Evaluation of High-Intensity Interval Training and Beta-Alanine Supplementation on Efficiency of Electrical Activity and Electromyographic Fatigue Threshold

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Abstract

Herda, AA, Smith-Ryan, AE, Kendall, KL, Cramer, JT, and Stout, JR. Evaluation of high-intensity interval training and beta-alanine supplementation on efficiency of electrical activity and electromyographic fatigue threshold. *J Strength Cond Res* 35(6): 1535–1541, 2021—The purpose of this study was to determine the effects of high-intensity interval training (HIIT) with or without β-alanine (BA) supplementation on the electromyographic fatigue threshold (EMG_{FT}) and efficiency of electrical activity (EEA) in young women. Forty-four women (mean ± *SD*; age [yrs]: 21.7 ± 3.7; height [cm]: 166.3 ± 6.4; body mass [kg]: 66.1 ± 10.3) were randomly assigned to one of 3 treatment groups. The supplement groups performed HIIT on the cycle ergometer 3 times·wk^{-1} for 6 weeks. Electromyographic fatigue threshold and EEA were assessed at baseline (PRE), after 3 weeks of training (MID), and after 6 weeks of HIIT (POST). Two 2-way mixed factorial analyses of variance (time [PRE vs. MID vs. POST] × treatment (BA vs. PL vs. CON)] were used to analyze EMG_{FT} and EEA with a predetermined level of significance α of 0.05. For EMG_{FT}, there was no interaction ($p = 0.26$) and no main effect for time ($p = 0.28$) nor treatment ($p = 0.86$); thus, there were no changes in EMG_{FT} regardless of training or supplementation status. For EEA, there was no interaction ($p = 0.70$) nor treatment ($p = 0.79$); however, there was a main effect for time ($p < 0.01$). Our findings indicated that neither training nor supplementation was effective in improving EMG_{FT} in women. Efficiency of electrical activity was altered, potentially because of a learning effect. Coaches and practitioners may not use these tests to monitor training status; however, they may find EEA as a useful tool to track cycling efficiency.

Key Words: fatigue, nutrition, aerobic exercise, HIIT

Introduction

High-intensity interval training (HIIT) is a popular training modality often used to maximize cardiovascular benefits in a relatively short amount of time compared with moderate-intensity continuous training (10). Several strategies for incorporating HIIT into a routine have been effectively implemented, including but not limited to short (5–30 seconds) repeated sprint intervals, moderate (1–2 minutes), or longer (2–4 minutes) intervals (3,6,10). However, interval durations of greater than one minute seem to be the most beneficial in enhancing these adaptations (6,40) and sufficient rest periods (29). Many of the reported benefits of chronic HIIT include increased maximal oxygen uptake ($\dot{V}O_2$peak) (20,25,31,40), lipid mobilization (20,36), and improved hydrogen ion (H^+) buffering capacity (6) due to repeated acute intramuscular changes (16,38). Of the reported benefits of HIIT, improving the intramuscular buffering capacity of H^+ is essential for delaying fatigue during high-intensity exercise (6).

Furthermore, improved intramuscular buffering capacity can be enhanced from many exogenous ergogenic aids including L-arginine, β-alanine, sodium bicarbonate, and sodium citrate (34). β-Alanine (BA), specifically, has been investigated extensively with several positive reports on aerobic performance. Studies have reported that BA supplementation alone can delay fatigue during exercise and improve performance (13,37), which is likely due to higher intramuscular carnosine levels improving H^+ accumulation buffering capacity (13). However, all of these reports have been conducted in trained individuals and men (7,8,13,14,18), leaving curiosity about whether these responses can be duplicated in women with the recommended loading (6.4 g·d^{-1}) and maintenance (3.2 g·d^{-1}) dose (12). Women have been reported to have a lower intramuscular concentration of carnosine (23) and may need a longer loading phase to maximize carnosine stores. It has also been suggested that sprint exercise training alone may increase muscle carnosine concentrations (8,35), although not all studies have reported this effect (18,24). What remain unclear is how neuromuscular fatigue may be attenuated and whether the combination of high-intensity exercise training and BA supplementation may affect exercise performance through mildly chronic (6 weeks) adaptations, specifically, in women.

