



Effects of Two-Minutes Versus Four-Minutes Active Recovery on A Booster $\text{VO}_{2\text{max}}$ Treadmill Test in Trained Males

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Abstract

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Maximal oxygen consumption ($\text{VO}_{2\text{max}}$) represents cardiovascular fitness. Several studies suggest that a Booster Max with a 2-minute (2min) active recovery improves $\text{VO}_{2\text{max}}$ in many individuals, but a 4-minute (4min) active recovery has not been studied. The purpose of this study was to compare the effects of 2min vs. 4min active recovery on $\text{VO}_{2\text{max}}$. In a counter-balanced order, 41 aerobically trained males completed a treadmill $\text{VO}_{2\text{max}}$ GXT (Max1). The trial was followed by either a 2min or 4min active recovery and a second bout (Max2) to volitional exhaustion. After 72 hours, participants completed the alternate condition. $\text{VO}_{2\text{max}}$ was analyzed using a 2×2 repeated measures ANOVA. A significant Recovery Duration × Exertion interaction was observed ($F(1,40) = 9.02$, $p = 0.005$, $\eta^2 = 0.184$), with post-hoc analyses showing a significant increase in $\text{VO}_{2\text{max}}$ from Max1 to Max2 only in the 4min condition. There was no significant main effect of Recovery Duration, $F(1,40) = 0.15$, $p = 0.701$, $\eta^2 = 0.004$, but a significant main effect of Exertion, $F(1,40) = 7.05$, $p = 0.011$, $\eta^2 = 0.150$, with higher values in Max2. $\text{VO}_{2\text{max}}$ increased from 52.56 ± 8.71 to 54.70 ± 8.84 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in the 4min condition, and from 53.35 ± 8.55 to 53.58 ± 8.99 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in the 2min condition. A greater proportion of participants achieved higher $\text{VO}_{2\text{max}}$ values following 4min (75.6%) compared to 2min (63.4%). Future research should employ different Booster Max protocols, including 4min recovery conditions in aerobically trained females and other aerobic athlete populations.

Keywords: Maximal oxygen consumption, aerobic capacity, cardiovascular fitness, exercise testing

Introduction

Maximal oxygen consumption ($\text{VO}_{2\text{max}}$) is used to assess cardiopulmonary function, aerobic capacity and efficiency of oxygen transport.¹ Improvements in $\text{VO}_{2\text{max}}$ support greater exercise performance, a primary goal for many athletes. $\text{VO}_{2\text{max}}$ is assessed using indirect calorimetry through graded exercise testing (GXT). Most commonly, a treadmill GXT is performed with incremental stages to volitional exhaustion to assess maximal oxygen consumption.^{2,3} Other commonly used testing modes (e.g., cycle ergometry) may produce $\text{VO}_{2\text{peak}}$ values that can be lower than treadmill-derived values due to modality-specific differences in muscle mass involvement. Another advantage of obtaining $\text{VO}_{2\text{max}}$ is its role in protocol development and selection. Protocols are typically selected based on the sport specificity of the sample population, ensuring they align with the athlete's training status, pace, and exercise mode.¹⁻³

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Common indicators supporting attainment of maximal exertion during graded exercise testing include a plateau in VO_2 despite increasing workload, attainment of a respiratory exchange ratio (RER) of ≥ 1.15 , a rating of perceived exertion (RPE) of ≥ 17 on the Borg (6-20) scale, and achievement of near-maximal heart rate ($\geq 95\%$ of age-predicted HRmax).⁴ These indicators are commonly used in combination in accordance with American College of Sports Medicine (ACSM) recommendations to support determination of maximal effort during graded exercise testing.⁵ HRmax was estimated using the traditional equation ($220 - \text{age}$).⁴ While a $\text{VO}_{2\text{max}}$ plateau is commonly used to support maximal exertion, some researchers have concluded it is not a strict prerequisite, as subjects may reach a plateau temporarily without achieving maximal exertion.^{6,7}

