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The Impact of Body Composition and Physical Fitness on Parasympathetic Reactivation in Firefighters

Nuray DEMİRALP [1A] **Hürmüz KOÇ** [2B]

[1] *Kastamonu University, Bozkurt Vocational High School Civil Defense and Firefighting Program, Kastamonu, TÜRKİYE*
[2] *Çanakkale Onsekiz Mart University Faculty of Sport Sciences, Coaching Education, Çanakkale, TÜRKİYE*

Address Correspondence to Nuray DEMIRALP: e-mail: ndemiralp@kastamonu.edu.tr

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A: Orcid ID: 0000-0002-3002-7752 B: Orcid ID: 0000-0003-1588-7583

Abstract

Firefighting involves aerobic and anaerobic physical activities that cause heart rates to rise from submaximal to above maximal levels. These varying demands can occur with each call firefighters respond to during their shift, imposing both acute and cumulative cardiovascular loads. Heart rate is commonly used to measure cardiovascular responses during disasters, emergencies, firefighting, and firefighting simulations. There is substantial evidence suggesting that heart rate recovery (HRR) parameters are associated with body composition and aerobic fitness. Therefore, the primary aim of this study is to determine the relationship between body composition, physical fitness, and HRR parameters in firefighters. This cross-sectional descriptive study was conducted among firefighters working in a metropolitan municipality. Using the G-Power 3.1 program, seventy-four firefighters (age = 32.61 ± 8.9 years, height = 1.76 ± 0.6 cm, weight = 83.9 ± 13 kg) volunteered to participate in this study. Body mass index (BMI), waist circumference (WC), and body fat percentage (BFP) were recorded for each subject. To determine aerobic fitness (VO_2max), each participant performed a submaximal exercise test on a treadmill. HRR was calculated as the difference between peak heart rates post-exercise (HRmax) and heart rates at the first and second minutes of the recovery phase, recorded as HRR1 and HRR2, respectively. The mean VO_2max and BMI of the participants were 48.32 ± 9.18 ml/kg/min and 27.10 ± 3.49 kg/m^2, respectively. No significant relationship was found between the HRR1 and HRR2 parameters and the variables of BMI, WC, and BFP in firefighters ($p>0.05$). However, positive significant relationships were detected between HRR1 and HRR2 and VO_2max ($p<0.05$). A statistically significant negative relationship was found between VO_2max and the variables of BMI, WC, BFP, and weight ($p<0.05$). These findings indicate that higher aerobic capacity is associated with better heart rate recovery and lower body fat percentage. The results of this study demonstrate that cardiovascular autonomic function is significantly related to maximum aerobic fitness. However, no measure of body composition appears to affect the overall HRR response of the firefighters. This research provides important insights into how the aerobic capacity of firefighters affects their heart rate recovery responses.

Keywords: Heart rate recovery, body composition, body mass index, physical fitness, firefighter.

Özet

Vücut Kompozisyonun ve Fiziksel Uygunluğun İtfaiyecilerde Parasempatik Reaktivasyona Etkisi

