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ORIGINAL

EFFECT OF RESISTANCE TRAINING ON LACTATE THRESHOLD IN DISTANCE RUNNERS

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ABSTRACT

Background: Lactate Threshold (LT) is characterized by the onset of a rapid increase in blood lactate levels as exercise intensity surpasses the body's clearance capacity. Traditional training for distance runners primarily emphasizes aerobic conditioning designed to enhance cardiovascular efficiency. **Purpose:** The study aims to evaluate the direct effects of incorporating resistance training on LT, heart rate, pace, and 5K race outcomes in competitive runners. Furthermore, the study explores gender-specific adaptations, filling a gap in the existing literature that has largely overlooked female-specific responses to strength-endurance training models. **Methods:** This study involved 100 subjects (57 male and 43 female), randomized into experimental (age 24.72±3.26) and control group (age 24.56±3.07). This experimental study was structured as a randomized controlled trial (RCT) with a parallel group design and a 12-month follow-up period. Outcome Measures such as Lactate Threshold, mean Heart Rate, Pace and time taken to Complete 5000m compared at the interval of 0, 6 and 12 months. **Results:** Experimental group exhibited a sustained and significant increase in LT (mean increase of ~28.2 mg/dl from baseline, $p < 0.01$). Running pace improved from 3.65 m/s to 3.94 m/s for experimental group. Female participants in the experimental group showed proportionally higher gains in LT (mean +29.7 mg/dl) and 5000m time improvement (mean −92 seconds), suggesting that resistance training confer relatively greater benefits to female endurance athletes. **Conclusion:** Raising LT helps athletes endure higher intensity efforts over longer periods before fatigue occurs.

KEYWORDS: Lactate Threshold, Distance Running, Resistance Exercise

1. INTRODUCTION

In the late 19th century, track and field competitions were first held, usually with athletes from competing schools and sporting organizations. Exercise physiology attracted a lot of attention due to national and international competitive sports and athletics. Over the past century, a lot of work has been done to examine record-breaking performances and champion athletes in an attempt to better understand human physiology. Competitive distance running is a rich field for study and investigation since it is a complex sport that involves mental toughness, endurance, and strategic execution. Running distances vary from 5000 meters to a whole marathon (42.19 kilometers/26.21 miles) (Joyner & Coyle, 2008). Anaerobic and aerobic metabolic systems are put to the test during the strenuous endurance sport of distance running. According to Faude, Kindermann, and Meyer , LT is among the most accurate physiological indicators for assessing the performance potential of distance runners (Faude et al., 2009). The lactate threshold marks the intensity at which blood lactate starts to climb beyond resting concentrations, indicating a move from mainly aerobic processes to anaerobic energy systems. In long races like the 5000-meter run, athletes who can sustain a larger proportion of their maximal aerobic capacity prior to reaching their LT typically do better (Coyle, 1995). In order to improve LT and increase aerobic capacity, distance runners' training regimens have historically placed a strong emphasis on interval training, continuous running, and tempo runs. Emerging studies point to resistance training as a valuable complement to endurance training, with benefits including enhanced running efficiency, improved neuromuscular control, and greater fatigue tolerance. It is frequently disregarded in endurance sport situations because of worries about muscle hypertrophy and decreased flexibility (Yamamoto et al., 2008). These advantages could result in a higher LT and a delayed beginning of blood lactate build-up. Despite growing evidence supporting the role of lactate threshold in endurance performance, limited studies have examined how structured resistance training over an extended duration directly influences LT in competitive distance runners. This gap underscores the need for further investigation to enhance performance optimization strategies. The resistance training increases muscle strength, musculotendinous stiffness, and motor unit recruitment, all of which can optimize force application during ground contact and lower running energy costs (Paavolainen et al., 1999). These physiological changes are especially important for long-distance runners who want to keep their speeds below their maximum while using the least amount of energy possible. Given the advantages resistance training may offer, further investigation into its impact on lactate threshold and performance variables in distance runners is both relevant and necessary. Endurance training's connection to lactate threshold has been widely studied, but the role of sustained resistance training has received comparatively little attention particularly over a six-month period, on LT adaptations in distance runners. Six months allows for sufficient time to observe physiological changes and performance outcomes. Understanding how resistance training influences LT is crucial, as LT is a reliable tool of endurance performance and training effectiveness. This study is important because it attempts to close a crucial gap between the paradigms of strength and endurance training. This study advances our knowledge of integrated training methods for endurance athletes by examining how resistance training affects lactate threshold in distance runners. Despite findings from Balsalobre-Fernández et al. indicating gains in running efficiency and time trial outcomes with resistance training (Balsalobre-Fernández et al., 2016), research focusing specifically on its effects on lactate threshold, cardiovascular responses, and pacing is still scarce. Furthermore, the current study tackles a problem that is frequently overlooked in sports science literature: gender-specific variations in reaction to resistance training. Compared to their male counterparts, female athletes may have distinct neuromuscular and metabolic responses, requiring a more sophisticated approach to training prescription (Komi, 1992). For coaches, trainers, and sport scientists looking to maximize performance outcomes through customized training regimens, the study's conclusions may have applications (Komi, 1992). The study focuses on experienced male and female distance runners who frequently participate in middle- to long-distance competitions and are between the ages of 18 and 30. The resistance training intervention will be added to their current endurance workouts over a scheduled duration of six to twelve weeks. Before and after the intervention, important performance metrics will be measured, such as lactate threshold levels, running pace, average heart rate, and 5000-meter time.

