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Physical fitness levels of South Korean national male and female firefighters

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Introduction

Firefighters (FFs) are required to be very physically fit to conduct special tasks in emergency situations.^{1,2} They have to wear heavy equipment, such as a self-contained breathing apparatus (about 20 kg), helmets and gloves to protect themselves from physical dangers and chemical hazards under extreme circumstances.^{3,4} Furthermore, they have to lift heavy loads and drag or carry victims while wearing self-protective gear.⁴ The heavy equipment and chaotic circumstances require FFs to have a high level of fitness.^{3–5}

Among many components of physical fitness (PF), aerobic fitness (AF) is the primary measures of PF for the determination of fit for duty.^{4–6} Previous researchers have shown that firefighters with higher aerobic fitness can perform their duties quicker, longer and with less fatigue.^{4–6} National Fire Protection Association (NFPA) in the United States has determined that a FF should have a minimum $VO_2\max$ of 42 ml/kg/min to perform their safety.^{5,7} The method of measurement varies among fire jurisdictions. A

combination of submaximal to maximal exertion protocols that either measure or predict the $VO_2\max$ of the FF have been utilized. In some cases, such as the Candidate Physical Ability Test (CPAT)⁵ or the CF-DND fire fit test,⁸ the aerobic component is nested in the performance of a series of job-related tasks completed in a prescribed amount of time.

Muscle strength and muscular endurance are also vital for FFs. A study conducted during the CPAT test showed that those who failed to complete the tests had lower 1-repetition maximum (RM) and muscular endurance than those who completed^{5,9} and Rhea MR, Alvar BA, R¹⁰ found that grip strength is associated with simulated firefighting performance. The National Fire Protection Association (NFPA) 1582, which is a guideline for American FFs, presents standards for muscle strength and muscular endurance in its fitness assessment components such as lower limb, abdomen, push-up, and pull-up.⁷ Also, many studies on fitness intervention programs for FFs have included evaluations of muscle strength and muscular endurance.^{11–13}

Body composition influences how fast FF can perform his or her duties,¹⁴ their risk for musculoskeletal injuries, and the efficiency with which their work is performed.¹⁵ Dennison, Mullineaux, Yates, Abel¹⁴ reported that unfit FFs performed their tasks 70%–80% more slowly than physically fit FFs. S.A. Jahnke, W.S.C. Poston, C.K.

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Haddock, Jitnarin¹⁵ reported that obese FFs had 5.3 times more musculoskeletal injuries than fit FFs. Furthermore, a study by Nogueira, Porto, Nogueira, Martins, Fonseca, Lunardi, de Oliveira¹⁶ revealed a strong relationship between body composition and AF. Researchers have suggested that fire departments should manage FF's body composition for health and performance.^{14–16}

In Korea, the national FFs' PF test is composed of six elements (grip strength, back strength, sit and reach, standing long-jump, sit-ups and shuttle-run).¹⁷ However, the aerobic assessment is a predictive measure, and the strength assessments are limited in their sensitive, and there are no measures of body composition. Therefore, the aim of this study was to obtain fitness data with more precise methods to compare with previous research. A secondary purpose was to examine potential gender differences.

Methods

Subjects

Participants were recruited in cooperation with two fire stations. The two stations were chosen considering the times of rescue working and the number of firefighters, which were the average level among fire stations in Seoul, and distance to the laboratory. They were requested with about a hundred subjects within limited compensation to fire stations, and they sent us a list of 102 participants randomly. A total of 102 Korea national FFs took part in this study (84 males and 18 females, mean age: 38.5 ± 8.85 years). We tried to make almost the same number of subjects between gender but the number of female firefighters was very lower than that of male firefighters. All participants were full-time FFs working in Seoul, South Korea. Participation began after the subjects were informed about the study and signed consent (CR318031). All participants were given compensation of 25,000 KRW (approximately 21 Dollars) for encouraging participation in this study.