Yangınla mücadele, kalp atış hızlarının submaksimalden maksimumun üzerine çıkmasına neden olan aerobik ve anaerobik fiziksel aktiviteleri içermektedir. Bu değişen talepler, itfaiyecilerin vardiya sırasında yanıt verdiği her çağrıda ortaya çıkabilmekte ve itfaiyecilere hem akut hem de kümülatif kardiyovasküler yük bindirmektir. Kalp atım hızı, afet ve acil durumlarda, yangınla mücadelede ve yangınla mücadele simülasyonları sırasında kardiyovasküler tepkileri ölçmek için yaygın olarak kullanılmaktadır. Kalp atış hızı toparlanma (HRR) parametrelerinin vücut kompozisyonu ve aerobik kondisyonla ilişkili olduğuna dair önemli kanıtlar bulunmaktadır. Bu nedenle, mevcut çalışmanın temel amacı, itfaiyecilerde vücut kompozisyonu ve fiziksel uygunluğun, HRR parametreleri arasındaki ilişkiyi belirlemektir. Kesitsel tanımlayıcı tipte planlanan çalışma, bir büyükşehir belediyesinde görev yapan itfaiyeciler arasında gerçekleştirilmiştir. G-Power 3.1 programı kullanılarak yetmiş dört itfaiyeci (yaş = 32,61 ± 8,9 yıl, boy = 1,76 ± 0,6 cm, ağırlık = 83,9 ± 13 kg), bu çalışmaya katılmaya gönüllü oldu. Her denek için beden kütle indeksi (VKİ), bel çevresi (BÇ) ve vücut yağ yüzdesi (VYY) kaydedildi. Aerobik uygunluğu (VO2max) belirlemek için, her katılımcı bir koşu bandı üzerinde submaksimal egzersiz testi gerçekleştirdi. HRR, egzersiz sonrası pik kalp atım sayıları (KAHmax) ile dinlenme fazının ilk iki dakikasındaki kalp atım sayıları arasındaki farklar olarak hesaplandı ve HRR1 ve HRR2 dakika olarak kaydedildi. Katılımcıların; VO2max ve BKİ ortalamaları sırasıyla; 48,32 ± 9,18 ml/kg/dk ve 27,10 ± 3,49 kg/m2 olarak bulunmuştur. BKİ, BÇ, VYY değerlerinin ile itfaiyecilerin HRR1 ve HRR2 parametreleri arasında anlamlı ilişki saptanmamıştır. (p>0,05). Ancak, HRR1 ve HRR2 ile VO2max ile pozitif yönlü anlamlı ilişkiler tespit edilmiştir (p<0,05). BKİ, BÇ, VYY ve kilo değişkenleri ile VO2max arasında negatif yönlü istatistiksel olarak anlamlı ilişki bulunmuştur (p<0,05). Bu bulgular, daha yüksek aerobik kapasitenin daha iyi kalp atış hızı toparlanması ve daha düşük vücut yağ yüzdesi ile ilişkili olduğunu göstermektedir. Bu çalışmanın sonuçları, kardiyovasküler otonomik fonksiyonun maksimum aerobik kondisyon ile önemli ölçüde ilişkili olduğunu göstermektedir. Bununla birlikte, hiçbir vücut kompozisyonu ölçüsünün, itfaiyecilerin genel HRR tepkisini etkilemediğini göstermektedir. Bu araştırma, itfaiyecilerin aerobik kapasitesinin, kalp atış hızı toparlanma tepkilerini nasıl etkilediğini anlamada önemli katkılar sağlamaktadır.

Anahtar Kelimeler: Kalp atış hızı toparlanması, vücut kompozisyonu, beden kütle indeksi, fiziksel uygunluk, itfaiyeci

INTRODUCTION

Firefighting is a high-risk profession where numerous physical and psychological stress factors pose countless threats to the health of firefighters. The physical demands of firefighting are characterized by the significant activation of the cardiovascular, metabolic, and hormonal systems (1,2). Heart rates exceeding 95% of the maximum (188-190 beats per minute), high oxygen consumption rates (33.6-49.0 ml/kg/min), and significant activation of the sympathoadrenal axis have been recorded during firefighting, demonstrating the substantial physiological stresses that arise during these tasks (1–4). In addition to the anxiety caused by unknown conditions, critical time urgency, extreme temperatures, fire smoke and toxic gases, and a heavy workload, the weight of personal protective equipment (including a self-contained breathing apparatus, approximately 25 kg) significantly contributes to the excessive physiological responses and substantial activation of the cardiovascular system in firefighters. Numerous studies have also proven that sudden cardiac events are the leading cause of duty-related fatalities among firefighters (5–8).Therefore, it is not surprising that nearly half of the on-duty deaths among firefighters in the past decade have been attributed to sudden cardiac events (9). Most of these sudden cardiac deaths occur during or shortly after firefighting activities. Researchers have shown that a firefighter's likelihood of experiencing sudden cardiac death after responding to a call is 2.2 to 10.5 times higher compared to non-emergency duties (10). Firefighting involves aerobic and anaerobic physical activities that cause heart rates (HR) to rise from submaximal to maximal levels. These varying demands can arise with every call firefighters respond to during their shifts, imposing both acute and cumulative cardiovascular strain (11).

