A comparison of sarcopenia prevalence between former Tokyo 1964 Olympic athletes and general community-dwelling older adults

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Abstract

Background: This study aimed to determine how increased muscle mass and athletic performance in adolescence contribute to the prevention of sarcopenia in old age, accounting for the type of sport, and the continuation of exercise habits. We compared the prevalence of sarcopenia, its components (low appendicular skeletal muscle mass, low muscle strength, and low physical function), and musculoskeletal pain using data from two cohorts: former athletes who competed in the 1964 Tokyo Olympics, and general community-dwelling older adults living in Kashiwa City, Chiba Prefecture.

Methods: We analyzed the data from 101 former Olympic athletes (mean age ± SD: 75.0 ± 4.4 years; 26% female) and 1,529 general community-dwelling older adults (74.1 ± 5.5 years; 49% women). We assessed sarcopenia (defined by the Asian Working Group for Sarcopenia revised in 2019) and musculoskeletal pain and considered potential confounding factors such as demographic characteristics, e.g., sex and exercise habits.

Results: The prevalence of sarcopenia was significantly lower in former Olympic athletes than general older adults (odds ratios [OR], 0.49; 95% confidence interval [CI], 0.20–0.94), especially with regards to superior appendicular skeletal muscle mass and muscle strength. This effect was more pronounced in individuals who continued their exercise and in athletes whose sporting discipline was classified as having a high exercise intensity. Conversely, low physical function (OR, 2.60; 95% CI, 1.16–6.07) and musculoskeletal pain (OR, 2.22; 95% CI, 1.24–3.97) were more prevalent in former Olympic athletes and in athletes who competed in sports with physical contact.

Conclusions: We observed a lower prevalence of sarcopenia and superior appendicular skeletal muscle mass and strength in the former Olympic athletes, especially among those that continued their exercise habits and those in sports with high exercise intensity. Conversely, low physical function and higher musculoskeletal pain scores were more prevalent in former

Olympic athletes, especially among athletes who competed in sports with physical contact. Our results warrant further promotion of exercise in adolescence and beyond as well as providing safety education, which is required to prevent the development of sarcopenia and musculoskeletal pain in old age.

Keywords: Athletes, frail elderly, sarcopenia, physical suffering, and musculoskeletal pain.

Introduction

As the global population ages, the question of how to extend healthy life expectancy has become an important issue in developed countries, particularly in super-aged societies such as Japan. In the era of 100-year lifespans, there is a need for specific measures to maintain and improve quality of life (QoL) and physical function throughout old age. One such measure that has recently gained attention is the prevention of sarcopenia in old age [1, 2]. Sarcopenia is defined as "a progressive and systemic skeletal muscle disease with an increased risk of health problems such as falls, fractures, loss of body function, and death," and is recognized within the International Classification of Diseases (ICD-10-CM) [3, 4]. Sarcopenia is diagnosed when a decrease in appendicular skeletal muscle mass is accompanied by a concomitant decrease in muscle strength and physical function. Recently, specific criteria for sarcopenia diagnosis in Asian populations have been proposed [5].

In recent years, early preventative measures have been emphasized in combating sarcopenia by increasing appendicular skeletal muscle mass, muscle strength, and physical function through better exercise habits in adolescence [1, 6]. Exercise habits developed and practiced during adolescence and early adulthood are thought to contribute to a healthier aging process. This means that a strong foundation of healthy and active lifestyles during adolescence coupled with muscle-mass built up from an earlier age is likely to be carried over into old age as above-average muscle mass. In fact, there is evidence that daily physical activity and exercise habits in later life contribute to healthy longevity into old age [7-10]. However, it remains unclear whether exercise habits in adolescence, which increase muscle mass and physical function, contribute to the prevention of sarcopenia in old age.

Regardless of differences in sporting disciplines, the athletic ability maximized by the exercise habits of elite athletes during their youth surpasses that of the average person. International studies have reported that elite athletes, such as Olympians, have a longer life expectancy than the average population [11-13]. Only Japan and a limited number of other countries possess comprehensive data sets regarding their respective Olympic athletes over the long term, which include the data of many Japanese athletes who participated in the 1964 Tokyo Olympics that have reached old age. To date, there have been no reports on geriatric medical outcomes in individuals from this database compared to their non-athlete community-dwelling peers. Consequently, it remains unclear why Olympic athletes have greater longevity [11].

The purpose of this study was to compare the prevalence of sarcopenia and its components (low appendicular skeletal muscle mass, low muscle strength, and low physical function) using data from two cohorts of older adults. The first cohort consisted of former athletes who competed in the 1964 Tokyo Olympics, and the second cohort consisted of a sample of general, community-dwelling adults in Kashiwa City, Chiba Prefecture. This study aimed to determine whether increased muscle mass and athletic performance in adolescence are associated with lower sarcopenia prevalence in old age, accounting for the type of sport, and the continuation of exercise post-Olympics. This study also considered that a history of high-intensity exercise might affect musculoskeletal pain. Musculoskeletal pain is associated with both psychological distress and reduced physical function [14, 15]. Thus, we considered musculoskeletal pain as a modifying factor. Our study emphasized a lifelong approach to sarcopenia prevention and elucidated the mechanisms by which Olympic athletes achieve improved longevity.

Methods

Study participants

A cohort of former Olympic athletes included participants from a prospective cohort study of 380 former athletes who participated in the 1964 Tokyo Olympics and who participated in the 13th follow-up of a survey conducted in 2016 (Tokyo Olympic Memorial Physical Fitness

Measurement; "Olympic Study"). Study participants with missing data regarding sarcopenia were excluded.

