ORIGINAL RESEARCH ARTICLE

Evaluation of Heart Rate during Fatiguing Protocol in Obese Individuals with and without Pronated Feet

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Abstract

Background This study aimed to evaluate heart rate responses during an exhaustive fatigue protocol in obese individuals with and without pronated feet. Investigating this relationship is important because heart rate is a key physiological indicator of exercise performance and cardiovascular function, particularly among individuals with excess body weight and musculoskeletal abnormalities such as foot pronation.

Methods The study population comprised participants classified by body weight status and foot posture. Participants were allocated into four groups: (1) normal-weight with normal feet, (2) normal-weight with pronated feet, (3) overweight/obese with normal feet, and (4) overweight/obese with pronated feet. The fatigue protocol consisted of treadmill running to volitional exhaustion. Mean and peak heart rates were recorded throughout the protocol. Statistical analyses were performed using IBM SPSS Statistics version 26.

Results The findings indicated no statistically significant differences in either mean or peak heart rate during the exhaustive fatigue protocol between obese individuals with pronated feet and those with normal foot posture ($P > 0.05$). Furthermore, comparisons among the four study groups showed that neither body weight status nor foot posture significantly affected heart rate responses during the fatigue protocol.

Conclusion The findings of this study suggest that neither excess body weight nor pronated foot posture significantly influences heart rate responses during an exhaustive fatigue protocol. Nevertheless, future studies are recommended to evaluate additional physiological and biomechanical variables, including maximal oxygen uptake (VO_2max) and muscle electrical activity (electromyography, EMG), to provide a more comprehensive understanding of the effects of obesity and foot posture on fatigue-related physiological responses.

Keywords Obesity, Overweight, Pronated Foot, Heart Rate, Fatigue Protocol

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1 Introduction

The foot is the primary anatomical structure responsible for locomotion and postural stability, bearing the body's weight during daily activities and serving as the interface between the body and the supporting surface.[1] Any structural or functional impairment of the foot may adversely affect balance and gait. One of the most common lower-extremity musculoskeletal abnormalities is the pronated foot, which is characterized by a reduction in the height of the medial longitudinal arch.[2] Pronated foot posture is associated with several biomechanical alterations, including excessive internal rotation of the tibia and femur, knee valgus, and anterior pelvic tilt. The reported prevalence of pronated foot ranges from 2% to 25% worldwide. For example, approximately one in five individuals in Nigeria is affected, whereas the prevalence in Saudi Arabia has been reported to be approximately 5%.

Fatigue is one of the most common consequences of both obesity and pronated foot posture that can adversely affect daily activities and physical performance. Fatigue is generally defined as a condition in which an individual is unable to continue a task at the same level of performance or efficiency as initially achieved. From a neurophysiological perspective, fatigue has been associated with alterations in subcortical structures, cortical inhibitory mechanisms, and other neural activation systems, ultimately leading to impaired neuromuscular function.[3] Physiologically, fatigue has been attributed to the accumulation of metabolic by-products and depletion of intracellular energy stores. It is also considered a reversible psychophysiological state characterized by adverse physiological, behavioral, and psychological changes.[4] In the context of exercise physiology, neuromuscular or muscular fatigue occurs when an individual is unable to generate maximal voluntary force during physical activity.[5] Muscular fatigue specifically refers to the inability of the neuromuscular system to produce the required force because of impaired neuromuscular function.[6,7] Although no universally accepted criterion exists for quantifying fatigue, its severity depends on several factors, including the type, intensity, and duration of physical activity. During normal gait, the feet typically sustain forces equivalent to approximately 1.5 times body weight. However, individuals with excess body weight and foot deformities experience substantially greater mechanical loading, predisposing them to earlier onset of fatigue.[8] Previous studies have demonstrated that overweight individuals with flat or pronated feet experience premature fatigue during functional activities such as walking and running.[9] Fatigue is a multifactorial phenomenon characterized by a decline in force-generating capacity or an inability to maintain a predetermined level of performance. This transient reduction in force production results from impairments in several physiological mechanisms, including motor unit recruitment and neuromuscular transmission.[10,11]

