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Age-related differences in muscle strength among Polish professional firefighters

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Abstract

Study aim: Assessment of muscle strength levels in different age groups of Polish firefighters, taking into account the influence of body composition. The aim of this study was also to assess the balance of synergistic flexor and extensor muscle groups in selected joints as a compensatory factor that reduces the risk of injury.
Material and methods: The study included 172 active professional firefighters from various centres across Poland were included in the analysis. The subjects were divided into three age categories: 20 to < 30 (I, n = 84), 30 to < 40 (II, n = 38), and 40 to < 50 years (III, n = 50). Measurements of torque were performed for 10 muscle groups: flexors and extensors in the main joints. Measurements were conducted in standard positions under static conditions.
Results and conclusions: The significant decline in strength was observed, which could be due to a change in the proportion of FFM to FM in total body mass as a function of age. The most rapid decline in strength was observed in the lower limb muscles. Therefore, it is suggested to increase the intensity training of lower limb strength among the oldest firefighters. Furthermore, although no significant differences were found in the H/Q ratio between age groups, all participants demonstrated values below the norm, which may indicate a increased risk of knee instability in this occupational group.
It is therefore suggested that the force proportion index should be one of the basic indicators of periodic preventive examinations assessing the physical fitness of firefighters.

Keywords: Firefighters – Mscle strength – H/Q ratio – Body composition

Introduction

The profession of a firefighter is one of the most dangerous occupations. Their work involves a significant burden, which varies depending on external conditions that necessitate various combinations of physical activities. External factors cause increased physiological and psychological responses (Gledhill & Jamnik, 1992; Oldham et al. 2000; Perroni et al. 2014a, 2015). Additionally, during rescue operations, firefighters often wear heavy protective clothing (thermal protection clothing, boots, helmet, breathing apparatus) and carry heavy rescue equipment (ladders, portable pumps, etc.). These factors affect their mobility in the field, metabolic efficiency, leading to increased fatigue and shortened work duration (Perroni et al. 2010; Qu & Yeo 2011; Bakri et al. 2012; Bilzon et al. 2001; Rodrıguez-Marroyoa et al. 2011). Studies have shown that the most common physical issues among firefighters are strains, sprains, and muscle pain (Karter & Molis 2010), as well as exhaustion caused by physical exertion (Poplin et al. 2012). An analysis of the frequency of injuries indicates that the lowest incidence occurs in firefighters aged 30-39 (Szubert & Sobala 2002).

When analyzing the nature of a firefighter's work, it must be acknowledged that physical fitness is a crucial element in the efficient and effective execution of rescue operations. A high level of overall fitness, particularly muscle strength, is essential for the safety of a firefighter's work (Nowak et al. 2018). Various studies have shown that there is a significant correlation between upper body strength and more effective performance in firefighting and reduced risk of injury (Michaelides et al. 2008; Rhea et al. 2004; Williford et al. 1999; Knapik et al. 2001). This also applies to lower body strength due to the significant

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number of load-bearing activities (forced entries, carrying equipment, transporting casualties, etc.). Therefore, many authors analyze the strength capabilities of both the upper and lower body (Cho et al. 2022). To assess upper body strength, grip strength measurement using a dynamometer or bench press is most commonly used. Lower body strength is measured using a standardized static test for the lower limbs (squats) or the vertical jump CMJ (Nazari et al. 2017; Nazari et al. 2018; Perroni et al. 2015a). A very important factor determining the strength capabilities of both the upper and lower body is the muscle mass and fat content, which are related to the firefighter's body dimensions and their changes with age (Wiśniewski et al. 2018). The distribution of individual body components along its entire length, combined with muscle strength, can also affect postural stability, which can influence the safety of firefighting activities (Wiszomirska et al. 2019).

Considering the nature of profession, it is necessary to take into account the physical and physiological capabilities related to age, where a decline in abilities during the professional activity period is to be expected. Studies on the relationship between physical activity and aging are relatively common in the literature; however, in relation to firefighters, this topic remains marginal (Rhea et al. 2004; Sluiter & Frings-Dresen, 2007; Davis et al. 2002; Perroni et al. 2014, 2015).

