

AGE IS A POOR PREDICTOR OF MAXIMAL STRENGTH IN COMPETITIVE POWERLIFTERS

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Abstract:

Age-related declines in muscular strength are well-documented; however, less is known about the long-term trajectories of individuals engaged in consistent high-level resistance training. This study examined the relationship between age and maximal strength in competitive powerlifters with competition records spanning multiple decades. Data were obtained from 61 powerlifters (45 men, 16 women) who participated in events sanctioned by drug-tested federations and had results both before the age of 40 and after the age of 60. A total of 3,379 competition entries were analyzed. Changes in absolute and relative strength, as well as in individual lifts (squat, bench press, and deadlift), were assessed using linear regression. Age explained a modest proportion of variance across all metrics (0.4%-15.6%). Among men, significant annual declines were observed in deadlift (-0.33% per year, $p < .01$), relative strength (-0.32% per year, $p < .01$), and squat (-0.17% per year, $p < .01$), with no significant changes in bench press or absolute strength. Among women, relative strength (-0.06% per year, $p < .01$) and squat (-0.11% per year, $p < .01$) showed small but significant declines, while bench press performance increased ($+0.27\%$ per year, $p < .01$). The rate and pattern of decline were steeper in men. Additional differences were observed between lifts, with deadlifts showing the steepest drop. Compared to non-athletic populations, the observed decline was substantially lower, indicating a protective effect of long-term resistance training. These findings suggest that chronological age alone is a poor predictor of strength decline among well-trained older adults. Moreover, the observed exercise- and sex-specific patterns underscore the need for stratified analyses in aging research. The small number of female participants limited statistical power, highlighting the importance of future studies with larger samples.

Keywords: *resistance training, performance decline, sex differences, predictive modeling, longitudinal analysis*

Introduction

A decline in muscular strength is a well-documented result of aging. It is consistently associated with reduced mobility, difficulty in performing daily tasks such as climbing stairs and rising from a chair, and loss of independence in older adults. These effects are seen across various populations and remain even after adjusting for body size or muscle mass, indicating a decrease in both muscle quality and quantity (Frontera, et al., 2000; Goodpaster, et al., 2006; Metter, Conwit, Tobin, & Fozard, 1997; Schiller, Strollo, & Metter 2000). This phenomenon is closely linked to sarcopenia—the gradual, age-related decline in skeletal muscle mass and strength, which raises the risk of frailty, falls, hospitalization, loss of independence, and death. Notably, strength loss often occurs before or is greater than the loss of muscle mass (Cruz-Jentoft, et al., 2019; Fielding, et al., 2011).

While strength typically begins to decline from the fourth decade of life onward, evidence shows

this process is not entirely inevitable. Resistance training has been shown to significantly improve both strength and physical function, even when initiated later in life. A recent umbrella review (McLeod, Currier, Lowisz, & Phillips, 2024) found that resistance training of various types consistently enhanced strength, muscle mass, and daily functional capacity in healthy older adults. Multi-joint or functional exercises were especially effective in achieving these results. Several studies further support the long-term benefits of resistance training in older populations. Bloch-Ibenfeldt et al. (2024) demonstrated that one year of supervised heavy resistance training in previously untrained retirees led to preserved leg strength for four years post-intervention. Similarly, O'Bryan et al. (2022) found that progressive resistance training improved strength, bone mineral density, and physical function while reducing fall risk, regardless of prior training history. As reported by Latella et al. (2024), improvements in strength were observed

even among masters powerlifting athletes over the age of 60, supporting the continued adaptability to resistance training across the lifespan. Grgic et al. (2020) reported significant increases in strength and muscle hypertrophy among adults aged 75 and older, as well as those aged 80 and older, in response to short-term resistance training interventions.

Taken together, these findings highlight resistance training as a key intervention for promoting healthy aging and preserving functional independence, demonstrating that maximal strength can be improved, not just maintained, even when structured training begins well beyond midlife (Bloch-Ibenfeldt, et al., 2024; Grgic, et al., 2020; Latella, et al., 2024; McLeod, et al., 2024; O'Bryan, et al., 2022).

Powerlifting offers a distinctive way to study long-term strength adaptation, as it is a sport where maximal force production is directly tested through three standardized compound exercises: the squat, bench press, and deadlift (SBD). Each athlete is allowed three attempts per exercise, and their best attempts are summed to generate a total score used for ranking. Competitions are stratified by sex, bodyweight, and age group, enabling structured comparisons across a wide range of athletes (Latella, Teo, Spathis, & van den Hoek, 2020; Latella, van den Hoek, & Teo, 2018).