In 2012, we commenced a prospective cohort study of community-dwelling adults aged over 65 years in Kashiwa City, Chiba Prefecture ("Kashiwa Study"). The general community-dwelling cohort of older adults in our present study included participants who completed the second follow-up of Kashiwa Study [16]. As with the other group, participants with missing sarcopenia data were excluded. A flow diagram summarizing the subject selection of each cohort is shown in Supplementary Figure 1.

Measures

Sarcopenia

The primary outcome measure of this study was the status of sarcopenia and its components: low appendicular skeletal muscle mass, low muscle strength, and low physical function. In our study, sarcopenia was diagnosed according to the Asian Union criteria (Asian Working Group of Sarcopenia 2019) as low appendicular skeletal muscle mass with concomitant low muscle strength or low physical function [5]. Low appendicular skeletal muscle mass was assessed via bioimpedance analyses and defined as <7.0 kg/m^2 in men and <5.7 kg/m^2 in women. Both cohorts were evaluated using a body composition analyzer (InBody); the Olympic Study used the InBody 720 (InBody Japan, Tokyo, Japan), and the Kashiwa Study used the InBody 430 (InBody Japan, Tokyo, Japan). All groups were assessed by trained examiners at the health check-up site. Subjects were measured in the standing position and re-measured in the event of a measurement error. Low muscle strength was assessed by measuring grip strength using a Smedley-type grip strength meter and defined as <28 kg for men and <18 kg for women. The Olympic Study cohort was tested once on each side while the Kashiwa Study cohort was assessed twice. Low physical function was defined as a typical walking speed <1.0 m/s. For all participants, we measured the time taken to travel 5 m between 11 m lanes [17]. All study members were familiar with the measurement protocols, and personnel from Kashiwa Study were present during the evaluation of the Olympic Study to calibrate the measurement methods.

Musculoskeletal pain

The secondary outcome measure of this study was musculoskeletal pain, which was quantified by a modified version of the Geriatric Locomotive Function Scale (self-administered GLFS-25; range: 0 to 16 points) [18]. Study participants answered the following four questions regarding any pain they experienced over the last month: (i) pain (including numbness) in the shoulders, arms, or hands; (ii) pain in the back, lower back, or buttocks; (iii) pain (including numbness) in the lower extremities; and (iv) how painful it was to move their body in daily life. Questions were answered using a five-point system: not painful/no pain (0), a little (1), moderate (2), considerable (3), or severe (4).

Classification of Olympic disciplines and post-Olympic exercise habits

The Olympic disciplines of the Olympic Study cohort were classified according to guidelines from the 8th Task Force on the Classification of Sports by the American College of Cardiology (Figure 1). Disciplines were ranked according to exercise intensity (low, medium, and high) and type (static exercise intensity, dynamic exercise intensity, and cardiovascular exercise load intensity) [19]. The classification of cardiovascular intensity sums a static component reflecting maximal voluntary muscle contraction and a dynamic component reflecting maximal oxygen uptake. When an athlete had participated in multiple disciplines, the athlete was categorized in the discipline with the highest cardiovascular score. Additionally, the intensity of physical contact during each sport was assessed according to the American Academy of Pediatrics' standards, consisting of three categories: no physical contact, limited contact, and with contact

[20].

Information regarding the exercise habits of the athletes younger than 50 years of age in the Olympic Study was acquired from a previously completed questionnaire that took place every four years after the 1964 Olympics to assess ongoing exercise habits

Other measures

Other measures were similarly assessed in both cohorts. Age, sex, and medical history (hypertension, diabetes, heart disease, stroke, and malignant neoplasms) were assessed during an interview with a trained nurse. To evaluate each cohort's support status and long-term care certification, The Olympic Study completed a self-administered questionnaire, with public information from Kashiwa City acquired to represent the Kashiwa Study [21, 22]. We developed a questionnaire to assess the study participants' alcohol-consumption, smoking, and exercise habits, as well as depressive tendencies. The Geriatric Depression Scale (GDS-5) was used to measure depressive tendencies, which was considered to be present when two or more of the five criteria were applicable [23]. Individuals were defined as having an exercise habit if they completed at least one moderate-intensity physical activity per week during their leisure time [24]. Food intake frequency (meat, fish, soybeans, eggs, dairy products, green-yellow vegetables, fruits, and potatoes) were evaluated if they were consumed at least once every two days [25].

Statistical analysis

Continuous variables were reported as means and standard deviations or medians and interquartile ranges for normally and non-normally distributed data, respectively. Categorical variables were reported as a number and percentage. The analyses were stratified by sex. A generalized linear model adjusted for sex and age was used to compare basic attributes between the two groups. Propensity scores were calculated between the two groups in the multivariate analyses. The variables used to calculate the propensity scores were (1) age, (2) sex, (3) medical history (hypertension, diabetes, heart disease, malignant neoplasms, and stroke), (4) support certification and nursing care needs, and (5) history of alcohol-consumption, smoking, and exercise habits. The C-statistic from the Receiver Operating Characteristic curve confirmed the validity of the propensity score.

