Research Square

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Effect of Six Months Resistance Training on Lactate Threshold in Distance Runners

J Ezhil Mathi

ezhilmathi48@gmail.com

Lovely Professional University

Zaki Anwer

Lovely Professional University

Kanav Khera

Lovely Professional University

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Abstract

Background

The lactate threshold (LT) is the highest level of effort an athlete can keep up for a long time without causing a noticeable increase in blood lactate levels. Running long distances causes muscles to use more lactate, which forces the body to take lactate out of the bloodstream.

Objectives

This study aimed to investigate the effect of six months of resistance training based on lactate threshold in distance runners.

Materials and 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). Pre and post data collected at 0 and at the end of 6 months with warm up and cool down for 10 mins each.

Results

Statistically significant differences were seen in experimental group compared with control group in outcomes such as LT stage (3.82 vs 3.18), mean HR (160.02 vs 157.02), time taken to complete 5000m (18:13.8 vs 19:00.1) and running pace (4.5 vs 4.3) ($p < 0.005$).

Conclusion

The result of the study suggests that the six months of resistance training on lactate threshold improve the distance running performance. It would be helpful for researchers to further investigate how different resistance training protocols and durations influence lactate threshold and endurance performance in diverse athletic populations.

Introduction

Track and field events originated in the late 19th century, typically involving athletes representing rival educational institutions and sports clubs. Competitive sports and athletics at national and international levels sparked significant interest in exercise physiology (Jain, n.d.). Numerous efforts have been made over the past century to understand human physiology by studying champion athletes and record-breaking performances (Joyner & Coyle, 2008). Competitive distance running is a multifaceted discipline

that includes endurance, mental resilience, and strategic execution, making it a rich area for research and exploration. Distance running ranges from 5000m to full marathon (42.19km/26.21miles). Resistance training is an exercise aimed at strengthening muscles in the body to achieve increased muscular strength, endurance, and power through resistance from external forces or weights. It may be a resistance band, free weights like dumbbells and barbells, weight machines, or other forms of loads through which body weight could serve as a form of resistance.

Although long-distance running is primarily an endurance-based activity, integrating resistance training into a runner's program leads to physiological and biomechanical improvements that translate to better performance by improved running economy, increased muscular strength, enhanced endurance performance, injury prevention, improved power, stride length and increased fatigue resistance (Kisner, Colby, & Borstad, 2017).

Anaerobic metabolism arises in the body when glucose breaks into the energy compound without enough oxygen, resulting in lactate synthesis. Lactate is initiated to serve both as a source of energy and a functional indicator of metabolic stress during prolonged high-intensity efforts, such as long-distance running (Svedahl & Macintosh, 2003). Once exercise intensity is great, the lactate production rate will exceed the lactate clearance rate signifying a shift from largely aerobic metabolism towards greater reliance on anaerobic mechanisms. The most common cause of lowered muscle pH (metabolic acidosis) is the increase in hydrogen ion concentration that is associated with accumulation of excess lactate. This given acidotic environment switches off muscle contraction, for instance by blocking the activity of energy-producing systems and reducing muscle's capacity to produce force (Carter, Jansson, & Kaijser, 2001). In exhaustive all-out exercise, it is the lactate concentration which exceeds the rate at which effective clearance and elimination occur from the blood, the so-called lactate threshold (LT) (Nikseresht et al., 2017). This is shown by a pH dip from 7.4 to 6.8, which is believed to impair performance and induce weariness. In essence, lactate threshold training (LT) makes the body's physiology more robust in terms of lactate generation and lactic acid clearance (Nummela, Hämäläinen, & Rusko, 2007). It serves as a reliable gauge of how well the body converts chemical energy into mechanical energy. Blood lactate concentration measurements have been used widely for training control and performance detection. The metabolic processes of LT, VO_2max, and running economy are essential for endurance exercise and performance. 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 lactate threshold is regarded by many researchers as the main predictor of endurance performance (Kenney, Wilmore, & Costill, 2022).

Previous studies have examined the relationship between endurance training and lactate threshold; however, limited research has focused on the impact of sustained resistance training, 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 predictor of endurance performance and training effectiveness.

