

Acute Cardiovascular Responses to the Harvard Step Test: Effects on Blood Pressure, Heart Rate, And Rate–Pressure Product in Apparently Healthy Adults

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ABSTRACT

Background: Submaximal exercise tests are widely used to assess cardiovascular function and autonomic regulation in apparently healthy individuals. The Harvard Step Test (HST) is a simple and standardized protocol that provides insight into cardiovascular adaptability to physical stress. Key hemodynamic parameters such as blood pressure (BP), heart rate (HR), and rate–pressure product (RPP)—an index of myocardial oxygen demand—serve as important indicators of cardiac workload (Gobel et al., 1978; Kenney et al., 2019).

Objective: This study evaluated the acute effects of the Harvard Step Test on systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate, and rate–pressure product in apparently healthy adults.

Methods: Twenty-four (n = 24) apparently healthy male participants were recruited. Baseline SBP, DBP, and HR were measured at rest. Participants performed the HST using standard procedures (Brouha et al., 1943). Post-exercise measurements were recorded immediately and during recovery. RPP was calculated as $SBP \times HR$. Data were expressed as mean $\pm$ standard deviation. Paired t-tests and repeated-measures ANOVA were used for comparisons, with significance set at $p < 0.05$.

Results: The HST elicited significant increases in HR, SBP, and RPP ($p < 0.05$), indicating increased cardiovascular demand and myocardial workload. DBP showed no significant change ($p > 0.05$). The elevated RPP suggests increased myocardial oxygen consumption during submaximal exercise.

Conclusion: The HST produces significant acute cardiovascular responses, particularly in HR, SBP, and myocardial workload, while DBP remains relatively stable. These findings support its utility as a simple, reliable tool for cardiovascular assessment.

KEYWORDS: Harvard Step Test; Cardiovascular Response; Heart Rate; Blood Pressure; Rate–Pressure Product; Exercise Physiology; Autonomic Function

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INTRODUCTION

Cardiovascular diseases (CVDs) remain the leading cause of global morbidity and mortality, accounting for an estimated

17.9 million deaths annually worldwide (World Health Organization [WHO], 2023). This underscores the need for simple, reliable, and cost-effective tools for early detection of cardiovascular dysfunction and risk stratification. Submaximal exercise tests are widely used in both clinical and field settings

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to evaluate cardiovascular performance, autonomic regulation, and functional capacity (Kenney et al., 2019).

The Harvard Step Test (HST), originally developed by Brouha et al. (1943), remains one of the most practical and widely utilized protocols for assessing cardiorespiratory fitness. It evaluates cardiovascular efficiency through standardized stepping exercise followed by heart rate recovery assessment, which reflects autonomic balance and cardiovascular adaptability (Draper & Swart, 2021).

Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) is considered the gold standard for assessing aerobic capacity; however, its direct measurement requires sophisticated equipment. The HST provides an indirect estimation based on heart rate recovery kinetics. Rapid heart rate recovery reflects efficient parasympathetic reactivation and is associated with reduced cardiovascular risk (Qiu et al., 2022; Tucker et al., 2018).

Beyond $\text{VO}_{2\text{max}}$ estimation, acute hemodynamic responses—including heart rate, blood pressure, and rate–pressure product—provide critical insight into cardiovascular workload. The rate–pressure product (RPP), defined as the product of systolic blood pressure and heart rate, is a validated non-invasive index of myocardial oxygen consumption (Gobel et al., 1978). During exercise, increases in HR and SBP elevate RPP, reflecting increased myocardial demand, while DBP remains relatively stable due to peripheral vasodilation (Hall & Guyton, 2021).

Despite its widespread use, most studies on the HST focus primarily on heart rate recovery and $\text{VO}_{2\text{max}}$ estimation, with limited emphasis on integrated hemodynamic parameters such as RPP, particularly in African populations. This represents an important gap in the literature.

Therefore, this study aimed to evaluate the acute effects of the Harvard Step Test on SBP, DBP, HR, and RPP in apparently healthy adults.

MATERIALS AND METHODS

Study Design and Setting

This study employed a quasi-experimental, within-subject (pre–post) design to evaluate acute cardiovascular responses to submaximal exercise. The study was conducted in the Physiology Laboratory of Federal University Birnin Kebbi, Nigeria. The design enabled comparison of baseline and post-exercise cardiovascular parameters within the same participants, thereby minimizing inter-individual variability and improving internal validity.

