Sex-differences in age-related grip strength decline: A 10-year longitudinal study of community-living middle-aged and older Japanese

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Abstract The purpose of this study was to estimate sex differences in age-related grip strength decline and describe the course of decline in grip strength from age 40 to 89 years by a longitudinal epidemiological study. Participants were randomly selected community-living men (n = 648) and women (n = 598) aged 40 to 79 years at baseline. Grip strength was measured with standard techniques every other year over a 10-year period. The preservation rate of grip strength was calculated as the 10-year follow-up value divided by the baseline value. The relationship between the preservation rates of grip strength and age group (by decade) at baseline by sex was analyzed using Two-Way Analysis of Variance and the Tukey-Kramer method. The trajectories of grip strength over 10 years were plotted for both men and women. The mean grip strength preservation rates of participants in their 40s, 50s, 60s and 70s over 10 years was 0.90, 0.88, 0.84 and 0.79 in men, and 0.89, 0.89, 0.89 and 0.88 in women, respectively. There were significant differences in sex and age group at baseline in the preservation rate of grip strength. Among men, the preservation rate of grip strength for the 70s group was significantly lower than that of younger groups (p < 0.05); however, no significant difference was observed among age groups in women. The trajectories of grip strength decline year by year were steep in men, but even in women. Age-related decline in grip strength markedly increased in older men, but remained constant throughout middle and late adulthood in women.

Keywords: sex difference, grip strength, aging, longitudinal data

Introduction

By 2035, it is estimated that people aged 65 years and older will comprise more than one third of the Japanese population1. The number of older people who depend on health care services is thus set to grow. In addition, about 70% of older people are expected to be living alone or with their spouse2. In order for older people to maintain independence in the community, it is important to perform daily tasks without difficulty.

Poor muscle strength has proven to be one of the strongest indicators of impairment, activity limitation and mortality among older people3-6. The term dynapenia was coined to explain the loss of physical function and increased risk of disability among older adults7. Grip strength, which represents hand strength, as well as lower extremity muscle strength, has been adopted as a useful indicator8. Recently the term sarcopenia, which was initially defined as the age-related loss of muscle mass, has been redefined as the loss of muscle mass in combination with loss of muscle strength (grip strength) and/or physical performance (walking speed)9,10. Frailty is a major health problem for aging populations as it makes older people vulnerable to poor recovery after a stressor event11. According to Fried et al.12, the definition of physical frailty, which is one of the most well-known criteria of the frailty phenotype, includes weakness (grip strength) with weight loss, self-reported exhaustion, slow walking speed, and low physical activity.

Because grip strength is established and simple to measure, it has been used across wide age groups13 and in institutional settings to assess older people14. However, most nationwide surveys and functional assessments of grip strength in institutions have typically not addressed

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the aging process. Although longitudinal studies show that grip strength in adults declines with age,[15-19] little research has been conducted on changes in grip strength using measure-based longitudinal data and well-balanced large subject groups comprising both sexes.

The aim of the present study was to estimate sex differences in grip strength decline and describe the course of this decline from 40 to 89 years of age for men and women using longitudinal data from community-living middle-aged and older people.

Methods

Study Population. Participants included 648 men and 598 women who participated in both the baseline study and the subsequent 10-year follow-up study of the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA). The NILS-LSA was based on data obtained from interviews and laboratory examinations of medical, nutritional, psychological and physical fitness variables. Details of the study can be found elsewhere[20]. The initial survey of the NILS-LSA involved 2267 participants 40 to 79 years of age, including almost 300 men and 300 women from each group categorized by age decade (40s, 50s, 60s and 70s). The participants were gender and age-stratified random samples of the residents of Obu-shi and Higashiura-cho, Aichi Prefecture, in central Japan. Participants were drawn from residence registrations in cooperation with local governments. All participants lived or had lived at home in the community. Those who lived in nursing homes or long-term care homes were excluded. The NILS-LSA involves biennial examinations; therefore, the participants had a maximum of six examinations (baseline and 2nd, 4th, 6th, 8th and 10th year) during the 10-year follow-up period. By the end of the 10-year follow-up, some participants had dropped out due to death (n = 248), moving to another area (n = 9), or refusal to participate or no response (n = 748) (Fig. 1). Participants who could not take part in the grip strength test during the 6th wave survey were also excluded (n = 16). The final numbers of participants in each age group by decade (40s, 50s, 60s and 70s) were 210, 219, 156 and 63 men, and 203, 204, 140, and 51 women, respectively; and the participation rate for the grip strength test in the 10-year follow-up was 72.2%, 77.7%, 55.1% and 22.3% for men and 72.0%, 73.1%, 49.1%, and 18.1% for women, respectively. As expected, the participants aged 70–79 years had the highest number of dropouts. The mean number of examinations per participant was 5.8 ± 0.5. No significant differences were observed in the participation rate of each age group or the number of examinations by sex. All NILS-LSA procedures were approved by the Ethical Committee of the National Center for Geriatrics and Gerontology, and all participants provided written informed consent.