Unlike studies of the general population, which often include sedentary or recreationally active individuals, powerlifters typically undergo structured, high-intensity resistance training over extended periods. This offers a rare chance to examine strength progression among individuals who maintain consistent training routines for decades. In contrast to short-term, small-sample laboratory studies, publicly available powerlifting competition data, primarily from the OpenPowerlifting database (OpenPowerlifting.org), contain ecologically valid performance records from over 300,000 lifters across multiple decades and age categories. These records include age, bodyweight, and maximal lifted weight per exercise, making them a valuable basis for retrospective longitudinal analysis (Latella, et al., 2018, 2020, 2024). However, a well-recognized limitation of these databases is that they do not include information on athletes' training history, training practices, or personal variables, thereby limiting the ability to fully account for sources of variation between athletes.

The present study aims to examine longitudinal changes in maximal strength among a cohort of powerlifters who have consistently competed over several decades, including both before the age of 40 and after the age of 60. By focusing on athletes with long-term adherence to structured resistance training, this study seeks to isolate the effects of aging on maximal strength from the confounding influence of inactivity or irregular training. The

analysis includes comparisons between men and women, as well as between the three powerlifting exercises—squat, bench press, and deadlift—offering insight into the patterns and variability of strength maintenance under real-world, long-term training conditions.

Methods

Study design

In this study a retrospective, longitudinal analysis of athletes' performance data was performed. The data were obtained from the Open Powerlifting database (<https://www.openpowerlifting.org>), accessed between February 12 and February 16, 2025. The Institutional Review Board at The Levinsky-Wingate Academic College approved this study (no. 46-100225), which was based on the existing public domain data.

Data extraction and preparation

The goal was to collect data from powerlifting competitions involving athletes who competed both before the age of 40 and after the age of 60, with gaps between competitions not exceeding five years, and to analyze changes in their achievements in similar competitions (same exercises, same equipment, etc.) over the years. We intentionally chose to analyze the performance of the same athletes over time, rather than comparing different athletes from various age groups competing simultaneously. This choice was based on the assumption that athletes from different age groups may vary in personal, physiological, or training-related characteristics that could skew the results and hide the true effects of aging on strength performance.

We limited our study to powerlifting competitions sanctioned by drug-tested federations to ensure that performance-enhancing substances did not influence the observed strength levels and changes over time. Data from equipped competitions (competitions performed with supportive equipment) were excluded, except for the single-ply competitions, as it is unclear what effect the use of assistive equipment has on performance and whether results in equipped competitions represent the actual physical strength of the athlete. Since raw (unequipped) competitions were not popular before the mid-2000s, we included single-ply competitions, which were the best available representation of athletes' physical strength prior to the raw era. For each athlete who met the inclusion criteria listed below, we downloaded the athlete's complete career data and removed only records that met the exclusion criteria.

For our analysis, we included data from athletes who had at least one record from a raw or single-ply competition at the age of 60 years or older with a successful attempt in all three exercises, and at least

one record from a raw or single-ply competition at the age of 40 years or younger with a successful attempt in all three exercises. In addition, athletes were required to have participated in at least five eligible competitions across their career. Finally, the gap between two consecutive competitions of any kind, including those later excluded from statistical analysis, could not exceed five years. Those requirements ensured that only athletes with continuous competitive activity over multiple decades, before the age of 40 and after the age of 60, were included in the longitudinal analysis.

Subsequently, certain records were excluded from each athlete’s dataset. Records from non-SBD competitions were removed. Competitions in which the athlete failed all three attempts for any of the SBD exercises were also excluded. In addition, competitions that were not sanctioned by a drug-tested federation were removed, as well as equipped competitions other than single-ply events.

For each eligible record, several fields were retrieved from the database. This included sex, date of competition, and the athlete’s bodyweight. We also recorded the type of equipment allowed at the competition: raw or single-ply. For performance outcomes, we extracted the highest successful attempt for squat, bench press, and deadlift, and the total, defined as the sum of these three best attempts. We also retrieved the GLP (goodlift points) score, a bodyweight-adjusted measure calculated using the goodlift formula, which was selected because it allows appropriate comparison across different weight classes (Kopayev, Onyshchenko, & Stetsenko, 2020).

