Firefighter Years: Mediating Effects of Years of Service on Physical Fitness

Original Research

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Open Access

Research in Health and Medicine

Published: January 10, 2025

Research in Health Sciences: *2025, Volume 5 (Issue 1): 1*

ISSN: 2768-492X

Abstract

Introduction: Firefighters' biological age and years of service (YOS) often vary significantly, as individuals may enter the profession at any age. YOS introduces cumulative occupational stressors that may mediate age-related declines in physical fitness. While age-related reductions in physical fitness are well-documented, the mediating effect of YOS on firefighters' fitness remains unclear. Thus, the purpose of this study was to investigate the mediating role of YOS in the relationship between age and physical fitness outcomes and assess whether sex moderates the effects of YOS on these outcomes.

Methods: A retrospective analysis of physical fitness testing data from 2019 to 2021 of 1,281 firefighters (1,136 males, 145 females; Age: 39.2 ± 9.3 years; YOS: 11.0 ± 7.3 years) was conducted. Fitness tests included maximum pull-ups (PL), push-ups within 60 seconds (PU), sit-ups within 60 seconds (SU), and a 3-minute step test to estimate VO_{2max}. Pearson's correlation tested the relationship between age and YOS, while path analysis evaluated YOS as a mediator between age and fitness outcomes. A moderation analysis examined the influence of sex on these relationships.

Results: Age and YOS were moderately correlated ($r = 0.66$). YOS fully mediated the relationship between age and SU ($p < 0.001$) and partially mediated the effects of age on PL ($p < 0.001$) and PU ($p < 0.001$). No mediation effect of YOS was observed for VO_{2max} ($p > 0.05$). Sex significantly moderated the relationship between age, YOS, and several physical fitness outcomes. Specifically, the relationship between age and pull-up performance was stronger for males ($b = -0.152, p < 0.001$) than females ($b = -0.065, p < 0.05$), while YOS was significantly related to pull-up performance in males ($b = -0.123, p < 0.001$) but not in females ($b = -0.071, p > 0.05$).

Conclusions: YOS exacerbates declines in musculoskeletal strength and endurance, independent of age, particularly in male firefighters. Fire departments should consider YOS and sex, alongside age, when designing fitness assessments and training programs to optimize performance and safety.

Key Words: occupational performance, health, emergency responders

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Introduction

Firefighting is one of the most physically demanding professions, requiring intermittent high-intensity physical work in hazardous environments.[1–3] Over time, the cumulative exposure to physical stress, toxic chemicals, and psychological trauma associated with firefighting increases the risk of chronic health issues[4] such as cardiovascular disease,[5] certain cancers,[6] and musculoskeletal injuries.[7] This cumulative burden not only elevates health risks but also accelerates the decline in physical fitness, with cardiac events being the leading cause of on-duty firefighter fatalities.[8] Alarmingly, most firefighters are classified as overweight or obese,[9,10] further compounding these risks. For instance, individuals who are obese have been found to incur greater rates of cardiovascular disease,[11] cancer,[12] and musculoskeletal injury.[13]

Adding to these challenges, the unique structure of the firefighting profession allows individuals to enter the profession at any age, provided they meet entry requirements. As a result, firefighters may exhibit greater variability in both biological age and years of service (YOS) compared to other tactical athlete populations with maximum age restrictions at entry.[14] Similar to other tactical athlete career paths, professional firefighters typically begin their careers by completing a training academy to enter the fire service.[15] Fire academies are designed to prepare recruits for occupational challenges by employing high levels of physical activity and rigorous training.[16] While recruits often maintain or improve their fitness during the academy,[16] research shows that physical fitness frequently declines after graduation.[16,17] Given the substantial evidence between physical fitness with firefighting performance,[18–20] health benefits,[21] reduced injury risk,[22–24] the relationship between YOS, age, and fitness warrants further exploration to address this decline.