A $\text{VO}_{2\text{max}}$ test is often terminated at volitional exhaustion; however, an individual may possess a greater capacity beyond the initial termination point. Researchers have examined a “Booster” Max test, in which $\text{VO}_{2\text{max}}$ is assessed after an active recovery followed by a second bout of exercise to volitional exhaustion. The premise of a Booster Max test is to provide an additional bout in which VO_2 may be re-assessed following active recovery. Prior research suggests that a Booster Max test may result in different VO_2 values compared with a traditional $\text{VO}_{2\text{max}}$ test. Differences between a standard GXT and a Booster Max test immediately following the active recovery phase have been examined.⁸⁻¹³ Similarly, varying recovery times have been evaluated to determine an optimal $\text{VO}_{2\text{peak}}$ with 2- and 3-minute Booster Max tests using a leg cycle ergometer GXT.¹⁴ Additional recovery times during a standard treadmill GXT have not been explored. In contrast, $\text{VO}_{2\text{max}}$ has been assessed using continuous and discontinuous (intermittent) exercise protocols. Discontinuous GXTs include 5-10 minute rest periods between stages, resulting in a significantly longer test duration compared to continuous GXTs, which consist of a single, uninterrupted bout of exercise, as in a standard $\text{VO}_{2\text{max}}$ test. Prior studies have also used a “verification stage” to confirm $\text{VO}_{2\text{max}}$. Verification testing is similar to a Booster Max test, but more closely resembles a discontinuous GXT, whereas a traditional Booster Max test is performed as a continuous GXT. Previous literature has examined individuals with varying fitness levels, including elite athletes and physically active individuals. In the present study, participants were classified as physically active based on meeting or exceeding the ACSM physical activity guidelines, defined as engaging in at least 30 minutes of moderate-intensity exercise 5 days per week, or 20 minutes of vigorous-intensity exercise 3 days per week, along with 2 days per week of resistance training.⁵ A 2-minute (2min) Booster Max test is most studied and has resulted in significant improvements in $\text{VO}_{2\text{max}}$ for many participants, although some studies reported meaningful but not statistically significant differences at the group level.⁸⁻¹¹ Individual responses vary: some participants benefit, while others show no change. Limited research has examined 3-minute recovery periods, with comparable results.^{13,14} The current literature lacks research on a 4-minute (4min) Booster Max test. Therefore, the purpose of this study was to determine whether a 4min active recovery following a treadmill GXT allows participants to achieve a higher $\text{VO}_{2\text{max}}$ in a subsequent Booster Max test when compared to the traditionally studied 2min recovery protocol.

Methods

Participants

This study included 41 aerobically active males. Each participant met or exceeded the ACSM physical fitness guidelines: at least 30 minutes of moderate-intensity exercise 5 days per week, or 20 minutes of vigorous-intensity exercise 3 days per week, with 2 days per week of resistance training. Participants were free of any musculoskeletal injuries within the past six months and any cardiovascular or uncontrolled metabolic disease in the past year. Exclusion criteria included

musculoskeletal injury within the previous six months, any cardiovascular or uncontrolled metabolic disease within the previous year, and a failure to meet the ACSM physical activity requirements. Additionally, female participants were excluded due to sex-related differences in body composition, hormonal profiles, and muscle-specific workload that may influence physiological responses to the exercise protocol. Restricting the sample to males was therefore intended to reduce potential biological variability and improve the internal consistency of the study population. An a priori power analysis was conducted using GPower 3.1 to determine the required sample size for a repeated-measures ANOVA. Based on a medium effect size (equivalent to Cohen's $f = 0.25$),¹⁵ with alpha set at 0.05, power ($1 - \beta$) at 0.80, and an assumed correlation of 0.50, the analysis indicated that a minimum of $N = 36$ was required. The final sample size ($N = 41$) exceeded the minimum required sample size and was sufficient to detect the anticipated effect. All participants provided written informed consent and completed a Physical Activity Readiness Questionnaire (PAR-Q) before participation, and the Institutional Review Board at Liberty University approved the protocol. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science.¹⁶ Participant demographics are presented in Table 1 as mean $\pm$ standard deviation.

Table 1. Participant demographics.

Age (yrs)	22.4 $\pm$ 4.1
Height (cm)	178.2 $\pm$ 7.6
Body mass (kg)	81.78 $\pm$ 2.7
Body fat %	14.6 $\pm$ 6.7