An analysis of injury frequency by age group showed lower rates among firefighters aged 30–39 years and the highest rates among those over 50 years old (Szubert & Sobala, 2002). During mandatory physical training, accidents were less frequent in the group under 40 years of age. The level of physical fitness is likely a key determinant in avoiding injuries and, in the context of professional work, an important factor in performing duties and handling physical demands. Therefore, a low level of fitness among firefighters is a critical issue concerning the correlation with injury risk and reduced work capacity. Studies by Michaelides et al. (2008), Rhea et al. (2004), Knapik et al. (2001), and Mattila et al. (2007) have shown a significant correlation between upper limb muscle strength and the speed and time of performing firefighting tasks, as well as between high fitness levels and reduced injury risk.

Other studies indicate a decline in strength among middle-aged and older individuals, both men and women (Hakkinen et al. 1995; Hakkinen et al. 1996), which can result in reduced work efficiency related to physical exertion, such as firefighting.

Therefore, the aim of this study was to assess the upper and lower limb and trunk strength of professional Polish firefighters and to analyse their strength in the context of age, taking into account the impact of body composition components. Furthermore, given the specific nature of work, which involves more frequent overload during landing, this study also aimed to assess muscle balance in selected joints as a compensatory factor that reduces the risk of injury. The stability of selected joints was analysed based on the calculated torque ratio (H/Q ratio) of the flexor and extensor synergist groups.

Material and methods

Participants

A total of 172 of the 179 registered, active professional firefighters from various centres across Poland were included in the analysis. Details about the study procedures of the recruitment, qualification phase and main study are provided in Figure 1.

All firefighters underwent a qualifying procedure that included a health status questionnaire, a medical examination approving their participation in the measurements, and an examination excluding injuries that could affect the accuracy of the measurements. Additionally, the inclusion criteria for the study were: providing written consent to participate in the study, being of legal age, and being actively employed as a firefighter. After inclusion in the study, participants were informed about the purpose and preparation required for the measurements. The subjects were divided into three age categories: 20 to < 30 years (I, $n = 84$), 30 to < 40 years (II, $n = 38$), and 40 to < 50 years (III, $n = 50$). Table 1 presents the mean ±SD values of the anthropometric variables.

Table 1. Mean ±SD of age [years], and anthropometric variables: body height (bh [cm]) and body mass (bm [kg]), and effect size describing particular groups

groups	age [years] (min-max)	bh [cm] (min-max)	bm [kg] (min-max)
I $n = 84$	22 ± 1.8 (19.5–27.8)	180.6 ± 6.77 (165–198)	79.4 ± 8.32^^ (63–103.6)
II $n = 38$	36 ± 2.7 (30.2–39.9)	179.9 ± 4.79 (170–193)	89.7 ± 9.39 (76–117)
III $n = 50$	44 ± 2.8 (40.1–50.0)	178.1 ± 5.03 (168–188)	87.2 ± 13.25 (64–113)
F $df = 2.169$		2.8	16.65
p		0.062	<0.001
η^2		0.036	0.165

post hoc differences $p < 0.05^*$; $p < 0.001^{**}$; $p < 0.001^{***}$: ^ I–III*; ^^ I–II***; I–III*

The statistical analysis revealed that the body mass of the study participants significantly differed between groups ($F_{5,166} = 7.59$; $p < 0.001$; $\eta^2 = 0.165$). Significant differences were found between groups I and II ($p < 0.001$) and I and III ($p < 0.01$).

