Age-associated Performance Decline and Sex Differences in Olympic Weightlifting

MARIANNE HUEBNER¹, DAVID E. MELTZER², and ARIS PERPEROGLU³

¹Department of Statistics and Probability, Michigan State University, East Lansing, MI; ²College of Integrative Sciences and Arts, Arizona State University, Mesa, AZ; and ³Department of Mathematical Sciences, University of Essex, Wivenhoe Park, Colchester, UNITED KINGDOM

ABSTRACT

HUEBNER, M., D. E. MELTZER, and A. PERPEROGLU. Age-associated Performance Decline and Sex Differences in Olympic Weightlifting. *Med. Sci. Sports Exerc.*, Vol. 51, No. 11, pp. 2302–2308, 2019. **Introduction:** The rate of decline in physical performance for women is thought to be faster than that for men at any age in the Masters age classes in weightlifting and other sports. We quantified the age-associated decline in Olympic weightlifting separately for women and men and investigated possible impact of perimenopausal years on the performance decline. **Methods:** Results from Masters Weightlifting competitions from 1993 to 2018 were compiled from original score sheets and meet results made available by International Weightlifting Federation. Quantile curves were estimated for the age-related performance decline, and confidence intervals (CI) for the fractional performance with reference age 35 yr were calculated. Age-related decline curves were estimated for different periods to examine changes in performance levels. **Results:** A total of 10,225 performance results for male and female weightlifters age 35 to 90 yr from 71 countries were included in the analysis. At age 40 yr compared with age 35 yr, the fractional performance is 0.947 (95% CI, 0.926–0.975), for men and 0.952 (95% CI, 0.898–0.986) for women while this is reduced to 0.723 (95% CI, 0.651–0.800) at age 60 yr for men and 0.604 (95% CI, 0.543–0.706) for women. Female performance levels before 2000 were worse; however, they have stabilized since 2013. **Conclusions:** The performances of women weightlifters have improved over the last 25 yr. Thus, previous publications do not reflect current physical capabilities of women. The age-associated performance decline for female weightlifters mirrors the decline for men except for an accelerated decline during a 10-yr period across the age range from late 40s to late 50s thus coinciding with a transition into menopause. **Key Words:** MUSCLE POWER, AGING, WOMEN, MENOPAUSE

Competitive sport performance declines with increasing age. This has been investigated in sports, such as weightlifting, swimming, triathlon, and track and field disciplines (1–4). There are differences in the decline of the performance levels, depending on the type of sport, that is, whether endurance or anaerobic function is emphasized, or whether the emphasis is on strength or on power. The total

weight lifted in the Olympic weightlifting competition exercises are effective measures of lower body power, strength, speed, balance, and coordination (5). Weightlifting training leads to an adaptation of musculoskeletal and cardiovascular systems and the power output of weightlifters exceeds that of other strength athletes (6 and references therein). Weightlifting exercises have become popular to augment training of athletes in other sports, and there has been a recent influx of women in the sport. In the 3-yr period, from 1993 to 1995, there were 40 female participants with a placement at the International Weightlifting Federation (IWF) World Masters Championships, whereas in 2018 alone, there were 336 female participants with a placement.

Previous research involved data sets of weightlifting performances before or shortly after women were allowed to compete in the Olympics in weightlifting for the first time in 2000 (4,7,8) and many studies focused on male athletes (9,10). With these older data sets it was estimated that women's performance decline was faster than those for men in weightlifting (7). However, performances of female weightlifters have improved dramatically over the past 5 yr, and none of these studies examined a potential impact of the transition to menopause. It is imperative to better understand physical capabilities with advancing age (6,11) to aid in developing safe and effective training programs for older individuals.

Address for correspondence: Marianne Huebner, Ph.D., Department of Statistics and Probability, Michigan State University, East Lansing, MI 48824; E-mail: huebner@msu.edu.