For multivariate analyses with categorical dependent variables (low appendicular skeletal muscle mass, low muscle strength, low physical function, sarcopenia, and having any musculoskeletal pain), adjusted odds ratios (OR) and 95% confidence intervals (95% CI) by propensity score were calculated using the binomial logistic regression analysis. For multivariate analyses with a continuous dependent variable (appendicular skeletal muscle mass, handgrip strength, usual gait speed, and musculoskeletal pain score), multiple regression analyses were used to calculate the adjusted partial regression coefficients and standard errors by propensity score. Continuous variables were normalized via logarithmic transformation. Any participants with missing data were excluded from the analyses. To determine sensitivity, we conducted the same analysis by sex and by post-Olympic exercise habits. All statistical analyses were performed using Statistical Package for the Social Sciences software (version 24.0; IBM Japan, Tokyo, Japan). A P-value of <0.05 was considered statistically significant.

Results

Study participants

Of the 2,044 participants in the Kashiwa Study, 1,536 participated in the second follow-up study. Of these, ten participants were excluded because their sarcopenia data was missing, and the remaining 1,526 subjects (mean age 74.1±5.5 years; 49% female) were included in the analyses. Of the 380 participants in the Olympic Study, 107 participated in the 13th follow-up survey. Of these, six participants were excluded because their sarcopenia data was missing, resulting in a total of 101 subjects (mean age 75.0±4.4 years, 26% female) included in the analyses.

Comparison of basic attributes

Basic attribute comparisons between the Olympic Study and the Kashiwa Study are presented in Table 1. When comparing former Olympic athletes and general older adults, there were no significant differences in age among both sexes. When basic attributes were compared after adjusting for age, we found no difference in BMI; however, skeletal muscle mass and grip strength were significantly higher, whereas walking speed under normal conditions and one-leg standing time with open eyes were lower in the Olympic Study. Additionally, the Olympic Study reported significantly higher musculoskeletal pain scores.

In terms of lifestyle, there were no differences in exercise habits; however, there were differences between groups in dietary habits. Athletes in the Olympic Study ate a significantly higher proportion of seafood, eggs, vegetables, and fruit at least once every two days. Further, former male Olympic athletes ate a higher proportion of meat. Alcohol consumption was significantly more prevalent among athletes in the Olympic Study, and former male Olympic athletes had a significantly considerable smoking habit. In terms of medical history, hypertension, heart disease, and stroke were less common among the athletes in the Olympic Study, although these results were not statistically significant. Former female Olympic athletes were more likely to have depressive symptoms.

Comparison of sarcopenia and musculoskeletal pain

Outcome comparisons between the Olympic Study and the Kashiwa Study are presented in Table 2. Athletes in the Olympic Study had a significantly lower prevalence of sarcopenia compared to athletes in the Kashiwa Study, even after propensity score adjustments (Men, 8.9% vs. 4.1%; Women, 7.8% vs. 4.0%), with this being a noteworthy association among men. However, these trends differed when each component of sarcopenia was compared. Although similar trends were found among men and women, there were significantly fewer Olympic Study subjects than Kashiwa Study subjects that had low appendicular skeletal muscle mass (Men, 32.2% vs. 22.9%; Women, 40.1% vs. 15.4%). On the other hand, lower physical function was significantly more common in the Olympic Study (Men, 3.0% vs. 10.7%; Women, 1.9% vs. 4.0%), with this association being noteworthy among men. There was no significant difference in the frequency of low muscle strength. There were significantly more individuals, particularly women, having any musculoskeletal pain after adjusting for propensity scores in the Olympic Study.

Quantitative comparison of sarcopenia components and musculoskeletal pain

When comparing sarcopenia components and musculoskeletal pain scores as a continuous variable, former Olympic athletes of both sexes tended to have higher muscle mass and strength, but also tended to walk slower and have higher musculoskeletal pain scores (Tables 3 and 4).

When comparing the results by continuation of exercise habits after 50 years of age, there was significantly more muscle mass and strength among former male Olympic athletes who continued to exercise after 50 years of age, but no significant association was found among those who did not continue. However, regardless of the continuation of the exercise routine, former Olympians had rather worse results in walking speed and pain scores. Former female Olympians had significantly higher muscle mass and strength as well as poorer gait speed and pain score results, regardless of whether they continued their exercise habits. Muscle mass and strength differed more in women who continued to exercise than in the general older population.

Sporting disciplines were classified according to three axes (static, dynamic, and cardiovascular load exercise intensities) and compared with sarcopenia and musculoskeletal pain scores (Tables 3 and 4). When comparing the type of sporting event, former male Olympians had significantly higher muscle mass and strength than sports competitors with higher Dynamic intensity and Cardiovascular intensity; higher static intensity was associated with muscle strength. Among females, regardless of exercise intensity, former Olympians had significantly higher muscle mass and strength than athletes with high Dynamic and Cardiovascular intensities. Among males, former Olympians had a lower walking speed, regardless of exercise intensity. Musculoskeletal pain scores tended to be higher at lower exercise intensities, and athletes with more physical contact were more likely to have musculoskeletal pain.

Discussion

In this study, we compared the prevalence of sarcopenia and musculoskeletal pain status among former Tokyo 1964 Olympic athletes and the general population of older adults living in Kashiwa City, Chiba Prefecture. As previously stated, the longitudinal Japanese dataset that tracked the Olympic Study into old age was extremely valuable and unique, and valuable insights were gained by comparing this data with a representative dataset of typical community-dwelling older adults. We observed a lower prevalence of sarcopenia in the Olympic Study, particularly with regards to superior appendicular skeletal muscle mass and muscle mass. This finding was more evident among those who had continued their exercise habits up to 50 years of age, and in athletes whose sporting discipline was classified as having a high exercise intensity. Conversely, physical function was lower among the Olympic Study, and this finding was higher in those who participated in sports that required more physical contact. Musculoskeletal pain scores were also higher in the Olympic Study, mainly in sports that were classified as having higher athletic intensity and requiring more physical contact.