A contributing factor to this decline in physical fitness may be differences in the environmental and clothing variables between academy training and full-time firefighting. For example, one key difference between training in the academy and working as a full-time firefighter is the environmental and clothing variables. In the field, firefighters regularly perform duties while wearing heavy and restrictive personal protective equipment (PPE),[25] which can significantly impact movement,[26] energy expenditure,[27] and thermoregulation.[28] Conversely, academy training often involves physical activity without PPE and/or in more controlled environments, potentially contributing to differences in physical demands and subsequent physical fitness outcomes. Full-time firefighters, or incumbents, are typically required to complete annual work performance exams while wearing PPE. However, these exams often fail to directly assess physical fitness due to the absence of national standards and the multidimensional nature of the evaluations.[29,30] To address this limitation, some fire departments have introduced annual physical fitness assessments to better monitor and maintain fitness levels.[31]

Anecdotally, firefighters refer to the cumulative burden from time in service (e.g., YOS) as "firefighter years," reflecting the detrimental health effects of the profession.[4] Interestingly, incumbent firefighters have been shown to exhibit greater epigenetic age acceleration compared to recruits, suggesting that YOS may compound the effects of biological aging on health and physical performance.[32] Although evidence strongly supports that both cardiorespiratory and musculoskeletal fitness decline with age,[33,34] the role of YOS in mediating this relationship remains underexplored. YOS is associated with increased occupational stressors,[35,36] which may further exacerbate declines in physical fitness. This raises important questions about the long-term impacts of firefighting on physical readiness and performance.

Therefore, the purpose of the present study was to investigate the influence of YOS on professional firefighters' performance on common physical fitness assessments employed by a fire department. Specifically, the study examined whether YOS mediates the relationship between age and physical fitness outcomes and explores sex as a moderating factor in these relationships. We hypothesized that years of service will mediate the relationship between age and physical fitness outcomes. By addressing this gap, the results can provide important insights into how YOS and sex contribute to age-related changes in physical fitness.

Scientific Methods

Participants

This study retrospectively analyzed data obtained from annual physical fitness testing mandated by a large fire department in the mid-Atlantic region of the United States. Physical fitness testing was completed at one facility from 2019 to 2021. Participants included for analysis in the present study were all incumbents. In total, deidentified data from 1281 participants (1136 males, 145 females, Age: 39.2 ± 9.3 years YOS: 11.0 ± 7.3 years) were included in the study. A retrospective analysis of deidentified data was approved by the George Mason University Institutional Review Board (IRB#: 1871116).

Protocol

The details of the annual physical fitness assessment have been previously reported.[37,38] After completing an annual physical examination with a physician to obtain medical clearance, firefighters participated in a standardized battery of physical fitness tests at the designated testing facility, which was the same facility for all records analyzed in the study. The physical fitness assessment included maximum pull-up repetitions, sit-ups performed in 60 seconds, push-ups performed in 60 seconds, and a 3-minute step test to estimate aerobic capacity (VO_{2max}). The pull-up assessment was performed first and repetitions required pulling the chin above the bar and returning to full elbow extension without using momentum, with the assessment ending upon grip release. Following a 2-minute rest, firefighters performed as many sit-ups as possible in 60 seconds. Repetitions required elbows to touch the knees and a buzzer to confirm full range of motion. After another 2-minute rest, firefighters completed a 60-second push-up test, ensuring proper depth by triggering a buzzer under the sternum and maintaining a straight body alignment throughout. Finally, after a 3-minute rest, aerobic capacity was evaluated using a 3-minute step test on a 41.3 cm box at a cadence of 88 beats per minute for females and 96 for males. Heart rate recorded immediately after the test was used to estimate VO_{2max} via the Queen step test formula.[39] These tests were selected by fire department staff based on their validity, reliability, ease of administration, and safety for firefighters.[39–42] Prior to the pull-up assessment firefighters completed a standard warm-up that consisted of 5-minutes of treadmill walking followed by 5-minutes of dynamic stretching focused on major muscle groups in the upper and lower extremity. Firefighters wore workout clothing (e.g., shorts, t-shirt, sneakers) for testing. All testing was conducted under the supervision of staff certified as Tactical Strength and Conditioning Facilitators, who provided standardized instructions to ensure consistency and safety.