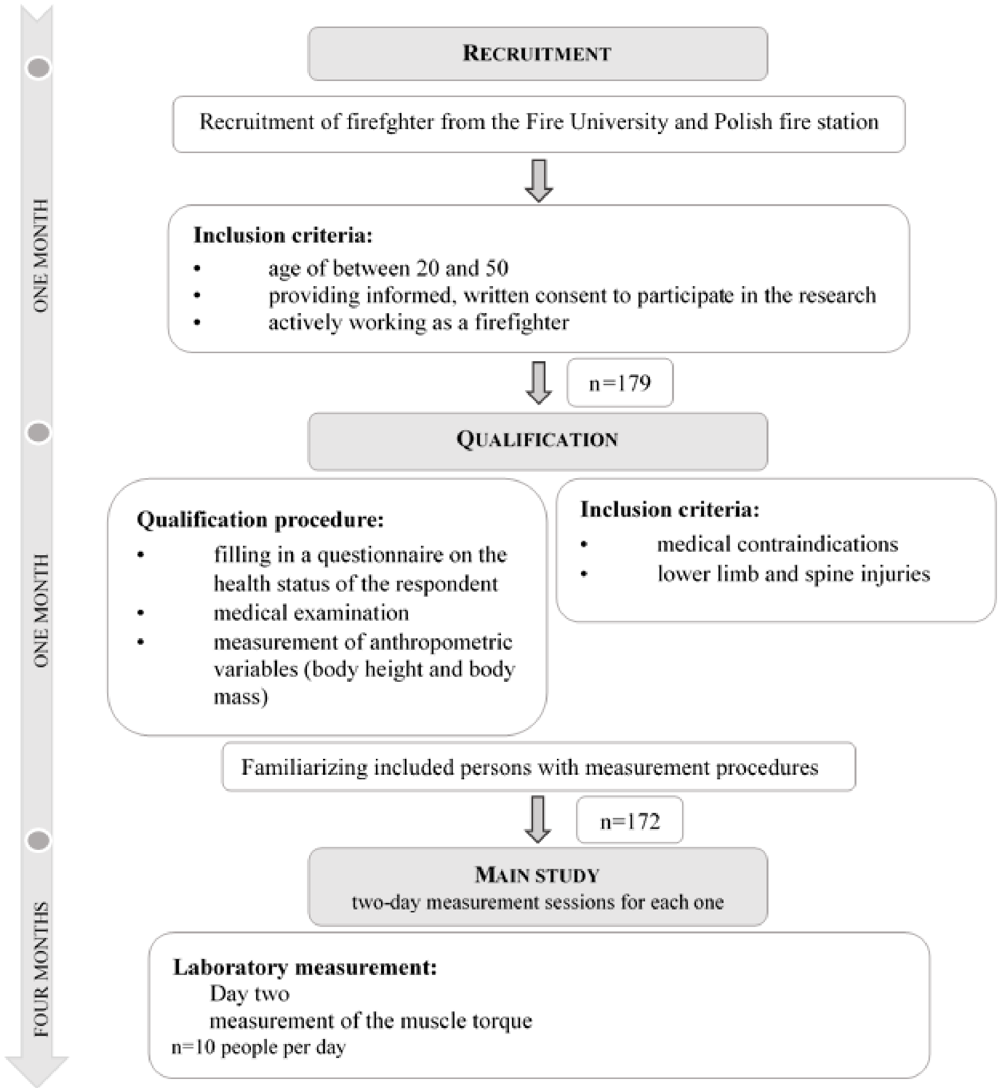

Figure 1. Details about the study procedures of the recruitment, qualification phase and main study

The consent of the ethics committee was obtained to conduct the research (Ethics Committee for Human Research at the Military Institute of Aviation Medicine in Warsaw; nr 01/15).

Methods

Measurements began with the assessment of basic anthropometric variables, such as body height (bh) measured to the nearest 0.5 cm using an anthropometer, and body mass (bm) measured to the nearest 0.5 kg. Body composition, including fat mass (FM), fat-free mass (FFM), was evaluated using the bioimpedance method (BIA) in the tetrapolar version with the BC-418 device (Tanita Co., Japan).