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Comparing competitors in Olympic weightlifting is challenging due to the different body weight categories and age groups. A motivation for body weight adjustment is that weightlifters with higher body mass consistently lift greater weight than lifters of lower body mass. Using world records and performances at Olympic games a logarithmic regression model has been used to estimate a set of so-called body weight coefficients, with a different coefficient assigned to each body weight; the coefficients are multiplied by total weight lifted in competition to compare the performance levels of athletes with different body weights (12). Decreasing muscle strength and power with older age necessitates the development of an analogous set of age coefficients to compare performances of athletes of different ages. This was achieved by first adjusting for body weight and then analyzing data from the 1991 World Postal Meet to derive age coefficients (10), that were then checked against performance data from US Masters weightlifters recorded during 1975 to 1992. These age coefficients were updated using data from 22 yr of male World Masters Championships by Meltzer and Faber to create the “Meltzer–Faber” age coefficients, adopted in 2016 by the Master’s Committee of the IWF for Masters athletes (http://www.iwfmasters.net/rules/2017_iwf_masters_rulebook.pdf), <http://www.mastersweightlifting.org/forms/meltzer.htm>). Although derived solely for male athletes, these age coefficients are currently applied to both men and women weightlifters. Previous research on power deterioration by age and sex in weightlifting concluded that there is a steeper decrease in performance levels for women than for men already beginning at age 35 yr (4,7). This would mean that the Meltzer–Faber age coefficients would not be applicable to women, and this is a motivation for this study to update the age-related decline curve for female weightlifting performances with data from recent years and illustrate changes by comparing such curves derived for different periods.

The purpose of our study is to quantify (i) age-associated decline in Olympic weightlifting (ii) sex differences and possible influence of perimenopausal years. This was achieved by analyzing 25 yr of performances at World Masters Weightlifting Championships 1993 to 2018. This includes athletes from 71 countries.

METHODS

Data from IWF World Masters Weightlifting Championships from 1993–2018 were compiled from competition results made available by the International Weightlifting Federation Masters Committee. The total weight (kg) lifted is the sum of the best snatch weight and best clean and jerk weight, if there was at least one of three attempts valid for both lifts. Results that do not include at least one valid snatch and one valid clean and jerk are not included in our sample. The number of body weight categories has varied over the years. From 1993 to 1997, there were 10 categories for men and nine for women, whereas from 1998 to 2016, there were eight categories for men and seven for women. In 2017 and 2018, there were eight categories each for

men and women. Exact body weights were available for each competition result. The total kg lifted was adjusted with the 2017 Sinclair formula, a body weight normalization technique that was officially recognized by the IWF up until late 2018 (12,13). Age groups in these competitions are in 5-yr increments, currently running from 35 to 70 yr or older for women and from 35 to 80 yr or older for men. In 1993 and 1994, the oldest age group for women was 55 to 59 yr; the 60- to 64-yr group was added in 1995, the 65- to 69-yr group in 2001, and the 70 yr or older group in 2011. Our findings are reported according to the STROBE statement (14).

The project protocol was reviewed by the Internal Review Board at Michigan State University and was granted an exempt status, since the data are publicly available.

Statistical methods. Quantile regression models are an extension of traditional regression models estimating curves for the median, quartiles, or other quantiles. Quantile smoothing is an effective tool to study changes in the conditional distribution of response variable such as the total weight lifted with a covariate such as age. Although theoretically quantile curves cannot cross, this does happen for small data sets. Quantile sheets explore the idea of least asymmetrically weighted squares to introduce a surface on two-dimensional domains (15–17). Thus, quantile functions $\mu(x, p)$ can be estimated for different quantiles p across a covariate x , for example age. P-splines are utilized to ensure a smooth function along the axis, and, by using tensor products of splines, ensure that quantile curves do not cross.

Since the qualifying standards used to be low for women to ensure higher participation levels, variation in performance levels can be large. Thus, we estimated the age-associated decline curves at the 90th percentile for the age range 35 to 70 yr. This age range is appropriate due to the small number of women in the 70 yr or older age group and to be able to compare male and female curves. Fractional performance at a specific age was defined as the ratio of the predicted body weight adjusted total lifted divided by the corresponding performance at age 35 yr.

Bootstrap resampling was used to draw confidence intervals (CI) around the estimated 90th percentile estimate. A random sample of 200 athletes was drawn at each iteration, and the model was refitted to obtain a new estimate. The process was repeated 1000 times for men and women, and CI were obtained for the performance decline at different ages. All analyses were performed using the statistical software R v. 3.5.1 and package gamlss v.5.1.2 (18)

RESULTS

A total of 10,225 performance results for male and female weightlifters age 35 to 74 yr (women), 35 to 90 yr (men) were included in the analysis (see Figure, Supplemental Digital Content 1, STROBE diagram for competition results included in the analysis, <http://links.lww.com/MSS/B628>). The number of results and number of athletes in different

TABLE 1. Number of results and number of athletes stratified by sex in IWF World Masters Championships 1993 to 2018