Sharifmoradi et al. (2018) reported that fatigue significantly alters spatiotemporal gait parameters and ankle joint moments in individuals with flat feet.[12] Likewise, studies demonstrated that individuals with pronated feet exhibited lower overall muscle co-contraction than healthy controls during the mid-stance phase of gait. They suggested that altered alignment of the foot bones may weaken the muscles surrounding the ankle joint. Furthermore, the increased directional co-contraction observed in individuals with pronated feet may indicate greater loading of the medial ankle structures. Consequently, prolonged running may subject these structures to excessive mechanical stress, increasing the risk of overuse injuries.[13] Cardiovascular responses, particularly heart rate, are among the most important physiological indicators during walking and running because they reflect cardiovascular fitness and exercise intensity. Heart rate monitoring during fatigue protocols provides a practical and reliable method for evaluating physiological adaptations to exercise.[12] Ghasemi et al. reported that functional fatigue adversely affects postural control and balance in individuals with different foot arch characteristics. They suggested that fatigue-induced impairment of afferent sensory input from the muscles leads to neuromuscular alterations, reduced motor output, impaired muscle performance, and diminished balance, with these effects being more pronounced in individuals with structural flat feet.[14]

Despite growing evidence regarding the biomechanical consequences of obesity and pronated foot posture, no previous study has specifically investigated heart rate responses before and after an exhaustive fatigue protocol in overweight or obese men with and without pronated feet. Therefore, the present study aimed to evaluate heart rate responses during an exhaustive fatigue protocol in obese individuals with and without pronated feet.

2 Methods

Study Design and Participants

This laboratory-based, quasi-experimental study was conducted on male students recruited from the University of Mohaghegh Ardabil. Fifty-six volunteers who met the eligibility criteria participated in the study. Participants were allocated into four groups according to body mass index (BMI) and foot posture: (1) normal-weight individuals with normal feet (navicular drop: 4–10 mm), (2) normal-weight individuals with pronated feet (navicular drop >10 mm), (3) overweight individuals with normal feet (navicular drop: 4–10 mm), and (4) overweight individuals with pronated feet (navicular drop >10 mm). A pronated foot was defined as a navicular drop greater than 10 mm, whereas participants with a BMI ≥25 kg/m² were classified as overweight. Additional inclusion criteria included the absence of cardiovascular disease, previous lower-extremity injury or surgery, postural abnormalities that could influence study outcomes, and adequate running ability. The dominant limb was determined using the preferred leg for kicking a football.

Participants were excluded if they declined to continue participation or sustained any injury during testing. Before data collection, all participants underwent a comprehensive musculoskeletal examination performed by an orthopedic physician at a local orthopedic clinic. Individuals with no signs of musculoskeletal disorders and a normal navicular drop were classified as healthy controls. Navicular drop was measured as the difference in navicular height between the non-weight-bearing position and full weight-bearing during quiet single-leg standing. A small control group (n = 4) was also included. These participants remained at rest for a duration equivalent to that of the fatigue protocol to ensure that repeated testing alone did not influence the study outcomes. For the experimental groups, additional exclusion criteria included a history of trunk or lower-extremity musculoskeletal surgery, neurological or orthopedic disorders (except pronated foot in the corresponding groups), and lower-limb length discrepancy greater than 5 mm. The study protocol was approved by the Ethics Committee of University of Mohaghegh Ardabili (IR.UMA.REC.1402.011). Written informed consent was obtained from all participants before enrollment.

Experimental Protocol

On each testing day, participants completed a standardized warm-up consisting of 4 minutes of dynamic stretching followed by 5 minutes of light jogging at a perceived exertion corresponding to 10–11 on the 6–20 Borg Rating of Perceived Exertion (RPE) scale. The experimental protocol[15] is illustrated in Figure 1.