After an individual warm-up, measurements of torque were performed for 10 muscle groups: flexors (flex) and extensors (ext) in the following joints: elbow (E) and shoulder (S) in a standing position, knee (K) and trunk (T) in a seated position, and hip (H) in a lying position. The methodology used was consistent with previous research by Iwańska et al. (2019). Measurements were taken under static conditions while maintaining standard positions (Knapik et al., 2019). The joint angles for the elbow, hip, knee, and trunk were 90°, while for the shoulder joint it was 0° (upper limb along the trunk). During the measurement, the subject was stabilized using appropriate straps, eliminating the influence of adjacent muscle groups on the result. A torque meter was used to automatically obtain the torque value [Nm]. The measurement was brief, lasting about 3 seconds, to eliminate the influence of fatigue on the result. The goal of the study was for firefighters to achieve maximum torque in each trial.

Each measurement was performed twice, and the maximum values of of the sum of muscle torques for the upper limb ($\sum T_{\text{upper limb}}$), lower limb ($\sum T_{\text{lower limb}}$), and the sum of trunk flexors and extensors ($\sum T_{\text{trunk}}$) were taken for analysis.

Additionally, the stability of selected joints was analysed based on the calculated torque ratio (H/Q ratio) of the flexor and extensor synergist groups using the formula:

H/Q ratio = $(T_{flex}/T_{ext}) \times 100\%$, where T_{flex} is the value obtained for the flexors, and T_{ext} is the value obtained for the extensors. This stability ratio assessment was conducted for the hip and knee joints.

Statistical analysis

In the analysis of results, basic statistical indicators (means, standard deviations, and ranges of variability) were used. All variables exhibited a normal distribution, which was verified using the Shapiro-Wilk test. Therefore, parametric tests were applied to assess changes as a function of age. A one-way analysis of variance (ANOVA) was used for body composition components and muscle torque measurements, with age as the fixed factor. Effect size was evaluated based on the Partial Eta Squared η^2 value (0.01–0.06: small effect, 0.06–0.14: medium effect, > 0.14: large effect). For significant age effects, a post-hoc analysis was performed using Tukey's test for different N. The Pearson correlation test was used to assess dependencies. Additionally, to illustrate changes as a function of age, the results of individual variables were approximated using a linear regression equation or a second-degree polynomial. Forecasting changes and expected strength levels for different age groups was performed using multiple regression analysis. A confidence interval threshold of $p < 0.05$ was adopted.

Results

Body composition analysis

Significant differences were revealed between groups of firefighters of different ages for all body composition variables (Table 2).

Table 2. Mean ±SD and range of variation body mass index (BMI) and body composition assessment: fat mass (FM), fat-free mass (FFM) and total body water (TBW) describing particular groups

groups	BMI (min-max)	FM % (min-max)	FFM % (min-max)
I n = 84	24.4 ± 1.85# (20–29)	11.3 ± 4.23# (2.7–20.4)	88.2 ± 3.75# (80–96)
II n = 38	27.7 ± 2.64 (23–35)	20.2 ± 4.49 (9.8–30.5)	79.8 ± 4.49 (70–90)
III n = 50	27.3±3.26 (21–36)	20.7±5.28 (10.9–31.0)	79.3±5.28 (69–89)
F df = 2.169	34.01	85.87	83.71
p	< 0.001	< 0.001	< 0.001
η^2	0.287	0.504	0.497

post hoc differences: # I-II***; I-III***

The lowest BMI value was observed in the group of the youngest firefighters. This index was significantly lower than that observed in the older groups ($F_{2,169}$ = 34.01; p < 0.001; η^2 = 0.287). The youngest firefighters also had the lowest fat mass (FM) and the highest fat-free mass (FFM). These variables significantly differentiated group I from the other groups (p < 0.001).