Although we observed a lower prevalence of sarcopenia in the Olympic Study at old age, this association was not statistically significant for athletes whose sporting discipline was classified as “low intensity” when compared to the Kashiwa Study. This indicated the need for at least a moderate exercise intensity to reduce the prevalence of sarcopenia. This was also true for subjects who lost their exercise habits by 50 years of age, although the relationship was more pronounced for subjects who had exercised before 50 years of age. These results suggest that maximizing muscle mass in adolescence may lead to a higher appendicular skeletal muscle mass in old age, contributing to sarcopenia prevention. Another characteristic of the athletes in the Olympic Study was their dietary choices. Although there were no significant differences in current exercise habits compared to the Kashiwa Study, former athletes consumed significantly more protein-based foods, such as meat, fish, and eggs, as well as more vegetables and fruits. Although the relationship between diet and sarcopenia is often examined in terms of dietary patterns rather than specific foods, it is known that fewer new cases of sarcopenia occur in older men who consume more protein, fruit, and vegetables [26, 27]. For former elite athletes, dietary choices made during active training may have led to healthy dietary habits in old age, which in turn may be related to sarcopenia prevention. Based on the above, we believe that the results of the present study support the hypothesis that exercise habits adapted during adolescence and adulthood contribute to a healthier aging process. In other words, the establishment of a solid foundation of healthy and active lifestyles during adolescence may have had a positive impact on eating habits in old age, which, combined with the muscle mass accumulated early in life, may have carried over into old age as above-average muscle mass. Differences in muscle mass were particularly pronounced in women. While this could be considered to be due to the extreme superiority of female former Olympians, there was no significant difference in BMI values, suggesting that the muscle mass of Japanese women may be too low.

Contrastingly, the present study showed that the Olympic Study had lower physical functioning and higher musculoskeletal pain scores. This finding was significantly more common in those who ceased their exercise habits before age 50 and in athletes who competed in high-intensity sports. Based on these results, competition in sports with high intensity and physical contact may result in reduced physical function and chronic musculoskeletal pain in old age. Additionally, the Olympic Study subjects who lost their exercise habits before age 50 reported lower physical functioning.

The Olympic Study subjects had superior appendicular skeletal muscle mass and also less frequently reported a history of hypertension and heart disease; therefore, we expected mortality would be lower in this group as described in previous studies [11-13]. However, concerning musculoskeletal pain, it is known that the prevalence of chronic musculoskeletal pain increases with age [28], and musculoskeletal pain in old age is also a risk factor for reduced daily living activities, physical and social frailty, and depression [29-31]. Therefore, we believe that this decline in physical function and increase in musculoskeletal pain may lead to limitations in daily life and social participation, which must be addressed with respect to QoL. Although it is essential to improve physical function in adulthood and into old age, it is also vital to prevent injuries and motor impairment. Injury prevention in adulthood has a positive long-term impact on health in old age.

This study had some limitations that should be addressed. Firstly, this study used the Kashiwa Study dataset as a representative of the general older population for comparison, and a propensity score was calculated to resolve differences in basic attributes between the two cohorts and to account for the smaller sample size of the former Olympic Study cohort. However, the propensity score was calculated only by measures that were uniformly evaluated between groups, and therefore, potentially significant confounding factors may have been overlooked in our analyses. Secondly, the two cohorts differed in their timing and surveying methods. The use of different measurement equipment may have had a minor effect on the values obtained. Thirdly, the effects of selection bias (healthy volunteer effect and survival effect) cannot be ruled out, as the data in this study are from cohorts that cooperated with their own studies and its follow-ups, particularly in the case of the former Olympic athlete cohort, who have been cooperating with the survey for many years. However, since both surveys were conducted on the assumption that the older participants were able to come to the survey site by themselves, it is unlikely that the different survey methods had a significant impact on the level of independence of the subjects.

Conclusions and Implications

In this study, we analyzed the cohort data that followed the lives of former Tokyo Olympians athletes and compared their experience of sarcopenia and musculoskeletal pain status to that of the general older population. We observed a lower prevalence of sarcopenia and superior appendicular skeletal muscle mass and muscle strength in the former Olympians, especially among those who continued their exercise habits as well as those whose sporting discipline was classified as having a high exercise intensity. Conversely, low physical function and higher musculoskeletal pain were more prevalent in the Olympic Study, especially among athletes who competed in sports with physical contact. In conclusion, there is a need to encourage physical activity in adolescence and adulthood while providing adequate education to prevent the development of sarcopenia and musculoskeletal pain in old age

Conflicts of interest: The authors have no conflicts of interest.

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Ethical considerations: This study was conducted according to the ethical standards established by the 1964 Declaration of Helsinki and later amendments, and prevailing national regulations and guidelines. The ethics committee of the Japanese Institute of Sports Sciences approved the study protocol for the Tokyo Olympic Memorial fitness test (2016-56). The ethics committee of the Life Science Department (The University of Tokyo) approved the protocol of the Kashiwa Study (#16-255). All participants in both cohorts provided their informed consent for testing and analysis of their data.