Furthermore, the LT seems to be the physiological measure that responds to endurance training the best, when compared to VO_2max and economy (McArdle, Katch, & Katch, 1996). Lactate is a continuously produced and utilized essential fuel and potential signalling molecule, even under fully aerobic conditions, rather than being a waste product of anaerobic metabolism (Denadai & Greco, 2022). Reduced lactate clearance, increased activation of fast-twitch motor units, and an imbalance between mitochondrial respiration, glycolysis, and ischemia (low blood flow) or hypoxia (low blood oxygen concentration) are important causes of poor performance (Robergs & Roberts, 1997).

Materials and Methods

100 subjects volunteered for the study, and they were grouped using simple random sampling from a pool of endurance-trained distance runners. They were randomized into the Experimental (n = 50) and control group (n = 50). Random assignments were done using the randomizer software to ensure unbiased group allocation. Subject's physiological data such as age, height (cms), weight (kgs), Body Mass Index (BMI), Resting respiratory rate, and practice hours (Table 1) have been collected. Baseline measurements were compared between the two groups to confirm there were no significant differences prior to the intervention. Figure 1 illustrates the mean average of Male and Female. Participants suffered any recent trauma, neurological conditions, pregnancy, comorbidity such as hypertension, diabetes mellitus, cardiac issues and use of any ergogenic aids were excluded. Data collected in and around the sports complex of Navi Mumbai with prior filled consent form.

Table 1
Demographic and Physiological characteristics of subjects at baseline

	Group	n	Mean	S.D.	t	P value
Age	Experimental	48	24.72	3.264	0.252	0.801
	Control	47	24.56	3.072		
Height (cms)	Experimental	48	172.98	3.335	0.232	0.817
	Control	47	172.78	5.108		
Weight (kgs)	Experimental	48	68.56	3.759	1.596	0.114
	Control	47	67.28	4.248		
BMI	Experimental	48	22.90	1.127	1.501	0.136
	Control	47	22.54	1.261		
Resting RR	Experimental	48	15.24	2.153	0.502	0.617
	Control	47	15.02	2.227		
Practice Hours	Experimental	48	2.28	0.497	2.237	0.028
	Control	47	2.56	0.733		
*p < 0.05 (Significant)						

Randomizer software is used to allot the subjects by 1:1 with SNOSE technique, single blinded. Subjects Lactate Threshold (LT) were measured by making them run on the computerized treadmill (AFTON) based on Bruce Protocol and the blood sample drawn at the end of each stage. Blood lactate (BL) threshold is considered when the subject BL level shows 4 mmol/L. StatStrip Xpress 2 handheld lactate analyzer (NOVA Biomedical, USA) used to read the blood lactate level with the help of Lancet at fingertip. The heart rate was recorded by Polar H9 to record the mean heart rate. Dietary chart has been maintained as per guidelines by dietician (Hamilton, Paton, & Hopkins, 2006; Sjödin, Jacobs, & Svedenhag, 1982; Tanaka et al., 1986).

Once the Lactate threshold level been estimated through Bruce Protocol (Table 2) (Acevedo & Goldfarb, 1989; Purcell, 2013; Academy of Nutrition and Dietetics, n.d.), the experimental group received the training protocol (Table No. 3), 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 (Nummela, Hämäläinen, & Rusko, 2007), and their intensity increased by 5% of mean HR of LT ± 5 till six months. The frequency of one session per week was chosen to prevent overtraining, considering participant's ongoing regular endurance training schedules, and to isolate the specific effects of LT-based resistance training (Table No. 3). The training intensity increased between 4–6 months by ± 5% of Mean HR with no change in session per week. Training sessions were supervised, and compliance was ensured by recording heart rate data using Polar H9

during each session. The routine training sessions were conducted on the control group, and the data was collected at the end of six months and compared for the significance of the study. Five subjects lost the follow-up in the study due to personal reasons (Fig. 2).

Table 2
Estimation of Lactate Threshold (Bruce Protocol) (Acevedo & Goldfarb, 1989; Purcell, 2013; Academy of Nutrition and Dietetics, n.d.)