A noninvasive means to identify the onset of neuromuscular fatigue is through surface electromyography (EMG) (1,2) and is

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commonly used to assess various aspects of muscle function and even dysfunction (19). Surface EMG represents a global pool of motor unit firing rates and recruitment under the surface area of secured electrodes. Electromyography fatigue threshold (EMG_{FT}) has been investigated extensively and has been reported to improve after HIIT in men (17,30), after supplementation of BA in men and creatine monohydrate in women (30,32), and is reliable over time with no intervention (22). However, these studies primarily use men as the target subject and often are conducted in moderately trained individuals. Thus, in theory, the EMG_{FT} should be sensitive to chronic adaptations caused by HIIT, BA supplementation, or a combination of the two. We have hypothesized that EMG_{FT} or work rate at which an individual could theoretically sustain for a prolonged duration without neuromuscular evidence of fatigue could be improved with anaerobic training or aerobic ergogenic supplements, such as HIIT and BA, respectively. The addition of HIIT, which also promotes improved aerobic performance, would purportedly be synergistic. Although this has been demonstrated in men, additional research is needed to evaluate further in women. Consequently, the purpose of this study was to determine the effects of HIIT with or without BA supplementation on EMG_{FT} and efficiency of electrical activity (EEA) in young women.

Methods

Experimental Approach to the Problem

This study was conducted in a randomized, double-blind, placebo-controlled, parallel design over 9 weeks. All testing included a maximal graded exercise test (GXT) on a cycle ergometer with open-circuit spirometry to determine maximal oxygen uptake ($\dot{V}O_2peak$) and an intermittent cycle ergometer test to determine EMG_{FT}. The EMG_{FT} was administered 2 times with 3–5 days of rest between to account for familiarization of the study methods. After baseline testing (PRE), all subjects were randomly assigned to one of 3 treatment groups: β-alanine (BA, $n = 12$), placebo (PL, $n = 18$), or control (CON, $n = 11$). The BA and PL groups were given supplements, but the CON group did not engage in exercise training or ingest any supplements for the duration of the study. The BA and PL groups performed HIIT on the cycle ergometer 3 times per week for a total of 6 weeks, and subsequent testing was conducted for all groups after the first 3 weeks of HIIT (MID) and after an additional 3 weeks of HIIT (POST).

Subjects

Forty-four healthy, recreationally active (1–5 hours of exercise· per week) women (18-34 years old) volunteered for this investigation and 41 completed the trial (Table 1). All subjects were informed of the study risks and benefits and signed a written form of informed consent as approved by the University of Oklahoma institutional review board for the protection of human subjects before any testing. The University of Oklahoma IRB approved the study. Supplement history was also recorded, and none of the subjects had taken any nutritional supplements within 9 weeks before their initial testing date. All subjects also provided a self-reported health history and exercise status in which they were determined to be recreationally active, not sedentary, and free of any neuromuscular, musculoskeletal, cardiovascular, or metabolic conditions. All subjects were familiar and comfortable with cycling on a stationary bike. Subject attrition included lack of time to commit ($n = 2$) and supplement interaction ($n = 1$). The study was not registered in a clinical trial database at the time of data collection.

Procedures

Graded Exercise Test. Graded exercise test was completed to determine the maximal work rate needed to calculate power output (watts) for training and to identify the work rate at which the gas exchange threshold (GET) occurred (GET_W) to identify the work rate for the EMG_{FT} test. Gas exchange threshold was identified by the metabolic software using the V-slope method as presented by Schneider et al. (28). The GXT was completed on an electronically braked cycle ergometer (Lode, Groningen, Netherlands). Before any bike tests, subjects' seat height was adjusted to ensure a 5° flexion of the knee joint at the bottom of the pedal stroke and was recorded for subsequent training and testing sessions. Manufacturer-provided straps were used to secure the feet to the pedals. Methods of the $\dot{V}O_2peak$ test were previously reported by Walter et al. (40), but in brief, subjects were instructed to pedal at 70 rpm using a step protocol. After a 5-minute warm-up at 50 W, the work rate increased 25 W every 2 minutes until the subject could no longer maintain 60 rpm (volitional exhaustion). Throughout the GXT, expired respiratory gases were collected and monitored using a metabolic cart (Parvo Medics, TrueOne 2400 Metabolic Measurement System, Sandy, UT), and GET was identified as the breaking point of ventilation (VE)/$\dot{V}O_2$, as previously reported (40). The work rate (in watts) obtained at $\dot{V}O_2peak$ (W_{MAX}) was subsequently used in determination of the training work rate (40). In addition, the work rate achieved at GET (GET_W) was used as the starting work rate for the EMG_{FT}. The test-retest reliability for the $\dot{V}O_2peak$ protocol, using 21 men and women, demonstrates a reliable 24-hour test-retest with an intraclass correlation coefficient (ICC) of 0.972 ($SEM = 0.261\ L{\cdot}min^{-1}$) and coefficient of variation of 5.2%.