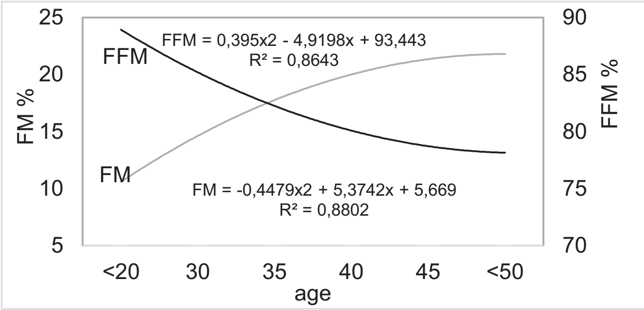

Figure 2. The values of fat mass (FM) and fat-free mass (FFM) as a function of age approximated using a second-degree polynomial

An increase in fat mass was observed along with a decrease in the percentage of fat-free mass as a function of the firefighters' age (Figure 2). A critical change in the ratio of fat-free mass (FFM) to fat mass (FM) was recorded in the second decade (30–40 years).

Results of muscle torque measurements

The muscular torque potential in the form of the sum of muscle torques of firefighters was assessed considering their age and body mass. Absolute values ($\sum T$ [Nm]) and relative values (normalized to body mass $\sum T/\mathrm{bm}$ [Nm/kg]) were compared. In the overall assessment, a significant effect of age was demonstrated for both absolute values ($F_{(2,169)}$ = 10.84; p < 0.001; η^2 = 0.113) and values normalized to body mass ($F_{(2.169)}$ = 36.01; p < 0.001; η^2 = 0.299). However, concerning relative values, the significance of body mass for the strength capabilities of the study participants was observed, particularly in the second age group (30–40 years). In this group, a greater contribution of body mass to developed strength was indicated (Table 3).

A significant positive correlation was found between body mass and the sum of muscle torque values (r = 0.305, p < 0.001), and a negative correlation with the age of the participants (r = –0.319, p < 0.001). No significant correlation was observed between $\sum T$ and the percentage distribution of body mass into fat mass and fat-free mass. However, a significant correlation was found between $\sum T$ and fat-free mass expressed in kilograms (r = 0.481; p < 0.001). Additionally, body composition variables significantly correlated with the age of the participants (p < 0.001). A positive correlation was observed for FM (r = 0.712; p < 0.001), and a negative correlation was found for FFM (r = – 0.705; p < 0.001).The results of the correlation analysis indicated that higher muscle torque values were manifested by participants with greater fat-free mass (FFM) compared to those with higher total body mass.

Table 3. Mean absolute ($\sum T$ [Nm]) and relative ($\sum T/\text{bm}$ [Nm/kg]) values of the sum of muscle torques for each age group

groups	$\sum T$ [Nm] (min-max)	$\sum T/\text{bw}$ [Nm/kg] (min-max)
I $n = 84$	2474 ± 347.9^ (1681–3816)	31.3 ± 4.83^^ (20.1–44.6)
II $n = 38$	2007 ± 431.8 (1711–3395)	26.9 ± 4.24 (19.9–37.2)
III $n = 50$	2163 ± 342,5 (1448–3234533)	25.2 ± 3.25 (16.5–34.4)
F $df = 2.169$	8.97	36.01
p	< 0.001	< 0.001
η^2	0.096	0.229

post hoc differences: ^ I-III***, II-III*; ^^ I-III***; # I-III***

In the next section, an attempt was made to analyze the changes and comparisons of the sum of muscle torques of the upper limb ($\sum T_{\text{upper limb}}$ [Nm]), lower limb ($\sum T_{\text{lowerlimb}}$ [Nm]), and the sum of muscle torques of the flexor and extensor trunk ($\sum T_{\text{trunk}}$ [Nm]) as a function of age. The mean values ±SD obtained for the age groups are presented in Table 4.

Table 4. Mean ±SD values (min; max) of the sum of muscle torques of the upper limb ($\sum T_{\text{upper limb}}$ [Nm]), lower limb ($\sum T_{\text{lower limb}}$ [Nm]), and the sum of muscle torques of the flexor and extensor trunk ($\sum T_{\text{trunk}}$ [Nm]) in different age groups

