Anthropometric and fitness predictors of operational preparedness among Malaysian firefighters: a clustering and multivariate logistic regression approach

Predictores antropométricos y de aptitud física de la preparación operacional entre los bomberos malasios: un enfoque de agrupamiento y regresión logística multivariante

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Abstract

Introduction: The evolving scope of responsibilities within the Malaysian Fire and Rescue Department necessitates a high level of physical and anthropometric readiness among firefighter recruits. Modern firefighting now encompasses complex land, sea, and air rescue operations alongside conventional fire suppression, requiring rigorous preparedness. Objective: This study aimed to evaluate the fitness and anthropometric profiles of Bomba recruits, identify key variables distinguishing excellent from average fitness performers, and develop a predictive model to classify future high-performing firefighters. Methodology: A total of 746 recruits underwent a final assessment of anthropometric and fitness parameters. K-means clustering was utilised to categorise recruits into Excellent Fitness Readiness (EFR) and Average Fitness Readiness (AFR) groups. Mann-Whitney U tests were then employed to determine significant differences in the measured variables between the groups. Subsequently, a logistic regression model was developed to predict the likelihood of recruits achieving EFR status. Results: Results indicated that five out of nine variables, the 2.4 km run, shuttle run, inclined pull-ups, standing broad jump, and sit-ups, significantly differentiated the two groups ($p < 0.05$). The regression model demonstrated strong predictive power (AUC = 0.94, sensitivity = 0.94, specificity = 0.77, accuracy = 89%). Notably, improved performance in pull-ups and standing broad jumps increased the likelihood of being in the EFR group by 66.8% and 4.3%, respectively. Conversely, slower shuttle and 2.4 km run times markedly reduced the odds by 85.8% and 33%. Discussion: These findings emphasise the operational relevance of targeted fitness parameters and provide a data-driven framework for optimising firefighter recruitment and training. Conclusions: These findings emphasise the operational relevance of targeted fitness parameters and provide a data-driven framework for optimising firefighter recruitment and training.

Keywords

Firefighter fitness readiness; anthropometric profiling; occupational performance; training optimization; logistic regression model.

Resumen

Introducción: La evolución del alcance de las responsabilidades dentro del Departamento de Bomberos y Rescate de Malasia exige un alto nivel de preparación física y antropométrica entre los reclutas. La lucha contra incendios moderna abarca ahora complejas operaciones de rescate terrestre, marítimo y aéreo, además de la extinción de incendios convencional, lo que requiere una preparación rigurosa. Objetivo: Este estudio tuvo como objetivo evaluar la condición física y los perfiles antropométricos de los reclutas de Bomba, identificar las variables clave que distinguen a los bomberos con un rendimiento físico excelente del promedio, y desarrollar un modelo predictivo para clasificar a los futuros bomberos de alto rendimiento. Metodología: Un total de 746 reclutas se sometieron a una evaluación final de parámetros antropométricos y de condición física. Se utilizó la agrupación K-means para categorizar a los reclutas en los grupos de Excelente Preparación Física (EFR) y Promedio Preparación Física (AFR). Posteriormente, se emplearon pruebas U de Mann-Whitney para determinar diferencias significativas en las variables medidas entre los grupos. Posteriormente, se desarrolló un modelo de regresión logística para predecir la probabilidad de que los reclutas alcanzaran el estatus EFR. Resultados: Los resultados indicaron que cinco de nueve variables (carrera de 2,4 km, carrera de ida y vuelta, dominadas inclinadas, salto de longitud desde parado y abdominales) diferenciaron significativamente a los dos grupos ($p < 0,05$). El modelo de regresión demostró un alto poder predictivo (AUC = 0,94; sensibilidad = 0,94; especificidad = 0,77; precisión = 89%). Cabe destacar que un mejor rendimiento en dominadas y salto de longitud desde parado aumentó la probabilidad de pertenecer al grupo EFR en un 66,8 % y un 4,3 %, respectivamente. Por el contrario, tiempos más lentos en la carrera de ida y vuelta y en la de 2,4 km redujeron notablemente las probabilidades en un 85,8 % y un 33 %. Discusión: Estos hallazgos enfatizan la relevancia operativa de los parámetros de aptitud física específicos y proporcionan un marco basado en datos para optimizar el reclutamiento y el entrenamiento de bomberos. Conclusiones: Estos hallazgos enfatizan la relevancia operativa de los parámetros de aptitud física específicos y proporcionan un marco basado en datos para optimizar el reclutamiento y el entrenamiento de bomberos.