Statistical Analysis

Preliminary analysis: A descriptive analysis of means and standard deviations for physical fitness outcomes were conducted (pull-ups, sit-ups, push-ups, VO_{2max}). Normality was assessed with the use of Shapiro-Wilk tests and visualized with Q-Q and density plots. None of the demographic or physical fitness variables were normally distributed (i.e., all Shapiro-Wilk p-values < 0.001) and common transformations (i.e., exponential, log, power) did not alter the distributions.[43] Eighty-three participants were removed from the analysis due to missing data or data points were 3 standard deviations above or below the mean for each variable. Descriptive statistics for the measures included in the main analysis were calculated. Differences by sex were evaluated using independent sample t-tests for continuous variables and chi-square tests of independence for categorical variables. Effect sizes for continuous measures were quantified using Cohen's d. Relationships between YOS, age, and physical fitness outcomes were assessed with Pearson's r correlation coefficient (r; magnitude, weak = 0.10 - 0.40, moderate = 0.41 - 0.70, strong > 0.70).[44]

Main analysis: A path analysis was used to test the mediating effect of YOS on the relationship between age and physical fitness outcomes. A follow up model was conducted to assess if there was a moderating effect of sex on the relationship between YOS and physical fitness outcomes between male and female participants. The relationships between age, YOS, and multiple physical fitness outcomes (e.g., pull-ups, push-ups, sit-ups, VO_{2max}) were inherently multidimensional. Path analysis enabled the modeling of these relationships within a single framework, capturing the interplay between variables while accounting for the shared variance among outcomes. Model estimations were conducted with the Lavaan package[45] using maximum likelihood estimates in the R environment (R Core Team, Vienna, Austria), alpha < 0.05. Quality of model fit was assessed with Chi-square goodness of fit (p > 0.05), comparative fit index (CFI; > 0.95), Tucker-Lewis index (TFI; > 0.95), and root mean squared error assumption (RMSEA; < 0.06).[46] A $p \leq 0.05$ was considered statistically significant a priori.

Results

The descriptive data and associations between YOS, age, and physical fitness outcomes are summarized in Tables 1 and 2. Males outperformed females on pull-ups, push-ups and VO_{2max}, but not curl-ups. A moderate positive correlation was observed between YOS and age ($r = 0.66, p < 0.001$). Both years of service and age demonstrated weak but statistically significant correlations with pull-ups, push-ups, and sit-ups ($p < 0.001$), while their correlations with VO_{2max} were nonsignificant. All physical fitness outcomes were positively associated with one another, with push-ups and pull-ups showing the strongest correlation (Table 2).

Years of Service Mediation

The model was overidentified ($X^2(2) = 10.077, p < 0.05$) demonstrated good fit to the data (CFI = 0.997, TLI = 0.974, RMESA [95% CI] = 0.056[0.025,0.093]. There was a significant direct effect between YOS and age ($b = 0.66, p <$ 0.001). The mediation analysis revealed that YOS significantly mediated the relationship between age and sit-up performance ($b = -0.116, p < 0.001$). Additionally, YOS partially mediated the effects of age on pull-up performance ($b = -0.172, p < 0.001$) and push-up performance ($b = -0.173, p < 0.001$). However, YOS did not mediate the relationship between age and VO_{2max} ($b = 0.004, p > 0.05$) performance. The path model, including direct and indirect effects, is presented in Figure 1.

Table 1. Characteristics of firefighters.

Variable	All Firefighters (n = 1281)	Male (n = 1136)	Female (n = 145)	p-value	Cohen's d
Age (years)	39.2 (9.3)	39.3 (9.4)	38.1 (8.6)	0.115	0.13
20-29 years	237 (18.5%)	211 (89.0%)	26 (11.0%)	0.110	
30-39 years	423 (33.0%)	367 (86.8%	56 (13.2%)		
40-49 years	412 (32.2%)	362 (87,8%)	50 12.1%)		
50-59 years	202 (15.8%)	189 (93.6%)	13 (6.4%)		
60+ years	7 (1.0%)	7 (100.0%)	0 (0.0%)		
Years of Service (years)	11.0 (7.3)	11.1 (7.4)	10.2 (6.1)	0.120	0.12
0-5 years	248 (19.4%)	218 (87.9%)	30 (12.1%)	0.077	
6-10 years	586 (45.7%)	522 (89.1%)	64 (10.9%)		
11-15 years	125 (9.8%)	107 (85.6%)	18 (14.4%)		
16-20 years	153 (11.9%)	130 (85.0%)	23 (15.0%)		
21-25 years	169 (13.2%)	159 (94.1%)	10 (5.9%)		
Pull-ups	5.6 (5.2)	6.0 (5.2)	1.9 (3.0)	<0.001	0.84
Curl-ups	43.1 (20.5)	43.2 (21.6)	42.0 (8.0)	0.184	0.06
Push-ups	35.3 (13.3)	36.7 (12.8)	24.0 (11.5)	<0.001	1.01
Aerobic Capacity (mL/kg/min)	45.3 (9.9)	46.1 (10.0)	38.6 (6.6)	<0.001	0.78

Values are mean (standard deviation) or n (%) for continuous and categorical variables, respectively. Pull-ups, Push-ups, and Curls-ups represent repetitions completed per exercise. Differences in continuous variables were assessed with independent sample t-tests and Cohen's d for effect sizes. Differences in categorical variables were assessed with the chi-square test of independence.