Electromyographic Fatigue Threshold

Electrode Placement and Instrumentation. Bipolar surface electrode (2.54 cm center-to-center) (Quinton Quik-Prep silver-silver chloride, Quinton Instruments Co., Bothell, WA) arrangements were placed on the right thigh over the lateral portion of the vastus lateralis muscle, midway between the greater trochanter and the lateral condyle of the femur (33). A single reference electrode was placed over the spinous process of the seventh cervical vertebrae. Interelectrode impedance was kept below 5,000 Ω by careful abrasion of the skin. The raw EMG signals were preamplified (gain × 1,000) using a differential amplifier (EMG 100C, Biopac Systems, Inc., Santa Barbara, CA) sampled at 1,000 Hz and band-pass filtered from 10 to 500 Hz (zero-lag eighth-order Butterworth filter). All raw EMG amplitude values were stored on a personal computer (Dell Inspiron 8200, Dell, Inc., Round Rock, TX) and were analyzed offline using custom written software (LabVIEW v 7.1, National Instruments, Austin, TX).

Electromyographic Fatigue Threshold Procedure. The EMG_{FT} was determined using the EMG amplitude values from the vastus lateralis muscle while cycling on an electronically braked cycle ergometer (Quinton Corival 400, Lode Medical Technology, Groningen, Holland) using the prerecorded seat height from the subjects' GXT. After a 5-minute warm-up at 50 W, the subjects performed 4, 120 seconds incrementally ascending work rates (range: 75–300 W) based on their most recently determined GET_W at a set cadence of 70 rpm. The GET_W was identified using the GET work rate during a $\dot{V}O_2peak$ test, as previously described (40). As $\dot{V}O_2peak$ changed with training adaptations, the GET_W was altered and the newly established GET_W was used in subsequent EMG_{FT} procedures. For example, if the GET occurred at 75 W, the initial work rate was set at

Table 1
Subject characteristics represented as mean and *SD* for all subjects in each treatment group.

	n	Age (y)	Height (cm)	Body Mass (kg)	$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})
β-Alanine	12	21.5 (2.4)	164.8 (6.2)	64.8 (12.2)	31.8 (6.0)
Placebo	18	21.7 (4.4)	167.0 (5.4)	67.9 (9.7)	30.5 (5.1)
Control	11	22.2 (4.1)	167.8 (8.9)	63.7 (11.1)	32.3 (8.0)

75 W for the EMG_{FT} and the subsequent work rates were 100, 125, and 150 W. Furthermore, after MID $\dot{V}O_2$peak assessment, if the GET occurred at 100 W, subsequent work rates were set at 125, 150, and 175 W for MID EMG_{FT}. Adequate rest (≥10 minutes) was given between bouts to allow subjects' heart rate to drop within 10 beats of their resting heart rate. This test was performed 2 times at the PRE time point, the first acting as a familiarization trial, with 1–2 days of rest in between trials.

Determination of Electromyographic Fatigue Threshold. The rate of rise in EMG amplitude values over time (EMG slope) from the 4 supramaximal power outputs was plotted over 120 seconds as previously described (39). Then the EMG slope coefficients were plotted against each of the 4 power outputs to determine EMG_{FT} (Figure 1). The line of best fit was extrapolated to the y-axis and the power output at which it intersected was defined as the EMG_{FT}. The test-retest reliability for the EMG_{FT} protocol was determined in our laboratory using 10 healthy male and female subjects measured 7–8 days apart. The ICC was 0.94 (*SEM* 5.03 W), which was higher than previously reported for the vastus lateralis (ICC = 0.65) by Pavlet et al. (27).