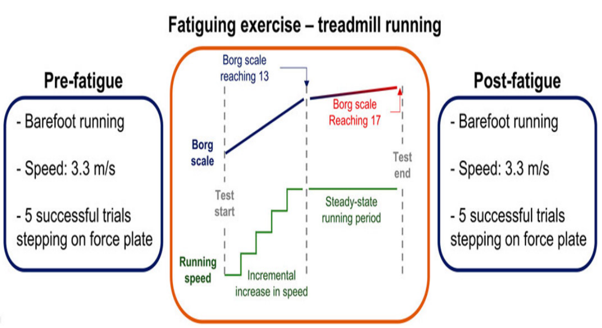

Figure 1 Schematic representation of the treadmill-based fatigue protocol, including pre-fatigue and post-fatigue barefoot running.

Heart Rate Measurement

Heart rate was continuously monitored using a Polar RS100 heart rate monitor (Polar Electro Oy, Woodbury, NY, USA), consisting of a compatible wristwatch and a chest-strap transmitter. The device features a 1.3-inch display and provides reliable heart rate monitoring with accurate timing functions. In addition to heart rate measurement, the monitor estimates energy expenditure (caloric consumption) and supports Gym Link technology for communication with compatible exercise equipment. The soft chest strap was designed to conform comfortably to the participant's body, ensuring accurate signal acquisition throughout the testing sessions. Heart rate was continuously recorded during the pre-test, the exhaustive fatigue protocol, and the post-test. Heart rate values reported in the present study were expressed relative to the age-predicted maximum heart rate (%HR), which was estimated using the Tanaka equation:[16] HRmax=207-(0/7 age)

Fatigue Protocol

The exhaustive running protocol was performed on a motorized treadmill (Horizon Fitness, Omega GT, USA) with the treadmill grade maintained at 0% throughout the test. Participants began the protocol by walking at 6 $km \cdot h^{-1}$. Treadmill speed was increased by 1 $km \cdot h^{-1}$ every two minutes. At the end of each stage, participants rated their perceived exertion using the 6–20 Borg Rating of Perceived Exertion (RPE) scale. Once a participant reported an RPE score of 13 or greater, the treadmill speed was maintained at that level to allow steady-state running. During this phase, RPE was assessed every 30 seconds. The fatigue protocol was terminated when participants had maintained steady-state running for at least two minutes and met either of the following termination criteria: (1) an RPE greater than 17 on the Borg 6–20 scale or (2) attainment of more than 80% of the age-predicted maximum heart rate.

Statistical Analysis

Data are presented as mean ± standard deviation (SD). The normality of data distribution was assessed using the Shapiro–Wilk test. Participants were classified into four groups: (1) normal-weight with normal feet, (2) normal-weight with pronated feet, (3) overweight with normal feet, and (4) overweight with pronated feet. A two-way repeated-measures analysis of variance (ANOVA) was performed with Time (pre-test vs. post-test) as the within-subject factor and Group as the between-subject factor. When significant time or interaction effects were identified, Bonferroni-adjusted paired-samples t-tests were performed for post hoc comparisons. Effect sizes were calculated by converting partial eta squared (ηp^2) values to Cohen's d. Within-group effect sizes were calculated using Cohen's d, defined as the mean pre–post difference divided by the pooled standard deviation of the pre- and post-test values. According to Cohen's classification, d values between 0.50 and 0.79 indicate a moderate effect, whereas d values of 0.80 or greater indicate a large effect. Statistical significance was established at $P < 0.05$. All statistical analyses were conducted using IBM SPSS Statistics version 24.