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References

1. Cruz-Jentoft, A.J., et al., Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing, 2019. 48(4): p. 601.
2. Mijnarends, D.M., et al., Muscle, Health and Costs: A Glance at their Relationship. J Nutr Health Aging, 2018. 22(7): p. 766-73.
3. Vellas, B., et al., Implications of ICD-10 for Sarcopenia Clinical Practice and Clinical Trials: Report by the International Conference on Frailty and Sarcopenia Research Task Force. J Frailty Aging, 2018. 7(1): p. 2-9.
4. https://www.icd10data.com/ICD10CM/Codes/M00-M99/M60-M63/M62-/M62.84 2020 ICD-10-CM Diagnosis Code M62.84. Sarcopenia [cited 2020 March 25].
5. Chen, L.K., et al., Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. J Am Med Dir Assoc, 2020. 21(3): p. 300-307 e2.
6. Sayer, A.A., et al., The developmental origins of sarcopenia. J Nutr Health Aging, 2008. 12(7): p. 427-32.
7. Martinez-Gomez, D., et al., Physical Activity and the Effect of Multimorbidity on All-Cause Mortality in Older Adults. Mayo Clin Proc, 2017. 92(3): p. 376-382.
8. Park, H., et al., Yearlong physical activity and sarcopenia in older adults: the Nakanojo Study. Eur J Appl Physiol, 2010. 109(5): p. 953-61.
9. Aoyagi, Y. and R.J. Shephard, Habitual physical activity and health in the elderly: the Nakanojo Study. Geriatr Gerontol Int, 2010. 10 Suppl 1: p. S236-43.
10. Hayasaka, S., et al., Physical activity and all-cause mortality in Japan: the Jichi Medical School (JMS) Cohort Study. J Epidemiol, 2009. 19(1): p. 24-7.
11. Lemez, S. and J. Baker, Do Elite Athletes Live Longer? A Systematic Review of Mortality and Longevity in Elite Athletes. Sports Med Open, 2015. 1(1): p. 16.
12. Garatachea, N., et al., Elite athletes live longer than the general population: a meta-analysis.

Mayo Clin Proc, 2014. 89(9): p. 1195-200.

13. Zwiers, R., et al., Mortality in former Olympic athletes: retrospective cohort analysis. BMJ, 2012. 345: p. e7456.
14. Yabe, Y., et al., Musculoskeletal pain and new-onset poor physical function in elderly survivors of a natural disaster: a longitudinal study after the great East Japan earthquake. BMC Geriatr, 2019. 19(1): p. 274.
15. Yabe, Y., et al., Musculoskeletal Pain is Associated With New-Onset Psychological Distress in Survivors of the Great East Japan Earthquake. Disaster Med Public Health Prep, 2019. 13(2): p. 295-300.
16. Tanaka, T., et al., "Yubi-wakka" (finger-ring) test: A practical self-screening method for sarcopenia, and a predictor of disability and mortality among Japanese community-dwelling older adults. Geriatr Gerontol Int, 2018. 18(2): p. 224-232.
17. Mijnarends, D.M., et al., Validity and reliability of tools to measure muscle mass, strength, and physical performance in community-dwelling older people: a systematic review. J Am Med Dir Assoc, 2013. 14(3): p. 170-8.
18. Seichi, A., et al., Development of a screening tool for risk of locomotive syndrome in the elderly: the 25-question Geriatric Locomotive Function Scale. J Orthop Sci, 2012. 17(2): p. 163-72.
19. Mitchell, J.H., et al., Task Force 8: classification of sports. J Am Coll Cardiol, 2005. 45(8): p. 1364-7.
20. Rice, S.G., M. American Academy of Pediatrics Council on Sports, and Fitness, Medical conditions affecting sports participation. Pediatrics, 2008. 121(4): p. 841-8.
21. Tsutsui, T. and N. Muramatsu, Care-needs certification in the long-term care insurance system of Japan. J Am Geriatr Soc, 2005. 53(3): p. 522-7.
22. Fukutomi, E., et al., Long-term care prevention project in Japan. Lancet, 2013. 381(9861):

p. 116.

23. Weeks, S.K., et al., Comparing various short-form Geriatric Depression Scales leads to the GDS-5/15. J Nurs Scholarsh, 2003. 35(2): p. 133-7.
24. Cleland, C.L., et al., Validity of the global physical activity questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. BMC Public Health, 2014. 14: p. 1255.
25. Caswell, B.L., et al., A 10-Food Group Dietary Diversity Score Outperforms a 7-Food Group Score in Characterizing Seasonal Variability and Micronutrient Adequacy in Rural Zambian Children. J Nutr, 2018. 148(1): p. 131-139.
26. Chan, R., J. Leung, and J. Woo, A Prospective Cohort Study to Examine the Association Between Dietary Patterns and Sarcopenia in Chinese Community-Dwelling Older People in Hong Kong. J Am Med Dir Assoc, 2016. 17(4): p. 336-42.
27. Karlsson, M., et al., Associations between dietary patterns at age 71 and the prevalence of sarcopenia 16 years later. Clin Nutr, 2019.
28. Crook, J., E. Rideout, and G. Browne, The prevalence of pain complaints in a general population. Pain, 1984. 18(3): p. 299-314.
29. Manchikanti, L., et al., Comprehensive review of epidemiology, scope, and impact of spinal pain. Pain Physician, 2009. 12(4): p. E35-70.
30. Nakai, Y., et al., Association between Chronic Pain and Physical Frailty in Community-Dwelling Older Adults. Int J Environ Res Public Health, 2019. 16(8).
31. Hirase, T., et al., Chronic pain is independently associated with social frailty in community-dwelling older adults. Geriatr Gerontol Int, 2019. 19(11): p. 1153-1156.
32. von Haehling, S., et al., Ethical guidelines for publishing in the Journal of Cachexia, Sarcopenia and Muscle: update 2017. J Cachexia Sarcopenia Muscle, 2017. 8: p. 1081-1083.

