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Young Females' Longitudinal Relationship of Endurance Performance - A Partial Regression Analysis

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Abstract: Coaches and practitioners strive to use methods based on outcome measurements that are evidence-based to maximize female athlete performance, but due to a lack female representation in exercise science research, this is often problematic. The primary goal was to investigate the correlation between maximal oxygen uptake, blood lactate, and running economy in young females. Secondarily, the objective was to observe the longitudinal association between alterations in maximal oxygen uptake, blood lactate, and running economy responses to six weeks of endurance training. Young female athletes (n = 18) were randomized into a weighted vest (n = 10) or non-weighted vest (n = 8) group. Two separate graded treadmill tests for maximal oxygen uptake, blood lactate, and running economy were performed at baseline and post-six weeks of endurance training, which occurred at a frequency of three times per week for six weeks. A slight positive relationship between baseline- maximal oxygen uptake and running economy, r = 0.33, and a moderate positive relationship between baseline- blood lactate and running economy, r = 0.46, were observed. After controlling body composition, a strong positive relationship between post- maximal oxygen uptake and running economy, r = 0.59, and a strong positive relationship between post- blood lactate and running economy, r = 0.85, were observed. This study shows baseline assessments of previously mentioned performance traits may not be related. A weighted vest is considered a safe and alternative ergogenic aid that can be incorporated into an endurance training program. A six-week endurance training program is sufficient time to induce cardiovascular adaptations and improve endurance performance.

Keywords: Maximal Oxygen Uptake, Blood Lactate, Running Economy, Aerobic Training

1. Introduction

An individual's free paced running speed is an example of a behavior that can be observed due to physiologic, psychological, and tactical feedback. This behavioral response is strongly correlated with physiological measures of endurance performance such as maximal oxygen uptake (VO_2 Max), blood lactate (BL), and running economy (RE) under normothermic conditions. As such, these elements are commonly referred to as the determinants of endurance performance (Joyner & Coyle, 2008; Thompson, 2017; van der Zwaard *et al.,* 2021).

The elements of endurance performance show how a person's VO_2 Max defines their maximum aerobic metabolism, below which the BL relates to the maximum sustained fractional VO_2 Max use or %VO_2 Max (Snarr *et al.,* 2018). The efficiency of oxidative adenosine triphosphate turnover at the fractional consumption of VO_2 Max is translated to locomotion and then determines running velocity (Lanferdini *et al.,* 2020). Maximal oxygen uptake and BL individually accounted for almost 90% of the variation in performance time, while the composite measure of RE and velocity at VO_2 Max explained about 95% (McLaughlin *et al.,* 2010; Schaun, 2017).

Elite distance runners have high VO_2 Max readings, a key performance indicator in distance sports (Billat *et al.,* 2001). Increased blood volume, capillary density, and mitochondrial density, with increased stroke volume (SV) as the primary cause, contribute to the high VO_2 Max values seen in elite distance runners (Thompson, 2017). Race timings have shown only a low to moderate connection with VO_2 Max within elite populations, even though VO_2 Max is relatively uniform in elite runners. As an alternative, it has been demonstrated that VO_2 Max at lactate threshold (LT) and velocity at LT are better indicators of distance running performance (Støa *et al.,* 2020).

One of the most significant factors affecting distance running performance is RE, defined as oxygen (O_2) uptake at a submaximal running velocity (Barnes & Kilding, 2015). It has been demonstrated that RE strongly correlates with and predicts distance running performance (Weston *et al.,* 2000). At the same steady state velocity, individuals with strong RE consume less oxygen (O_2) than those with poor RE (Saunders *et al.,* 2004). While individuals have equal VO_2 Max values, RE might vary by as much as 30%, which could account for performance discrepancies (Barnes & Kilding, 2015). Storing and releasing elastic energy in tendons causes this variance in RE. The amount of energy stored and released in a tendon during a specific movement mostly depends on the tendon's moment arm, with the quantity of stored energy increasing as the moment arm's size decreases (Scholz *et al.,* 2008). The moment arm of the Achilles tendon and running economy are highly correlated in the distance running (Scholz *et al.,* 2008).

Fatigue and BL buildup are frequently linked. These kinetics have distinct patterns, and the BL concentration shows a balance between the generation and elimination of lactate (Goodwin *et al.,* 2007). The conversion of pyruvate to lactate can be stopped without any energy loss as pyruvate has an oxidation potential or, to a lesser extent, acts as a substrate to produce glucose and glycogen. The remaining 92% of energy is produced when pyruvate is oxidized. Skeletal muscle can utilize lactate as a substrate at rest and during submaximal exercise, heart muscle, and kidney cortex (Brooks, 2020; Hargreaves, 2000). Lactate threshold is defined as the exercise intensity or VO_2 Max at which blood lactate concentration gradually rises during continuous activity or the intensity at which lactate production and removal occur to the same degree. Fatigue is linked to a declining running pace during a race. When running effort exceeds LT, BL accumulates (Brooks, 1985). A decline in RE correlates with both an increase in intensity and an increase in duration.