Study Population and Sampling

The study included twenty-four ($n = 24$) apparently healthy male undergraduate students aged 18–30 years recruited from the Department of Physiology using purposive sampling.

Inclusion Criteria

- Apparently healthy individuals with no known cardiovascular, respiratory, or metabolic disorders
- Not currently on medications affecting cardiovascular function
- Non-smokers
- Willingness to participate with written informed consent

Exclusion Criteria

- History of hypertension, cardiac disease, or respiratory illness
- Use of stimulants or substances affecting heart rate or blood pressure
- Inability to complete the exercise protocol

Ethical Considerations

Ethical approval was obtained from the Institutional Health Research Ethics Committee of Federal University Birnin Kebbi. All procedures conformed to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to participation. Confidentiality and anonymity were strictly maintained, and participants were free to withdraw at any stage without penalty.

Experimental Protocol

Pre-Experimental Preparation

Participants were instructed to:

- Avoid caffeine, alcohol, and strenuous physical activity for at least 24 hours prior to testing
- Have adequate rest the night before the experiment

On the test day, participants rested in a seated position for 10 minutes in a quiet, temperature-controlled environment before baseline measurements were obtained.

Harvard Step Test Procedure

The Harvard Step Test was conducted according to the standardized protocol described by Brouha et al. (1943). Participants performed stepping exercise on a 50 cm high bench at a rate of 30 steps per minute, guided by a metronome.

- Duration: 5 minutes or until voluntary exhaustion
- Participants were instructed to stop immediately if they experienced dizziness, chest discomfort, or excessive fatigue
- A trained investigator supervised all sessions to ensure safety and protocol adherence

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Measurements

Blood Pressure

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using a calibrated aneroid sphygmomanometer (Riester, Germany) with a stethoscope (3M Littmann Classic III). Measurements were taken:

- At baseline (pre-exercise)
- Immediately post-exercise
- During recovery at 1, 3, and 5 minutes

All measurements were obtained in the seated position following standard guidelines.

Heart Rate

Heart rate (HR) was assessed by manual palpation of the radial pulse and expressed in beats per minute (bpm). Measurements were taken:

- At rest
- Immediately after exercise
- During recovery (1, 3, and 5 minutes)

Rate–Pressure Product (RPP)

The rate–pressure product, an index of myocardial oxygen demand, was calculated as:

$RPP = SBP \times HR$

where SBP is systolic blood pressure (mmHg) and HR is heart rate (beats per minute).

Data Collection Procedure

All data were recorded using standardized data collection sheets. Measurements were conducted in the morning hours to minimize circadian variation. Instruments were calibrated prior to use, and all measurements were performed by trained personnel to ensure reliability and reproducibility.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version XX (IBM Corp., Armonk, NY, USA). Results were expressed as mean ± standard deviation (SD).

- **Paired t-test** was used to compare pre-exercise and post-exercise values
- For multiple time-point comparisons (baseline, immediate, 1, 3, and 5 minutes), **repeated-measures ANOVA** was applied, followed by post hoc analysis where appropriate
- Statistical significance was set at $p < 0.05$

RESULTS

Participant Characteristics

A total of twenty-four ($n = 24$) apparently healthy male undergraduate students participated in the study and completed the Harvard Step Test protocol successfully. All participants were within the young adult age range (18–30

years), with no reported history of cardiovascular or respiratory disorders.

Changes in Cardiovascular Parameters Across Test Phases

Mean values of heart rate (HR), systolic blood pressure (SBP), and rate–pressure product (RPP) across the different phases of the Harvard Step Test are presented in Table 4.1.

Table 1: Cardiovascular Responses Across Test Phases ($n = 24$)

Phase	HR (bpm)	SBP (mmHg)	RPP (SBP × HR)
Pre-test	69.33	111.67	7747.50
During exercise	78.75	124.17	9771.67
1 min recovery	73.00	120.00	8774.17
3 min recovery	70.92	113.54	8047.50
5 min recovery	69.75	113.12	7890.83

Descriptive Trends in Cardiovascular Responses

Heart rate increased markedly during exercise, followed by a progressive decline during recovery toward baseline values. A similar pattern was observed for systolic blood pressure and rate–pressure product, with peak values recorded during exercise and gradual reductions during the recovery phase. Diastolic pressure (not shown) demonstrated minimal variation across test phases.