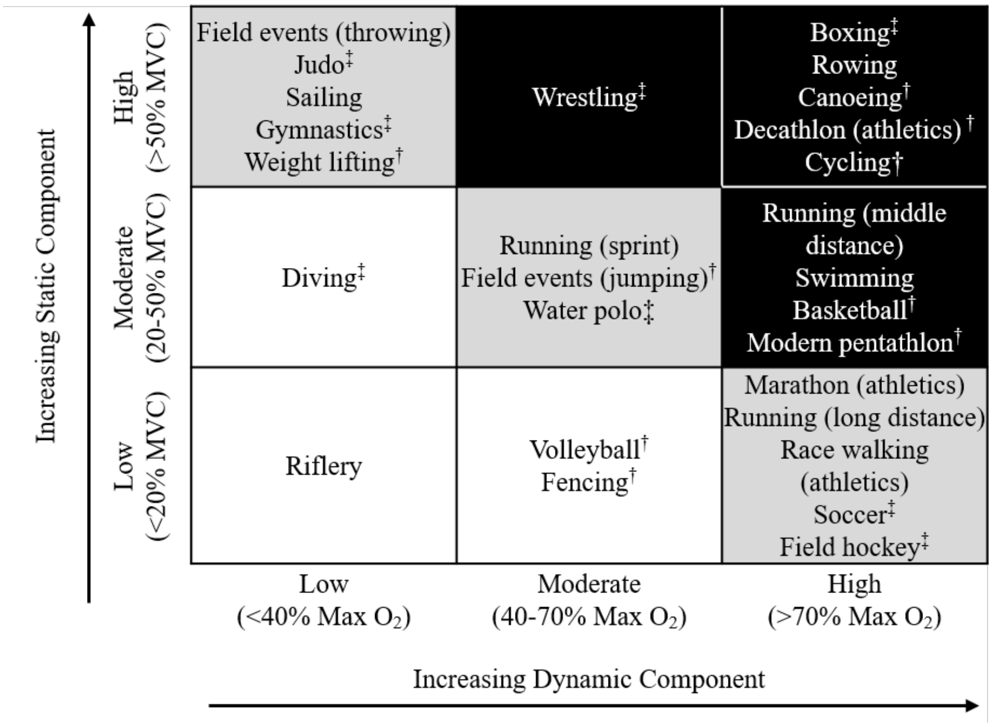

Figure legends

Figure 1. Olympic sporting disciplines classified by intensity and body contact.

Notes: This classification was based on peak static and dynamic components achieved during competition. The increasing dynamic component was defined in terms of the estimated percent of maximal oxygen uptake (Max O_2) achieved and resulted in an increased cardiac output. The increasing static component was related to the estimated percent of maximal voluntary contraction (MVC) reached and resulted in an increased blood pressure load. The total cardiovascular demands (cardiac output and blood pressure) are divided into three categories of low (white), moderate (grey), and high (black) intensity. † and ‡; Classification of sports according to body contact (†, limited-contact; ‡, contact)

Supplementary figure 1. Flow diagram showing the recruitment and inclusion of subjects from the two study cohorts: The Kashiwa Study of general community-dwelling older adults and the Olympic Study of former Olympic athletes.

Table 1. Comparison of characteristics between former Olympians and general older adults.

	Men			Women		
	Community -dwellers	Former Olympians	*P**	Community -dwellers	Former Olympians	*P**
Number of participants	779	75		747	26	
Age, years	74.0±5.5	75.5±4.5	*.202*	73.8±5.4	74.4±3.3	*.281*
Physical measures						
Body mass index, kg/ m^2	23.3±2.8	23.7±2.7	*.321*	22.5±3.1	22.2±2.7	*.642*
Appendicular SMI, kg/m^2	7.29±0.73	7.35±1.2	*<.001*	5.87±0.64	7.39±1.9	*<.001*
Low appendicular SMI	32.2%	22.9%	*<.001*	40.1%	15.4%	*.001*
Handgrip strength, kg	33.9±5.9	36.1±12	*<.001*	22.0±4.0	25.8±8.5	*<.001*
Low muscle strength	12.6%	12.3%	*.951*	10.8%	8.7%	*.744*
Usual gait speed, m/sec	1.51±0.26	1.23±0.20	*<.001*	1.52±0.24	1.29±0.21	*<.001*
Low physical performance	3.0%	10.7%	*.002*	1.9%	4.0%	*.002*
Sarcopenia	8.9%	4.1%	*.041*	7.8%	4.0%	*.023*
One-leg standing, time	60 (29-60)	27 (10-52)	*<.001*	60 (24-60)	20 (9-57)	*<.001*
Musculoskeletal pain score	2.0 (0.0-4.0)	3.0 (1.0-5.3)	.002	2.0 (0.0-4.0)	4.0 (2.0-7.0)	.006