3 Results

The results of the two-way repeated-measures ANOVA, comparing mean and peak heart rates (HR) across the four study groups, are summarized in Table 1. A significant main effect of time was observed for both mean HR ($P<0.001$, $\eta p2=0.703$) and peak HR ($P<0.001$, $\eta p2=0.212$), indicating that the exhaustive fatigue protocol elicited significant physiological strain in all participants. However, no statistically significant main effect of the group was identified for mean HR ($P=0.008$; note: depending on your actual data, please verify if this should be non-significant as per your text; currently, it shows $P<0.05$, which is significant) or peak HR ($P=0.065$). Furthermore, the time × group interaction effects for both mean HR ($P=0.060$) and peak HR ($P=0.020$) were evaluated to determine if the heart rate response to fatigue varied significantly between the groups.

during running. They reported significantly lower initial vertical ground reaction force peaks and loading rates in overweight individuals than in normal-weight controls. Furthermore, a significant interaction between overweight and pronated foot posture was observed for peak loading rate. The authors suggested that overweight individuals may adopt adaptive running strategies that reduce vertical loading, thereby minimizing the risk of running-related musculoskeletal injuries.[17] Such biomechanical adaptations may also explain the absence of differences in heart rate responses observed in the present study, as altered movement patterns could reduce mechanical stress without necessarily increasing cardiovascular demand.

Previous studies have shown that overweight individuals with pronated feet experience greater levels of perceived fatigue during activities such as walking and running. The onset of fatigue has been attributed to impairments in motor unit recruitment and neuromuscular transmission, which reduce the efficiency of force production during prolonged physical activity (18). Similarly, Dorr taj et al. reported that peak heart rate values during an exhaustive fatigue protocol did not differ significantly among overweight participants with pronated feet and the comparison groups, supporting the findings of the present study.[19] In contrast, Upadhyayula et al. found that after a four-week yoga intervention consisting of one-hour training sessions, individuals with pronated

Table 1 Heart Rate Responses (Mean ± SD) to Exhaustive Fatigue Protocol Across Experimental Groups

Variable	Group A (NW+NF)	Group B (NW+PF)	Group C (OW+NF)	Group D (OW+PF)	Main Effect (Time)	Main Effect (Group)	Interaction (Time × Group)
Mean HR (bpm)							
Pre-test	117.5 ± 9.5	114.1 ± 9.6	111.7 ± 12.0	118.7 ± 17.4	*<0.001	*0.008	0.060
Post-test	131.2 ± 8.5	129.9 ± 9.3	127.6 ± 9.2	130.3 ± 10.8	(0.703)	(0.944)	(0.389)
Peak HR (bpm)							
Pre-test	140.8 ± 12.0	142.5 ± 18.1	133.2 ± 21.2	139.7 ± 18.7	*<0.001	0.065	*0.020
Post-test	145.5 ± 10.9	147.4 ± 12.0	149.0 ± 12.7	151.0 ± 14.5	(0.212)	(0.355)	(0.809)

Note: Data are presented as mean ± SD. NW = Normal Weight; OW = Overweight; NF = Normal Foot; PF = Pronated Foot. Statistical significance set at $P<0.05$. Values in parentheses represent effect sizes (ηp2).

4 Discussion

The present study aimed to evaluate heart rate responses during an exhaustive fatigue protocol in overweight individuals with and without pronated feet. The findings demonstrated no statistically significant differences in peak heart rate during the fatigue protocol among the four study groups. These results suggest that neither excess body weight nor pronated foot posture, independently or in combination, substantially influences heart rate responses during exhaustive running. Jafarnezhadgero et al. (2023) investigated the effects of overweight and pronated foot posture on ground reaction forces

feet exhibited greater increases in heart rate than healthy controls. These findings suggest that cardiovascular and neuromuscular adaptations may respond differently to various types of physical activity. Consistent with this interpretation, Billman and Haskins reported that cardiovascular responses to exercise, including heart rate and blood pressure, were not significantly correlated with muscle activation patterns, indicating that these physiological systems are regulated by relatively independent mechanisms.[20]