2. Materials & Methodology

Necessary Institutional Ethics Committee approval was obtained before initiating the study and registered with CTRI. This experimental study included participants of 5000 mts distance runners from sports association and the participants were randomized into experimental and control group. Sample size estimated with power of study in 0.80, Effect size was 0.5, Alpha is 0.05 and Confidence level was 95% the sample size is 90 (N=45 in Experimental Group and N= 45 in Control Group). Considering 10% dropout the sample size increased to 100 (N=50 in Experimental and N= 50 in Control Group). Subjects included with Normal BMI, aged between 18-30 years with minimum 2 hrs/day level of practice. Participants were following dietary intake as prescribed by dietician (Purcell, 2013). A certified statistician created the randomization schedule using verified software (Randomizer software). A list of randomization tables was created using 6- block randomization in the ratio of 1:1 for the two treatment groups. After verifying participant eligibility, a total of 100 individuals were randomized using a predetermined schedule, with each receiving a unique identification number and an assigned treatment. The investigator randomly allocated subjects in a 1:1 ratio to either of the two groups according to the randomization schedule. Once the Lactate threshold level been estimated through Bruce Protocol (Table No.2) (Acevedo & Goldfarb, 1989; Purcell, 2013), the experimental group received the training protocol (Table No.1), where they made to run at their mean HR of LT ± 5 bpm for 3 months, based on the lactate threshold training principle that exercising near the LT enhances metabolic adaptation and endurance performance (Paavolainen et al., 1999), and their intensity increased by 5% of mean HR of LT ± 5 till six months. A frequency of one session per week was selected to avoid overtraining, given the participants' continued endurance training routines, and to specifically assess the effects of LT-focused resistance training (Table No. 3). Between months 4 and 6, training intensity was increased by approximately ±5 percent of the average heart rate, while the number of weekly sessions remained unchanged. Training sessions were supervised, and compliance was ensured by recording heart rate data using Polar H9 during each session (Figure 1).

