dynapenia and aging: an update. J Gerontol A Biol Sci Med Sci, 2012, 67: 28–40. [Medline] [CrossRef]
11) Craig CL, Marshall AL, Sjöström M, et al.: International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc, 2003, 35: 1381–1395. [Medline] [CrossRef]
12) Murase N, Katsumura T, Ueda C, et al.: Validity and reliability of Japanese version of International Physical Activity Questionnaire. Kousei no Shihyo (Journal of Health and Welfare Statistics), 2002, 49: 1–9 (in Japanese).
13) Franz JR, Kram R: How does age affect leg muscle activity/coactivity during uphill and downhill walking? Gait Posture, 2013, 37: 378–384. [Medline] [CrossRef]
14) Canning KL, Brown RE, Jamnik VK, et al.: Individuals underestimate moderate and vigorous intensity physical activity. PLoS One, 2014, 9: e97927. [Medline] [CrossRef]
15) Schaller A, Rudolf K, Dejonghe L, et al.: Influencing factors on the overestimation of self-reported physical activity: a cross-sectional analysis of low back pain patients and healthy controls. BioMed Res Int, 2016, 2016: 1497213. [Medline] [CrossRef]
16) Washburn RA: Assessment of physical activity in older adults. Res Q Exerc Sport, 2000, 71: 79–87. [Medline] [CrossRef]
17) Caspersen CJ, Powell KE, Christenson GM: Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep, 1985, 100: 126–131. [Medline]
18) Ainsworth BE, Haskell WL, Herrmann SD, et al.: 2011 Compendium of Physical Activities: a second update of codes and MET values. Med Sci Sports Exerc, 2011, 43: 1575–1581. [Medline] [CrossRef]
19) Patil RB, Doddamani BR, Bhutkar M, et al.: A comparative study of physical fitness among rural farmers and urban sedentary group of Gulbarga District. Al Ameen J Med Sci, 2012, 5: 39–44.