Palabras clave

Preparación física del bombero; perfil antropométrico; rendimiento ocupacional; optimización del entrenamiento; modelo de regresión logística.

Introduction

Firefighting is a physically and psychologically demanding occupation that requires personnel to perform under extreme conditions, often involving high temperatures, hazardous environments, and time-critical rescue tasks. These duties necessitate a high level of physical readiness, including cardiovascular endurance, muscular strength, agility, and power (Michaelides et al., 2011; Williams-Bell et al., 2009). Globally, fire departments have increasingly recognized the need to assess and monitor physical fitness to ensure both individual safety and operational effectiveness (Dawes et al., 2017; Sheaff et al., 2010).

In Malaysia, the Fire and Rescue Department (commonly known as Bomba) has expanded its scope of responsibilities to include firefighting, technical rescues, disaster response, and community safety initiatives (Atikah et al., 2015). This broadened operational role demands that new recruits enter service with a foundational level of fitness that supports these multifaceted tasks. However, there is limited empirical evidence evaluating whether current anthropometric and physical fitness benchmarks reliably predict operational readiness within the Malaysian context.

Previous research has indicated that certain fitness parameters such as aerobic capacity, agility, upper body muscular endurance, and lower body explosive power are strongly associated with performance in simulated and real-world firefighting tasks (Gonzalez et al., 2024; Nazari et al., 2018). Yet, there remains a need to delineate which specific attributes most effectively differentiate high-performing recruits from their average-performing counterparts, particularly in developing national contexts where localized standards may vary.

In response, the present study aims to: (i) evaluate the anthropometric and fitness profiles of Malaysian firefighter recruits, (ii) identify variables that significantly distinguish between excellent and average fitness readiness levels using robust statistical techniques, and (iii) develop a logistic regression model to predict the likelihood of recruits achieving excellent fitness classification. By identifying critical predictors of firefighter readiness, this study contributes to the optimization of selection, training, and deployment strategies within the Malaysian fire service and similar occupational settings.

Method

Participants

A total of 746 firefighter trainees participated in this study, comprising 697 males and 49 females. The average age and body mass index (BMI) for male participants were 26.51 ± 3.90 years and 23.09 ± 2.25 kg/m^2, respectively, while female participants had an average age of 24.55 ± 3.52 years and a BMI of 22.88 ± 2.27 kg/m^2. All participants were enrolled at a firefighter training academy located in Terengganu, Malaysia. Notably, these individuals were selected from various states across the country, ensuring a diverse sample. Prior to data collection, both the trainees and their instructors were briefed on the study's objectives, and verbal informed consent was obtained. Ethical approval for the research was granted by the departmental research ethics committee (MC/UMT/PSH/2023/01).

Anthropometric and Fitness Evaluation

This study incorporated a comprehensive set of anthropometric and fitness assessments to evaluate participants' physical characteristics and performance capabilities in accordance with a previously documented procedure (Abdullah et al., 2016). The assessment covered a range of physical and anthropometric measures, including height, weight, BMI, a 2.4 km endurance run, shuttle run, inclined pull-ups, standing broad jump, and sit-ups.

Height was measured in meters using a stadiometer, with participants standing barefoot and upright, heels together, and backs against the device. Body weight was recorded in kilograms using a calibrated digital scale, with participants wearing minimal clothing and no footwear. BMI was then calculated using the standard formula: weight (kg) divided by height squared (m^2) (Maliki et al., 2018).

