ORIGINAL ARTICLE

Knees on fire: Investigating the impact of knee discomfort on cardiovascular fitness among Malaysian firefighters

Rosnah Ismail, DrPH[1], Nor Hisham Mohammad, MBA[2], Ismail Abdul Ghani, BMgt (Hons)[2], Ashrul Riezal Asbar, BMEng[2], Loganayagi Subrumanion, MBBS[1], Ahmad Uzsair Umair Mohd Johar, MCommHSc. (Occupational Health)[1,3], Hanizah Mohd Yusoff, PhD[1]

[1]Department of Public Health Medicine, Faculty of Medicine, Universiti Kebangsaan Malaysia, Kuala Lumpur Campus, Cheras, Kuala Lumpur, [2]Fire and Rescue Department of Malaysia, Putrajaya, Malaysia, [3]International Islamic University Malaysia, Gombak Campus, Kulliyah of Education Building, Kuala Lumpur

ABSTRACT

Introduction: Firefighters require optimal cardiovascular fitness (CVF) to effectively perform fire suppression activities and other essential tasks. However, knee discomfort can reduce their engagement in leisure-time physical activity (LTPA), subsequently affecting their CVF during individual field-based testing. This study aimed to determine the impact of knee discomfort on CVF and to assess the necessity of adjusting field-based CVF test scores for firefighters experiencing such physical limitations.

Materials and methods: This study used secondary data from 5,680 firefighters, collected between September and October 2023. A final 3,885 datasets that met the eligibility criteria were included for analysis. Knee discomfort was assessed using the Cornell Musculoskeletal Discomfort Questionnaire, with scores derived from the Rasch Measurement Model based on three items: frequency, severity, and work interference due to knee discomfort.

CVF was estimated using self-reported field-based CVF tests, including the time taken to run 2.4 km, the beep test (level and shuttle), and the 6-minute walking test. VO_2 max estimation was calculated as a proxy for CVF. Multiple linear regression was used to analyse the impact of knee discomfort on CVF, controlling for age, male gender, sleep duration, intensity of weekly LTPA, and perceived work demands. Cohen's effect size ($f2$) was observed, with values of 0.02, 0.15, and 0.35 indicating small, medium, and large effect sizes, respectively.

Results: The prevalence of knee discomfort among operational firefighters was 51.3%. Of these, 43.9% described the discomfort as mild, while 77.9% reported that it did not interfere or only slightly interfered with their work. LTPA ($\beta = 0.70$; 95%CI: 0.55, 0.85; $p < 0.001$) and knee discomfort scores ($\beta = -0.04$; 95%CI: -0.05, -0.03; $p < 0.001$) were associated with CVF among the participants, after controlling for age and gender. However, the impact of knee discomfort on CVF was negligible ($f2 = 0.012$).

Conclusion: Knee discomfort showed a statistically precise yet negligible effect on CVF, indicating that adjustment of field-based CVF test scores is unnecessary. However, for firefighters experiencing severe knee discomfort, a more lenient test, such as the 6-minute walking test, should be considered rather than exempting them from assessment.

KEYWORDS:
Firefighters, knee discomfort, cardiovascular fitness, physical activity, prevalence

INTRODUCTION

Firefighters face numerous health risks due to the physically demanding nature of their work, high metabolic demand, and substantial physical exertion required for their essential tasks. Maintaining optimal cardiovascular fitness (CVF) is crucial, with a recommended VO_2 max of 42 ml/kg/min (12 metabolic equivalents [METs]). Firefighters with a VO_2 max at or below 28 ml/kg/min (8 METs) are restricted from performing many critical tasks.[1] Compliance with this optimal standard is vital, as the use of self-contained breathing apparatus (SCBA) during firefighting operations places significant physiological demands on the body. SCBA use has been shown to reduce peak power generation and oxyhaemoglobin saturation, lowering VO_2 max by 14.9% and maximal exercise performance by 4.8% due to the additional weight of the SCBA pack.[2]