Efficiency of Electrical Activity. The mean of the slopes across the 4 work rates was calculated and identified as the EEA as described by deVries (9), where a lower EEA represents a better trained individual and valid metrics can be obtained with submaximal intensities. The original methodology was proposed using isometric contractions rather than dynamic, such as cycling, until Housh et al. (15) examined whether EEA was significantly related to critical power. Following similar methods as Smith et al. (30), EMG slopes were calculated in response to the four various work rates per individual per time point and compared between trials and treatment groups (Table 2).

Training Protocol. After PRE testing, subjects were required to visit the laboratory on 3 nonconsecutive days per week for 3 weeks to perform the HIIT. After the first 3 weeks of HIIT, subjects' $\dot{V}O_2$peak, GET_W, and EMG_{FT}, were reassessed followed by another 3 weeks of HIIT training with an increased volume and intensity from the initial training period as presented by Walter et al. (40). Posttesting occurred after the final 3 weeks of HIIT training. All HIIT was performed on the same cycle ergometer adjusted to the previously recorded seat height. Subjects warmed up at 50 W for 5 minutes followed by five, 2-minute exercise bouts at a predetermined percentage of their $\dot{V}O_2$peak work rate using a fractal periodization scheme. The intervals began at 90% of the work rate obtained at $\dot{V}O_2$peak and increased 5% every other training session back down to 90% in an undulating manner up to 115% by training week 6, as described in Walter et al. (40). One minute of passive recovery was allowed between each set. Training compliance was documented, and any individual failing to complete >80% of their training sessions (n = 2) was removed from the study and subsequent data analysis.

Supplementation Protocol. After PRE testing, subjects were randomly assigned to either the β-alanine (BA), placebo (PL), or control (CON) group. Subjects in the BA and PL groups received unlabeled white packets containing the supplement. In the first 3 weeks of supplementation and training, the subjects were instructed to consume the packet's contents 4 times per day for 21 days in water. β-alanine loading has been recommended at 6.4 g per day for at least 3 weeks, followed by a maintenance dose of 3.2 g per day (12). The BA group consumed a flavored powder blend of 1.5 g of β-alanine and 15 g of dextrose in 4–8 ounces of water, whereas the PL group consumed an identically flavored powder containing 16.5 g of dextrose. Subjects consumed 2 doses

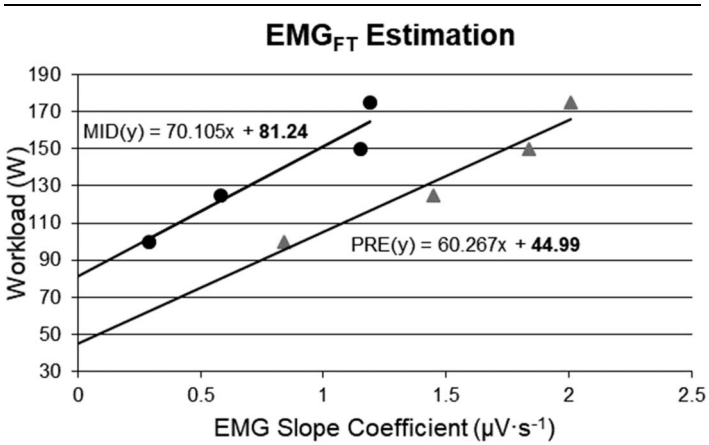

Figure 1. Electromyographic fatigue threshold (EMG_{FT}) determination example for PRE and MID for one subject. The relationship between EMG amplitude and time for the 4 power outputs used in the EMG_{FT} test where the greatest slope point was a result from the highest power output. The line of best fit depicts the relationship for the power outputs versus slope coefficients with the y-intercept defined as the EMG_{FT}.