To evaluate cardiovascular endurance, participants ran 2.4 kilometers (1.5 miles) on a level track, with their completion time recorded in seconds. Aerobic capacity and agility were further assessed using a

shuttle run, where participants repeatedly sprinted between two markers placed 20 meters apart, following progressively faster audio signals (Charles et al., 2017). The test ended when participants could no longer maintain the required speed, and both time and the sum of laps were documented.

Upper body and back strength were measured using the inclined pull-up test, where participants performed as many correct repetitions as possible on an inclined bar. Lower body explosive power was assessed through the standing broad jump, with participants jumping forward from a standing position. The distance from the take-off line to the nearest heel upon landing was measured in centimeters.

Abdominal muscular endurance was assessed using a timed one-minute sit-up test, during which participants performed as many correctly executed repetitions as possible. Additionally, participants' ages were recorded in years, calculated from their date of birth.

Fitness Scoring System

The firefighting department used a 0–5-point scale to evaluate each fitness test based on established performance benchmarks. For instance, achieving 37 or more sit-ups or chin-ups earned the maximum score of 5, with every 5 fewer repetitions resulting in a one-point deduction. A standing broad jump of 240 cm or more also scored 5, with a 10 cm decrease lowering the score incrementally. Similarly, completing the shuttle run in 10 seconds or the 2.4 km run in 11 minutes awarded 5 points, with a 0.5-second delay causing a lower score. The cumulative score from all five tests was utilised for clustering analysis.

Data Pre-processing and Analysis

The collected anthropometric and fitness data were first compiled and subjected to pre-processing procedures to ensure consistency and accuracy. To address the issue of varying units across different parameters, min-max normalization was applied (Ab Rasid et al., 2024). This scaling technique transforms all variables to a common range, typically between 0 and 1, ensuring that each feature contributes equally to the analysis. By doing so, it prevents variables with larger numerical scales from disproportionately influencing the model outcomes.

K-means Clustering Analysis

K-means clustering is an unsupervised machine learning method used to divide data into k distinct, non-overlapping clusters. Each data point is assigned to the cluster whose mean is closest, ensuring exclusive membership (Taha et al., 2009). The goal is to maximize similarity within clusters (intra-cluster) while minimizing similarity between clusters (inter-cluster), thereby enhancing the clarity of group distinctions (Razali et al., 2017).

In this study, k-means clustering was applied to categorize the recruits based on their performance in physical fitness tests and anthropometric measurements. To determine the proximity between data points, Euclidean distance was used as the distance metric, facilitating the formation of optimal and meaningful clusters.

Development of Multivariate Logistic Regression Model

A multivariable binary logistic regression was conducted using the variables identified as important through the feature importance analysis. This statistical method was employed to determine which anthropometric and fitness profiles could significantly predict the likelihood of a firefighter recruit being classified as excellent or average. By modeling the probability of recruits' profiles as a binary outcome (excellent vs. average), the logistic regression provides insights into the relative contribution of each variable while controlling for the influence of others.

The data were analyzed using the Forward Stepwise Selection method based on the Likelihood Ratio approach. Results are presented as odds ratios (OR) along with 95% confidence intervals (CI) to indicate the strength and precision of associations. To assess the explanatory power of the logistic regression model, Nagelkerke's R^2 was calculated and interpreted using the following thresholds: small (0.02–0.13), medium (0.13–0.26), and large (>0.26) effect sizes (Nazarudin et al., 2024).

Model fit was evaluated using the Hosmer-Lemeshow goodness-of-fit test. Additionally, the model's discriminative ability was assessed through the area under the curve (AUC) of the Receiver Operating Characteristic (ROC) curve, which was generated based on the predicted probabilities of each variable. All statistical analyses were performed using Jamovi ver 2.4 for Windows. A p-value of less than 0.05 was considered statistically significant.