	Men	Women
No. results (no. athletes)	8385 (3172)	1840 (893)
Years		
1993–2000	2450 (1199)	219 (110)
2001–2009	2757 (1302)	431 (186)
2010–2012	976 (656)	181 (116)
2013–2015	991 (705)	311 (223)
2016–2018	1211 (984)	698 (571)
Age groups, yr		
35–39	998 (730)	431 (332)
40–44	1204 (818)	437 (296)
45–49	1066 (687)	355 (219)
50–54	989 (629)	247 (145)
55–59	1006 (599)	157 (92)
60–64	1024 (547)	125 (69)
65–69	873 (447)	65 (36)
70–74	630 (349)	23 (13)
75–79	396 (193)	
80+	199 (96)	

age groups and for different years are shown in Table 1. The number of women competing at the World Masters Championships has recently begun to approach the number of men, with 571 women compared with 984 men recording a result during 2016 to 2018. By comparison, the number of women in 1993 and 1994 was well below 10% of the number of men.

Sex differences in weightlifting performance as a function of age are illustrated in Figure 1 using data from 2013

to 2018. The male curve mirrors the Meltzer–Faber age decline that was derived previously using male World Championship data from 1993 to 2014. The female, at 90th percentile, diverges from the male curve at about age 45 yr, followed by a steeper decline, and then runs parallel to the male curve after about age 55 yr (Fig. 2). This could be accounted for by hormonal changes due to menopause where the loss of muscle strength and hand grip strength has been well documented (19). The fractional performance at age 40 yr compared with age 35 yr is 0.947 (95% CI, 0.926–0.975) for men and 0.952 (95% CI, 0.898–0.986) for women, whereas this is reduced to 0.723 (95% CI, 0.651–0.800) at age 60 yr for men and 0.604 (95% CI, 0.543–0.706) for women (Table 2). Confidence bands for the 90th percentile for men and women are shown in Figures 2 and 3. Decline curves at the 5, 10, 15, ..., 95th percentiles for women are included in the supplemental content (see Figure, Supplemental Digital Content 2, Performance decline curves for women at different percentiles, <http://links.lww.com/MSS/B629>). Age-related performance decline curves for women in different periods show an increase in performance levels from 1993 to 2013 for all ages, and no further improvement for the most recent two periods (Fig. 4). A linear regression model was fitted to investigate whether differences were significant between the periods. Results indicated that there was no significant difference

FIGURE 1—Age-associated performance decline for male and female weightlifters. Meltzer–Faber age coefficients adjusted to age 35 yr are included as a dashed reference line.

FIGURE 2—Age-associated performance decline for men and bootstrap confidence bands based on 90th percentile for men and women. Meltzer–Faber age coefficients adjusted to age 35 yr are included as a dashed reference line.

for periods 2013 to 2015 to 2016 to 2018 ($P = 0.423$), whereas the difference between periods 2001 to 2012 and 2016 to 2018 was different ($P = 0.0092$).

DISCUSSION

A total of 10,225 results from male and female weightlifters age 35 to 90 yr (women, 35 to 74 yr) from 25 yr of IWF World Masters Weightlifting Championships with athletes from 71 countries were analyzed. This is the first study to analyze a large dataset of elite women weightlifters from recent years, and to consider the influence of perimenopausal years for female athletes. The main findings were as follows: (i) There is an accelerated age-associated performance decline for women in perimenopausal to menopausal years; (ii) The performance decline for women at all other ages approximately mirrors that of men.

These results differ from previous publications on weightlifting in several ways. Thé and Ploutz-Snyder (8) fitted linear regression models to performances of 51 female and 312 male athletes competing in the 2000 World Masters Weightlifting Championships, but found the explained variability was low, in particular for women. Anton et al. (7) used American and World record data from 2002, applied regression models to pooled body weight data for age decline curves, and concluded that women experience a greater age-associated decline in sports that require more explosive and complex movements such as weightlifting. Baker and Tang (4) assumed an exponential curvilinear

decline to model performance decline with increasing age and found a steeper decline for women than for men starting already at age 30 yr. Such mathematical models do not take hormonal life cycles of women into account, and the data used to fit these models underestimate performance levels that have dramatically improved as more women competed in the sport.

Physical performance and the influence of menopausal status have been studied in various populations, showing the association with declining strength through the musculoskeletal system (20). There is a strong association between decrease in androgens and estrogens with age and age-related decline in muscle and bone mass and strength. For men, circulating testosterone levels decrease by approximately 1% to 3% per year. Although women have much lower testosterone concentration compared with men, the postmenopausal levels are approximately 15% of premenopausal levels, and estrogen levels substantially decrease during the first year of menopause (19). This is accompanied by accelerated decline in muscle mass

TABLE 2. Fractional performance at different ages compared to performance level at age 35 yr with 95% bootstrap CI stratified by sex.