Firefighters' occupational demands require repetitive pulling, pushing, lifting, carrying, and dragging while wearing 20 kg of protective gear and SCBA.[3] These demands can trigger a cascade of musculoskeletal injuries, with the knee joint being the most commonly affected.[4] Other joints, including the head, neck, shoulders, elbows, arms, hands, back, thighs, and feet, are also impacted,[5] further compromising the holistic function of weight-bearing knee joints. A systematic review of tactical athletes found that firefighters face an increased risk of developing osteoarthritis in their knees and hips, with symptoms worsening during the third and fourth decades of life.[6]

Knee disorders present a dual challenge. On the one hand, firefighters may lose interest in unsupervised leisure-time physical activities (LTPAs) due to discomfort. On the other hand, engaging in such activities without proper supervision increases the risk of injury to the ankles, knees, and legs,[7]

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Corresponding Author: Loganayagi Subrumanion
Email: loganayagi0302@gmail.com

often resulting from poor exercise technique, insufficient training experience, lack of warm-up, or fatigue.[8] A decline in physical activity can lead to measurable reductions in CVF and conditioning in less than a week.

The fear of being deemed unfit for operational deployment due to knee injuries often leads firefighters to adopt a "safe play" practice rather than engaging in active training.[9] Many firefighters refrain from unsupervised exercise, unaware of the principle that "mobility is medicine." Their primary concern is avoiding medical interventions that could compromise functioning and lead to lost workdays. However, despite these apprehensions, firefighters remain motivated to undertake field-based CVF tests to maintain their operational status within their teams. In light of these challenges, the present study aimed to determine the impact of knee discomfort on CVF and to assess the necessity of adjusting field-based CVF test scores for firefighters experiencing such physical limitations (Figure 1).

MATERIALS AND METHODS

Study design and sampling

This study utilised national secondary data from 5,680 firefighters collected cross-sectionally via an online platform between September 8 and October 27, 2023. A final 3,885 datasets that met the eligibility criteria were included in the analysis. To meet the inclusion criteria, firefighters i) had to be active and permanently appointed firefighters, ii) be currently placed in a Fire and Rescue Operation Unit, iii) have a job title grade KB 19/KUP 22 or KB 22/24/26, iv) have at least 2 years of work experience, v) provide consent to participate in the study, and vi) provide their results from a field-based CVF test involving a 2.4 km run, beep test (level and shuttle) or 6-minute walking test. Firefighters were excluded if they i) were voluntary or auxiliary firefighters, ii) were on medical leave for more than 3 months, iii) had returned from another country within the last 7 days, iv) were on study leave or training for the past 3 months, v) regularly took analgesics prescribed by an orthopaedic specialist or rehabilitative doctor, vi) were receiving regular medical follow-up for a musculoskeletal disorder, vii) were pregnant, and viii) had experienced an accident or injury outside of working hours within the past 3 months.

The final sample comprised 3,885 responses, exceeding the minimum requirement calculated using G*Power and the F-test family for multiple linear regressions.10 A fixed model assuming R^2 deviation from zero was used, with an α error probability of 0.05, statistical power of 0.80, a small effect size ($f^2 = 0.02$), and seven predictors.11 Based on these parameters, the minimum required sample size was 725. Accounting for a 20% anticipated non-response rate, the target sample size was 906. Post-hoc analysis indicated that the study achieved a statistical power of 99.99% based on an observed effect size of $f^2 = 0.012$ and an α error probability of 0.05. Purposive sampling was employed, whereby respondents were selected from the primary dataset according to predefined inclusion and exclusion criteria to ensure eligibility.

Data collection

Before data collection, participants were provided with a link to an information sheet detailing the study's purpose and scope. They were informed that participation was voluntary and that confidentiality would be maintained through the use of anonymous identification numbers. Informed consent was obtained from all participants. Ethical approval for the study was granted by the Research Ethics Committee of Universiti Kebangsaan Malaysia (Code: JEP-2023-164).

Data were collected using an online self-administered questionnaire comprising seven sections: demographic information, work demands, task characteristics, LTPA, CVF, sleep duration, and the Cornell Musculoskeletal Discomfort Questionnaire focused on the knee region. All sections underwent cognitive debriefing to ensure clarity and alignment with the colloquial language used by the firefighters. The demographic section included items focused on variables such as age, gender, marital status, and years of service in the Fire and Rescue Department of Malaysia

Measures

Work Demand

An adapted version of Van Veldhoven and Meijman's eight-item questionnaire[12] was used to assess the psychological work demands of firefighters, based on previous research.[13] Responses were rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The original questionnaire reported a Cronbach's α coefficient of 0.80,[14] while the Cronbach's α value for the current study was 0.85, indicating good internal consistency. The items were modified from questions into statements, such as "I have to work fast," "I have to work under time pressure," and "I work in comfort".