Table 2

EMG_{FT} work rates (in watts) subjected to each subject at all time points.*

	PRE					MID					POST				
	W1	W2	W3	W4		W1	W2	W3	W4		W1	W2	W3	W4	
Placebo	75	100	125	150	↑	100	125	150	175	=	100	125	150	175	
	100	125	150	175	↑	125	150	175	200	=	125	150	175	200	
	100	125	150	175	↑	125	150	175	200	↓	100	125	150	175	
	100	125	150	175	↑	125	150	175	200	↑	150	175	200	225	
	100	125	150	175	↑	150	175	200	225	↓	125	150	175	200	
	100	125	150	175	↑	150	175	200	225	↓	125	150	175	200	
	100	125	150	175	↑	125	150	175	200	↓	100	125	150	175	
	100	125	150	175	↑	125	150	175	200	↓	75	100	125	150	
	100	125	150	175	↓	75	100	125	150	↑	150	175	200	225	
	100	125	150	175	=	100	125	150	175	↑	150	175	200	225	
	125	150	175	200	↓	100	125	150	175	↑	150	175	200	225	
	100	125	150	175	↑	125	150	175	200	=	125	150	175	200	
	125	150	175	200	↑	150	175	200	225	↑	175	200	225	250	
	175	200	225	250	↑	200	225	250	275	=	200	225	250	275	
	150	175	200	225	↓	125	150	175	200	↑	150	175	200	225	
	75	100	125	150	↑	150	175	200	225	=	150	175	200	225	
	125	150	175	200	=	125	150	175	200	↑	150	175	200	225	
	100	125	150	175	↑	125	150	175	200	=	125	150	175	200	
B-Alanine	75	100	125	150	↑	125	150	175	200	↑	150	175	200	225	
	75	100	125	150	=	75	100	125	150	↑	100	125	150	175	
	100	125	150	175	=	100	125	150	175	=	100	125	150	175	
	125	150	175	200	↑	150	175	200	225	=	150	175	200	225	
	100	125	150	175	↑	125	150	175	200	=	125	150	175	200	
	75	100	125	150	=	75	100	125	150	↑	125	150	175	200	
	100	125	150	175	↑	125	150	175	200	=	125	150	175	200	
	100	125	150	175	=	100	125	150	175	=	100	125	150	175	
	100	125	150	175	↑	125	150	175	200	↓	100	125	150	175	
	100	125	150	175	=	100	125	150	175	=	100	125	150	175	
	75	100	125	150	↑	100	125	150	175	=	100	125	150	175	
	100	125	150	175	↑	150	175	200	225	↓	100	125	150	175	
Control	150	175	200	225	↑	175	200	225	250	↑	200	225	250	275	
	75	100	125	150	=	75	100	125	150	↑	175	200	225	250	
	125	150	175	200	=	125	150	175	200	↑	150	175	200	225	
	125	150	175	200	↑	150	175	200	225	↓	125	150	175	200	
	100	125	150	175	=	100	125	150	175	=	100	125	150	175	
	75	100	125	150	=	75	100	125	150	=	75	100	125	150	
	125	150	175	200	↓	100	125	150	175	=	100	125	150	175	
	75	100	125	150	=	75	100	125	150	=	75	100	125	150	
	75	100	125	150	=	75	100	125	150	=	75	100	125	150	
	125	150	175	200	↓	75	100	125	150	↑	100	125	150	175	
	100	100	125	150	=	100	125	150	175	↓	75	100	125	150	

*Symbols indicate an increase (↑), decrease (↓), or no change (=) in the work rate from the subsequent testing session. Familiarization and PRE were identical for work rates.

in the laboratory on training days: 30 minutes before and immediately after each training session. The remaining 2 doses were taken outside the laboratory later that day at the subject's leisure where all consumed doses were recorded on a dosing log. On nontraining days, subjects were asked to mix and consume their supplements on their own 4 times per day. After MID testing, the subjects were instructed to consume the packet contents 2 times per day for 21 days (maintenance) in water. Compliance with the supplementation protocol was documented, and any individual falling below 70% consumption was considered noncompliant and excluded from analysis. No subjects were removed for noncompliance of supplementation as none fell below this threshold. Any incidence of unmasking the BA, from reported paresthesia, was noted, but neither the dose nor administration was changed unless a subject felt adverse regarding the sensation ($n = 1$), in which case the subject voluntarily withdrew from participating. The CON group participated only in the assessments at familiarization, PRE, MID, and POST to monitor repeat testing sessions' learning effect. A flowchart presenting recruitment, allocation, and participation is depicted in Figure 2.

Statistical Analyses

Two, 2-way mixed factorial analyses of variance (ANOVAs) (time [PRE vs. MID vs. POST] × treatment [BA vs. PL vs. CON]) were used to analyze the effect of HIIT and supplementation on EMG_{FT} and EEA. Interactions would be further decomposed to evaluate group differences at each time point and additional one-way ANOVAs to identify time-specific changes within each group with post hoc analyses. In addition, Pearson product-moment correlation (r) was calculated to identify the relationship between GET_W and EMG_{FT}. Before all statistical analyses, the alpha level was set to $p \leq 0.05$ to determine statistical significance. Data were analyzed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corporation, Armonk, NY).