Aerobic fitness test (VO_2 max)

AF was assessed with a gas analyzer (Quark CPET, Cosmed, Roma, Italy). The Bruce protocol¹⁸ was used for the graded incremental treadmill test. Calibration was conducted 30 min before the test with a gas mixture and a 3-L syringe. The participants were equipped with a strap (H10, Polar, Kempele, Finland), and were asked to walk on a treadmill for one to 2 min at 6 km/h to adapt to the device and warm-up. A respiratory mask was strapped onto the participants, then testing was initiated. The rating of perceived exertion scale (RPE) (1–10) was assessed every minute to check the physical load of the participant.¹⁹ The test was stopped when the subject satisfied more than two of the following four criteria: i) respiratory exchange ratio (RER) ≥ 1.15 , ii) heart rate (HR) above 95% HRmax, iii) VO_2 max plateau, and iv) RPE ≥ 9 . VO_2 max was reported in ml/kg/min. After the test was finished, the subjects were asked to walk until their heart rate dropped to 50% of their maximal heart rate.

Muscle strength & muscular endurance

Muscle strength and muscular endurance were measured using an isokinetic dynamometer (HUMAC NORM, CSMi, MA, USA) with angular velocities at 60°/sec (5 repetition) and 180°/sec (15 repetitions) for knees and shoulders.^{20,21} Between sets, subjects were allowed 1 min rest time. Trunk test was conducted at 60°/sec only.²² All tests were conducted at flexion and extension. Peak-torque (NM) units were used for the muscle strength measurements and muscular endurance was expressed as total work (J).

Table 1

Basic characteristics of the Korean national firefighters.

	Males (n = 84)	Females (n = 18)
Age (year)*	39.7(8.94)	32.7(5.72)
Height (cm)*	173.9(4.38)	162.9(7.84)
Body mass (kg)*	74.4(8.32)	57.0(5.82)
Lean mass (kg)*	52.4(5.43)	35.6(3.04)
Fat mass (kg)	18.73(4.39)	19.16(4.11)
% Fat (% of body mass)*	25.1(3.96)	33.4(4.64)
BMI (kg/m ²)*	25.1(2.37)	22.3(2.46)
Resting SBP (mmHg)*	126.8(13.09)	108.7(7.47)
Resting DBP (mmHg)*	81.4(12.27)	71.2(8.16)
Pre-exercise HR (bpm)	75.5(11.26)	80.3(11.35)

The data are presented as the mean (SD), * $p < 0.05$. BMI = body mass index, DBP = diastolic blood pressure, HR = heart rate, SBP = systolic blood pressure.

Grip strength

Grip strength was measured with a grip dynamometer (TKK-5401, Takei, Niigata, Japan). The participants stood straight by the width of the pelvis and adjusted the dynamometer bar around their second finger joints. The participants grasped the instrument strongly with their right hand first, then with their left hand. Each side was repeated twice and the average was calculated.²³ Grip strength was reported in kilograms (kg).

Body composition

Height was estimated using an extensometer. Then, the participants rested 5 min in a sitting position, and blood pressure was measured for each subject using a blood pressure monitor (BPBIO320S, Inbody Co, Seoul, Korea). Body mass was measured by dual-energy X-ray absorptiometry (DXA) (Discovery W, Hologic Inc, MA, USA). The calibration of the DXA was conducted 20 min prior to each test. The Asian mode was chosen for ethnicity. DXA data included body mass (kg), lean mass (kg), fat mass (kg), fat percentage (%), and body mass index (BMI) (kg/m²). All subjects had no food or liquids within 4 h of the test. All tests were conducted by the same operator, respectively.

Statistical analyses

All data were analyzed using SPSS version 22.0 (SPSS, IBM Corporation, IL, USA). The data are presented as the mean \pm standard deviation (SD). An independent t-test was used to compare the differences between the two groups (male firefighters (MFFs) and female firefighters (FFFs)). Pearson's Chi-square test was performed to investigate differences in the distribution of BMI, fat percentages, and AF by gender. Statistical significance was set at p -value < 0.05 .