Task characteristics

The task characteristics questionnaire was adapted from a previous study,[13] with the number of items was expanded to 14 to avoid double-barrelled questions and to incorporate feedback obtained through cognitive debriefing. Items were rated on a five-point Likert scale, ranging from 1 (low severity) to 5 (critical). The original questionnaire reported Cronbach's α coefficients ranging from 0.72 to 0.92.[15] In the present study, after removing one item related to workload imbalance to enhance statistical validity, Cronbach's α was 0.90, indicating excellent internal consistency. Typical items included "degree of uncertainty," "exposure to human loss," and "traumatic incidents".

LTPA

LTPA evaluation was based on self-reports for 12 types of activities commonly performed by firefighters during the week. These included jogging for more than 15 minutes, cycling for more than 15 minutes, using gym equipment, and engaging in sports like badminton, table tennis, tennis, volleyball, and football. LTPA was quantified using the metabolic equivalent of task (MET) based on the 2024 Compendium of Physical Activities.[16] For example, leisure cycling at 15 km/h corresponds to 5.8 METs, while jogging at a pace of 7.5 min/km corresponds to 8.5 METs. The MET value for gym-based physical activities was multiplied by the reported intensity category: Category 1: < 8 repetitions x 3

sets; Category 2: 8 repetitions x 3 sets; Category 3: 9–20 repetitions x 3 sets, and Category 4: > 20 repetitions x 3 sets. Similarly, the MET value of each sports activity was multiplied by the reported duration category: Category 1: < 75 minutes/week; Category 2: 75–150 minutes/week; and Category 3: > 150 minutes/week. The total METs were summed and averaged by the number of activities per week.[17]

CVF
CVF, proxied by VO_2 max, was estimated using self-reported field-based CVF tests, such as the time taken to run 2.4 km, the beep test (level and shuttle), and the 6-minute walking test.

For the 2.4 km run test, the VO_2 max was calculated using the following equation from previous research,18 which is available online:[19]

VO_2 max, in mL/kg/min = (483 / time) + 3.5.

In this, "time" is the time taken to finish the 2.4 km run in minutes.

For respondents who completed the beep test, an online calculator was used to estimate VO_2 max values based on their age, gender, test level, and the number of shuttles completed.[20] For those who completed the 6-minute walking test, the distance walked (in metres) was used to calculate walking speed (in metres per minute).[21] This value was then used in the following equation to estimate VO_2 max:

VO_2 max = 3.5 ml/kg/min + (speed in m/min × 0.1)

When more than one self-reported field-based CVF test was available, the 2.4 km run time was prioritised due to its higher reliability, as firefighters are more accustomed to this test compared to the recently introduced beep test or six-minute walk test, which may be harder to recall accurately and have limited familiarity.

Age and gender were controlled for in the analysis due to their established influence on CVF.

Sleep duration
Sleep duration was assessed using a single-item measure with three response categories: less than 5 hours, more than 5 but less than 7 hours, and more than 7 hours. For analytical purposes, the responses were subsequently recategorized dichotomously as less than 5 hours and 5 hours or more to enhance statistical power.

Knee discomfort
Knee discomfort was assessed using the Malay-translated version of the Cornell Musculoskeletal Discomfort Questionnaire.[22] Total scores were derived using the Rasch Measurement Model based on three polychotomous response items: frequency of discomfort, intensity of discomfort, and the extent to which discomfort interfered with work. The Cronbach alpha was 0.93. The Rasch Measurement Model was used to convert ordinal scores into interval-level data, following verification of unidimensionality assumptions, thereby enhancing both the validity and interpretability of the results.