Protocol

This study employed a counterbalanced, within-subject crossover design. Each participant completed a PAR-Q and informed consent form to ensure understanding and agreement with the protocol and procedures. Participants completed two experimental conditions (2min and 4min active recovery) separated by 72 hours. Participants were assigned to alternating sequences (2min followed by 4min or 4min followed by 2min) to achieve a counterbalanced design and minimize potential order effects. Participants were instructed to refrain from exercise before the first test and during the 72-hour interval between tests to ensure adequate recovery. All testing sessions for each participant were conducted at approximately the same time of day (e.g., 8:00 am and 9:00am) to minimize within-participant variation due to diurnal effects. Testing procedures, equipment, and environmental conditions were standardized across participants and testing sessions, and consistent instructions and external encouragement were provided by the research team. Nutritional intake was not strictly controlled; participants were instructed to maintain their normal dietary, sleep, and hydration habits and to avoid atypical foods, supplements, or behaviors prior to testing. Anthropometrics were measured prior to testing. Standing height was measured using a wall-mounted stadiometer. Body mass and body composition (body fat %) were assessed using a bioelectrical impedance analyzer (InBody Co., Ltd., Seoul, Korea). Participants completed a self-paced warm-up (~5-10 minutes) to approximate conditions of their regular training sessions. Participants wore a heart rate monitor (Polar H10, Polar Electro Oy, Kempele, Finland) and were instructed on the Borg (6-20) RPE scale. Participants were then fitted with a face mask connected to a metabolic cart (ParvoMedics TrueOne 2400 metabolic cart) to measure gas exchange. Both treadmill tests used a modified version of the Costill/Fox Fast $\text{VO}_{2\text{max}}$ treadmill protocol.¹⁷ This protocol was selected due to its suitability for aerobically trained individuals and its running-specific incremental design, which is appropriate for $\text{VO}_{2\text{max}}$ assessment in this population. Speed increased incrementally each minute, first from 2.2 to 3.4 mph, then by 1.1

mph until 8.9 mph, where it remained constant. The incline increased by 2% every other minute thereafter. Upon reaching volitional exhaustion (Max1), the speed and grade of the treadmill were immediately reduced to 2.5 mph and 0% grade for an active recovery of either 2 or 4 minutes. Upon completion of the recovery period, the treadmill speed and grade were returned to the final workload achieved during Max1. Participants exercised once again to volitional exhaustion (Max2). Max1 served as the GXT for determination of $\text{VO}_{2\text{max}}$ using established maximal exertion criteria. Max2 served as a subsequent verification bout performed following active recovery, during which the highest obtained VO_2 value was recorded under identical conditions. Heart rate was monitored and recorded each minute, and RPE was recorded at the end of each stage as three separate ratings: overall RPE, leg RPE, and respiratory (breathing) RPE. Ventilation (VE) and RER were recorded every 30 seconds using the metabolic cart. RER values were recorded at the point of volitional exhaustion corresponding to $\text{VO}_{2\text{max}}$ across both exertions and recovery conditions. During each trial, maximal exertion was confirmed by meeting ≥ 2 of the following criteria: a plateau in VO_2 (defined as an increase of $<150 \text{ mL min}^{-1}$ with increasing workload), attainment of an $\text{RER} \geq 1.15$, achievement of $\geq 95\%$ of age-predicted HR_{max} , and an $\text{RPE} \geq 17$. HR_{max} was estimated using the traditional equation $(220 - \text{age})$.⁴ It is acknowledged, however, that age-predicted HR_{max} equations exhibit inter-individual variability and may not accurately reflect true maximal heart rate in all individuals.¹⁸

Statistical Analysis

Statistical analysis was completed using the IBM SPSS software (Version 31.0.1.0; IBM Corp., Armonk, NY, USA). Normality was assessed using Shapiro-Wilk tests. $\text{VO}_{2\text{max}}$ values were analyzed using a 2×2 repeated measures ANOVA with factors of Recovery Duration (2min vs 4min) and Exertion (Max1 vs Max2). Significant main effects and interactions were evaluated, with significance accepted at $p < 0.05$. When a significant interaction was observed, simple effects analyses were performed using paired-samples t-tests to compare Max1 and Max2 within each recovery condition (2min and 4min). HR, VE, RER, RPE, and time to exhaustion (TTE) were analyzed descriptively and presented as mean $\pm$ standard deviation for each condition. All analyses were performed using relative $\text{VO}_{2\text{max}}$ ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). A beneficial response was defined as any positive change in $\text{VO}_{2\text{max}}$ from Max1 to Max2, regardless of magnitude or statistical significance. Partial eta squared (η^2) was calculated as a measure of effect size for repeated-measures analyses to quantify the magnitude of differences between trials and conditions, with values interpreted as small (~ 0.01), medium (~ 0.06), and large (~ 0.14). Cohen's d for paired comparisons was calculated for significant and non-significant post-hoc comparisons using the paired-samples t statistic and interpreted as small (0.20), medium (0.50), and large (0.80) effects.