Results

The demographic characteristics and body composition of the Korean national FFs are shown in Table 1. All items were significantly different ($p < 0.05$) between the two groups, with the exception of fat mass ($p = 0.694$) and Pre-exercise_HR ($p = 0.10$).

The results of the VO_2 max testing are shown in Table 2–a. The mean VO_2 max was 42.27 ml/kg/min for MFFs and 35.93 ml/kg/min for FFFs. The absolute VO_2 max and the relative VO_2 max were significantly different between the two groups (MFFs vs. FFFs) ($p < 0.05$). However, the RER and the peak HR showed no difference between the two groups.

Table 2–b shows the distribution of VO_2 max values for MFFs and FFFs classified according to NFPA guidelines.⁷ By the chi-

Table 2a
Average values of measured VO₂ max of the Korean national firefighters.

	Males	Females
Absolute VO ₂ max (L/min)*	3.19(0.49)	2.04(0.27)
Relative VO ₂ max (ml/kg/min)*	42.27(6.36)	35.93(4.81)
RER	1.25(0.11)	1.27(0.08)
Peak HR (bpm)	181.00(14.83)	181.06(10.14)

The data are presented as mean (SD), * $p < 0.05$ RER = respiratory exchange ratio, HR = heart rate.

squared analysis, there was a significant difference between the two groups ($p < 0.05$). While 53.6% of the MFFs met the minimum standard of 42 ml/kg/min, only 11.1% of the FFFs met that standard.

The results of muscle strength and muscular endurance of knee, shoulder, trunk, and grip strength are shown in Table 3. Among the isokinetic factors, the proportional difference between males and females was the greatest in shoulder strength. The right and left shoulder peak torques were 103.1 Nm and 93.3 Nm in MFFs and those for FFFs were 37.5% and 37.4% (38.7 Nm and 34.9 Nm), respectively, of the male peak torques. The smallest gap was in right knee extension (FFFs were 62.4% of the value for MFFs).

Table 4–a and 4–b present BMI and fat percentage distributions, respectively. BMI cutoffs were applied according to the World Health Organization (WHO) Asian-Pacific criteria.²⁴ There was a significant difference in the distribution of BMIs by gender ($p < 0.05$, $\chi^2 = 17.090$). The fat percentages of the participants were classified using the Korean fat percentage criteria.²⁵ There was no significant difference in fat percentage distribution by gender ($p = 0.05$, $\chi^2 = 1.446$).

The AF and grip strength of the FFs is compared to FFs data from different nationalities in Tables 5 and 6. Data selection was based on average ages and the latest research data was selected for each country. However, the average age was not compared to FFFs, because there have been only a few studies on FFFs. Data on Sweden FFs showed that they had the highest VO₂ max and grip strengths (58.0 ml/kg/min and 61 kg, respectively), while Korean MFFs had the lowest values (42.27 ml/kg/min and 49.8 kg, respectively). FFFs from Canada and the UK had the highest VO₂ max, at 46.6 ml/kg/min.

Discussion

The purpose of this study was to investigate the AF, muscle strength, muscular endurance and body composition of Korean national FFs to understand their current fitness levels. Based on data from 102 FFs, the VO₂ max of male and FFFs was 42.27 ml/kg/min and 35.93 ml/kg/min, respectively. Only 53% of the males and 11% of the females met the minimum aerobic requirements for FFs. Among the isokinetic results, shoulder extension strength showed the greatest difference between MFFs and FFFs. The grip strength of MFFs was 49.9 kg and that of females 30.8 kg, which were 80% and 76%, respectively, of other FFs. MFFs had a mean fat percentage of 25.1%, while that of FFFs was 33.4%. About 57% of the males and 72% of the females had fat percentages over 25% and 30%, respectively.