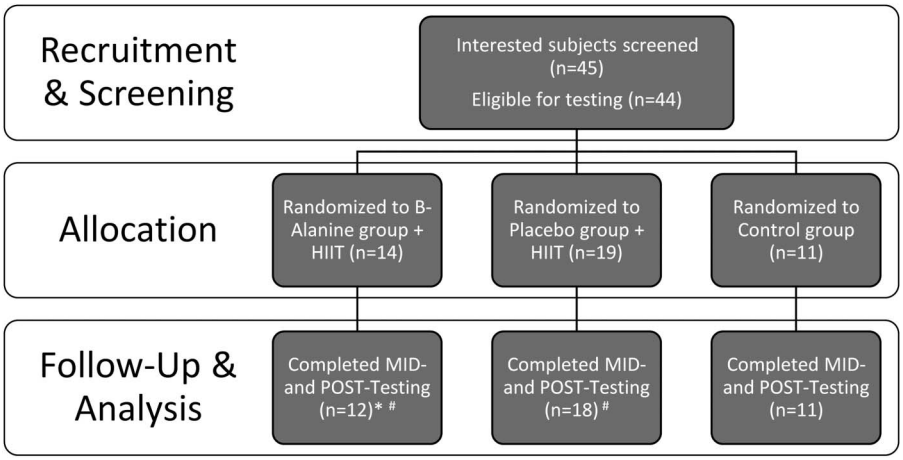

Figure 2. Study design and subject flow diagram. *1 subject withdrew due to adverse effect of paresthesia; #2 subjects were dropped due to non-compliance of testing schedule. HIIT = high-intensity interval training.

Results

Two-way mixed factorial results for EMG_{FT} indicated there was no significant interaction for treatment group × time ($F_{4,76} = 1.346$; $p = 0.26$; effect size: partial eta-squared ($\eta_p^2 = 0.066$), no main effect for time ($F_{2,76} = 1.346$; $p = 0.28$; $\eta_p^2 = 0.033$), and no main effect for treatment ($F_{2,38} = 0.148$; $p = 0.86$; $\eta_p^2 = 0.008$). Efficiency of electrical activity indicated no significant interaction ($F_{4,76} = 0.498$; $p = 0.70$; $\eta_p^2 = 0.032$) and no main effect for treatment ($F_{2,38} = 0.143$; $p = 0.79$; $\eta_p^2 = 0.009$). However, there was a main effect for time ($F_{2,76} = 5.398$; $p = 0.007$; $\eta_p^2 = 0.152$) where post hoc analyses indicated all groups improved EEA from PRE to MID ($p = 0.03$) but no additional change at POST ($p > 0.05$). Electromyographic fatigue threshold and EEA are presented in Table 3 for each treatment group at each time point, including the familiarization. The correlation between EMG_{FT} and GET_W indicated positive and significant relationships at PRE ($r = 0.760$, $p < 0.001$), MID ($r = 0.433$, $p = 0.004$), and POST ($r = 0.514$, $p < 0.001$). Individual response plots for EMG_{FT} and EEA are provided in Figure 3 displaying the variability of the subject's responses.

Discussion

This study was the first to examine HIIT's effects with and without BA supplementation on EMG_{FT} in healthy college-aged women and indicated no significant difference in EMG_{FT} among treatment groups. The EEA was also examined, and all groups improved EEA from PRE to MID regardless of the intervention or treatment implemented. Efficiency of electrical activity decreased (better efficiency) for all individuals regardless of the intervention they were randomized to, suggesting there may have been a learning effect on the EMG_{FT} procedure.