Results

Data are presented as mean $\pm$ standard deviation. Out of 41 participants, 36 benefited from a Booster Max test of either or both active recovery durations, but 5 people did not benefit from either. A 2×2 repeated measures ANOVA revealed no significant main effect of Recovery Duration, $F(1,40) = 0.15$, $p = 0.701$, $\eta^2 = 0.004$, but a significant main effect of Exertion, $F(1,40) = 7.05$, $p = 0.011$, $\eta^2 = 0.150$. The interaction between Recovery Duration and Exertion was also significant, $F(1,40) = 9.02$, $p = 0.005$, $\eta^2 = 0.184$. Post-hoc analyses revealed no significant difference between Max1 and Max2 in the 2min recovery condition ($t = -0.595$, $p = 0.555$, Cohen's d = 0.09). In contrast, $\text{VO}_{2\text{max}}$ was significantly higher in Max2 compared to Max1 in the 4min recovery condition ($t = -3.823$, $p < 0.001$, Cohen's d = 0.60). No significant difference was observed between recovery conditions at Max1 ($t = 1.693$, $p = 0.098$) or at Max2 ($t = -1.243$, $p = 0.221$). Descriptive means are

presented in Tables 2 and 3. RER values were lower during Max2 compared to Max1 across both recovery conditions. Additionally, individual data suggest that 63.4% of subjects demonstrated a positive response (+ 2.22 mL/kg/min) from the 2min active recovery, whereas 75.6% of subjects demonstrated a positive response (+ 2.94 mL/kg/min) from the 4min active recovery. Only 5 out of 41 (12.2%) did not improve with either Booster Max test.

Table 2. Booster Max results (2min).

	Max1	Max2
VO _{2max} (mL/kg/min)	53.35 ± 8.55	53.58 ± 8.99
HR _{max} (bpm)	192.61 ± 6.63	191.8 ± 7.14
RER	1.10 ± 0.07	0.95 ± 0.06
TTE (seconds)	627.21 ± 173.90	96.50 ± 25.20

Table 3. Booster Max results (4min).

	Max1	Max2
VO _{2max} (mL/kg/min)	52.56 ± 8.71	54.7 ± 8.84
HR _{max} (bpm)	192.68 ± 6.94	192.17 ± 7.18
RER	1.12 ± 0.07	0.95 ± 0.08
TTE (seconds)	618.45 ± 192.68	108.93 ± 28.73

Note. Values are presented as mean ± standard deviation. VO_{2max} = maximal oxygen consumption; TTE = time to exhaustion; HR_{max} = maximal heart rate; RER = respiratory exchange ratio.

Discussion

Assessing cardio-respiratory fitness is important for tracking progress and guiding training. Implementing a Booster Max test may result in higher VO_{2max} values in some individuals. Previous studies included division I-III athletes, cross-country runners, basketball players, and soccer players.⁸⁻¹⁴ This current study examined physically active non-athletes, a group that has been sparsely studied in this field of research. Additionally, a 4min Booster Max test has not been previously investigated. The purpose of this study was to determine whether a 4min active recovery following a treadmill GXT allows participants to achieve a higher VO_{2max} in a subsequent Booster Max test when compared to a 2min recovery protocol. Individual and mean group results showed that aerobically fit males achieved higher VO_{2max} scores from Max1 to Max2, suggesting that a Booster Max test may influence observed VO_{2max} values in some individuals across repeated maximal efforts. Both Booster Max tests improved VO_{2max}, but 31 of 41 subjects (75.6%) demonstrated a positive response following the 4min Booster Max test and 26 of 41 (63.4%) demonstrated a positive response following the 2min Booster Max test. Previous studies using a 2min Booster Max test in athletes did not achieve statistically significant mean group differences.^{12, 14, 19} Despite non-significant results between groups, VO_{2max} values were higher during Max2 than Max1 for the majority, showing individual improvements with the addition of a Booster Max test. RER values were obtained at volitional exhaustion and corresponded to the highest attained VO₂ value in each trial. Although mean RER values during Max2 were below traditional secondary maximal exertion thresholds, attainment of maximal effort was supported by additional established criteria including a VO₂ plateau, RPE of ≥17, and ≥95% age-predicted HRmax.