Statistical analysis
Ordinal scores were transformed into interval-level data using the Rasch Measurement Model, replicating the procedure described in previous research.[23] The conversion was applied as follows:

USCALE = (wanted range) / (current range)
UMEAN = (wanted low) – (current low x USCALE)

Descriptive statistics were calculated using IBM SPSS version 29. Firefighters' characteristics, including demographic and other variables, were presented as frequencies and percentages, as well as means with standard deviations (SDs). Multiple linear regression was used to analyse the impact of knee discomfort and intensity of LTPA per week on CVF, controlling for age, male gender, sleep duration, perceived work demands, and task characteristics. Cohen's effect size (f^2) for multiple linear regression was observed, with values of 0.02, 0.15, and 0.35 indicating small, medium, and large effect sizes, respectively. The effect size, f^2 was calculated using the following formula:[24]

$f^2 = R^2\text{included} - R^2\text{excluded} / 1 - R^2\text{included}$

Where:

R^2included = R^2 when the total knee score is included in the model.
R^2excluded = R^2 when the total knee score is excluded in the model.

RESULTS

Most of the participants were male (96.7%), aged between 30 – 34 years old (20.3%) had job grade KB19/KUP22 (85.9%), and slept for more than 5 hours each night (74.7%). Over one week, 3,734 firefighters (96.1%) engaged in exercise or sport during their leisure time, with 77.8% reporting moderate levels of LTPA intensity.

Approximately 51.3% of participants reported experiencing knee discomfort, with the highest prevalence (20%) observed among those aged between 40 – 45. Among those with knee discomfort, 43.9% described the discomfort as mild and 77.9% indicated that it did not interfere or only slightly interfered with their work. Those with knee discomfort had statistically significantly lower LTPA values (M = 5.18, SD = 1.38 METs) compared to those without knee discomfort (M = 5.32, SD = 1.27 METs; t(3883) = 3.26, p < 0.001, Cohen's d = 0.11), indicating a negligible effect size.

Overall, 26% of participants had a VO2 max estimation of 42ml/kg/min or more, meeting the National Fire Protection Association requirement (Table I). Those with a VO2 of 42ml/kg/min or more had statistically significantly higher LTPA values (M = 5.56, SD = 0.99 METs) compared to those with a VO2 max less than 42ml/kg/min (M= 5.14, SD = 1.41 METs; t(3883) = 8.72, p < 0.001, Cohen's d = 0.32), indicating a small effect size. Table II shows the multiple linear regression of knee discomfort on CVF, adjusted for LTPA, age,

Table I: Descriptive Analysis

Profile	n	%	Mean (SD)	95% CI for Mean
Age			39.00 (8.85)	38.72, 39.28
20-24 years	85	2.2		
25-29 years	565	14.5		
30-34 years	790	20.3		
35-39 years	577	14.8		
40-44 years	730	18.8		
45-49 years	544	14.0		
50-54 years	465	12.0		
55 years and above	129	3.4		
Gender				
Male	3755	96.7		
Female	130	3.3		
Position grade				
KB19 /KUP 22	3336	85.9		
KB22/24/26	549	14.1		
Sleep duration				
5 hours and less	983	25.3		
More than 5 hours	2902	74.7		
Work demand			26.84 (4.18)	26.71, 26.97
Task characteristics			35.60 (5.87)	35.42, 35.79
Total leisure-time physical activity, MET/week			48.60 (19.08)	48.00, 49.20
Leisure time physical activity intensity:				
Sedentary (0 - 2.9)	160	4.1		
Moderate (3 - 5.9)	3023	77.8		
High (6 and above)	702	18.1		
Knee discomfort				
Yes	1994	51.3		
No	1891	48.7		
Frequency of knee discomfort, n=1994				
Never	52	2.6		
1-2 times/week	713	35.8		
3-4 times/week	489	24.5		
Once everyday	395	19.8		
Several times every day	345	17.3		
Level of knee discomfort, n=1994				
None	47	2.4		
Slight	872	43.7		
Moderate	646	32.4		
High	429	21.5		
Knee discomfort with work interference, n=1994				
Not at all	675	33.9		
Slightly	949	47.6		
Substantial	370	18.5		
Knee discomfort score, n=1994	33.45 (10.09)	33.00, 33.89		
Cardiovascular fitness, n=3885	37.26 (7.63)	37.02, 37.50		
Less than 42, ml/kg/min	2875	74.0		
42 and above, ml/kg/min	1010	26.0		

Note: MET =metabolic equivalent of task

and gender. Despite the large sample size (n = 3,885) and narrow confidence intervals, the effect was negligible (f^2 = 0.012), indicating no need to adjust field-based CVF test scores for knee discomfort.