The NFPA recommends an AF by 12 METs (Metabolic equivalent of task),⁷ corresponding to 42 ml/kg/min,¹⁸ for FFs or FF candidates. For those who are below the set criterion (10METs, 8METs) are required to do an additional training program or are limited to perform the duties.⁷ Moreover, problems in AF has been associated with injuries during firefighting. Gerald S. Poplin, Denise J. Roe, Wayne Peate, Robin B. Harris, Burgess²⁶ revealed that the risk of sprains or strains in FFs with a VO₂ max under 43 ml/kg/min was 2.2 times more than physically fit FFs, representing that improvement of 1MET of aerobic capacity is shown to decrease the

Table 2b
Distribution of VO₂ max in the Korean national firefighters classified according to NFPA guidelines.

VO ₂ max (ml/kg/min)	≤27.9	28–34.9	35–41.9	≥42	χ^2
Males (n = 84)	2 (2.4)	8 (9.5)	29 (34.5)	45 (53.6)	15.402*
Females (n = 18)	1 (5.6)	7 (38.7)	8 (44.4)	2 (11.1)	–
Total (n = 102)	3 (2.9)	15 (14.7)	37 (36.3)	47 (46.1)	–

Data are presented as number (%), * $p < 0.05$ Below 42 ml/kg/min, the firefighters are counseled to increase their fitness. Below 35 ml/kg/min, the firefighters are prescribed are required aerobic fitness program. Below 28 ml/kg/min, the firefighters are advised by the Authority Having Jurisdiction to consider restricted job tasks.

probability of injuries by 14%. According to the NFPA guidelines, Korean national MFFs were aerobically fit enough to conduct firefighting tasks (Table 2–a). However, 40% (34 out of 84) of the MFFs fell into the category of FFs needing an AF prescription and two of them should have been restricted from performing firefighting tasks (Table 2–b). The AF of Korean MFFs was the lowest among FFs in all other countries (Table 5). The AF of Korean FFFs was 35.93 ml/kg/min, which was 80% of the level of Korean MFFs. According to NFPA guidelines,⁷ only two Korean women FFs met the AF standard needed to perform firefighting duties, while one fell into the range requiring restricted firefighting tasks (Table 2–b). Compared to the AF of FFs in other countries (Table 5), the VO₂ max of Korean FFFs was about 78% of the level of those in other countries and the average VO₂ max of FFFs in three countries was approximately 46 ml/kg/min (Table 5).^{27,28}

Rhea MR, Alvar BA, R¹⁰ demonstrated that grip strength was an indispensable factor in firefighting tasks. However, there is no minimum required grip strength set for FFs. As shown in Table 6, the grip strength of Korean MFFs was the lowest among international FFs. In most countries, the grip strength of MFFs was around 60 kg. However, the grip strength of Korean MFFs was approximately 83% of the average level. Only one study measured the grip strength of FFFs.²⁸ The grip strength of Korean FFFs was about 76% of Canadian FFFs.²⁸ The highest grip strength cutoff in the PF test for Korean MFFs is 60 kg, similar to the average grip strength of MFFs in other countries. However, the highest cutoff for Korean FFFs is 40 kg, which is lower than that for FFFs in other countries.²⁹ In the case of shoulder strength in 60 deg/sec, it showed a trend that Korean MFFs were slightly higher than normal males, and Korean FFFs were almost the same compared to the ordinary women.^{30,31}