Individual variability occurred in response to both Booster Max tests, with some participants demonstrating substantial increases in VO_{2max}, while others showed minimal changes. A beneficial response was defined as any positive change in VO_{2max} from Max1 to Max2, regardless of magnitude. This approach does not account for typical measurement variability or biological

variation inherent to $\text{VO}_{2\text{max}}$ testing and may therefore overestimate the number of meaningful responses. Differences in aerobic training background may have influenced recovery, as training status can affect recovery kinetics and tolerance to repeated maximal exercise efforts.²⁰ Moderately trained individuals reported that a 4min recovery was more favorable, whereas more highly trained individuals had mixed preferences, regardless of differences in $\text{VO}_{2\text{max}}$. Subject effort and tolerance to fatigue may have also contributed to performance outcomes, although RPE values were consistent with maximal effort across trials.

Extrinsic motivation, equipment calibration, test preparation, and testing environment remained constant across all testing sessions. Despite standardized conditions, individual responses varied. Several factors may have contributed to the observed results. Although the active recovery period may have facilitated partial physiological recovery between bouts, residual peripheral fatigue may still have influenced performance during Max2. The relative contribution of metabolic recovery and peripheral fatigue was not assessed in the present study. Phosphocreatine (PCr) resynthesis occurs rapidly following high-intensity exercise but is not fully restored within the early recovery period ($\leq 2\text{--}4$ min),²¹⁻²³ and training status has been associated with faster PCr resynthesis and improved recovery between repeated high-intensity exercise bouts.²⁴⁻²⁷ These physiological factors may help explain why some individuals are able to achieve similar or higher $\text{VO}_{2\text{max}}$ values during a subsequent bout following a short recovery period. Variability in responses may have also been related to protocol features, including one-minute stages or intensity, but this was observed descriptively rather than tested statistically. Finally, while verbal encouragement remained consistent, intrinsic motivation may have varied between participants and across testing days, contributing to individual differences in performance.

The results of this current study were comparable to previous Booster Max studies.⁸⁻¹¹ It should be noted that a portion of the existing Booster Max literature is derived from conference abstracts, posters, and theses, reflecting the emerging and limited nature of peer-reviewed research in this area. The results have practical implications for both research and applied exercise testing. Administering a Booster Max test may help elicit higher $\text{VO}_{2\text{max}}$ values in physically active males compared to a traditional single-stage GXT, which is critical for monitoring aerobic fitness and evaluating the effectiveness of training interventions. Even small improvements in measured $\text{VO}_{2\text{max}}$ may provide meaningful insight into an individual's aerobic capacity.

Oxygen delivery capacity during exercise is a primary limiting factor for $\text{VO}_{2\text{max}}$, influenced by genetics and training variability, including type, variety, and frequency of training.¹ The results are applicable only to physically active male individuals. Booster Max testing has not been studied in novice athletes, the general population, or children and adolescents. Despite adequate recovery between trials, peripheral fatigue may have impacted performance. Nutritional status was not strictly controlled; participants were advised to maintain habitual eating habits and avoid unfamiliar foods or supplements prior to testing. Other potential limitations included stress, sleep quality and quantity, internal motivation, and familiarity with the testing procedures and equipment (e.g., mask and treadmill), which may have influenced performance during subsequent testing sessions. No familiarization session was conducted prior to testing, and therefore improvements observed during subsequent trials may partially reflect familiarization effects related to the treadmill protocol, testing equipment, or Booster Max procedure. A beneficial response was defined as any positive change in $\text{VO}_{2\text{max}}$ from Max1 to Max2, which does not account for typical measurement variability or biological variation inherent to $\text{VO}_{2\text{max}}$ testing and may affect the interpretation of responder classification. Future research should

consider incorporating typical error and smallest worthwhile change approaches to better define meaningful changes in $\text{VO}_{2\text{max}}$ and improve classification of positive responses.

This study demonstrated that while recovery duration alone did not significantly influence $\text{VO}_{2\text{max}}$, a significant interaction between recovery condition and exertion indicated that changes in $\text{VO}_{2\text{max}}$ from Max1 to Max2 differed between conditions, with a greater increase following the 4-minute active recovery in this sample. These findings suggest that recovery duration may influence the magnitude of change observed during a Booster Max protocol in certain individuals.

In applied exercise testing settings, incorporating a Booster Max protocol may provide additional information regarding an individual's aerobic performance across repeated maximal efforts compared to a traditional single-stage $\text{VO}_{2\text{max}}$ test. However, these effects were dependent on the interaction between recovery duration and exertion, suggesting that recovery duration may influence individual responses rather than producing uniform improvements. Practitioners should be aware that recovery duration may influence observed maximal values in some individuals; however, either 2min or 4min active recovery protocols may be appropriate depending on testing context and participant characteristics. Future research should further examine the influence of training status, sex, age, and motivational factors on Booster Max responses.

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