We also calculated several derived fields for each record. The performance percentage for each individual exercise was defined as the highest successful attempt at that competition divided by

the athlete’s lifetime best in the same exercise. The performance percentage for total was calculated as the total achieved at the competition divided by the athlete’s lifetime best total, and the performance percentage for GLP was computed as the GLP score at the competition divided by the athlete’s lifetime best GLP score. We also calculated an accurate age for each record. Because the database reported age in half-year increments and some records lacked age information, we estimated each athlete’s date of birth based on their age at the most recent competition, then calculated their age for all other competitions using this estimated birthdate.

Statistical analysis

A linear regression analysis was applied to assess the proportion of variance in strength performance explained by age across five measures. In addition, the annual rate of change in strength was calculated for each measure. Allowed equipment (raw, single-ply) was included as a fixed factor in all regression models to control for its potential effect on each of the strength-related outcome variables. The analysis was conducted separately for each variable and each sex, using JASP 0.19.3.0.

Results

After excluding records that did not meet our criteria, 61 athletes (45 men and 16 women) with a total of 3,379 records were included in our statistical analysis. The average number of competitions per athlete was 51.4 ± 28.1 for men and 63.1 ± 37.7 for women. Demographic data at baseline and the last recorded competition are presented in Table 1.

The mean of each athlete’s largest gap between two consecutive competitions of any kind, including competitions that were later excluded from the

Table 1. Demographic data at baseline and the last recorded competition (mean ± SD)

	Baseline		Last competition	
	Men	Women	Men	Women
Age (years)	32.79 ± 6.47	34.09 ± 6.24	63.17 ± 3.68	64.28 ± 5.13
Weight (kg)	81.38 ± 14.16	57.30 ± 12.84	88.91 ± 16.72	65.67 ± 19.85

Table 2. Analysis of age as an explanatory variable for strength performance and annual change in strength

	Men			Women		
	Annual rate of change (%)	p-value	Proportion of variance explained (R ²)	Annual rate of change (%)	p-value	Proportion of variance explained (R ²)
Total	-0.18%	<.01*	13.6%	0.03%	.4	2.3%
GLP	-0.32%	<.01*	10.8%	-0.06%	.05*	1.7%
Squat	-0.17%	<.01*	11.3%	-0.11%	<.01*	7.7%
Bench	0.00%	.88	5.3%	+0.27%	<.01*	0.4%
Deadlift	-0.33%	<.01*	15.6%	-0.01%	.6	1.7%

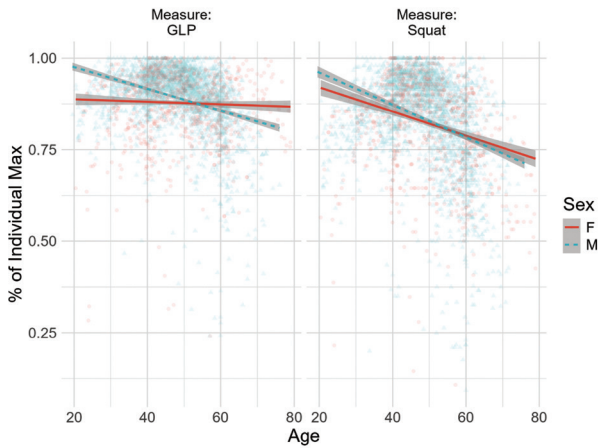


Figure 1A. Linear trends in age-related changes in GLP and squat performance, expressed as percent of each lifter's individual maximum, shown separately for men and women.

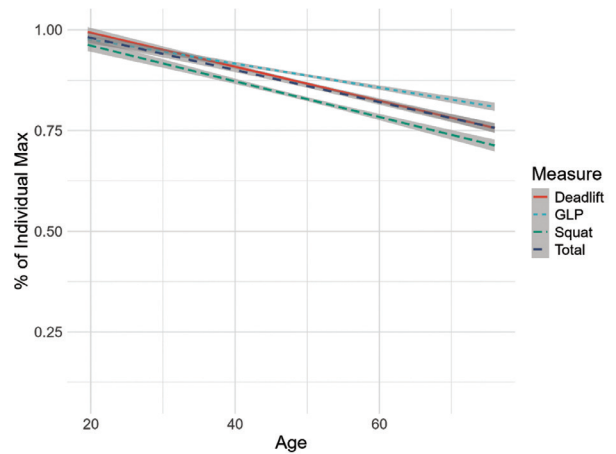


Figure 2A. Linear trends in age-related changes in total, GLP, squat, and deadlift performance among men, expressed as percent of each lifter's individual maximum.

statistical analysis, was $3.08 \text{ years} \pm 0.95$ for men and $2.34 \text{ years} \pm 1.14$ for women. For all competition records, the average absolute strength (Total) was $629\text{kg} \pm 123$ for men and $360\text{kg} \pm 75$ for women.