We have previously reported improvements in $\dot{V}O_2$peak and GET after 3 and 6 weeks of HIIT in college-aged women (40). In this study, the intensities of the work rates used during the EMG_{FT} test were established based on the GET_W from the GXT, where work rates ranged from 75 to 300 watts. From the familiarization trial, EMG_{FT} work rates remained constant for PRE trials. Subsequently, the work rate was modified up or down to reflect the respective change in GET_W. The individual work rates used for the EMG_{FT} trials at PRE, MID, and POST are reported in Table 2. The percent change scores of 5.8%, −2.1%, and 11.3% from PRE to MID; −8.7, 11.3, 4.7% from MID to POST; and −3.3, 9.0, and 16.5% from PRE to POST for BA, PL, and CON, respectively, indicate that the EMG_{FT} test may be less sensitive in determining neuromuscular changes after 6 weeks of HIIT and β-alanine supplementation, which is in agreement with Kendall et al. (17). Furthermore, EMG_{FT} has been reported to be reliable in a nonintervention setting (22), however, less sensitive to tracking changes with effective interventions (26). Cycling is a common means of exercise in the college-aged population, as the university offers a variety of indoor cycling classes in addition to students cycling in and around campus for transportation and recreation.

Under similar testing conditions, it has been reported that no significant changes occurred in EMG_{FT} with creatine supplementation in men (39). On the contrary, Smith et al. indicated improvements in EMG_{FT} after creatine (32) and β-alanine supplementation (30) in women and men, respectively. If the fatigue threshold or work rate at which an individual could theoretically sustain for a long duration without neuromuscular evidence of fatigue could be improved with anaerobic or aerobic ergogenic supplements, then the addition of HIIT, which also promotes improved aerobic performance, would purportedly be synergistic. However, that is not what our results indicated. A higher

Table 3

Group mean ± (*SE*) for EMG_{FT} and EEA.*

		EMG_{FT} (W)				EEA ($\mu V \cdot s^{-1}$)		
	n	Fam	PRE	MID	POST	PRE	MID	POST
β-Alanine	12	104.2 ± 6.3	110.5 ± 6.5	116.9 ± 4.7	106.8 ± 8.9	1.1 ± 0.3	0.3 ± 0.2†	0.5 ± 0.1†
Placebo	18	112.6 ± 7.2	115.4 ± 9.4	112.9 ± 8.7	125.7 ± 7.4	1.1 ± 0.4	0.6 ± 0.2†	0.5 ± 0.1†
Control	11	121.2 ± 10.6	105.4 ± 13.4	117.4 ± 16.6	122.9 ± 11.9	1.0 ± 0.2	0.7 ± 0.2†	0.8 ± 0.2†

*EMG_{FT} = electromyographic fatigue threshold; EEA = efficiency of electrical activity.
†Indicates a difference from PRE ($p < 0.05$).

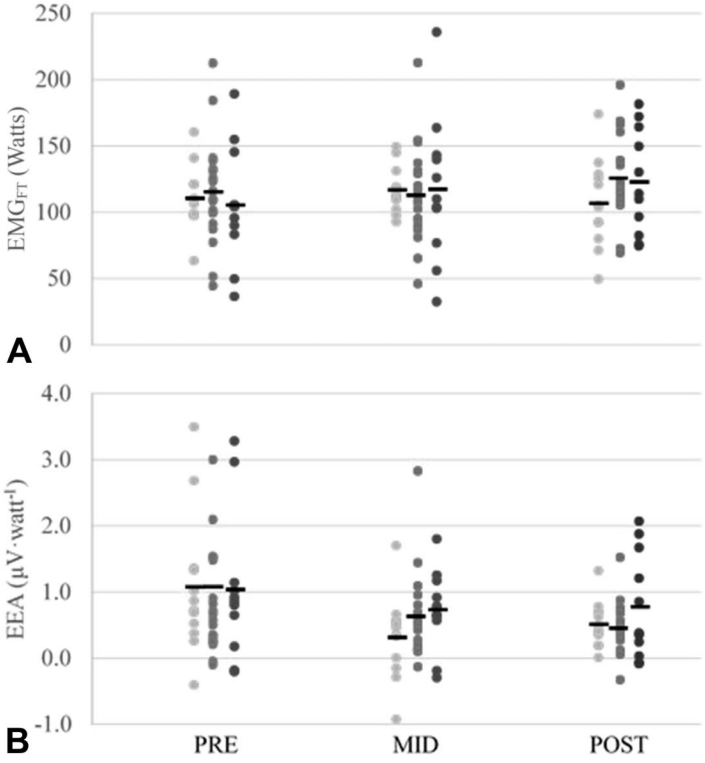

Figure 3. Individual (A) EMG_{FT} and (B) EEA responses represented across time points for all groups (BA: light gray; PL: med gray; CON: dark gray). The black dash in each column represents the group mean. EMG_{FT} = electromyographic fatigue threshold; EEA = efficiency of electrical activity; BA = β-alanine; PL = placebo; CON = control.