According to U.S FF mortality data, one of the leading causes of death in FFs is cardiovascular or cerebrovascular disease, accounting for about 49% of the FF fatalities occurred on duty.^{32,33} Cardiovascular and cerebrovascular diseases are strongly associated with fat, BMI, and blood pressure.^{34,35} Obese FFs were found to have a higher risk for cardiovascular diseases than a normal-weight group of FFs.³⁵ Korean MFFs had slightly higher body fat percentages than FFs in other countries. These results were consistent with the data on the fat percentages of the Canadian (18.8%)²⁸ and the U.K FFs (20.6%).²⁷ Korean MFFs are not required to have perfect body compositions, however, they may need to control their fat mass to improve their health and their firefighting ability. The body composition of Korean FFFs was thin-outside-fat-inside (TOFI).³⁶ Fifty percent of them had BMIs within the normal range (Table 4–a). However, 72% of them had excessive body fat. Elevated percentages of body fat might impair FFs' ability to normally conduct their duties in emergency situations. Michaelides, Parpa, Henry, Thompson, Brown³⁷ found a negative relationship between fat percentages and FF performance on six types of tasks such as CPAT. FFs who took more time to complete the tasks had 10% higher body fat compared to those who took less time.³⁷ Many studies have also shown a significant association between body

Table 3
Peak torques and muscular endurance of bilateral knees, shoulders, and trunk and the average grip strength of the Korean national firefighters.

Part	Angular velocity (unit)	Movement	Males		Females	
			Right	Left	Right	Left
Knee*	60°/sec (Nm)	Extension	184.8(38.7)	178.0(37.5)	115.4(20.2)	110.3(19.0)
		Flexion	95.23(19.1)	93.0(24.4)	55.4(12.7)	50.5(11.6)
	180°/sec (J)	Extension	2107.1 (361.3)	2033.7 (372.0)	1276.1 (202.2)	1230.6 (226.0)
		Flexion	1162.4 (252.0)	1150.7 (264.7)	654.7 (142.8)	600.8 (168.2)
Shoulder*	60°/sec (Nm)	Extension	103.1 (24.4)	93.31(29.3)	38.7(8.4)	34.9(6.2)
		Flexion	69.7 (14.3)	65.9(12.9)	37.4(4.3)	35.4(5.1)
	180°/sec (J)	Extension	1653.2 (390.4)	1526.4 (406.2)	672.4 (156.3)	600.4 (145.1)
		Flexion	1281.12 (270.0)	1290.0 (305.8)	570.6 (144.4)	581.9 (152.0)
Trunk*	60°/sec (Nm)	Extension	277.0 (45.0)		165.9 (21.7)	
		Flexion	245.8(48.1)		139.8 (25.3)	
Grip strength (kg)*		single	49.80(5.70)		30.76(7.14)	
		Combined	99.64(11.49)		64.89(14.16)	

The data are presented as mean (SD), * $p < 0.05$ The indication (*) shows statistical difference between males and females of each part.

Table 4a
Distribution of BMIs of the Korean national firefighters.

BMI	Underweight	Normal	Overweight	Obese	χ^2
Males	0 (0)	15 (17.9)	24 (28.6)	45 (53.6)	17.090*
Females	1 (5.6)	9 (50.0)	6 (33.3)	2 (11.1)	
Total	1 (1.0)	24 (23.5)	30 (29.4)	47 (46.1)	

The data are presented as numbers (%), * $p < 0.05$.

The BMI cutoffs used were <18.5 kg/m², 18.5–22.9 kg/m², 23.0–24.9 kg/m², ≥ 25.0 kg/m² for underweight, normal, overweight, and obese, respectively.

Table 4b
Number and percentage of body fat of the Korean national firefighters.

% Fat	Low	Average	High	χ^2
Males	9 (10.7)	27 (32.1)	48 (57.1)	8.982*
Females	1 (5.6)	4 (22.2)	13 (72.2)	
Total	10 (9.8)	31 (30.4)	61 (59.8)	

The data are presented as numbers (%), * $p < 0.05$.

The criteria for low, average, and high fat percentages in males was $<20\%$, 20% – 24.9% , and $\geq 25\%$ and was $<25\%$, 25% – 29.9% , and $\geq 30\%$ in females, respectively.

Table 5
VO₂ max of the Korean national firefighters compared to firefighters in other countries.