The regression analysis for each variable, along with the proportion of variance explained by age (R^2), is summarized in Table 2.

As shown in Table 2, men exhibited consistent and statistically significant declines in strength measures (Total, GLP, Squat, and Deadlift), with age accounting for a moderate proportion of the variance (ranging from 5.3% to 15.6%). In contrast, women exhibited lower and less consistent changes, with lower explained variance (ranging from 0.4% to 7.7%) and non-significant trends in Total and Deadlift.

A graphical representation of the age-related decline in strength is provided in Figures 1A, 2A, and 2B. Only statistically significant trends are displayed: Figure 1A illustrates sex-specific differences in age-related strength changes; Figure 2A presents the significant age-related trends across the different strength measures in men; and Figure 2B presents the corresponding significant trends observed in women.

Discussion and conclusions

The main finding of this study is that age was a relatively weak predictor of maximal strength among powerlifters who maintained long-term high-level resistance training. Although strength declined with age, the magnitude and pattern of decline differed between exercises and between sexes, with men showing steeper reductions, especially in the deadlift and in relative strength, while women exhibited smaller and less consistent changes. Overall, the age-related decline observed in this highly trained population was substantially lower than the decline typically reported in non-athletic or recreationally active older adults.

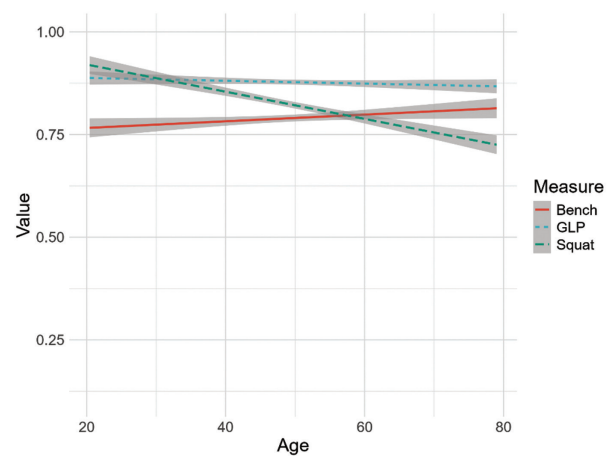


Figure 2B. Linear trends in age-related changes in GLP, bench-press, and deadlift performance among women, expressed as percent of each lifter's individual maximum.

Powerlifting participation patterns in the broader database revealed several distinct athlete trajectories across the lifespan. Some athletes stop competing early. Others return to competition after long breaks. The third group begins competing only later in life. The final group consists of athletes who continue competing consistently for many years. Our analysis focused exclusively on this last group, which maintained uninterrupted competition histories over multiple decades. This approach allowed us to isolate the effects of aging while reducing confounding influences related to inconsistent training exposure.

Previous studies examining the correlation between age and strength among powerlifting athletes typically compared various age groups competing simultaneously, utilizing a cross-sectional study design (Hernández Ugalde, 2022; Latella, et al., 2018). This approach may bias results and lead to an underestimation of performance in older athletes. In powerlifting, athletes' strength

can increase for ten years or more, as shown by Latella et al. (2024). Therefore, athletes who began competing at an older age and those who returned to the sport at an older age may exhibit lower performance not because of aging itself, but rather due to insufficient time to accumulate strength gains. Furthermore, Stones (2019), who studied masters marathon runners, found that faster runners entered the sport at a younger age and competed more frequently. These findings support the notion that including athletes who began the sport later in life can lower the average performance of master athletes for reasons unrelated to age. Therefore, it is recommended that, when investigating the impact of age on maximal strength, research should focus on longitudinal data from the same individuals over time rather than comparing outcomes across distinct groups of younger and older subjects.

Sex comparison

The results of the current study revealed that age effects were significant in both men and women; however, the decline was consistently steeper in men, with age explaining a greater proportion of the variance in strength, as shown for relative strength (GLP) and squat performance. No other exercise exhibited parallel, significant age trends in both men and women, preventing further direct comparison. These sex differences in the rate of decline are not unique to powerlifters and have also been observed in the general population. Goodpaster et al. (2006) conducted a study on adults aged 70-79, examining changes in strength and muscle mass over a three-year period. Like the current findings, they reported that the proportional loss of strength was greater in men than in women. Changes in leg lean mass followed a similar sex-specific pattern.