Results

Table 1 presents the differences in anthropometric and fitness performance profiles between the two firefighter groups. It includes group labels, sample sizes, medians, standard deviations, Mann-Whitney U statistics, and corresponding p-values. It could be observed that the excellent fitness group showed significantly better performance than the average fitness group in the 2.4 km run, shuttle run, inclined pull-up, standing broad jump, sit-ups, and had a lower BMI ($p < 0.05$). No significant differences were found in height, weight, or age between the groups.

Table 1. Group Comparison of Anthropometric and Fitness Profiles of the Recruits

Anthropometric and Fitness Profile	Anthropometric and Fitness Profile Group		
	Excellent Fitness Group (n = 520)	Average Fitness Group (n = 226)	P-Mann-Whitney
2.4 km Run (m/s)	10.08±1.08	10.54±1.23	0.001*
Shuttle Run (s)	10.00±0.59	10.69±0.74	0.001*
Inclined Pull-Up (reps)	10.00±6.20	6.00±3.59	0.001*
Standing Broad Jump (cm)	220±21.70	200±20.08	0.001*
Sit-Up (reps)	53±6.73	50±5.86	0.001*
Body Mass Index (BMI)	22.7±2.16	23.62±2.41	0.001*
Height (m)	1.7±0.06	1.7±0.06	0.246
Weight (kg)	64.0±6.48	63.1±7.63	0.451
Age (yrs.)	26±4.01	26±3.64	0.233

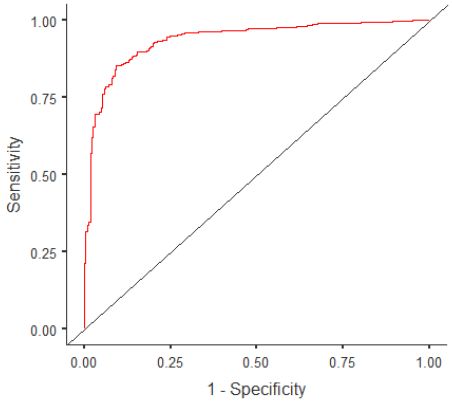
Values are presented as median±standard deviation
*Significant difference across the two groups ($p < 0.05$).

Table 2 presents the overall fit statistics for the logistic regression model predicting firefighter fitness readiness. The model demonstrated a strong fit with a Nagelkerke R^2 of 0.652, indicating that the included predictors explained 65.2% of the variance in fitness group classification. The likelihood ratio test was statistically significant ($\chi^2 = 461$, df = 6, $p = 0.001$), confirming that the model significantly improves prediction over a null model. The non-significant Hosmer-Lemeshow test ($p = 0.891$) suggests good calibration between predicted and observed outcomes. Additionally, Figure 1 illustrates the Receiver Operating Characteristic (ROC) curve of the developed logistic regression model. The model achieved an accuracy of 89%, specificity of 0.77, sensitivity of 0.94, and an area under the curve (AUC) of 0.94, further accentuating its strong global classification performance. These results confirm the model's robustness, high discriminative power, and predictive validity in identifying firefighters with excellent fitness readiness. It is worth noting that all explanatory variables included in the logistic regression model were selected after confirming the absence of multicollinearity. Variance Inflation Factor (VIF) values for all predictors were below the conventional threshold of 5, indicating no significant multicollinearity and supporting the reliability of the regression coefficients.

Table 2. Logistic Regression Model Performance Parameters

				Overall Model Test			
Deviance	AIC	BIC	Hosmer Lemeshow (p)	R^2N	χ^2	df	p
454	468	500	0.891	0.652	461	6	0.001

Figure 1. ROC Curve of the model developed (Accuracy 0.887; specificity = 0.774; sensitivity = 0.937; AUC = 0.936).