DISCUSSION

This study aimed to evaluate the impact of knee discomfort on CVF among firefighters and to assess whether score adjustments are warranted for those experiencing such physical challenges. Two factors, knee discomfort and LTPA, were found to be associated with CVF among the participants after controlling for age and gender.

Knee discomfort was found to be prevalent among the participating firefighters, consistent with observations from Western populations.[5] While age is a known contributor, occupational exposures also play an important role. Prolonged dynamic and static loading during firefighting duties likely increases patellofemoral biomechanical stress. Retrospective analyses have further identified distinctive trochlear lesions in firefighters undergoing arthroscopy for seemingly unrelated meniscal or ligamentous injuries.[25] This finding challenges the traditional view that anterior cruciate ligament, medial collateral ligament, and meniscal tears are the predominant pathologies resulting from athletic loads.[26] Instead, it suggests that firefighting tasks may give rise to a broader spectrum of knee pathologies. For example, SCBA

Table II: Factors influencing cardiovascular fitness among firefighters (n=3885)

Variables	Simple Linear Regression				Multiple Linear Regression				
	95% CI for β				95% CI β				
	β	Lower Limit	Upper Limit	p-value	β	Lower Limit	Upper Limit	t-test	p-value
Age	-0.44	-0.46	-0.42	<0.001	-0.43	-0.45	-0.41	36.81	<0.001
Male gender	4.46	3.14	5.79	<0.001	5.82	4.70	6.94	10.20	<0.001
Leisure-time physical activity	1.01	0.83	1.19	<0.001	0.70	0.55	0.85	9.06	<0.001
Knee discomfort	-0.07	-0.08	-0.06	<0.001	-0.04	-0.05	-0.03	6.53	<0.001
Sleep <5 hours	-0.32	-0.87	0.23	0.253					
Work demand	0.06	0.01	0.12	0.029					
Work characteristics	-0.02	-0.06	0.03	0.477					

Note: CI = Confidence Interval, Forward method (R2 = 0.306); the model reasonably fits well; model assumptions are met; no multicollinearity problem, the effect of knee discomfort on cardiovascular capacity is negligible i.e. $f2$= 0.012

carriage during firefighting activities alters firefighters' body kinematics, such as reducing step length, increasing hip and knee flexion ranges of motion, and increasing the centre of mass deviation, which results in the highest load of internal force being placed on the knee.[4,27]

Although ageing is a well-established factor contributing to CVF decline,[28] the present study shows that the additional effect of knee discomfort on CVF is minimal. Several explanations may account for this negligible effect. Firefighters' passion for their profession, their strong sense of camaraderie with shift partners, and their altruistic commitment to supporting fellow emergency responders [29] may result in them overlooking or tolerating physical challenges, including knee discomfort. Furthermore, psychological resilience, developed through repeated exposure to risk and sacrifice, may diminish the perceived significance of knee pain.[30] Importantly, firefighters are also highly aware that maintaining fitness is essential for both personal safety and operational effectiveness, an expectation reinforced by organizational standards and public trust. Consequently, many of them engage in regular exercise and sports during leisure time, which may buffer any potential negative effects of knee discomfort on CVF. Taken together, these occupational, psychological, and behavioural factors help explain why knee discomfort, while common, exerts little measurable influence on cardiovascular fitness in this population.

The benefits of regular physical activity in mitigating age-related physiological decline have been well-established in the last three decades. Exercise can attenuate age-related decline in VO_2 max, lower mean blood pressure and systemic vascular resistance, preserve lean body mass while reducing fat deposits, increase high-density lipoprotein levels, decrease triglyceride levels, enhance bone mineral content, improve basal metabolic rate, boost muscle strength, and support cognitive functioning.[31] Recent findings suggest that ageing is also associated with significant telomere shortening, leading to gradual cellular deterioration. However, regular physical activity appears to preserve telomere length. Adults who engage in high levels of physical activity have been estimated to have a "reversed biological clock," appearing biologically 9 and 7.1 years younger than those with sedentary and moderately active lifestyles, respectively.[32]