Having musculoskeletal pain, pain score > 0)	66.5%	74.7%	.023	71.3%	87.5%	.012
Daily habits						
Current exercise	80.1%	73.3%	.440	75.2%	24.0%	.440
Food intake, >1/2 day						
Meat	52.0%	63.0%	.071	55.2%	83.3%	.006
Fish	64.7%	81.1%	.004	66.3%	84.0%	.045
Eggs	63.2%	81.1%	.002	62.2%	87.5%	.012
Soy beans	78.8%	76.7%	.675	85.3%	88.0%	.705
Dairy products	81.6%	90.4%	.060	90.9%	92.0%	.850
Vegetables	48.7%	87.7%	<.001	62.2%	96.0%	<.001
Fruits	45.1%	84.9%	<.001	56.6%	80.0%	.020
Alcohol, daily or quit	76.9%	87.8%	.030	25.3%	61.5%	<.001
Smoking, daily or quit	72.5%	54.2%	.001	5.4%	8.0%	.566
Medical history and chronic condition						
Hypertension	46.5%	38.4%	*.183*	39.0%	34.6%	*.655*
Diabetes mellitus	15.7%	11.0%	*.285*	9.0%	7.7%	*.822*

Heart disease	21.4%	19.2%	*.652*	14.2%	0.0%	*.075*
Malignant neoplasm	19.4%	28.0%	*.056*	10.6%	7.7%	*.637*
Stroke	7.5%	4.1%	*.278*	5.2%	0.0%	*.232*
Depressive symptoms	9.9%	12.0%	*.561*	15.8%	38.5%	*.002*
Need for long-term support	1.5%	4.0%	*.138*	5.1%	3.0%	*.633*

Notes: SMI, skeletal muscle mass index.

* is indicative of p-values that were adjusted by age using logistic regression.

Table 2. Comparison of prevalence of sarcopenia status and musculoskeletal pain between former Olympians and community-dwelling older adults.

	Low muscle mass	Low muscle strength	Low physical performance	Sarcopenia	Having any musculoskeletal pain
	aOR (95%CI)	aOR (95%CI)	aOR (95%CI)	aOR (95%CI)	aOR (95%CI)
Overall					
Community-older adults	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Former Olympic athletes	0.41 (0.24 to 0.70)*	0.79 (0.40 to 1.56)	2.60 (1.16 to 6.07)*	0.49 (0.20 to 0.94)*	2.22 (1.24 to 3.97)*
Men					
Community-dwellers	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Former Olympic athletes	0.47 (0.25 to 0.89)*	0.80 (0.37 to 1.73)	2.64 (1.04 to 6.74)*	0.37 (0.14 to 0.93)*	1.88 (1.04 to 3.58)*
Women					
Community-dwellers	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Former Olympic athletes	0.26 (0.11 to 0.77)*	0.73 (0.17 to 3.22)	2.40 (0.30 to 19.93)	0.91 (0.21 to 4.03)	4.05 (1.12 to 16.54)*

Notes: aOR, adjusted odds ratio; CI, confidence interval; B, partial regression coefficient; SE, standard error.

* indicated the significantly significant data points (P<.050).

Odds ratios were adjusted by propensity score calculated using age, sex, alcohol and smoking habits, medical history, and long-term support needs.

Table 3. Quantitative comparison of co-primary outcomes between former Olympians and community-dwelling older men.

			Muscle mass	Muscle strength	Physical performance	Musculoskeletal pain, score
			Appendicular SMI, kg.m^2	Handgrip strength, kg	Usual gait speed, m/sec	
		%	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
All Former Olympic athletes' men		100%	0.19 (0.07 to 0.33)*	2.52 (0.80 to 4.25)*	-0.28 (-0.34 to -0.21)*	0.86 (0.14 to 1.59)*
Continuing exercise after age 50 or not						
Athletes who stopped exercise before age 50		58.7%	0.09 (-0.17 to 0.52)	1.55 (-1.12 to 4.23)	-0.27 (-0.35 to -0.19)*	0.77 (0.17 to 1.71)*
Athletes who continuing exercise after age 50		41.3%	0.20 (0.12 to 0.52)*	3.12 (0.99 to 5.26)*	-0.29 (-0.38 to -0.19)*	0.99 (0.08 to 2.05)*
Differences in sports discipline †						
Dynamic component	Low	17.3%	-0.42 (-0.89 to 0.06)	-1.05 (-4.98 to 2.87)	-0.32 (-0.46 to -0.17)*	2.14 (0.43 to 3.85)*
	Middle	26.7%	0.17 (-0.17 to 0.51)	-0.15 (-3.08 to 2.79)	-0.30 (-0.42 to -0.19)*	-0.01 (-1.23 to 1.20)
	High	56.0%	0.27 (0.01 to 0.55)*	5.33 (3.02 to 7.64)*	-0.25 (-0.33 to -0.16)*	1.02 (0.03 to 2.00)
Static component	Low	21.3%	-0.33 (-0.75 to 0.09)	-1.61 (-5.25 to 2.04)	-0.28 (-0.42 to -0.14)*	2.12 (0.55 to 3.68)*
	Middle	37.3%	0.27 (-0.02 to 0.56)	3.31 (0.90 to 5.71)*	-0.27 (-0.36 to -0.17)*	0.39 (-0.64 to 1.42)
	High	41.3%	0.01 (-0.32 to 0.33)	3.55 (0.85 to 6.25)*	-0.21 (-0.31 to -0.10)*	0.69 (-0.48 to 1.85)
Cardiovascular demands	Low	9.3%	-0.81 (-1.43 to -0.30)*	-3.35 (-1.42 to 3.39)	-0.34 (-0.54 to -0.14)*	2.48 (0.29 to 4.68)*
	Middle	45.3%	0.10 (-0.18 to 0.39)	0.98 (-1.42 to 3.39)	-0.28 (-0.37 to -0.19)*	0.82 (-0.21 to 1.84)

	High	45.3%	0.40 (0.10 to 0.69)*	5.50 (2.99 to 8.01)*	-0.26 (-0.36 to -0.17)*	0.54 (-0.52 to 1.60)
Physical contact	Non-contact	41.3%	0.51 (0.21 to 0.82)*	0.23 (-0.24 to 2.82)	-0.24 (-0.34 to -0.15)*	0.52 (-0.58 to 1.63)
	Limited-contact	29.3%	-0.38 (-0.76 to 0.01)	4.99 (1.78 to 8.19)*	-0.28 (-0.41 to -0.16)*	0.79 (-0.58 to 2.16)
	Contact	29.3%	0.05 (-0.28 to 0.38)	3.42 (0.55 to 6.29)*	-0.35 (-0.42 to -0.21)*	1.31 (0.12 to 2.50)*

Notes: SMI, skeletal muscle mass index; B, partial regression coefficient, CI, confidence interval.