Age, yr	Men		Women		MF
	Median	95% Bootstrap CI	Median	95% Bootstrap CI	
40	0.947	0.926–0.975	0.951	0.898–0.986	0.944
45	0.896	0.852–0.945	0.879	0.806–0.949	0.891
50	0.844	0.780–0.908	0.813	0.716–0.875	0.838
55	0.786	0.712–0.861	0.691	0.634–0.785	0.774
60	0.723	0.651–0.800	0.604	0.543–0.706	0.708
65	0.659	0.592–0.730	0.542	0.455–0.639	0.645
70	0.593	0.532–0.659	0.496	0.340–0.579	0.574

FIGURE 3—Age-associated performance decline for women and bootstrap confidence bands based on 90th percentile for men and women. Meltzer–Faber age decline adjusted to age 35 yr are included as a dashed reference line.

and strength (20,21). To our knowledge, ours is the first study that shows age-related decreases in weightlifting performances at World Championships for women at ages reflecting perimenopausal years.

A markedly steeper decrease in performance levels was seen for women than for men already beginning at age 35 yr or younger (4,7,8). This phenomenon can be explained because these studies used world records or World Championships data before 2000 or 2002 for the model fitting. Due to societal restrictions on participation by women in a wide variety of sports, and the fact that women could compete in weightlifting in the Olympics for the first time only in 2000, it is unlikely that such early data reflect the full capabilities of elite female athletes. When we use a subset of our data from 1993 to 2000, we can replicate this steeper decline for women than for men seen in these previous studies. After 2000, a new period began, during which many women at various performance levels have entered the sport of weightlifting; therefore, comparisons between different age ranges are difficult. However, for younger women, ages 35 to 45 yr, the age decline curve approached that of the men, and diverged at older ages. More reliable data can be obtained after 2012, particularly with the significant further increases in the participation levels of women that occurred after that time. In 2013 to 2015, there was an improvement in performance for older women and the decline for women after age 55 yr parallels that men. No further improvement of female performance levels across age was seen when comparing age-related decline curves

for the 90th percentile in the periods 2013 to 2015 and 2016 to 2018. Previous publications (4,7) used world records to derive age decline curves that consist of only seven or eight data points or fewer, one per body weight group, for men and women, respectively, in each age class, and a curve was fitted to the pooled data for the body weight categories (7). Instead, our approach is based on using information on all available data. That has the benefit that we consider a broader spectrum of performances taking into account individual variation rather than relying only on a few observations by top athletes. Instead of using a very limited set of data points we apply nonparametric approaches based on p-splines on the full set of data.

There are several limitations of our study. First, due to possible contamination of world record performances because of performance enhancing drugs despite established drug testing procedures, it is possible that models using world record data may not yield true estimates of age-associated performance decline. Although it is the case that undetected doping violations cannot be excluded from the World Championships data in our study, we excluded all results from athletes who were found to violate antidoping policies at any one time point. Data from 4 female and 44 male athletes were removed. During the period 2013 to 2017, the number of results removed accounted for 0.5%. Potentially, there could be an increase in variation and thus larger CI without impacting the main trends we have identified. Second, although exact body weights were available, athletes tend to aim for a body weight at the upper end of a body weight class. Thus, the distribution is multimodal,

FIGURE 4—Age-associated performance decline for female weightlifters for periods 1993 to 2000, 2001 to 2012, 2013 to 2018. As a reference dashed lines are Meltzer–Faber age coefficients adjusted to age 35 yr.

and this can lead to sparse competition results for intermediate body weights. We dealt with this problem by using spline interpolation between body weights. Third, because the participation level across age ranges, especially for women, continues to rise, it cannot be excluded that the performance levels are underestimated. There are not many female athletes older than 65 yr in this data set. However, we assured ourselves that the estimated age decline curve for women did not change for recent periods. A major strength of this study is the ability to examine the effect of age in a large, internationally diverse population of top-level female athletes age 35 to 74 yr using 25 yr of data from World Championships that enabled us to observe changes during perimenopausal years.

To conclude, we observed that age-associated performance decline for female weightlifters mirrors the decline for men except for an accelerated decline during a 10-yr period across the age range from late 40s to late 50s thus coinciding with a transition into menopause. This was achieved by examining the

data without strong mathematical modeling assumptions that would prescribe the form of decline, thus considering the possibility that the age curve for women could have a different functional form from those of men. This study provides new information related to age-associated performance decline for women weightlifters.

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