	$\sum T_{\text{upper limb}}$ [Nm] (min-max)	$\sum T_{\text{lower limb}}$ [Nm] (min-max)	$\sum T_{\text{trunk}}$ [Nm] (min-max)
I $n = 84$	438 ± 76.1^ (267–617)	1114 ± 185.6^^ (729–1710)	923 ± 153.6# (654 –1488)
II $n = 38$	435 ± 74.9 (289–610)	1060 ± 198.6 (767–1576)	912 ± 188.9 (628–1400)
III $n = 50$	373 ± 60.8 (245–533)	985 ± 167.1 (679–1522)	804 ± 155.2 (453–1200)
Fdf=2.169	13.92	7.77	8.97
p	< 0.001	< 0.001	< 0.001
η^2	0.141	0.084	0.096

post hoc differences: ^ I-III***, II-III***; ^^ I-III**; # I-III***, II-III*

Based on the analysis, significant differences in strength levels were found in the upper limb ($F_{2,169} = 13.92$; $p < 0.001$; $\eta^2 = 0.141$), the lower limb ($F_{2,169} = 7.77$; $p < 0.001$; $\eta^2 = 0.084$), and the sum of trunk muscle torques ($F_{2,169} = 8.97$; $p < 0.001$; $\eta^2 = 0.096$) between the studied groups. The level of the sum of muscle torques in the lower limb ($\sum T_{\text{upper limb}}$) was similar in the first two groups, with significant differences only between group I and group III ($p < 0.001$). For $\sum T_{\text{lower limb}}$, statistically significant differences at the level of $p < 0.001$ were observed between I and III group. Additionally, in the case of the sum of trunk muscle torques, the oldest firefighters had values 12.8% lower compared to the youngest group ($p < 0.001$) and 11.8% lower ($p < 0.01$) compared to the men aged 30–40.

The rate of change in strength with age for individual limb was analyzed using a linear regression equation ($y = a + bx$). The equation was created using the results of all participants, with the regression coefficient (b) predicting the rate of change in strength capabilities as a function of the participants' age. The fastest decline was found for the lower limb muscles ($\sum T_{\text{lower limb}} = 1238.8 - 5.51\text{age}$), followed by the trunk muscles ($\sum T_{\text{trunk}} = 1036.1 - 4.76\text{age}$). The smallest decrease in strength was observed for the upper limb ($\sum T_{\text{upper limb}} = 502.92 - 2.67\text{age}$).

Table 5 presents the H/Q ratio results for the proportion of knee and hip flexor to extensor muscle strength.

Table 5. Mean ±SD values of the flexor (T_{flex}) to extensor (T_{ext}) muscle strength ratio (H/Q ratio) for the knee and hip joints in the respective groups

groups	H/Q ratio %	
	knee-joint	hip-joint
I $n = 84$	42.6 ± 10.16	56.4 ± 9.59^
II $n = 38$	41.1 ± 13.51	52.5 ± 10.41
III $n = 50$	42.3 ± 11.05	58.7 ± 10.93
$Fdf = 2.169$	0.233	4.123
p	0.793	< 0.05
η^2	0.003	0.047

post hoc differences: ^ II-III*

The mean value of the flexor to extensor muscle strength ratio (H/Q ratio) for the knee joint muscles was almost the same across all groups, with no significant differences found between the groups. Significant differences in strength ratios were observed for the hip joint muscles ($F_{(2,169)} = 4.12$; $p < 0.05$). However, the Partial Eta Squared in this case was low ($\eta^2 = 0.047$).

Discussion

The most common causes of injuries occurring during firefighters' work include falls, burns, impact injuries, and musculoskeletal strains. Of the 1395 (45.5%) ever-injured firefighters and paramedics, there were 2372 injuries reported between the years 2005 and 2013. Therefore, 41.2% ($n = 977$) of reported injuries were repeat injuries to the same person over the 9-year period (Widman, et al., 2018). When analyzing the occurrence of injuries across age groups, Szuber and Sobala (2002) noted an increase in the frequency of injuries with age. The highest percentage of injuries was found in individuals over 50 years old, with significantly lower rates observed in firefighters aged 30-39. Also it was shown of that among the professionally active Polish firefighters under study that, the highest sum of muscle torques was obtained by the representatives of the youngest group, while the lowest was achieved by the oldest. The difference was approximately 12.6% and was observed over two decades. A similar reduction in strength (about 13–14%) was found by Perroni et al. (2014). However, when considering the body mass of the participants and comparing the relative values of muscle torque per 1 kg of body weight, the difference between the decades was even greater (19.7%). In this case, the differences between the first and second age groups (14.2%) already indicated an increasing contribution of body mass to muscle strength values among firefighters aged 30–40.