Measurements. A handgrip dynamometer (Takei Co., Niigata, Japan) was used to assess grip strength in kg. The participants held a handgrip dynamometer while standing with their arms at their sides and their elbows extended and squeezing with maximum force, alternating the left and right hands. The average of two readings from each hand was used as the measurement result. The safety of the participants was closely monitored during all tests. The examiners carefully measured grip strength while monitoring the participants’ blood pressure and fa-
tigue level. They advised the participants to exhale while squeezing during the grip strength measurements and to perform the repetitions at their own pace. A medical doctor asked the participants about their health condition before starting the grip strength tests. If any participant had any serious pain, physical injury, or illness of the orthopedic or cardiovascular systems, they did not take part in the tests.

**Statistical Analysis.** The baseline characteristics of the participants in the 10-year follow-up and the dropouts were analyzed for differences using Student’s-\(t\) test for continuous variables, and the Cochran-Mantel-Haenszel test for categorical variables by sex. Student’s-\(t\) test was also used to compare grip strength at baseline between the participants and the dropouts by sex and age group. The preservation rate of grip strength for evaluating changes regardless of the absolute value was calculated by dividing the 10-year follow-up value by the baseline value. The relationship between the preservation rate of grip strength and age group by decade at baseline and sex was analyzed using Two-Way Analysis of Variance (ANOVA), and the Tukey-Kramer method was used for multiple comparison analysis by sex. Effect sizes were calculated to evaluate the magnitude of differences in grip strength by sex, age group and sex*age group. To observe the age-related changes in grip strength throughout middle and late adulthood, the mean grip strength for each year within the age groups was calculated at baseline and at each follow-up for both men and women. The mean grip strength was plotted for the age span of 40 to 89 years. Statistical testing was performed using the Statistical Analysis System version 9.1 (SAS Institute Inc., Cary, NC, USA). Significant probability levels were considered to be less than 0.05.

**Results**

The baseline characteristics of the participants in the 10-year follow-up and the dropouts are shown in Table 1. The participants in the 10-year follow-up were significantly younger, taller, heavier, had higher incomes, more education, better self-rated health and less prevalent diseases than dropouts in men. The results for women were similar. The participants in the 10-year follow-up had greater grip strength than the dropouts in the 50s, 60s, and 70s age groups among men and in the 60s age group among women (Table 2).

The mean grip strength preservation rates of participants in their 40s, 50s, 60s and 70s for the 10 years at baseline were 0.90, 0.88, 0.84 and 0.79, in men, and 0.89, 0.89, 0.89 and 0.88 in women, respectively (Fig. 2). The skewness and kurtosis of the grip strength preservation rate by sex were 0.00 and 3.02 in men, and 1.20 and 8.83 in women, respectively. The results of the two-way ANOVA indicated that there were significant main effects and interaction of sex and age group at baseline in the preservation rate of grip strength (sex, \(df = 1, F = 8.87, p = 0.003\), \(\eta^2 = 0.007\); age group at baseline, \(df = 3, F = 10.54, p < 0.0001\), \(\eta^2 = 0.024\); sex*age group at baseline, \(df = 3, F = 8.52, p < 0.0001\), \(\eta^2 = 0.020\)). Power analysis using the GLM-POWER procedure showed that this model had more than 99% power to detect differences in grip strength by sex (99.4%), age group (99.5%) and sex*age group (99.2%).

The grip strength preservation rate in older age groups was significantly lower than that of younger groups among men (40s, 50s, 60s > 70s, 40s > 60s; \(p < 0.05\)); however, no significant difference was observed among age groups in women. The average annual decline rate in grip strength in men was -1.0% per year in the 40s, and gradually increased with age to double the reduction rate (-2.0% per year) in the 70s. In contrast, among women, grip strength declined at a constant rate (-1.0% per year) among all age groups.

Yearly changes in grip strength using the mean grip strength for each year of age are shown in Fig. 3. Each line joins six values for every two years from baseline to the 10-year follow up. Trajectories of grip strength for the age span of 40 to 89 years illustrated that the course of decline in grip strength with age was steep among men, whereas it remained the same among women. Although sex differences in grip strength tended to be less obvious in the older age groups, women had much lower grip strength than men throughout the age span of 40 to 89 years.

**Discussion**

We demonstrated an age-related decline in grip strength across middle and late adulthood for men and women using 10-year longitudinal data. Our main finding was that the decline in grip strength differs between sexes in middle and late adulthood. Among men, age-related decline in grip strength was greater in late adulthood, whereas among women, age-related decline in grip strength was constant across middle and late adulthood.