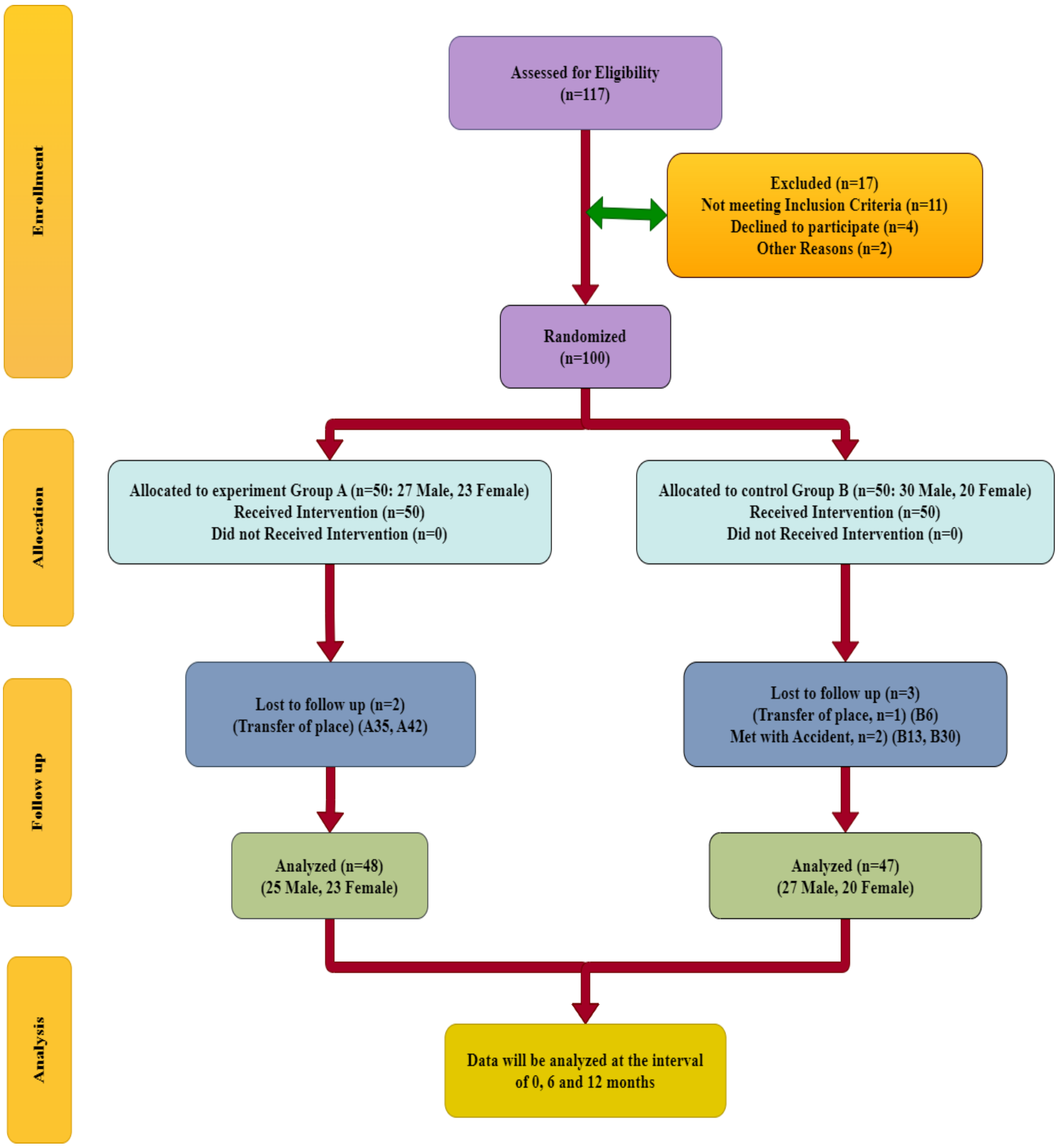

Figure 1: Consort Chart

Table 1: Determination of lactate Threshold (Acevedo & Goldfarb, 1989; Sjödin et al., 1982; Tanaka et al., 1986)

STAGE	SPEED (MPH/KMPH)	GRADE (INCLINATION)	DURATION	INTERPRETATION
1	1.7/2.7	10 %	3 min	-60 sec recovery b/w each stage to collect blood sample and to record mean HR -LT stage is where the lactate level is ≥ 72 mg/dl (4 mmol/L)
2	2.5/4.0	12 %	3 min	
3	3.4/5.5	14 %	3 min	
4	4.2/6.8	16 %	3 min	
5	5.0/8.0	18 %	3 min	
6	5.5/8.9	20 %	3 min	
7	6.0/9.7	22 %	3 min	