Heart rate (HR) is commonly used to measure cardiovascular responses during disasters and emergencies, firefighting, and firefighting simulations (12,13). Time and frequency domain analyses of spontaneous heart rate variability (HRV) based on R-R interval series in electrocardiography are important indicators for evaluating cardiac autonomic modulation in different functional states for both healthy and clinical populations. This outcome is widely used as a reliable non-invasive tool for monitoring cardiac autonomic function (14,15). Based on the markedly elevated heart rate responses observed during firefighting activities among firefighters, the hypothesis posits that subsequent inappropriate activation of the sympathetic nervous system may increase the risk of sudden cardiac death (16). The post-exercise heart rate recovery (HRR) period is a widely utilized method for assessing the influences of the autonomic nervous system, including sympathetic and parasympathetic functions. HRR refers to the decrease in heart rate immediately following the cessation of exercise, predominantly due to the reactivation of parasympathetic or vagal nerve activity (17,18). The initial decrease in heart rate following exercise is largely attributed to the reactivation of the parasympathetic nervous system, primarily through input from the vagus nerve (19,20). HRR is considered a non-invasive and clinically useful measure for assessing the parasympathetic nervous system's ability to regain control of the sinoatrial node of the heart after physical exertion. Previous research has shown that the decrease in heart rate in the first minute after exercise (≤12 beats/min) is an independent predictor of all-cause and cardiovascular mortality, including in asymptomatic individuals (19). Given the high sympathetic nervous system activity linked to cardiovascular stress during firefighting and the subsequent risk of developing dangerous arrhythmias, using HRR measurements is crucial for assessing the reactivation of the parasympathetic nervous system after exertion among firefighters (21,22). Recent studies conducted with firefighters have measured the dynamic interaction between the sympathetic and parasympathetic nervous systems during recovery following exercise through Heart Rate Recovery (HRR). It has been found that firefighters with higher fitness levels exhibit enhanced HRR kinetics after both submaximal and maximal exercise, suggesting that physical fitness may positively influence the recovery of the autonomic nervous system in firefighters (23,24).

There is significant evidence showing that the autonomic control of heart rate is associated with body composition and aerobic fitness. For instance, poor HRR and HRV have been correlated with higher levels of body mass index (BMI), larger waist circumference (WC) measurements, and higher body fat percentages (BFP) (25,26). Research also indicates that the level of obesity is associated with poor HRR response after exercise in non-firefighter populations (26,27). In obese individuals, clinical studies have observed reductions in parasympathetic nervous system activity, which, combined with weight gain, can contribute to the poor HRR response post-exercise due to the delayed reactivation of the parasympathetic nervous system (25). Given the high prevalence of obesity among both active-duty firefighters and military firefighters, coupled with the significant sympathetic nervous system activity associated with firefighting, there is a need to identify the impact of body composition on firefighters' HRR response (28,29).

Due to the elevated heart rate (HR) response observed during firefighting activities, it has been hypothesized that the inappropriate increase in sympathetic nervous system activation following such activities may contribute to the risk of sudden cardiac death. We hypothesized that HRR, as a measure of parasympathetic reactivation, would be associated with obesity, central adiposity, and body fat measurements. Additionally, we anticipated a positive correlation between HRR and exercise performance, suggesting that greater parasympathetic activity would correspond to faster vascular recovery and an improvement in overall fitness.

METHOD

Research population and sample: This cross-sectional descriptive study sampled firefighters serving in a metropolitan area. The sample size was determined using the G-Power 3.1 program, with effect sizes classified according to Cohen's (1992) criteria of small, medium, and large effect sizes (30) The study comprised 74 volunteer firefighters, surpassing the initially calculated sample size of 68 participants with a power (1-β) of 0.90, effect size of 0.4, and alpha value of 0.05. Inclusion criteria required participants to have no diagnosed chronic illnesses confirmed by a physician and to be physically capable of engaging in physical activity. Before conducting physical tests and measurements, participants were assessed using the "Physical Activity Readiness Questionnaire (PAR-Q)" to identify any health conditions that could potentially hinder their participation in these activities. This questionnaire consists of seven items used to determine whether participants' medical needs and overall health are suitable for physical performance tests and exercise sessions. If a participant answered "yes" to any of these seven questions, they were excluded from participating in physical activity (31).