Lindle et al. (1997) have also noted that men exhibit a steeper decline in strength with age, and that age accounts for a greater proportion of the variance in strength among men compared to women. According to their results, older women exhibited significantly greater enhancement during the stretch-shortening cycle than younger women, younger men, and older men, indicating a superior ability to store and utilize elastic energy. This mechanism may help explain the continuous increase in bench-press performance observed among women in the current study, as the bench-press includes a substantial eccentric phase. It may also help account for the slower rate of strength decline observed in the squat among women, since the squat likewise involves a prominent eccentric component.

These sex-based patterns are further reflected in cross-sectional differences between age groups, as Latella et al. (2018) reported when they analyzed powerlifting competition data to assess changes exclusively in relative strength (defined as the ratio between lifted weight and body mass) across the

squat, bench press, and deadlift. Their findings indicated a more pronounced and consistent decline in relative strength among men across most age groups and exercises. Moreover, the proportion of variance in relative strength explained by age was higher in men in all three exercises, suggesting that aging has a more substantial predictive effect on strength performance in men.

In contrast to those findings, Hernández Ugalde (2022) explored data from powerlifting athletes aged 12-76 who competed between 1972 and 2020 and did not find sex-related differences in the rate of decline in relative strength based on GLP or other relative strength formulas. These differences may be attributed to the fact that, unlike our methodology, he compared different athletes, including those with short-term competition histories, and encompassed both equipped and unequipped events.

Hormonal changes with aging may also contribute to sex differences in strength decline. In women, the sharp reduction in estrogen during menopause has been associated with decreases in muscle mass and strength, and several studies have shown that hormone-replacement therapy (HRT) can help attenuate these declines (Greising, Baltgalvis, Lowe, & Warren, 2009; Ronkainen, et al., 2009; Skelton, Greig, Davies & Young, 1999; Taafe, et al., 2005). In men, age-related reductions in testosterone are likewise linked to loss of muscle mass and strength, and testosterone-replacement therapy (TRT) has been shown to improve strength in older men (Goldspink, 2012). However, TRT is prohibited in drug-tested powerlifting federations (Wilks, 2011). Importantly, the competition database used in the present study does not include information on the use of HRT or TRT, so the potential influence of hormone therapy cannot be assessed.

Another possible explanation for the sex differences observed in the current study concerns differences in bodyweight and initial absolute strength. In our cohort, men were heavier and stronger at baseline, and previous research shows that individuals with higher bodyweight or greater initial strength may experience a faster rate of decline over time (Goodpaster, et al., 2006). This factor may help explain the steeper declines observed among men. However, our dataset did not include enough athletes in comparable weight categories to evaluate this possibility directly, and therefore, no firm conclusions can be drawn regarding this explanation.

Rate of decline by exercise

The results of the current study revealed that strength changes varied across different exercises and that the proportion of variance explained by age also differed between them. Among men, deadlift performance declined more rapidly than squat

performance, and age explained a greater proportion of the deadlift variance. Among women, age explained a greater proportion of the variance in squat performance than in bench press performance. Additionally, while strength declined in the squat, it continued to increase, somewhat unexpectedly, in the bench press.

These findings suggest that the rate of strength decline may differ across exercises for various reasons. Such differences have been reported in both athletic and general populations. This pattern is consistent with findings from Latella et al. (2018), who analyzed cross-sectional powerlifting data and reported that both the rate of strength decline and the proportion of variance explained by age differed across exercises. As in the present study, their results showed that performance does not decline uniformly across exercises. In men, the highest R^2 value was observed in the squat, followed by the bench press and the deadlift, suggesting that age was most predictive of squat performance. However, in terms of actual performance decline, the deadlift and bench press showed larger reductions with age than the squat. Among women, they reported lower R^2 values overall, with the highest in the squat, followed by the bench press and deadlift—partially aligning with the current findings, particularly regarding the weaker age association in the bench press. This is further supported by more recent data from Latella et al. (2024), who visualized longitudinal trends and similarly observed a greater age-related decline in deadlift performance compared to the squat and bench press among older men.

In the general population, concentric strength appears to decline more rapidly with age than eccentric strength, particularly in women. Lindle et al. (1997) reported that only men experienced reductions in muscle quality with eccentric contractions, whereas both men and women showed declines in concentric strength. This may help explain why exercises with a significant eccentric component, such as the bench press, exhibit different patterns of decline compared to those emphasizing concentric effort initiated from rest, like the deadlift. Differences in age-related decline also emerge when comparing different body regions, rather than types of muscle action. In a 12-year longitudinal study of healthy older males, Frontera et al. (2000) found strength declined across all tested muscle groups, with larger reductions in the lower limbs compared to the upper limbs.