Inferential Statistics (Repeated-Measures ANOVA)

Repeated-measures ANOVA revealed statistically significant differences in cardiovascular parameters across test phases.

Table 2: Repeated-Measures ANOVA Summary

Variable	F-value	p-value	Interpretation
Heart Rate	9.84	< 0.001	Significant
SBP	11.08	< 0.001	Significant
RPP	19.85	< 0.001	Highly significant

All variables demonstrated significant time-dependent changes ($p < 0.05$), indicating a strong cardiovascular response to the Harvard Step Test.

Graphical Representation of Responses

- **Figure 1:** Changes in heart rate across test phases
- **Figure 2:** Changes in systolic blood pressure across test phases
- **Figure 3:** Changes in rate–pressure product across test phases

All variables showed a consistent pattern of elevation during exercise followed by gradual recovery toward baseline.

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DISCUSSION

The present study demonstrated significant increases in heart rate, systolic blood pressure, and rate–pressure product during the Harvard Step Test, followed by gradual recovery toward baseline values. These findings reflect normal cardiovascular adaptation to submaximal exercise and are consistent with established physiological principles.

Cardiovascular Response and Autonomic Regulation

The observed increase in heart rate during exercise is mediated by sympathetic activation and parasympathetic withdrawal, leading to increased sinoatrial node firing and cardiac output (Hall & Guyton, 2021). The subsequent decline during recovery reflects parasympathetic reactivation, a key indicator of cardiovascular fitness and autonomic efficiency. Faster heart rate recovery has been strongly associated with reduced cardiovascular mortality (Tucker et al., 2018; Qiu et al., 2022).

Blood Pressure Response

The significant rise in systolic blood pressure observed in this study reflects increased stroke volume and cardiac output during exercise. In contrast, diastolic blood pressure remained relatively unchanged, likely due to reduced peripheral resistance resulting from vasodilation in active skeletal muscles (Kenney et al., 2019). This pattern is consistent with normal hemodynamic responses to dynamic exercise.

Rate–Pressure Product and Myocardial Workload

The significant increase in RPP confirms elevated myocardial oxygen demand during exercise. RPP is widely recognized as a reliable non-invasive surrogate for myocardial workload (Gobel et al., 1978). The progressive decline during recovery indicates efficient cardiovascular regulation and restoration of baseline metabolic demand.

Comparison with Previous Studies

These findings align with previous studies reporting similar cardiovascular responses during submaximal exercise (Kenney et al., 2019; Draper & Swart, 2021). Additionally, Qiu et al. (2022) demonstrated that impaired heart rate recovery is associated with increased cardiovascular risk, further supporting the clinical relevance of these measurements.

Autonomic Regulation

Heart rate elevation during exercise is driven by sympathetic activation and vagal withdrawal, increasing cardiac output to meet metabolic demand. Recovery reflects parasympathetic reactivation, an established marker of cardiovascular fitness (Tucker et al., 2018).

Blood Pressure Dynamics

The rise in systolic blood pressure reflects increased stroke volume and cardiac output. Stable diastolic pressure is due to

reduced peripheral resistance from vasodilation in active muscles (Kenney et al., 2019).

Myocardial Oxygen Demand

RPP increased significantly, confirming elevated myocardial workload. This aligns with Gobel et al. (1978), who established RPP as a reliable surrogate of myocardial oxygen consumption.

Clinical and Physiological Significance

The rapid return of HR and BP toward baseline suggests efficient autonomic control and preserved cardiovascular fitness. Impaired recovery patterns are known predictors of cardiovascular risk (Qiu et al., 2022).

The findings are consistent with Draper and Swart (2021), who reported similar cardiovascular responses in submaximal exercise testing.

CONCLUSION

The findings of this study demonstrate that the Harvard Step Test induces significant and predictable cardiovascular responses in apparently healthy individuals. There were marked increases in heart rate, systolic blood pressure, and rate–pressure product during exercise, followed by a gradual return toward baseline during recovery. These responses reflect normal autonomic and cardiovascular adjustments to submaximal exercise.

Therefore, the Harvard Step Test remains a simple, reliable, and cost-effective tool for assessing cardiovascular function, myocardial workload, and autonomic recovery in healthy populations.

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