The increase in body fat content, along with the simultaneous decrease in the percentage of fat-free mass (FFM) observed from around the age of 30, is likely related to the reduction of muscle proteins, as reported by other researchers (Cohn et al., 1980; Janiszewska, 2013), what may explain the results of this research. Additionally, general studies indicate that muscle mass decreases after the age of 30 (Roubenoff, 2003; Keller & Engelhardt, 2014), and after the age of 50, it reduces at an average rate of 6% per decade (Janssen, 2010).

However, despite the observed effect of increased body mass contribution to strength among the studied firefighters, it should be noted that the torque value obtained in group III was significantly higher compared to men around the age of 50 who were long-distance runners as well as physically inactive men (Iwańska et al., 2019). The oldest firefighters achieved higher values compared to the other groups by 24% and 16% for the absolute values of the sum of muscle torques, and by 14% and 20% for the values relative to body mass.

The correlations between total body mass (bm), fat-free mass (FFM), and the age of the participants with the sum of muscle torques (ΣT) can be described using a multiple regression model. Based on this model, it is possible to predict changes in strength over the course of one year and the value increase associated with changes in fat-free body mass content.

Each of the partial correlation coefficients was significant ($p < 0.001$). The result of such a model is illustrated by the forecasting equation:

$$T = 1031.8 - 15.601\text{age} + 15.828\text{FFM} + 8.687\text{bm}$$

The equation predicts that the age variable in the studied group of firefighters has the greatest impact on the level of the torque developed. For an individual who is one year older, the strength level will decrease by 15.601 units, with other variables remaining constant. However, if the fat-free body component (FFM) increases by 1 unit or is maintained at a high level, it will delay the decline in torque. Maintaining high physical activity can significantly delay or even reverse age-related changes, significantly affecting muscle enzyme activity (Niclas et al., 1995). For the study participants, this is undoubtedly of even greater importance, as their physical fitness often directly impacts the quality of their rescue operations. Most injuries occurring in firefighting work, specifically sprains, ranging between 42% and 62%, result from compensatory actions of the lower back and lower limbs during which muscle groups must demonstrate a high level of body stabilization are associated with lifting, holding, and carrying external loads (Giguère & Marchand, 2005; Coca et al., 2010; Park et al., 2010; Chiou et al., 2012). In firefighting tasks, the fire hose itself, when filled with water, weighs approximately 50 kg, which necessitates appropriate tension and energy expenditure related to the force developed by the working muscles.

In this study, to illustrate the rate of strength decline, the results of the sums of individual biokinematic chains were approximated using a simple regression equation. By using such regression equations, it can be indirectly predicted that the rate of change will be represented by the coefficient b. The smallest change in strength was observed for the upper limb muscles, with a regression slope coefficient of $b = -2.67$. The highest change was observed for the lower limb muscles (with a coefficient $b = -5.51$) and slightly lower for the trunk muscles (with $b = -4.76$). This is quite concerning considering that a significant proportion of injuries among rescuers and paramedics are related to back injuries (Hogya & Ellis, 1990). Andersson (1997) demonstrated a close correlation between lumbar spine disorders and the weights lifted and carried. Most spinal disorders result from improper execution of movement activities, excessive loading during lifting, and weakening of the muscular system. During lifting, the front part of the intervertebral disc is compressed while the rear part is stretched, which can lead to damage to this structure, especially with the continuous repetition of such activities. Levander et al. (2000) analyzed mechanical loads in simulated, most common working positions of rescuers and paramedics. They used a biomechanical model of spinal movements developed by Marras et al. (1993). The most dangerous tasks for the lumbar spine were moving the injured from one place to another. The authors also highlight the asymmetric loading of the spine, particularly when carrying heavy patients down stairs. This poses the greatest threat to the discs and ligaments, as performing such actions causes simultaneous twisting and bending of the trunk.