Table 2: Lactate Threshold Training Protocol (Acevedo & Goldfarb, 1989; Sjödin et al., 1982; Tanaka et al., 1986)

MONTH	TRAINING INTENSITY	FREQUENCY
0-3	Mean HR of LT (±5)	1/week
4-6	Increase in 5% Mean HR of LT (±5)	1/week
7-9	Increase in 5% Mean HR of LT (±5)	2/week
10-12	Increase in 5% Mean HR of LT (±5)	2/week

* Warm Up and Cool Down Included for 10 Min Each in Every Exercise Session

3. Results and Analysis

Data was collected at the interval of 0,6 and 12 months and analysed by using SPSS software version 26.0. To evaluate differences between groups, an independent t-test was utilized; within-group variations were examined through repeated measures ANOVA. No notable differences were found at baseline between the control and experimental groups for physiological factors such as age, height, weight, BMI, resting respiratory rate, and practice duration.

The outcome measures such as LT stage/level, mean HR, time taken to 5000 m and pace were also non-significant at baseline among two groups (Table 3). Although the mean value shows a difference in practice hours, it was statistically non-significant ($p > 0.05$). Since the difference existed before the intervention, it was not influenced by it; both groups followed their normal training schedules throughout the study. The experimental group differed only in the addition of a structured resistance training program targeting the lactate threshold.

Table 3: Comparison at Baseline between both the Groups

PARAMETERS	GROUP	N	MEAN	S. D.	T	P VALUE
LT STAGE/LEVEL (1/2/3/4/5/6/7)	Experimental	48	2.95	0.41	0.47	0.562#
	Control	47	2.91	0.37		
MEAN HR	Experimental	48	154.27	3.45	0.92	0.356#
	Control	47	154.63	2.51		
TIME TAKEN TO 5000 M (IN SECS)	Experimental	48	1185.67	73.03	0.81	0.412#
	Control	47	1181.91	66.65		
TIME TAKEN TO 5000 M (HH:MM:SS.000)	Experimental	48	19:45.6	00:41.2	0.71	0.212#
	Control	47	19:41.9	00:39.6		
PACE (M/S)	Experimental	48	4.2	0.25	0.41	0.314#
	Control	47	4.2	0.23		

*# for p > 0.05 (non-significant), * for p < 0.05 (significant), and ** for p < 0.01 (highly significant).*

Lactate Threshold Stage/Level was significantly increased in experimental group 4.92±0.52 at 12 months as compare to baseline 2.95±0.41. (p<0.021) (Fig 2)

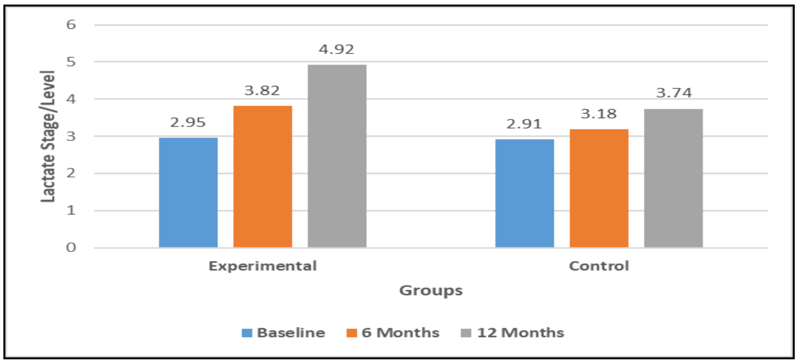

Figure 2: Baseline to 12 Months Mean Comparison of Lactate Threshold

Improvement in time taken to Complete 5000 mts from baseline to 12 months 19.45.6 min vs 16.07.6 min found significant. (Fig 3)