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 ≥ 36 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 3
Lactate Threshold Training Protocol (Acevedo & Goldfarb, 1989; Purcell, 2013)

Month	Training Intensity	Frequency
0–3	Mean HR of LT (± 5)	1 session/week
4–6	Increase in 5% Mean HR of LT (± 5)	1 session/week
* Warm up and cool down included for 10 min each in every Exercise session		

Statistical Analysis

The SPSS (Version 26) software tool was used for statistical analysis. Means and standard deviations are used to represent the data. To compare groups, the unpaired t test is employed.

Results and Analysis

There were no discernible differences between the groups at the start of the trial, except for practice hours where the control group practiced (2.56 h/day) more than the experimental group (2.28 h/day). Although the mean value shows a difference in practice hours, it was statistically non-significant ($p > 0.05$). This difference was pre-existing and not part of the intervention; both groups continued their regular training routines throughout the study. The added LT-based resistance training was the only structured difference introduced to the experimental group. End of six months training session the

experimental group seen with significant differences in all outcomes such as LT stage, mean HR, time taken to complete 5000m and pace. The experimental group could reach the given target of 5000m by 124.39% more reduction in time (1 min 32 secs) than the control group, which improved by only 41 secs (t value 10.79, $p < 0.05$). Their running pace also increased by 7.14%, from 4.2 to 4.5 m/s, with a significant 29.49% increase in lactate stage from 2.95 to 3.82 (Table 4 and Table 5).

Table 4
The comparison of parameters at Baseline (0 months)

Outcome	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 5000m(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		

Table 5
Comparison of Parameters at 6 months

Outcome	Group	N	Mean	S. D.	t	P value
LT Stage/Level (1/2/3/4/5/6/7)	Experimental	48	3.82	0.388	10.79	0.000**
	Control	47	3.18	0.388		
Mean HR	Experimental	48	160.02	2.412	10.065	0.000**
	Control	47	157.02	3.292		
Time Taken to 5000m(in secs)	Experimental	48	1093.68	47.654	6.831	0.000**
	Control	47	1140.04	30.724		
Time Taken to 5000 m (hh:mm:ss.000)	Experimental	48	18:13.8	00:47.6	6.822	0.000**
	Control	47	19:00.1	00:30.7		
Pace (m/s)	Experimental	48	4.578	0.2063	6.714	0.000**
	Control	47	4.382	0.1304		

Discussion

Significant role of Resistance training on Lactate Threshold (LT) in distance runners seen in the aspects of time taken, pace, mean heart rate and lactate tolerance. These findings align with and extend previous work that linked LT-based training to improved endurance performance metrics, particularly in trained runners (Ghosh, 2004; Tanaka et al., 1986). However, this study uniquely demonstrates these benefits over a sustained six-month resistance training period, which has been less explored. The running efficiency of experimental could be improved due to better lactate clearance, enhanced blood flow and mitochondrial density enable faster lactate removal and thus delaying its accumulation. LT training raises the intensity level at which lactate begins to accumulate, allowing runners to sustain higher speeds before fatigue sets in. Improved buffering capacity led to adaptations in the muscles ability to neutralize hydrogen ions, mitigating the effects of acidosis (Ghosh, 2004).

Resistance training at LT exhibited a stronger correlation and the ability to sustain a high fractional utilization of VO_2max for a longer length of time postpones the onset of metabolic acidosis. distance running performance is superior to maximum aerobic capacity (VO_2max). Training at LT intensity increases both aerobic and anaerobic capacity through improvement in efficiency of the body's handling of lactate accumulation (Ghosh, 2004). This in turn results in some physiological adaptations, all contributing, among which are increased blood volume, increased capillary density, and greater mitochondrial density, that lead to improved endurance performance. Our observed improvements in lactate clearance and heart rate efficiency are consistent with previous studies showing increased mitochondrial density and oxidative enzyme activity following LT-based training (Holloszy & Coyle, 1984;

Costill, Fink, & Pollock, 1976). Importance is attributed to increased stroke volume in optimizing cardiovascular efficiency and endurance capacity (Morin et al., 2012; Kanstrup & Ekblom, 1984).