Anthropometric measurements: Height was measured using a stadiometer (SECA; Seca Instruments Ltd, Hamburg, Germany) with ±0.1 mm precision, while participants stood in anatomical position, feet together, and body weight evenly distributed on both feet. Body weight was measured using a digital scale (Tanita BC-545, Tanita Corp, Tokyo, Japan) with a precision of ±0.05 kg. Participants were instructed to remove their shoes and wear light sports attire (such as shorts and a t-shirt) during the measurement. Body Mass Index (BMI) was calculated using the formula "weight/height2 (kg/m2)." Waist circumference was measured with a tape measure at the umbilical level while participants stood upright with their abdomen relaxed.

Exercise Test: The Bruce protocol treadmill exercise test was conducted to determine firefighters' submaximal VO2max values. All tests were supervised by a healthcare professional and a sports scientist. The test started at a speed of 2.74 km/h (1.7 mph) and a 10% incline, with the treadmill incline increased by 2% every three minutes (32,33). During each three-minute incline increment, participants' instantaneous heart rates and perceived exercise difficulty levels were recorded. Test termination criteria were considered to determine when participants reached maximum effort during the test. These criteria included reaching above 85-90% of Maximum Heart Rate and perceiving a difficulty level above 16 at the end of exercise. The total duration spent by the participant in minutes during the test was considered as the "T" test score. The Maximum Heart Rate (HRmax) was calculated using the Karvonen method (220 - age). The numerical value obtained at the end of the applied test protocol was recorded as the participants' score. All data were transferred to a computerized environment. The Bruce Protocol Formula used for estimating VO2max for males is VO2max = $14.8 - (1.379 \times T) + (0.451 \times T^2) - (0.012 \times T^3)$ (33).

Heart Rate Recovery Index (HRR): Data were recorded from participants following a treadmill exercise test for the analysis of the HRR index. All participants underwent a treadmill exercise test according to the Bruce protocol. Differences between the maximum heart rates measured just before terminating the exercise (peak heart rate) and the heart rates measured during the first and second minutes of the recovery phase were denoted as HRR1 and HRR2, respectively. Participants were subjected to the treadmill exercise test under Bruce protocol guidelines and heart rate monitoring. After reaching the target maximum heart rate, they transitioned to the rest phase. The heart rate during the first minute of the rest phase was recorded, and HRR was calculated by subtracting the heart rate at the highest point from this recorded value. A result of 12 beats per minute or higher was considered normal.

Ethical Considerations: The study received approval from the Clinical Research Ethics Committee of Kastamonu University Faculty of Medicine (2023-KAEK-51), and institutional permissions were obtained from the Metropolitan Municipality Fire Department where the study was conducted. Participants were informed about the research, and written and verbal consent were obtained from each participant.

Statistical Method: The data were analyzed using IBM SPSS. Descriptive statistics were reported for the unit count (n), percentages (%), mean (X), standard deviation (SD), median (M), minimum (min), and maximum (max) values. Normality of the numerical variables was assessed using the Shapiro-Wilk test. Correlation analysis was conducted to examine the relationship between independent variables (body composition parameters; BMI, WC, BF%, and VO2 max) and cardiovascular autonomic modulation indicators (HRR1, HRR2), with statistical significance set at $p<0.05$.

FINDINGS

Table 1. Descriptive statistics for participants' demographic characteristics (n=74).

Parameters	**Statistics**
Age, (*years*)	
X ± SS	32,61±8,99
M (min-max)	29 (23-60)
Marital Status, *n* (%)	
Single	37 (50%)
Maried	37 (50%)
Educational Status, *n* (%)	
High School	18 (24,3%)
Bachelor' s degree and above	56 (75,7%)
Working Hours as a Firefighter, (*years*)	
X ± SS	8,27 ± 7,37
M (min-max)	4 (2-40)
Total Working Time, (*years*)	
X ± SS	10,86 ± 8,72
M (min-max)	7,5 (2-40)
Smoking Use, *n* (%)	
Yes	41 (55,4%)
No	33 (44,6%)
* **Smoking Status**, *n* (%)	
Less than 10 years	26 (63,4%)
Over 10 years	15 (36,6%)

Descriptive statistics are presented as mean (X), standard deviation (SD), median (M), minimum (min), maximum (max), number (n), and percentage (%) values. * Percentages are calculated based on respondents who answered "Yes" (Multiple choice).