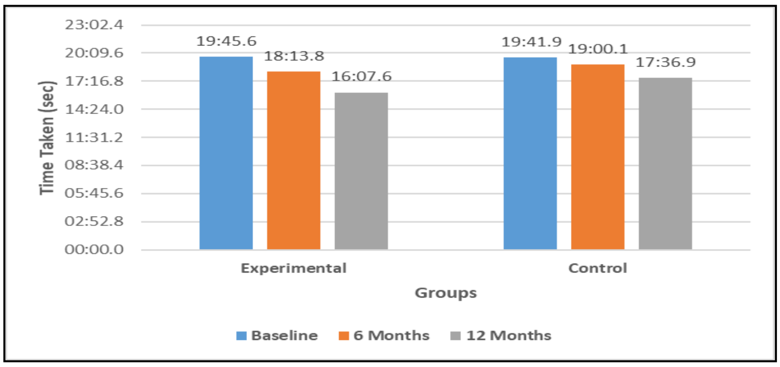

Figure 3: Baseline to 12 Months Mean Comparison of Time Taken to Complete 5000 mts

The experimental group with the resistance training shows significant increase in the pace after 12 months as compare to baseline 5.1 m/s vs 4.2 m/s. (Fig 4).

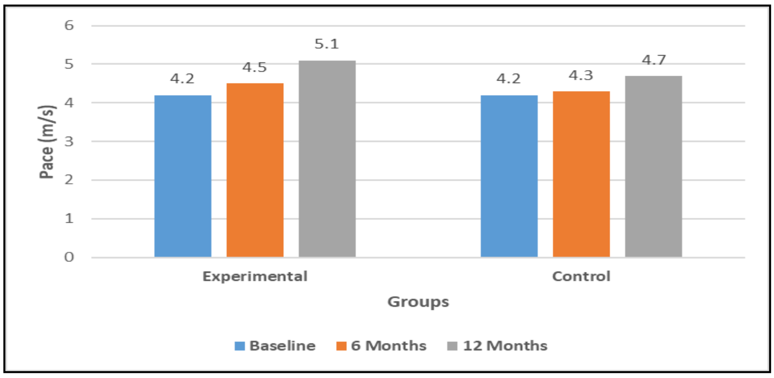

Figure 4: Comparison of Pace to Complete 5000 mts

There is not much difference in male and females in lactate threshold levels after resistance training but still in males the lactate levels are less as compare to females (Fig 5).

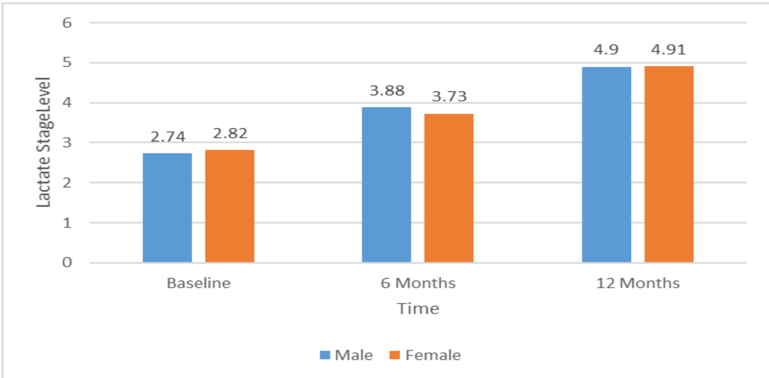

Figure 5: Comparison of Mean Lactate Levels in Males vs. Females

Table 4: Comparison of Outcomes at the end of 12 Months between Groups

PARAMETERS	GROUP	N	MEAN	S. D.	T	P VALUE
LT STAGE/LEVEL (1/2/3/4/5/6/7)	Experimental	48	4.92	0.528	8.246	0.000**
	Control	47	3.74	0.565		
MEAN HR	Experimental	48	166.16	3.507	5.198	0.000**
	Control	47	159.32	3.285		
TIME TAKEN TO 5000 M (IN SECS)	Experimental	48	967.4	69.873	5.782	0.000**
	Control	47	1056.62	60.579		
TIME TAKEN TO 5000 M (HH:MM:SS.000)	Experimental	48	16:07.6	01:09.8	5.779	0.000**
	Control	47	17:36.9	01:00.6		
PACE (M/S)	Experimental	48	5.192	0.3795	5.678	0.000**
	Control	47	4.752	0.2659		