Table 2. Correlations between years of service, age, and physical fitness outcomes.

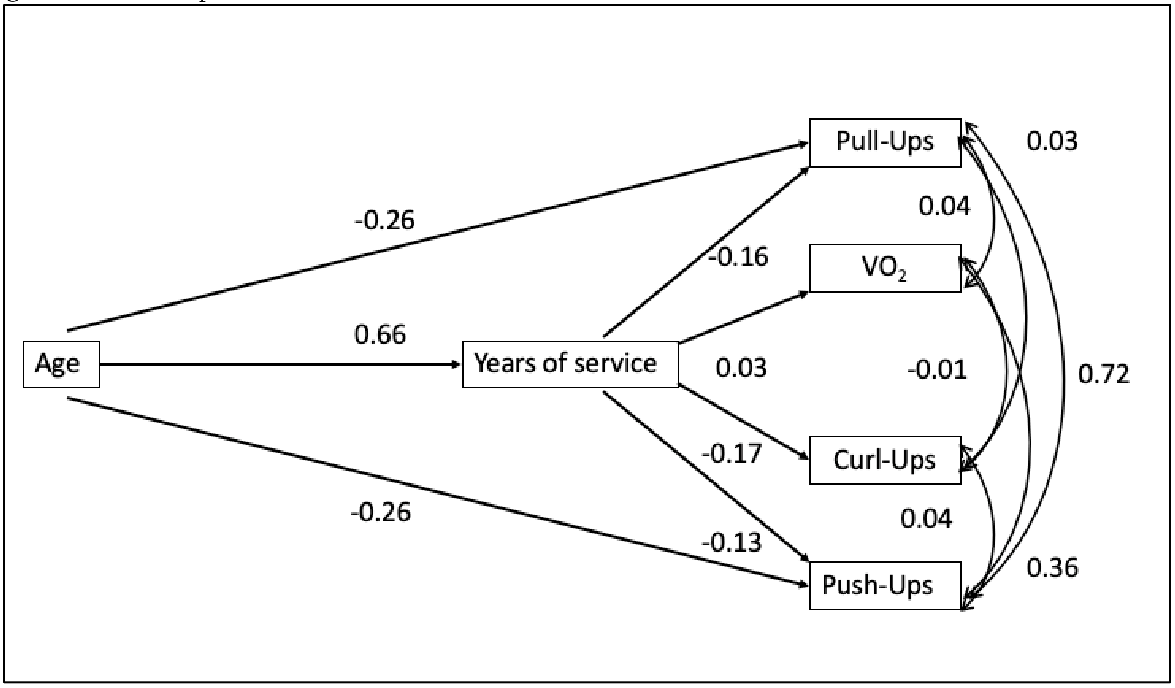
	YOS	Age	Pull-ups	Push-ups	Curl-ups	VO_{2max}
YOS	1.00					
Age	0.66***	1.00				
Pull-ups	-0.33***	-0.37***	1.00			
Push-ups	-0.31***	-0.35***	0.74***	1.00		
Curl-ups	-0.17***	-0.18***	0.53***	0.56***	1.00	
VO_{2max}	0.01	-0.01	0.28***	0.31***	0.23***	1.00

Table shows Pearson correlation coefficients between fitness variables.
***Significant correlation between variables at significance level of p<0.001. Abbreviations: YOS= Years of service.