Male firefighters					
Country(region)	Subject number (n)	Age (year)	VO ₂ max (ml/kg/min)	Measurement	Reference
Korea	84	39.7(4.4)	42.3(6.4)	D	
Canada (Ontario)	33	41.5(6.5)	51.6(6.8)	D	28
Germany (Munich)	41	39(9)	45.0(6.0)	D	38
Italy (n.a)	18	41–42	53.2(4.8)	ID	39
U.K (Gloucestershire)	50	40(10)	50.9(6.3)	ID	27
Finland (n.a)	21	38(7)	48.0(5)	ID	40
U.S (Colorado)	947	37.1(9.8)	45.8(6.1)	ID	33
Brazil (Brazilia)	4237	39(n/a)	42.4(n/a)	ID	16
Female firefighters					
Country	Subject number (n)	Age (year)	VO ₂ max (ml/kg/min)	Measurement	Reference
Korea	18	32.7(5.7)	35.93(4.8)	D	
Canada (Ontario)	3	31.7(1.5)	46.6(3.5)	D	28
U.K (Gloucestershire)	12	37(7)	46.6(7.4)	ID	27
U.S. (Colorado)	76	38.0(10.1)	45.8(6.1)	ID	33

The data are presented as mean (SD).

D: VO₂ max directly measured with a gas analyzer, ID: VO₂ max indirectly measured without a gas analyzer.

composition and the physical performance of FFs.^{3,29,37} Furthermore, the fat percentage was negatively correlated with VO₂ max which is the most crucial parameter of a FF's PF.³² Compared to FFFs in other countries, Korean national FFFs had much higher fat percentages. The mean fat percentage was 21.2% for U.S. FFFs,³³ 26.9% for UK FFFs,²⁷ and 18.7% for Canadian FFFs.²⁸ When the body mass and fat percentage of Korean FFFs were taken under consideration, their lean mass was much lower than that of FFFs in other countries. Therefore, Korean FFFs need to decrease their fat percentages to assure the quality of performance and efficient completion of their duties. Moreover, authorities should continue to measure and observe their body compositions.

The differences between the gender in this study are consistent with other investigations, in that males tend to be taller, heavier, stronger and have higher AF levels. The AF level from other countries that assessed both MFFs and FFFs averaged 48 ml/kg/min and 45 ml/kg/min,^{16,27,28,33,38–40} respectively (Table 5). This was much greater than the 42 ml/kg/min and 35 ml/kg/min values from this study of MFFs and FFFs. However, the results are similar to findings by Noh, Lee, Young, Park, Lee, Seo, Kang, Ahn, Song¹⁷ of Korean FFs. One of the potential reasons for the lower values in Korean firefighters may be due to the National Standard of 43 times shuttles (34 ml/kg/min) for FFFs and 78 times shuttles (45 ml/kg/min) for

Table 6
Comparison of grip strengths between male Korean national firefighters and those in other countries.

Country	Subject number (n)	Age (year)	grip strength (kg)	Reference
Korea	84	39.7(4.4)	99.6(11.5)	
Canada (Ontario)	46	33.5(9.42)	118.1(17.6)	29
U.S. (California)	48	43(8)	117(15)	32
Germany (Munich)	41	39(9)	58.7(7.1)	38

The data are presented as mean (SD).

Germany was presented as the average of each hands.

MFFs.^{17,41}

There are several limitations to this study; the size of the sample; participants were from a convenience sample; participants may have been in different work rotations, which may have impacted their physical state. Due to the rotation, measurements were not made in the same environmental conditions.

Conclusion

The physical fitness values of Korean FFs tended to be lower than FFs from other Countries for both males and females. One concern is the low aerobic fitness of the Korean FFs relative to published standards. Based on the AF standards, some Korean FFs would be considered unfit to serve. This may be due to the Korean entrance requirements being low compared to other countries or that Korean FFs become less fit overtime, aerobically and body fat percentage. It could benefit from improving standards or fitness training through exercise guidelines.

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Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

CRediT authorship contribution statement

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