Several factors influence low plasma lactate levels during a competition: muscle fiber type, VO_2 max, running economy, and the ability to maintain high VO_2max levels during races (Kounalakis et al., 2008). VO_2max utilization strongly correlates with performances across various distances such as 5 km and 10 miles (Costill, Thomason, & Roberts, 1973; Londeree, 1986). Endurance training also allows the muscles to use lactate, where its removal from circulation is improved (Gladden, 2000). After endurance training, there is generally a decrease in lactate production during a given workload because of increased mitochondrial size, number and enzymatic activity (Holloszy & Coyle, 1984). Collectively, these adaptations increase the energy production from mitochondrial respiration, thereby reducing lactate accumulation at a given intensity of work. 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.

Running places considerable stress on the cardiovascular and musculoskeletal systems. Endurance athletes are usually characterized by an efficient oxygen transport system, increased heart volumes, and higher capillary densities (Keul et al., 1982). These structural adaptations are thought to enhance cardiac pumping efficiency, leading to a greater stroke volume and cardiac output-factors determining maximal oxygen uptake (Blomqvist & Saltin, 1983). Several mechanisms have been proposed for the increase in lactate threshold (LT) associated with endurance training, such as an increase in blood flow to the trained muscles, enhanced oxidative capacity of muscle cells, and changes in muscle fiber recruitment patterns that preferentially activate red and oxidative muscle fibers.

In this study, we measured blood lactate levels throughout extended running sessions and discovered that the pace rose with time. In light of the results presented, Tanaka et al. discovered that lactate readings allowed them to determine running speed at the onset of lactate accumulation, allowing them to predict running performance beforehand. That is, lactate readings can determine an individual's performance, regardless of whether he is a swimmer or a runner (Tanaka et al., 1986). The long-distance runner's gastrocnemius muscle had a larger percentage of type I muscle fibers (79%) following resistance exercise training. Furthermore, the long-distance group had a considerably larger ($p < 0.05$) oxidative potential as determined by the activity of the mitochondrial enzyme succinate dehydrogenase (Costill, Fink, & Pollock, 1976). The capillary density in muscle tissue also showed a favorable correlation with this. Running can be made quicker, more efficient and injury-free by improving running economy, stride mechanics, ground contact time, ground reaction force (GRF), and fatigue resistance (Brooks, 2009).

High running economy is physiologically necessary for distance running performance; in terms of biomechanics, this high economy results from the execution of optimal mechanical patterns that prevent inefficient movements while applying forces in the proper amount, direction and timing. Veteran athletes

have lower blood lactate concentrations, which can be explained by a lower proportion of type II muscle fibers, decreased lactate dehydrogenase activity, and increased oxidative enzyme activity. These factors help to clear lactate by reducing lactate production and carbohydrate utilization (Coggan et al., 1990).

Training just above the anaerobic threshold is known to increase aerobic capacity and anaerobic threshold levels (Ghosh, 2004). Improvements in submaximal endurance performance occur mostly by increasing muscle oxidative capacity (Dantas & Doria, 2015). Changes in oxidative enzyme activity, rather than changes in maximal oxygen uptake, appear to influence running performance by endurance athletes and are implicated in substrate utilization during submaximal exercise (Jansson & Kaijser, 1987; Moore et al., 1987). Previous research pointed to a strong relationship between increases in blood or plasma lactate and performance in distance running. Additionally, it has been shown that endurance training lowers blood lactate levels at a given absolute or relative exercise intensity, which may indicate an increased reliance on fat metabolism and/or an improved aerobic breakdown of energy substrates (Holloszy & Booth, 1976).

Conclusion

This study demonstrated that six months of resistance training at the Lactate Threshold (LT) led to significant improvements in distance runner's performance, specifically in time taken, pacing, mean heart rate, and lactate tolerance. Further, it underscores the importance of tailoring resistance training to an athlete's needs, in order to include not only physiological but also psychological factors in an effort to gain the maximum gains in performance. 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.