The findings of the multivariate regression model are presented in Table 3. The logistic regression model identified four significant predictors of excellent fitness classification among firefighter recruits, namely: 2.4 km run, shuttle run, inclined pull-up, and standing broad jump ($p < 0.05$). The model accounts for 65.2 % of the recruits' likelihood of being categorised as excellent, of average fitness level (Negelkerke R2=62.2) based on the parameters. In essence, for every 1-second delay in a 2.4 km run, the odds of being in the excellent fitness category decreased by 33.4% (OR = 0.666, 95% CI: 0.5171–0.859), suggesting faster performance is strongly associated with excellence. Similarly, each additional second taken in the shuttle run reduced the likelihood of excellent fitness classification by 85.8% (OR = 0.142, 95% CI: 0.0838–0.241). Conversely, better performance in inclined pull-ups and standing broad jump significantly increased the odds of excellent fitness classification by 66.8% (OR = 1.668, 95% CI: 1.5243–1.826) and 4.3% (OR = 1.043, 95% CI: 1.0271–1.060), respectively. Sit-up count and BMI were not statistically significant predictors in the model ($p > 0.05$). These observed odds ratios highlight the practical impact of each variable on fitness classification emphasizing the importance of agility training as well as the value of upper body strength. These findings could guide targeted training interventions to improve recruit readiness and support evidence-based selection criteria.

Table 3. Multivariate Regression analysis for extracting significant parameters in differentiating excellent and average firefighter recruit category

						95% CI	
Predictor	Estimate	SE	Z	p	OR	Lower	Upper
Intercept	12.0685	4.13307	2.92	0.004	1743.133	52.872	5.7508
2.4 km Run (m/s)	-0.4058	0.12941	-3.14	0.002*	0.666	0.5171	0.859
Shuttle Run (s)	-1.9509	0.26962	-7.24	0 .001*	0.142	0.0838	0.241
Chin-Up / Inclined Pull-Up	0.5119	0.04609	11.11	0 .001*	1.668	1.5243	1.826
SBJ (cm)	0.0423	0.00792	5.34	0 .001*	1.043	1.0271	1.006
Sit-Up (rep)	-0.0254	0.02148	-1.18	0.236	0.975	0.9347	1.017
BMI	0.0631	0.05447	1.16	0.247	1.065	0.9573	1.185

Note: *p<0.05; SE=Standard Error; OR = Odd Ratio

Discussion

The primary aim of the present study was to evaluate the anthropometric and fitness variables associated with the classification of firefighter recruits into excellent and average performance categories, and to develop a logistic regression model capable of predicting fitness readiness. The model achieved a high level of classification accuracy, with robust statistical performance demonstrated by a Nagelkerke R^2 of 0.652, a non-significant Hosmer-Lemeshow test ($p = 0.891$), and an AUC of 0.94. Key predictor variables identified included inclined pull-ups, standing broad jump, shuttle run, and 2.4 km run, all of which significantly contributed to the classification of recruits. The Mann-Whitney U test confirmed these results, showing that the Excellent Fitness Group (EFR) significantly outperformed the Average Fitness Group

(AFR) across all key fitness measures, except for height, weight, and age, where no significant differences were found.

The findings of this study highlighted the role of specific anthropometric and fitness attributes in classifying the preparedness of firefighter recruits. Consistent with previous literature, cardiovascular endurance (2.4 km run), anaerobic agility (shuttle run), upper body muscular endurance (inclined pull-ups), and lower-body explosive power (standing broad jump) emerged as significant predictors of excellent fitness performance (Dawes et al., 2017; Michaelides et al., 2011). These variables align closely with the physical demands of firefighting tasks, which often require rapid movement, muscular strength, and sustained effort under physically taxing conditions (Williams-Bell et al., 2009). The identification of these key fitness parameters highlights the importance of incorporating exercises such as squats, deadlifts, and aerobic conditioning into firefighter training programs. Focusing on these targeted components ensures that training aligns with job-specific demands, ultimately improving performance and operational readiness (Mohamed et al., 2024).

The logistic regression model demonstrated strong predictive performance, with excellent discriminative ability (AUC = 0.94) and substantial explanatory power (Nagelkerke R^2 = 0.652), confirming its effectiveness in assessing recruit readiness. Among the predictors, the shuttle run emerged as the most influential (OR = 0.142), underscoring the critical role of agility and quick directional change skills, particularly relevant in scenarios such as confined-space navigation and emergency extractions. Moreover, agility and aerobic capacity are shown to be essential for navigating hazardous environments, as reported by previous researchers (Dennison et al., 2012). This finding supports the operational value of incorporating agility assessments into firefighter selection and training protocols (Gledhill & Jamnik, 1992).