The current study demonstrated that firefighters continue to engage in moderate physical activities during their leisure time, despite experiencing knee discomfort. Individuals who participate in at least a moderate level of physical activity (600–3000 MET-min/week) may attain VO_2 max values of 44.0 ml/kg/min or higher.[33] Such improvements are largely attributed to lower arterial stiffness, which results in enhanced cardiovascular health. Regular physical activity promotes cardiovascular adaptations by improving oxygen delivery, inducing vasodilation and angiogenesis within the vasculature, and stimulating mitochondrial biogenesis in peripheral tissues, such as adipocytes, skeletal muscle myotubes, and cardiomyocytes.[34] Additionally, it exerts anti-inflammatory effects,[35] further enhancing overall cardiovascular function and efficiency.

Improving cardiovascular function enhances the heart's ability to pump blood to the lungs and throughout the body. As a result, blood flow to the skeletal muscles can increase by 20- to 50-fold during peak muscle perfusion,[36] leading to a 17- to 24-fold increase in VO_2 max compared to resting values.[37] The demands of physical activity, which drive muscular adaptations, induce changes in both muscle fibre composition and function. Regular physical activity improves the ability of muscles to extract oxygen from the blood, thereby reducing the burden on the heart to supply additional blood to meet muscular demands. Additionally, capillaries, which are the smallest blood vessels, undergo dilation, enhancing their capacity to deliver oxygen to the tissues and effectively remove waste products.[38]

Engaging in an adequate amount of physical activity is a powerful, non-pharmacological strategy for improving CVF. It functions similarly to a beta-blocker by lowering resting heart rate and reducing blood pressure.[39] Physical activity has been recognised as an effective stress reliever, reducing levels of stress hormones such as cortisol and adrenaline while promoting the release of "happy chemicals" like endorphins.[40] This response reduces the cardiovascular strain caused by stress hormones. Furthermore, regular physical activity can reduce atherogenic markers by improving endothelial function, decreasing inflammation, and favourably modifying lipid profiles, including increasing levels of high-density lipoprotein and optimising triglyceride concentrations.

Strengths and Limitations

This study represents the first national investigation in Malaysia to determine the association between knee discomfort and CVF among firefighters. Despite the inherent limitations of cross-sectional designs, this approach was deemed the most suitable for assessing the study variables. All research instruments demonstrated robust validity and were appropriately matched to their respective domains. Data collection via an online survey using Google Forms enabled rapid, large-scale participation, which was supported by the regimented organisational structure of the firefighting workforce. Although self-reported data may be subject to recall or social desirability bias, the consistency of VO_2 max estimates with previous internal published firefighter data supports the plausibility of our findings. This method was selected for its feasibility in a large operational workforce and was applied consistently across participants.

The use of purposive sampling, while appropriate for targeting the study population, inherently limits external validity and restricts the generalisability of the findings beyond the specific occupational group examined. However, this approach was necessary to capture the unique characteristics of firefighters, thereby ensuring the relevance and applicability of the results to this high-risk occupational setting. Sampling error was minimised by the use of a substantial sample size and adequate responder variability, strengthening the study's external validity. However, the cross-sectional nature of the study limits the ability to infer causality. Future research employing two-wave or multi-wave longitudinal panel designs is recommended to clarify temporal relationships and more definitively establish the mediating role of LTPA.

A key limitation is the exclusion of work-related physical activity, which is critical for accurately assessing occupational fitness demands. However, this was partially mitigated by focusing on leisure-time physical activity, a domain more amenable to standardised measurement. The sample was relatively homogeneous, focusing exclusively on operational firefighters rather than the entire firefighter hierarchy, yet this enhances the internal validity by reducing variability in occupational exposure. Lastly, the use of self-administered questionnaires and retrospective recall of LTPA may have introduced recall bias, although the use of validated instruments and clear instructions was intended to minimise this risk.

CONCLUSION

LTPA and knee discomfort scores were found to be associated with CVF among the participant firefighters, after controlling for age and gender. Even with a large sample size ensuring precise results, knee discomfort showed only a very small impact on cardiovascular fitness, indicating that field-based CVF test scores do not need adjustment for this factor. However, for firefighters reporting severe knee discomfort, the implementation of more accessible assessments, such as the 6-minute walking test, is recommended.

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