work rate would increase the demand of the working muscle; thus, EMG activity should increase throughout a high-intensity bout of cycling exercise in the quadriceps muscles (4,5), specifically, the VL. Subsequently, if a work rate is less demanding the rate of rise in EMG activity would be reduced, decreasing the slope of the extrapolated line to a potentially greater EMG_{FT}. Consequently, this is not the case in this study.

The HIIT protocol used a 2:1 work-to-rest ratio using 2-minute active cycling and 1-minute passive rest to mimic the duration of the $\dot{V}O_2$peak protocol and the 4 EMG_{FT} work duration bouts, as we were trying to maintain consistency with the duration of active cycling time. Maclaren et al. (21) suggested the decreases in muscle pH due to maximal exercise may be responsible for fatigue-induced increases in motor unit recruitment and the corresponding increase in EMG amplitude as represented with a greater slope coefficient at higher work rates. To complement the HIIT-induced improvements in intramuscular buffering capacity, β-alanine supplementation has also been reported to increase buffering capacity by increasing carnosine concentration in various athletes (7,14). The hypothesized resultant HIIT-induced performance (reduced fatigue) and synergistic BA response would theoretically result in a diminished pH response to exercise. The lower EMG response slopes corresponding to the respective work rates across all groups were not evident, as EMG_{FT} remained unchanged for all groups over the 9 weeks study duration in this study. Furthermore, women have been reported to have lower intramuscular carnosine than men (23) and may have an altered intramuscular response to BA loading and maintenance as there was no difference from the groups that did not supplement.

We have previously reported an increase in GET_W in the HIIT-trained groups (40), and adjusting the EMG_{FT} test work rates based on these responses could be speculated to alter the EMG_{FT} and EEA responses up or down to reflect the different work rates used. To maintain the EMG_{FT} protocol's consistency, the current study adjusted work rates for EMG_{FT} based on training adaptations rather than maintaining the 4 work rates from the PRE trial, however, some remained the same as indicated in Table 2. To elaborate, if the GET_W increased or decreased, the initial work rate of the EMG_{FT} was adjusted accordingly instead of staying the same as the work rates used during PRE. It seems that the higher initial workloads for the subsequent EMG_{FT} test presented higher EMG_{FT} scores, and 31.2% of the variability in EMG_{FT} can be accounted for by changes in GET_W. Related, the EEA seems to have reflected this shift as well. The overall correlation between these 2 variables indicated a positive ($r = 0.559$) and significant ($p < 0.001$) relationship. Electromyographic fatigue threshold was initially tested twice, on separate days to factor any learning effect (11). Both of the PRE EMG_{FT} (familiarization and PRE) were based on one single $\dot{V}O_2$peak assessment at PRE. However, the decrease in EEA from PRE to MID for all subjects may indicate a further learning effect, separate from the familiarization trial for improved electrical efficiency regardless of intervention or CON. The present limitations include how the work rate for the EMG_{FT} test was based on the newly recorded GET_W from the $\dot{V}O_2$peak tests, rather than remaining constant throughout the study duration. An additional limitation would be the lack of monitoring the control group (that did not participate in HIIT). They were instructed to maintain their usual activity but were not asked to record exercise volume (aerobic or anaerobic) and, therefore, may have been training, directly impacting the current study's internal validity due to lack of external control.

Practical Applications

Electromyographic fatigue threshold theoretically represents the power output that can be sustained without indication of neuromuscular fatigue. This study did not report changes in EMG_{FT} with HIIT or supplementation in healthy college-aged women. The current study results in women counter our hypothesis that EMG_{FT} would be sensitive to physiological changes due to HIIT or supplementation. Practitioners who may use this technique for identifying the theoretical onset of neuromuscular fatigue must remain cautious and consistent while reassessing individuals for tracking changes due to training or other interventions. Future studies should maintain consistency among testing visits and perhaps use a more sensitive test in examining neuromuscular adaptations to HIIT or supplementation of any kind.

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