Abbreviations

LT	Lactate Threshold	BMI	Body Mass Index
RR	Respiratory Rate	SNOSE	Sequentially Numbered, Opaque, Sealed Envelopes
BL	Blood Lactate	HR	Heart Rate
CONSORT	Consolidated Standards of Reporting Trials	SPSS	Statistical Package for Social Sciences

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Research Committee of Dr. G. D. Pol Foundation's YMT College of Physiotherapy (Ethics Approval No. YMT/BPTh/165/25 Dated 07/03/2025). Each participant signed an informed consent form. All methods were performed in accordance with the Declaration of Helsinki and relevant guidelines.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Not Applicable.

Author Contribution

All authors contributed

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Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

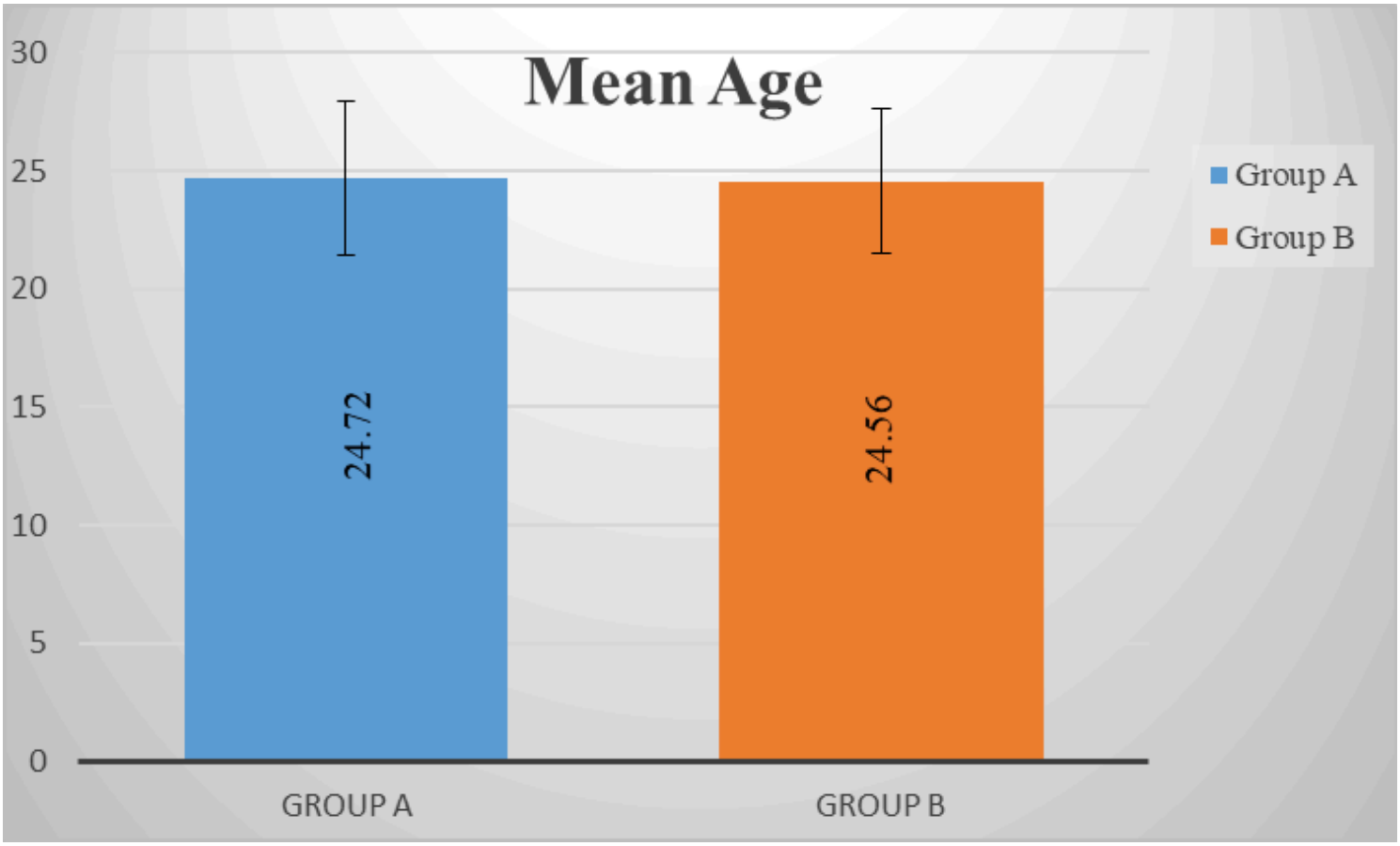


Figure 1

Mean age Comparison between groups

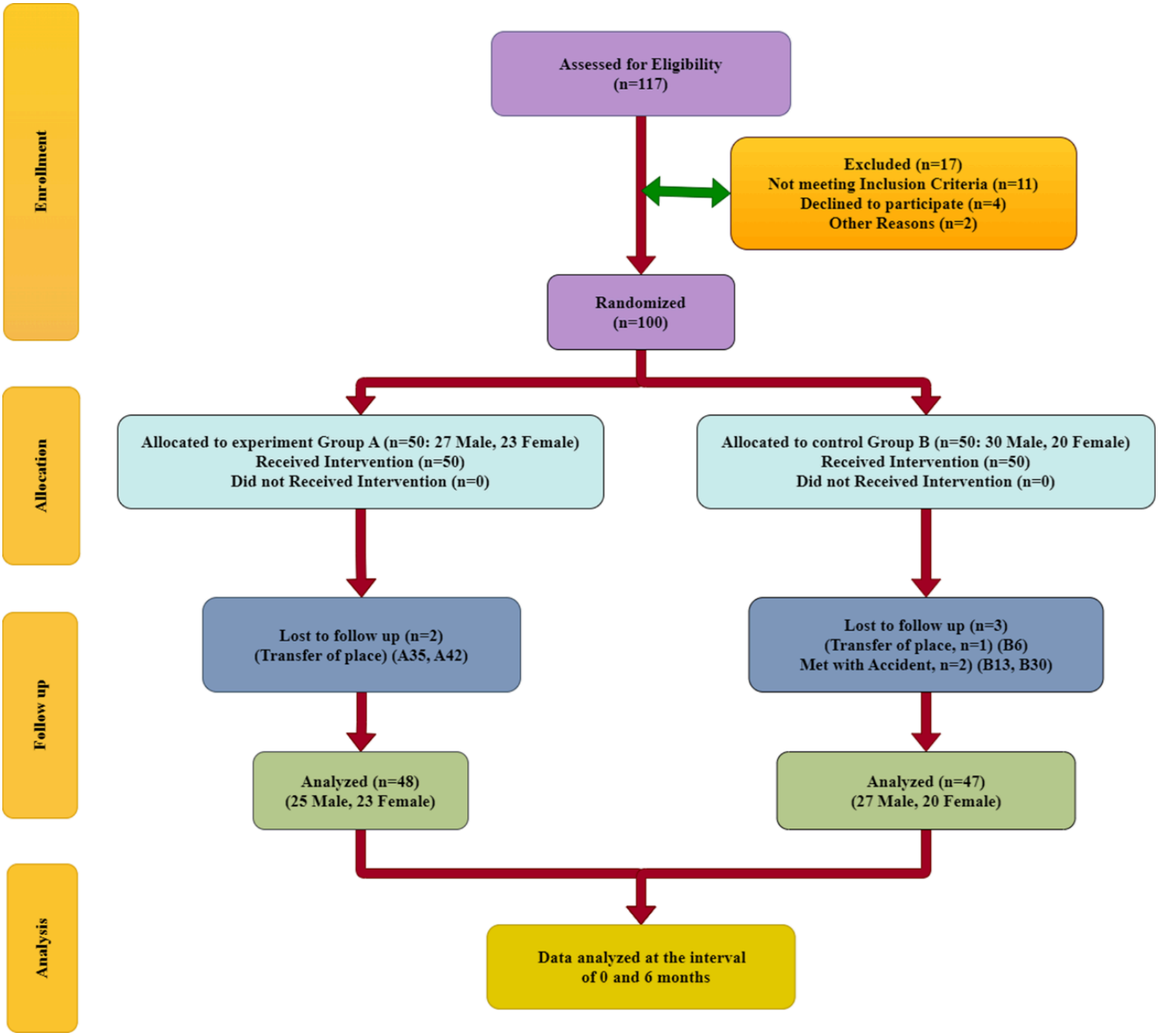


Figure 2

CONSORT Flow Chart