Conversely, the findings demonstrated that conventional anthropometric measures such as height, weight, and BMI were not significant predictors of fitness excellence, echoing prior research that emphasizes functional performance over body size in tactical populations (Sheaff et al., 2010). The non-significant influence of sit-ups may also indicate a limited role of isolated core endurance in discriminating high performers, warranting further exploration of more integrated core function assessments. While height and weight contribute to BMI calculations, their direct impact on specific fitness attributes appears limited. Similarly, although age can influence physical performance, previous research suggests that consistent training can effectively counteract age-related declines (Henderson et al., 2007). This indicates that high performance is not inherently dependent on age or body size. Supporting this, previous investigators found that targeted fitness programs significantly enhance job performance among firefighters, regardless of age or body type (Stevenson et al., 2017).

Comparatively, studies in temperate countries often highlight aerobic endurance and muscular strength as essential, but may underemphasize agility and heat-adaptive performance due to less extreme environmental stressors (Gledhill & Jamnik, 1992; Michaelides et al., 2011). In contrast, Malaysian firefighters operate in high-heat, high-humidity conditions that elevate the importance of cardiovascular efficiency and thermoregulation capacity (Ras et al., 2023). These findings, therefore, have potential applicability to other countries with similar climates and topographies, such as those in Southeast Asia (e.g., Indonesia, Thailand), Central Africa, or parts of South America, where firefighting involves navigating urban density, tropical heat, and diverse terrain. By contextualizing fitness standards within regional environmental demands, this study provides a framework for localized recruitment and training protocols globally.

Conclusions

This study employed robust statistical modeling, including logistic regression analysis, to identify key anthropometric and fitness predictors that distinguish high-performing firefighter recruits. The results demonstrated that performance in the shuttle run, inclined pull-ups, 2.4 km run, and standing broad jump were significant discriminators between excellent and average fitness groups. The Mann-Whitney U test further confirmed that the Excellent Fitness Readiness (EFR) group significantly outperformed the Average Fitness Readiness (AFR) group across these parameters, while no meaningful differences were observed in height, weight, or age. These findings emphasize the operational relevance of agility,

muscular endurance, cardiovascular capacity, and explosive strength in firefighting performance, rather than static anthropometric traits. While such fitness metrics are vital for assessing readiness and suitability for entry into fire service roles, they alone may not fully capture professional performance potential, which also depends on psychological resilience, technical proficiency, and situational adaptability.

Practical Application and Future Direction

The findings of this study provide fire service agencies with a data-driven framework to enhance recruitment and training strategies by identifying key fitness and anthropometric markers predictive of high performance. By integrating these predictors into screening protocols, departments can more effectively select candidates with optimal physical readiness, thereby improving operational efficiency, reducing injury risk, and ensuring safer, more capable firefighting personnel. Future research should explore longitudinal tracking of recruits to assess how baseline fitness and anthropometric profiles predict long-term job performance and retention. Additionally, integrating psychological resilience and task-specific simulation assessments may provide a more comprehensive model for firefighter readiness.

Limitations of the study

While this study provides valuable insights into the fitness and anthropometric predictors of firefighter readiness, certain limitations should be acknowledged. First, the sample was drawn exclusively from a single national training cohort, which may limit the generalizability of findings across different regions or training institutions within Malaysia. Second, the analysis did not stratify results by gender due to the low representation of female recruits, potentially overlooking sex-specific performance differences. Third, although the model demonstrated strong predictive power, it was based solely on cross-sectional data; longitudinal tracking would be essential to evaluate how initial fitness profiles relate to long-term operational performance and retention. Lastly, psychological, cognitive, and task-specific competencies were not considered, which may also influence readiness but fall outside the scope of physical and anthropometric assessment.

Conflict interest

The authors have no conflict of interest to declare.

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