The average height of the participants was found to be 1.76 ± 0.06 cm, with an average weight of 83.98 ± 13.05 kg and a mean BMI of 27.10 ± 3.49 kg/m². According to BMI classification, 21 individuals (28.4%) were classified as normal weight, 40 (54.1%) as overweight, and 13 (17.6%) as obese. The average body fat percentage was 19.88 ± 5.54%, waist circumference averaged 93.47 ± 10.18 cm, hip circumference averaged 102.78 ± 7.48 cm, and waist-to-hip ratio averaged 0.91 ± 0.06 units, VO_2max level of the participants was determined as 48,32 ± 9,18 ml/kg/min. (Table 2).

Table 2. Descriptive statistics for participants' physical fitness characteristics (n=74).

Parameters	**Statistics**
Body Height, (*m*)	
X ± SS	1,76 ± 0,06
M (min-max)	1,8 (1,7-2)
Body Weight, (*kg*)	
X ± SS	83,98 ± 13,05
M (min-max)	81,8 (60-123,8)
Body Mass İndex, (kg/*m²*)	
X ± SS	27,10 ± 3,49
M (min-max)	27,3 (19,8-37)
Body Mass İndex Class, *n* (%)	
Suitable	21 (28,4%)
Overweight	40 (54,1%)
Obesity	13 (17,6%)
Body Fat Percentage, (%)	
X ± SS	19,88 ± 5,54
M (min-max)	20,5 (6,7-29,9)
Waist Circumference, (*cm*)	
X ± SS	93,47 ± 10,18
M (min-max)	92,5 (67-122)
Hip Circumference, (*cm*)	

X ± SS	102,78 ± 7,48
M (min-max)	102 (89-121)
Waist Hip Ratio, (%)	
X ± SS	0,91 ± 0,06
M (min-max)	0,9 (0,7-1,1)
VO$_2$ max Level, ***(ml/kg/min)***	
X ± SS	48,32 ± 9,18
M (min-max)	46,8 (30,1-74,3)

Descriptive statistics are presented as mean (X), standard deviation (SD), median (M), minimum (min), maximum (max), number (n), and percentage (%) values.

Table 3. Descriptive statistics for participants' HRR data (*n*=74).

Parameters	**Statistics**
Max. KAH (beat/min)	
X ± SS	176,12 ± 10,59
M (min-max)	176 (144-197)
HR $_{60}$*(beat/min)*	
X ± SS	130,51 ± 14,2
M (min-max)	126,5 (88-165)
HR $_{120}$*((beat/min)*	
X ± SS	109,68 ± 16,27
M (min-max)	110 (84-144)
HRR$_1$. *((beat/min)*	
X ± SS	56,2±15,7
M (min-max)	58(12-82)
HRR$_2$. *((beat/min)*	
X ± SS	80,5±15,1
M (min-max)	84(39-110)

HR$_{60}$: heart rate at 60 seconds post-exercise; HR$_{120}$: heart rate at 120 seconds post-exercise; HRR$_1$: heart rate recovery at 60 seconds; HRR$_2$: heart rate recovery at 120 seconds

As seen in Table 4, there is a statistically significant positive relationship between HRR at minute 1 and HRR at minute 2 (p<0.05). There was also a positive relationship between HRR$_1$, HRR$_2$, and VO$_2$max (p<0.05), indicating that higher VO$_2$max values are associated with better heart rate recovery. Negative relationships were found between BMI, waist circumference (WC), body fat percentage (BF%), weight variables, and VO$_2$max (p<0.05), suggesting that higher cardiovascular fitness levels are associated with lower BF%, WC, and BMI.

Table 4. Correlations between body composition and HRR indices (*n*=74).