The results of our study, when compared to the general population, also confirm the observed phenomenon of greater muscle strength loss in the lower limbs compared to the upper limbs (Frontera et al., 1991).

In muscle strength assessment, evaluating the stability of individual joints, particularly in the lower limbs, is extremely important. This is crucial when there is a need to quickly develop maximum force values during high-intensity and dynamic movements. It was found that in virtually all age groups, knee joint stability was similar. The H/Q ratio, with the exception of group II, remained nearly at the same level. This indicates that there is a proportional loss of strength in the knee joint for both extensors and flexors. However, the low values of the H/Q ratio for both the knee and hip joints are concerning.

For the knee joint, it is assumed that the H/Q ratio value should range between 45-60% (Nosse, 1982; Iwańska et al., 2019), and for the hip joint, between 60–80% (Bennell et al., 1998) with approximately 50% being considered optimal for healthy knee joint function, depending on the measurement method, angular velocity, and joint (Kim & Hong, 2011; Tabor et al., 2021; Mbada et al., 2021). Values below 45% may indicate insufficient hamstring strength relative to quadriceps, which could compromise joint stability and increase the risk of anterior cruciate ligament (ACL) injuries and other knee pathologies.

In our studies, the index ranged between 41–43% for the knee joint and 52–59% for the hip joint, indicating a significant contribution of the strength of flexor muscles to their stability. This is likely due to the mechanics of the tasks performed during rescue operations (lifting, pulling, etc.). These differences, although dependent on the conditions in which the muscle works (angular velocity, type of work, body position), can represent a risk of injury in diagnostics and may also reflect susceptibility to injuries (Rosene et al., 2001).

However, this result is not unusual in firefighter populations. For example, Miratsky et al. (2021) reported similar H/Q ratios in professional firefighters, ranging from 42 to 45%. This may reflect occupational adaptations, particularly due to repetitive load-bearing tasks involving prolonged squatting, stair climbing, or carrying equipment, which can lead to a disproportionate strengthening of the quadriceps relative to the hamstrings.

The findings of the current study provide information for developing appropriate training programs to increase work efficiency and reduce injuries among firefighters. An instructor, with knowledge of the rate of decline in strength capabilities with age, can more effectively adjust training and select adequate training load values to make the decrease in work efficiency less noticeable and more focused on increasing work safety.

Conclusion

A limitation of our study was the lack of randomization in the recruitment of study participants. However this study demonstrates the importance of maintaining a high level of muscle strength for firefighters, especially in older age groups.

Given the nature of the work, its diversity, and the significant demands placed on rescuers of all ages, it is suggested that training programs be tailored to the needs of different age groups. The goal of such programs should be to effectively improve firefighters' neuromuscular function and minimize the impact of aging on the effectiveness of rescue operations.

Particular attention should be paid, in older age groups, to the need for increased lower limb strength training, which has been shown to decline most rapidly with age and show the greatest differences compared to younger groups.

Furthermore, all participants demonstrated values of the hamstring-to-quadriceps ratio (H/Q) below the norm, which may indicate a generally increased risk of knee instability in this occupational group.

It is therefore suggested that the force proportion index should be one of the basic indicators of periodic preventive examinations assessing the physical fitness of firefighters.

During follow-up examinations of firefighters, special attention should be paid to the torque ratio (H/Q) of the synergistic flexor and extensor muscle groups. Both too low (< 40%) and too high (> 60%) levels of physical activity may be associated with an increased risk of injury due to muscle imbalances – either due to quadriceps dominance or excessive hamstring activity in the presence of weakened quadriceps. Therefore, preventative strength training aimed at developing the hamstring muscles is recommended for all groups.

A carefully selected high-intensity training program can contribute to increased maximal strength and reduce the physiological decline in physical performance associated with age and body composition

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