*, the significantly significant difference (*P<.050*) compared with community-dwelling older adults as reference group.

Statistic values were adjusted by a propensity score calculated using age, alcohol and smoking habits, medical history, and long-term support needs.

[†], The increasing dynamic intensity was defined in terms of the estimated percent of maximal oxygen uptake achieved and resulted in an increased cardiac output. The increasing static component was related to the estimated percent of maximal voluntary contraction reached and resulted in an increased blood pressure load. The total cardiovascular demands were considered by cardiac output and blood pressure.

Table 4. Quantitative comparison of co-primary outcomes between former Olympians and community-dwelling older women.

			Muscle mass	Muscle strength	Physical performance	Musculoskeletal pain, score
			Appendicular SMI, kg.m^2	Handgrip strength, kg	Usual gait speed, m/sec	
		%	B (Std error)	B (Std error)	B (Std error)	B (Std error)
All Former Olympic athletes' women		100%	1.48 (1.19 to 1.77)*	4.34 (2.53 to 6.15)*	-0.24 (-0.34 to -0.14)*	2.02 (0.80 to 3.23)*
Continuing exercise after age 50 or not						
Athletes who stopped exercise before age 50		57.7%	1.23 (0.86 to 1.60)*	2.69 (0.37 to 5.02)*	-0.27 (-0.40 to -0.14)*	2.14 (0.54 to 3.74)*
Athletes who continuing exercise after age 50		42.3%	1.86 (1.41 to 2.30)*	6.72 (3.93 to 9.50)*	-0.19 (-0.34 to -0.04)*	1.85 (0.03 to 3.67)*
Differences in sports discipline						
Dynamic component	Low	23.1%	2.35 (1.78 to 2.93)*	0.36 (-3.05 to 3.77)	-0.17 (-0.37 to 0.03)	2.78 (0.20 to 5.36)*
	Middle	42.3%	1.51 (1.08 to 1.93)*	3.83 (1.05 to 6.60)*	-0.24 (-0.39 to -0.09)*	2.05 (0.23 to 3.87)*
	High	34.6%	0.81 (0.32 to 1.31)*	8.30 (5.17 to 11.43)*	-0.28 (-0.45 to -0.11)	1.51 (-0.52 to 3.54)
Static component	Low	34.6%	1.65 (1.17 to 2.13)*	5.43 (2.02 to 8.84)*	-0.26 (-0.44 to -0.08)*	2.65 (0.62 to 4.68)*
	Middle	50.0%	0.69 (0.31 to 1.07)*	3.78 (1.36 to 6.21)*	-0.26 (-0.39 to -0.13)*	1.39 (-0.27 to 3.06)
	High	15.4%	3.71 (3.04 to 4.39)*	4.38 (0.21 to 8.56)*	-0.12 (-0.36 to 0.12)	2.82 (-0.48 to 6.12)
Cardiovascular demands	Low	42.3%	1.24 (0.80 to 1.68)*	2.17 (-0.79 to 5.13)	-0.26 (-0.42 to -0.10)*	2.67 (0.84 to 4.49)*
	Middle	26.9%	2.60 (2.07 to 3.12)*	2.78 (-0.37 to 5.92)	-0.15 (-0.33 to 0.03)	1.55 (-1.01 to 4.11)

	High	30.8%	0.81 (0.32 to 1.30)*	8.30 (5.17 to 11.43)*	-0.28 (-0.45 to -0.11)*	1.51 (-0.52 to 3.54)
Physical contact	Non-contact	42.3%	0.85 (0.43 to 1.27)*	5.43 (2.80 to 8.07)*	-0.17 (-0.38 to -0.11)*	1.35 (-0.56 to 3.26)
	Limited-contact	38.5%	1.64 (1.17 to 2.10)*	6.19 (3.04 to 9.33)*	-0.24 (-0.39 to -0.10)*	2.27 (0.35 to 4.19)*
	Contact	19.2%	2.61 (1.99 to 3.24)*	-0.54 (-4.28 to 3.20)	-0.27 (-0.44 to -0.10)*	2.79 (0.21 to 5.36)*

Notes: SMI, skeletal muscle mass index; B, partial regression coefficient, CI, confidence interval.

*, the significantly significant difference (*P<.050*) compared with community-dwelling older adults as reference group.

Statistic values were adjusted by a propensity score calculated using age, alcohol and smoking habits, medical history, and long-term support needs.

†, The increasing dynamic intensity was defined in terms of the estimated percent of maximal oxygen uptake achieved and resulted in an increased cardiac output. The increasing static component was related to the estimated percent of maximal voluntary contraction reached and resulted in an increased blood pressure load. The total cardiovascular demands were considered by cardiac output and blood pressure.