Rate of strength decline

Compared with previous studies of healthy older adults and non-competitive populations, the rates of strength decline in our study are substantially slower. It is worth noting that our study, together with a previous study on competitive

powerlifters (Latella, et al., 2024), investigated strength decline using multi-joint exercise (SBD), whereas most studies on the general population have relied on single-joint assessments (Frontera, et al., 2000; Goodpaster, et al., 2006; Lindle, et al., 1997; Maden-Wilkinson, McPhee, Jones, & Degens, 2015). However, studies comparing both modalities found no meaningful differences in the rate of age-related decline (Thompson, Whitson, Sobolewski, & Stock, 2018; Whitson, 2016). This supports the validity of comparing our results with those of the general population.

In a large-scale cross-sectional study of 654 individuals aged 20-93, Lindle et al. (1997) reported age-related declines in strength of approximately 8-10% per decade in both men and women. Notably, a very small percentage (<1%) of the subjects participated in any regular resistance exercise. This extremely low exposure to resistance training may account for the more rapid strength losses observed in their cohort, compared to the attenuated declines seen in our trained subjects. In a 12-year longitudinal study of healthy, recreationally active older men, Frontera et al. (2000) reported statistically significant declines in isokinetic strength across multiple muscle groups. Annual rates of strength loss ranged from 1.4% to 2.5%. Goodpaster et al. (2006) reported annualized declines in strength of 3.6% in males and 2.8% in females aged 70-79, based on a large cohort of generally healthy, non-trained, community-dwelling older adults. Finally, Maden-Wilkinson et al. (2015) found that maximal knee extension force among physically active males aged 72.2 was 60% of the value measured in younger subjects aged 22.8, indicating an approximate annual decline of 1.03%.

Similar conclusions were drawn by Maddalozzo, Cardinal, Li, and Snow (2004), who observed that postmenopausal women who engaged in regular physical activity maintained greater strength and lean mass than their sedentary counterparts. Likewise, Goldspink (2012) emphasized that although aging reduces the muscles' ability to respond to physical stress, regular physical activity can help slow down this process. Together, these findings support the notion that regular training, even in non-athletic populations, can slow, though not entirely prevent, the age-associated decline in maximal strength.

Previous research on powerlifting athletes has also demonstrated a slower rate of strength decline in this population. Latella et al. (2024) reported an annual decline of 0.35%. Our results demonstrate an even slower rate of decline, and, for women's bench press, no decline at all. The much lower rates of decline observed in our sample and other studies on powerlifting athletes likely reflect the long-term training history and continued high-level training of this population. Taking together, these findings

provide robust evidence that long-term, uninterrupted participation in high-level strength training can substantially mitigate age-related declines in strength. These results support the practical recommendation to implement high-intensity resistance training in aging populations, as it can reduce, and in some cases prevent, age-related strength decline. Similar conclusions were reported by Bloch-Ibenfeldt et al. (2024), who demonstrated that heavy resistance training initiated at retirement age produced sustained improvements in strength for several years post-intervention, unlike lower-intensity protocols.

In summary, our findings indicate that (1) age is a relatively weak predictor of maximal strength among long-term competitive powerlifters; (2) the rate of strength decline varies across exercises and between men and women, with some combinations, such as the bench press in women, showing no decline at all; and (3) consistent, high-intensity resistance training has the potential to attenuate or even prevent age-related strength loss significantly. These conclusions emphasize the importance of longitudinal data, exercise- and sex-specific anal-

ysis, and training history when evaluating strength trajectories in aging populations.

Limitations and future directions

Some limitations of this study should be acknowledged. The number of athletes who met the inclusion criteria was relatively small, particularly among women, due to the limited availability of public data that aligned with the study design. This likely contributed to the absence of statistically significant associations for certain variables, which restricted the ability to conduct specific parts of the analysis. Furthermore, the Open Powerlifting database does not include other potentially relevant factors, such as injury history, hormone replacement therapy, or training characteristics during the periods between competitions.

Future studies should employ a similar methodology, utilizing larger datasets and, when available, non-public databases. Adding more detailed background data on the athletes would allow for a deeper understanding of the factors that affect long-term strength maintenance.

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