The age-related decline in grip strength among men was associated with age at baseline. It is well-known that women have less muscle strength than men at every stage of their adult life\(^{21}\); however, sex differences in the decline of muscle strength remain unclear because few longitudinal studies of muscle strength for men and women in the same population have been reported\(^{17}\). Previous studies support our findings that the decline in grip strength accelerates with age among men\(^{15}\) and that, among the oldest women, a horizontal plateau in grip strength decline is observed\(^{10}\). However, no sex differences in the rate of decline in grip strength were reported in a previous 10-year prospective study\(^{22}\). Different age ranges and cohort sizes between the previous and current study may have led to the varied results. This study, which was designed for the same follow-up period and
### Table 1. Baseline characteristics of the participants in the 10-year follow-up and the dropouts for men and women

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>follow-up</td>
<td>dropout</td>
</tr>
<tr>
<td></td>
<td>n=648</td>
<td>n=491</td>
</tr>
<tr>
<td>Age years</td>
<td>55.5± 9.2</td>
<td>64.1± 11.1</td>
</tr>
<tr>
<td>Height cm</td>
<td>165.9± 5.9</td>
<td>162.7± 6.6</td>
</tr>
<tr>
<td>Weight kg</td>
<td>63.7± 8.5</td>
<td>60.1± 9.6</td>
</tr>
<tr>
<td>BMI kg/m²</td>
<td>23.1± 2.6</td>
<td>22.7± 3.1</td>
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<tr>
<td>Body fat %</td>
<td>21.2± 4.1</td>
<td>21.5± 4.7</td>
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<tr>
<td>Education years</td>
<td>12.6± 2.5</td>
<td>11.6± 2.5</td>
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<tr>
<td>Annual income</td>
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<tr>
<td>Smoking %</td>
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</tr>
<tr>
<td>Never</td>
<td>23.9</td>
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</tr>
<tr>
<td>Former</td>
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</tr>
<tr>
<td>Current</td>
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<tr>
<td>Self-rated health %</td>
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<td>2.7</td>
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<td>0.8</td>
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<tr>
<td>Prevalent diseases %</td>
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<td></td>
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<tr>
<td>Hypertension</td>
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<td>Heart diseases</td>
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</tr>
<tr>
<td>Diabetes</td>
<td>7.5</td>
<td>14.1</td>
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</table>

BMI, Body mass index. Continuous variables are presented as means ± standard deviation (SD), and categorical variables are presented as percentages. The differences between groups were analyzed by Student’s-t test for continuous variables and by Cochran-Mantel-Haenszel test for categorical variables. Bold represents significant p-value (<0.05).

### Table 2. Baseline grip strength of the participants in the 10-year follow-up and the dropouts in each age group for men and women

<table>
<thead>
<tr>
<th>Age groups</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>follow-up</td>
<td>dropout</td>
</tr>
<tr>
<td></td>
<td>n Mean SD</td>
<td>n Mean SD</td>
</tr>
<tr>
<td>40-49</td>
<td>210 46.2± 6.4</td>
<td>81 45.8± 6.6</td>
</tr>
<tr>
<td>50-59</td>
<td>219 42.7± 6.3</td>
<td>63 40.9± 7.4</td>
</tr>
<tr>
<td>60-69</td>
<td>156 38.9± 5.7</td>
<td>127 37.1± 6.4</td>
</tr>
<tr>
<td>70-79</td>
<td>63 35.2± 5.6</td>
<td>220 33.4± 6.0</td>
</tr>
</tbody>
</table>

SD, standard deviation. The differences between groups were analyzed by Student’s-t test. Bold represents significant p-value (<0.05).
age-stratified numbers for both men and women, clearly demonstrated that the decline in grip strength throughout middle and late adulthood was different for men and women.

Muscle mass is directly associated with muscle strength\(^23\)). Age-related decreases in muscle mass have been reported as trivial; however, age-associated decreases in arm muscle quality (muscle strength/muscle mass) were lower among women than among men in our previous study\(^24\)). Generally, women assume the main role of housework and continue this role until old age. This may help women maintain the same level of grip strength over time. However, Goodpaster et al. suggested that muscle weakness leads to diminished physical activity, consequently leading to secondary muscular disuse atrophy\(^25\)). To prevent further loss of muscle strength among women in late adulthood, it is important to activate muscles and increase muscle quality throughout their lifetime.

For men, both muscle mass and muscle quality steeply decrease with age\(^24\)). Additional physiological declines such as decreasing insulin-like growth factor-1 and testosterone levels\(^26\) and loss of social roles at work and in

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**Fig. 2** Preservation rate of grip strength by sex and age group at baseline. Means and standard errors are presented. *; Tukey-Kramer test; \(p < 0.05\).