4. Discussion

In this study, trained distance runners' lactate threshold (LT) and performance metrics were examined over a 12-month period in relation to a structured resistance training (RT) program. The findings showed that LT, heart rate (HR), running pace, and time to finish a 5000-meter run all significantly improved with RT, and that these improvements persisted over time. Resistance training is believed to elevate lactate threshold by various mechanisms, including enhanced buffering capacity, more efficient running economy, stronger muscles, and increased activation of motor units, as noted by Aagaard and Andersen (Aagaard & Andersen, 2010). By decreasing the subjective effort during submaximal sessions, endurance performance may improve. Research has shown that concurrent resistance and endurance training enhances anaerobic and aerobic systems in athletes (Rønnestad et al., 2011; Vikmoen et al., 2016). These results are consistent with other research showing that resistance exercise can improve LT by delaying the commencement of blood lactate buildup (Millet et al., 2002; STØREN et al., 2008). Unlike short-term interventions in earlier studies, our six-month protocol allowed for progressive overload, resulting in measurable endurance gains, supporting the theory that longer durations may lead to more robust physiological adaptation. This provides new insights into how resistance training tailored to LT can contribute to long-term endurance improvement. The experimental group had a substantially greater heart rate after the intervention (166.16 ± 3.50 at 12 months) than the baseline group (154.27 ± 3.45). This may seem counterintuitive, but it is in line with research showing that trained subjects have greater peak heart rates during incremental testing because of enhanced cardiac output and stroke volume efficiency. Furthermore, increased aerobic capacity and tolerance for higher-intensity workloads are indicated by greater HRs at higher LT stages. Tesch et al., who reported higher maximum HR and VO2max after strength-endurance training, have shown similar patterns (Tesch et al., 1990). The experimental group's 5000-meter run times were significantly shorter (from 19:45.6 to 16:07.6 minutes, $p < 0.0001$) and faster (from 4.2 m/s to 5.1 m/s). These enhancements highlight the beneficial effects of RT on running economy, which are corroborated by earlier studies that demonstrated better stride mechanics and decreased ground contact time after strength training (Balsalobre-Fernández et al., 2016; Beattie et al., 2014). Paavolainen et al. suggest that enhanced neuromuscular coordination and reduced energy expenditure during running may explain the improvements in 5K times seen after explosive strength training in endurance athletes (Paavolainen et al., 1999). Additionally, a meta-analysis by Blagrove et al. found that strength training positively impacts middle- and long-distance performance as well as running economy in competitive runners (Blagrove et al., 2018; Paavolainen et al., 1999). All variables improved for both male and female individuals in the experimental group, however pace improvements and 5000-meter completion time reductions were marginally greater for male participants. Sex-specific variations in muscle mass, hormone profiles, and neuromuscular responses to RT could be the cause of these results (Kraemer & Ratamess, 2005). Resistance training is beneficial for both sexes in terms of aerobic performance markers, as seen by the roughly equal increases in heart rate and lactate threshold between the sexes.

5. Conclusion

The study highlights the significance of resistance training in enhancing lactate threshold, a key determinant of endurance performance. Resistance-trained athletes demonstrated notable gains in a number of physiological and performance metrics. Resistance training resulted in quantifiable improvements in greater levels of intensity over extended periods of time. A more effective cardiovascular response was noted, with better running economy, athletes were able to reach and sustain faster speeds. Longer performance at higher intensities was made possible by an enhanced buffering capacity that postponed the onset of tiredness. Future research should explore individualized resistance training protocols across various sports levels and examine their long-term effects on both physiological and psychological performance markers.

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