Parameters	**HRR$_1$.**	**HRR$_2$.**	**BMİ.**	**WC**	**BF(%)**	**BW**	**Age**
HRR$_2$	**r=0,812 p<0,001**						
BMİ	r=-0,103 p=0,384	r=-0,068 p=0,566					
WC	r =-0,159 p= 0.176	r =-0,131 p=0,267	**r =0,733 p<0,001**				
BF	R =-0,175 P=0,135	R=-0,112 P=0,342	**r=,0789 p<0,001**	**r= 0,721 p<0,001**			
BW	r=-0,095 p=0,419	r=-0,075 p=0,527	**r=0,872 p<0,001**	**r=0,728 p<0,001**	**r=0,730 p<0,001**		
Age	**r=-0,535 p<0,001**	**r=-0,470 p<0,001**	**r=0,369 p<0,001**	**r=0,421 p<0,001**	**r=0,353 p=0,002**	**r=0,254 p=0,029**	
VO$_2$max	**r = 0.324, p < 0.01**	**r = 0.381, p < 0.01**	**r=-0,409 p<0,001**	**r=-0,457 p<0,001**	**r=-0,351 p=0,002**	**r= -0,352 p=0,002**	**r=-0,350 P=0,002**

Bold-written spearman correlation coefficients (r) indicate statistically significant results (p<0.05).

DISCUSSION AND CONCLUSION

The aim of this study was to investigate the impact of body composition and physical fitness on post-exercise HRR in firefighters. It was hypothesized that measurements of BF%, BMI, and WC would significantly influence HRR responses. Contrary to this hypothesis, the study findings indicate that none of the body composition measures significantly affected overall HRR response in firefighters. However, VO2max values showed positive and significant correlations with HRR1 and HRR2 (Table 3).

In our study, it was found that body composition did not significantly affect the overall HRR response during rest periods among firefighters. This contrasts with previous research that identified significant relationships between various body composition measurements and HRR responses (27,34). Similarly, previous studies have predominantly used HRR60 and/or HRR120 measurements to characterize participants HRR responses. In their study examining post-exercise recovery in firefighters, Cornell et al. (2021) found no significant relationship between BMI, WC, BF%, and HRR, which aligns with our findings (21).

Cardiovascular fitness has been correlated with firefighting performance. Additionally, high cardiorespiratory fitness contributes to reducing the risk of sudden cardiac events while firefighters are engaged in their occupational activities (1,11). Similarly, it has been shown that post-exercise conditioning improves parasympathetic reactivation in well-trained athletes (35). In our study, based on firefighters' exercise test results, VO2max values show positive and significant correlations with HRR1 and HRR2 (Table 4). Similarly, in a study investigating the relationship between VO2max and HRR parameters in firefighters following submaximal and maximal exercise activities, firefighters with higher VO2max values demonstrated a faster decrease in HRR (24). High physical fitness is associated with improved recovery of the autonomic nervous system after maximum effort; this can mitigate the already heightened sympathetic nervous system activation during tasks of maximum or near maximum intensity among firefighters, compounded by factors such as advancing age and high BMI. This is particularly relevant during firefighting activities, where maximum effort is typically exerted. This is also the time when the risk of sudden cardiovascular events is highest during duty. Therefore, increasing physical fitness has been recognized as a method to reduce cardiovascular risk factors and combat sudden cardiac death incidence among the firefighter population. Moreover, combining improved physical fitness with reductions in obesity can also assist in developing adaptations specific to the autonomic nervous system. Low fitness levels among male firefighters have been associated with the risk of both electrocardiographic and non-electrocardiographic abnormalities during both maximum exercise testing and rest periods (36).

While the current study's findings offer valuable insights into the impact of body composition and physical fitness on HRR responses among firefighters, a population underrepresented in scientific literature, its strength is constrained by a small sample size (n = 74). Furthermore, the study exclusively included male firefighters, complicating the assessment of potential gender-mediated effects on the association between body composition, physical fitness, and HRR responses.

HRR response was characterized only after submaximal exercise in this study. Furthermore, the current study did not include aspects inherent to the occupational duties of firefighting, such as heat stress or the use of personal protective equipment, which add additional cardiovascular and physiological burdens to firefighters. Therefore, future research should encompass larger sample sizes comprising actively serving firefighters from various fire departments and should utilize both submaximal and maximal exercise paradigms to further characterize responses under conditions with and without heat stress and personal protective equipment. Moreover, while previous research has identified improvements in parasympathetic nervous system activity as a result of weight loss, the most effective interventions to investigate such adaptations in the firefighter population are currently unknown (27,34). It is believed that in the future, research exploring the effects of diverse health and fitness interventions such as aerobic exercise, resistance training, dietary behavior modifications, and others on BF adaptations among firefighters will be crucial.

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