Sex Moderation

The pooled sample model examining the effect of sex on firefighters' physical performance fit the data well (X^2 (4) = 10.41, $p < 0.05$; CFI= 0.997; RMSEA= 0.050 [0.013, 0.0.88]). Next, all paths were constrained to be equal across sexes to assess model fit (X^2 (11) = 38.60, $p < 0.05$; CFI = 0.998; RMSEA= 0.063 [0.042, 0.055). Forcing equality of paths across men and women resulted in a significantly worse fit (ΔX^2 (7) = 28.19, $p < 0.05$), indicating moderation by sex. Subsequently, paths were selectively freed based on modification indices. The final model, allowing the direct paths of age and YOS on pull-ups to vary across sexes, demonstrated excellent fit (X^2 (9) = 12.89, $p < 0.05$; CFI = 0.998; RMSEA= 0.026 [0.000, 0.055]). The chi-squared difference test confirmed that the final model fit the data significantly better than the constrained model (DX^2(2) = 25.70, $p < 0.001$). The final model revealed that sex moderated the relationship between age and pull-up performance, as well as between YOS and pull-up performance. Specifically, the relationship between age and pull-up performance was stronger for males (b = -0.152, $p < 0.001$) than for females (b = -0.065, $p < 0.05$). Similarly, the relationship between YOS and pull-up performance was significant for males (b = -0.123, $p < 0.001$) but nonsignificant for females (b = -0.071, $p > 0.05$). These results indicate that both age and YOS have a greater negative impact on pull-up performance in males than in females.

Figure 1. Mediation path model.



Straight arrows represent direct effects (regression coefficients) between variables in the model. Curved arrows indicate covariances between fitness outcomes.

Discussion

To our knowledge, this is the first study to investigate the mediating role of YOS in the relationship between age and physical fitness outcomes in professional firefighters. Our findings partially supported the first hypothesis, revealing that YOS fully mediated the relationship between age and sit-up performance, indicating a compounded decline in core strength due to cumulative service. Additionally, YOS partially mediated the effects of age on upper-body strength and endurance, as demonstrated by significant negative indirect effects on pull-up ($p < 0.001$) and push-up performance ($p < 0.001$). Importantly, the moderation analysis showed that sex significantly ($p < 0.05$) influenced the relationships between age, YOS, and physical fitness outcomes for pull-ups and push-ups, highlighting sex-specific differences in how these factors interact. The relationship between YOS and firefighter physical fitness is likely multifaceted.

One plausible explanation for the findings is that older firefighters with greater YOS may experience reduced measures of physical fitness due to a complex interplay of factors, including chronic exposure to traumatic events, physical wear and tear, and evolving job demands. The result of such acute and chronic stressors on the musculoskeletal system could lead to a greater risk of injury.[47] For instance, Negm et al.[48] reported that greater YOS was significantly associated with a higher incidence of upper-body musculoskeletal injuries. Pain associated with musculoskeletal injuries can alter motor control adaptations, reducing range of motion and force production capabilities.[49] These adaptations may persist even after the initial injury has healed due to detraining, which would contribute to long-term decrements in performance.[50] Furthermore, the relationship between YOS, upper-extremity and core strength may be influenced by both the frequency and severity of injuries sustained over a firefighting career. Interestingly, Fletcher et al.[51] found that individuals working in jobs with the 'worst' conditions experienced declines in their health, with effects varying by demographic group. This suggests that the impact of musculoskeletal injury on performance may be influenced by factors such as age and sex. It is important to note that the relationship between YOS and musculoskeletal injury is likely bidirectional. While increased YOS may lead to more injuries, the presence of musculoskeletal injury may also influence a firefighter's ability to perform their duties effectively, potentially leading to early retirement or role changes.[47]

Another explanation for the findings is that older firefighters with greater YOS may adopt different strategies to cope with occupational stress. It has been reported that firefighters with greater YOS are less likely to report symptoms of traumatic stress related to occupational incidents,[52] this may not necessarily indicate reduced impact. Instead, it could reflect developed coping mechanisms or underreporting due to occupational culture. Poor coping strategies following trauma[53] have been associated with fatigue, post-traumatic stress disorder, anxiety, and depression, which in turn have been linked to reductions in physical fitness and activity.[54] However, the impact of these factors on occupational performance may vary among individuals and be influenced by organizational support systems and training programs.[55,56] Resilience plays a crucial role in this context.[55] For example, Igboanugo et al.[57] reported that resiliency among firefighters has been found to reduce the impact of stress-related disorders from work-related stressors. Chronic exposure to traumatic events may reduce firefighters' resilience, placing them at increased risk of mental health and stress-related disorders. Cumulatively, these prior findings are suggestive that reductions in occupational performance due to greater YOS may be associated with stress related disorders, unlike reductions associated with biological aging.[33]

The effects of chronic exposure to traumatic events may interact with the natural biological aging process,[33] making it challenging to isolate the specific impact of YOS on performance. Future research should adopt a more comprehensive approach, including longitudinal studies that incorporate both self-reported measures of stress-related disorders and objective measures of occupational performance. Furthermore, examining the potential positive adaptations that occur with increased YOS would provide a more balanced understanding of the relationship between experience and occupational performance in firefighters.