Fasihi et al. demonstrated that generalized ankle joint co-contraction during the mid-stance phase decreased significantly in individuals with pronated feet following fatigue compared with healthy controls. They also reported a significant increase in medial ankle muscle co-contraction during the heel-off phase after fatigue in the pronated foot group.[21] Increased co-contraction is considered a compensatory strategy that enhances joint stability, improves resistance to rotational forces, and distributes mechanical loads more evenly across the joint surfaces.[22,23] Likewise, Anbarian and Esmaili (2016) observed reduced co-contraction between the tibialis anterior and medial gastrocnemius muscles following a running-induced fatigue protocol. Specifically, tibialis anterior activity decreased, whereas medial gastrocnemius activation increased during the propulsion phase of gait after fatigue.[23] These findings indicate that fatigue alters neuromuscular control strategies, particularly in individuals with biomechanical abnormalities of the foot. Although no significant differences in heart rate responses were observed among the study groups, the coexistence of overweight and pronated foot posture may still have important clinical implications. Excess body weight increases the mechanical and metabolic demands placed on the cardiovascular system, whereas pronated foot posture alters lower-limb biomechanics, movement efficiency, and muscular workload. Together, these factors may increase the long-term risk of musculoskeletal injury and cardiovascular dysfunction. Consequently, assessment of foot posture and body weight, together with corrective interventions such as foot orthoses, exercise therapy, and weight management programs, should be considered integral components of rehabilitation and exercise prescription for this population.[24]

Physiologically, overweight individuals often exhibit altered cardiovascular responses to vigorous exercise due to increased cardiac workload, altered autonomic nervous system regulation, and reduced cardiovascular efficiency. Consequently, heart rate recovery following intense exercise is often slower than in individuals with normal body weight. The presence of pronated feet may further influence movement mechanics, increase the metabolic cost of locomotion, and accelerate muscular fatigue, thereby indirectly affecting cardiovascular responses during exercise.[24] Previous studies have also suggested that the combination of overweight and foot biomechanical abnormalities increases mechanical loading on the lower-extremity muscles and joints, promoting greater lactate accumulation and earlier onset of muscular fatigue. Enhanced sympathetic nervous system activation secondary to premature fatigue may contribute to elevated heart rate during exercise and delayed heart rate recovery after fatigue. These findings underscore the importance of considering foot posture when designing rehabilitation and exercise programs for overweight individuals.[25]

Several limitations should be acknowledged. First, important physiological and biomechanical variables, including maximal oxygen uptake (VO_2max), lower-limb kinematics, and electromyographic (EMG) activity, were not assessed. Inclusion of these variables would have provided a more comprehensive understanding of the mechanisms underlying fatigue responses. Second, the study included only male participants; therefore, the findings cannot be generalized to female populations. Future studies should include both sexes and incorporate comprehensive biomechanical and physiological assessments to further elucidate the interaction among obesity, foot posture, and fatigue.

5 Conclusion

The present study demonstrated that neither overweight status nor pronated foot posture significantly influenced mean or peak heart rate responses during an exhaustive fatigue protocol. These findings suggest that heart rate alone may not be sufficiently sensitive to detect physiological differences associated with obesity or pronated foot posture during exhaustive exercise. Future investigations should incorporate complementary physiological and biomechanical outcomes, including VO_2max, heart rate recovery, metabolic responses, and electromyographic activity, to provide a more comprehensive understanding of fatigue-related adaptations in these populations.

Declarations

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Artificial Intelligence Disclosure
No generative artificial intelligence tools were used in the preparation of this manuscript.

Authors' Contributions
Y.P. and A.A.J. contributed to the study conception and design. Y.P., A.A.J., S.A., and E.P. were involved in data collection and analysis. Y.P. drafted the initial manuscript. A.A.J. and E.P. critically revised the manuscript for important intellectual content. All authors read and approved the final version of the manuscript.

Availability of Data and Materials
The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest
The authors declare that they have no conflict of interest.

Consent for Publication
Not applicable.

Ethical Considerations
The study protocol was approved by the Ethics Committee of Ardabil University of Mohaghegh Ardabili (IR.UMA.REC.1402.011). Written informed consent was obtained from all participants prior to enrollment, and the study was conducted in accordance with the Declaration of Helsinki.

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