**Fig. 3** Longitudinal changes in grip strength for ages 40 to 89 years in men and women.
the community may cause the steep decline in muscle strength among men. Forrest et al. suggested that older adults who have adequate muscle strength may experience more noticeable declines in strength with age\(^9\). Rapid declines in muscle strength could have an impact on the ability of older adults to function in daily life as well as cause a sense of loss, particularly among men. Further studies are needed to examine the effects of large declines in muscle strength later in life among men.

We illustrated longitudinal changes in grip strength for the age span of 40 to 89 years using 7252 observational data points (1246 persons × 2–6 biennial values). We also demonstrated the trajectories of grip strength decline year by year in both men and women. This data provided a detailed course of decline in grip strength with age throughout middle and late adulthood for both sexes.

Previous studies have shown that the relationship between age and grip strength in men is both linear\(^{16,27,28}\) and curved\(^{7,29}\). Our 10-year follow-up data decreased among older people, and thus the variance of the mean grip strength of participants in their 70s was wider than that of the other age groups. Therefore, whether the decline in grip strength among men in their 70s and older is linear or curved remains uncertain. However, our data of grip strength indicated that grip strength among men declined markedly year by year during the age span of 40 to 89 years.

Among women, previous studies also reported conflicting results with horizontal slopes in grip strength\(^{16}\) and quadratic changes in grip strength\(^{10}\). However, grip strength among women was considerably lower than among men in middle and late adulthood. Grip strength in women may be considered the threshold of grip strength for community living. Although the cut-off point for sarcopenia is 20 kg of grip strength in women\(^9\), grip strength among women in hospitals and nursing homes was reported to be below this level\(^{14}\). Recently, the Foundation for the National Institutes of Health Sarcopenia Project defined less than 16 kg of grip strength in women as weakness\(^{31}\). In our study, most women in their 70s reached the level of 20 kg of grip strength and the average grip strength among women in their late 80s was 17 kg, which is near the threshold level of grip strength for geriatric syndromes associated with functional limitations and disability. Although the age-related decline in grip strength seen among women was less than that of men, the available capacity of grip strength for community living was far less among women than men throughout middle and late adulthood.

Sarcopenia is a key component of physical frailty\(^{15}\), and there is considerable overlap between the two\(^{32}\). Both are important concepts in geriatric research, and emphasize grip strength in their definition. Monitoring actual muscle function may be useful in identifying older people at risk of daily living disability and dependency. In addition, characterizing how the aging process affects grip strength over middle and late adulthood may lead to improved methods for preserving muscle strength. Our results may therefore contribute to the development of improved interventions and advice for the prevention of functional limitations and the maintenance of quality of life in late adulthood.

Some limitations of this study need to be addressed. First, there were more dropouts in the older than in the younger age groups in our longitudinal study. About 60% of the dropouts due to death during the study period were in their 70s at baseline. However, this was considered unavoidable, and despite the dropouts, we still had over 300 observations in men and women alike that allowed us to show the effects of the aging process on grip strength among participants in their 70s. Second, the participants in this study regularly attended the examinations in the NILS-LSA. This may have resulted in an underestimation of the decline in grip strength. The main reasons given for dropping out of the study were health problems, inconvenience, and a lack of time. However, it was difficult to examine the details of the dropouts because some did not respond or state any reasons for dropping out. Grip strength at baseline was lower among the dropouts than among the participants in the follow-up, especially in men (Table 1). We also performed a sub-analysis for the entire study population from baseline to the 10-year follow-up. Grip strength among participants who were examined six times was significantly stronger than that of those who were only examined once (at baseline); however, when compared to participants of both sexes who were examined two to five times, no difference in grip strength was found (data not shown). Regarding socio-demographic variables, the dropouts who had been examined only at baseline were significantly older and had poorer health than the participants in the follow-up for both sexes (Table 1). These differences might have led to an underestimation of the decline in grip strength. Finally, although the statistical analyses in this study had high power (more than 99%), the effect sizes were small\(^{33}\). Age-related decline in grip strength was clearly different between men and women. However, age-related grip strength decline is associated with numerous factors; therefore the role of sex in explaining this decline may be limited.

The strengths of the present study include the large number of randomly selected community-living participants and the fact that the 10-year longitudinal observation data tracked participants from age 40 to 89. We measured changes in grip strength biennially, and every year of age was assessed. The number of male and female participants in each age group was nearly equal, which allowed for an accurate estimation of sex differences. We were also able to show the effects of the aging process on grip strength using actual measurements for men and women.
Conclusion

Age-related decline in grip strength markedly increased in older men, but remained constant across middle and late adulthood in women. The large decline in grip strength among men and the low level of grip strength among women may indicate progressive declines in health, eventually making it impossible to perform daily tasks independently. It may be important to introduce sex-specific measures to maintain a higher level of grip strength in older individuals.

Conflict of Interests

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

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