The finding that YOS may mediate the relationship between age and muscular physical fitness provides a potential explanation for the contrasting results in previous studies.[58–60] For example, the results of a study by Findley et al.[58] indicated no significant age-related changes in push-up performance among 159 male firefighters (aged 20–49) but reported a decline in sit-up performance with age. Similarly, Kirlin et al.[59] found no age-related differences in push-up or sit-up performance among female firefighters (aged 20–54). In contrast, in a larger study of 1,361 firefighters (90% male) Martin et al.[60] reported a negative relationship between age and pull-up, push-up, and sit-up performance. Importantly, none of these studies accounted for YOS in their analyses, which may partially explain the inconsistencies and highlights the value of the current study in addressing this gap. Nevertheless, while physical fitness is critical, fire departments are ultimately concerned with how these fitness measures translate into the ability to perform essential operational tasks on the fireground.

In terms of how YOS may impact operational readiness, greater musculoskeletal strength and endurance have been linked to faster completion times on firefighting physical ability tests and individual tasks.[29,61] Previous studies[19,62,63] provide evidence that an increase in age is significantly associated with a reduction in occupational task performance among firefighters. For instance, Michaelides et al.[19] and Ras et al.[62] both reported a positive relationship between age and time to complete firefighter physical ability tests involving common occupational tasks such as stair climbing, hose lifting and dragging, overhead sledgehammer swinging, and hose pulling with hydrant hookup. Adding to these findings, the current study suggests that YOS, independent of age, may have an adverse effect on firefighters' physical fitness. This decline in physical fitness could directly impair the ability to perform these operational tasks efficiently, highlighting the importance of considering YOS in physical fitness assessments and training protocols to maintain occupational readiness.

The moderation analysis revealed that sex significantly influenced the relationship between age, YOS, and physical fitness outcomes, with stronger declines in upper-body strength observed in male firefighters compared to females. This finding may reflect differences in occupational roles and exposure patterns typically encountered by male and female firefighters.[64] Due to physiological differences,[65] male firefighters may be tasked with heavier physical labor or more physically demanding tasks during emergency responses, which may accelerate declines in upper-body strength due to cumulative workload and overuse injuries. In contrast, female firefighters, who may face additional barriers to entry and retention in the profession,[64] might engage in targeted training or adaptations that mitigate the effects of aging and YOS on fitness outcomes.[66] Moreover, the physiological differences between sexes,[65] such as hormonal variations[67] and muscle mass distribution,[68] could contribute to these patterns.

The study is not without limitations. Due to its cross-sectional design, it cannot establish causal relationships between YOS, age, and physical fitness outcomes. Additionally, much of the data was collected retrospectively during the late stages of the COVID-19 pandemic, which may have influenced the results. Firefighters experienced a COVID-19 infection rate three times higher than the general public, contributing to increased medical leave, stress, and anxiety.[69,70] These factors could have affected physical fitness levels and performance during the study period. Furthermore, no significant relationships were observed between YOS, age, and VO2max, which may be attributed to the use of a submaximal step test. This method has been shown to have low agreement with maximal aerobic testing, potentially limiting its accuracy.[71] Future research should address these gaps by employing longitudinal designs to explore how YOS interacts with age and physical fitness outcomes over time. Additionally, studies should consider incorporating more accurate measures of aerobic capacity and examining differences in these relationships across male and female firefighters to provide a more comprehensive understanding.

Conclusions

In conclusion, while age-related reductions in physical fitness are well-documented,[72] our findings indicate that YOS in firefighting (aka firefighter years) may exacerbate these declines, particularly in core strength as measured by sit-ups. Given the physical demands of firefighting, upper-body and core strength are essential for performing critical occupational tasks effectively and safely. This study highlights the importance of incorporating YOS, alongside age, into fitness assessments and occupational performance evaluations for firefighters. Fire departments and practitioners should account for the substantial variability in biological age and YOS when interpreting fitness assessment results and designing training programs. Tailored interventions that address the cumulative effects of YOS may help mitigate declines in musculoskeletal fitness and enhance occupational readiness.

Acknowledgements

None.

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