The professionalism and profile of female sports have increased dramatically in recent years (Fink, 2015). To achieve the objective of optimum athlete performance, coaches and practitioners try to include evidence-based strategies. Given the small population of females involved in sports performance research, data and programming on males, frequently serves as the foundation for developing sport and training regimens tailored to women (Costello *et al.,* 2014). During training, a weighted vest (WV) distributes an external mass across the chest and upper torso. WVs are quite versatile and may be used for a variety of workouts, including plyometric exercises, and running (Rantalainen *et al.,* 2012). Wearing a weighted vest while exercising can increase muscular strength and endurance without requiring additional training sessions (Rantalainen *et al.,* 2012). Increased demands on the circulatory, respiratory, and muscular systems during a run with a weight vest can lead to an increase in lower-body strength and endurance (Barnes *et al.,* 2015). Therefore, the main goal of the current study was to examine the partial relationship between female athletes' VO_2 Max, BL, and RE. Secondarily, the goal was to track how VO_2 Max, BL, and RE change after six weeks of endurance training.

2. Materials and Methods

2.1 Participants

Eighteen females (21.7±0.8 years; 69.1kg±13.4kg) exercised for at least 150 minutes per week (Table 1).

Table 1. Participant demographics, mean (SD)

	Total (n = 18)		
	WV (n = 10)	**Non-WV (n = 8)**	***p*-value**
Age (years)	21.8 ± 0.9	21.5 ± 0.7	0.468
Height (m)	1.69 ± 0.1	1.69 ± 0.1	1.000
Weight (kg)	67.7 ± 14.1	70.4 ± 11.5	0.673
BMI (kg/m²)	23.9 ± 3.6	24.9 ± 3.0	0.517
%BF	27.6 ± 7.1	29.2 ± 6.1	0.610
FFM (kg)	48.7 ± 8.9	50.2 ± 5.9	0.677

BMI = body mass index; %BF = body fat; FFM = fat-free mass

All subjects completed the PAR-Q+ and ePARmed-X+ questionnaires and had no musculoskeletal injuries, cardiovascular diseases, or metabolic disorders. The Institutional Review Board (IRB) at a small University approved this study. Before participating in this study, everyone gave written, informed consent. The current study conformed to the standards established by the up-to-date version of the Declaration of Helsinki. All procedures carried out in the present study adhered to ethical principles.

2.2 Procedures

Subjects were randomly assigned to either a 10% body mass (BM) weighted vest (WV) group (n = 10) or a non-WV group (n = 8). A series of graded exercise treadmill tests (GXT) measured VO_2 Max, BL, and RE at a pre-planned treadmill protocol in all 18 female subjects. A 10%BM WV and a non-WV group experienced endurance training (ET) three times weekly for six weeks, lasting 60 to 90 minutes each. The GXT and maximal lactate steady-state test (MLSS) were performed in a time greater than 24 hours but less than 72 hours. The average running speed of the subjects during the 30-minute run was calculated using training records they kept throughout the ET program. Their fitness tracker or heart rate monitor was used to measuring the distance traveled.

The Human Performance Laboratory received the subjects for baseline testing. Information was gathered and recorded on the subject's birthdate, age, height, weight, and body mass index (BMI), fat-free mass, and body composition with the use of an InBody 270 (Cerritos, CA, USA). Subjects were made aware of the nature and intent of the testing and instructed to avoid vigorous activity for 24 hours before the test. Moreover, guidelines were given to avoid large meals and caffeine four hours before testing. All individuals were accustomed to the tools and the testing methods to reduce test anxiety.

2.3 Human Performance Laboratory Testing

Using the PNOĒ metabolic analyzer (Palo Alto, CA; USA), resting VO_2 was measured for one minute as part of baseline testing. Before the test, standing still, the resting heart rate (HR) was recorded for a minute using a wireless signal from the metabolic analyzer (Polar H1, Lake Success, NY, USA). The subjects next completed a five-minute submaximal walk on a treadmill (CT800 Spirit Treadmill, Spirit Fitness; Jonesboro, AR; USA) at 4.8 km/h with a 1% slope. The VO_2 Max GXT was kept at a constant 1% treadmill incline to simulate jogging on the ground. As previously practiced, the GXT began with an initial speed of 6.4 km/h and increased by 1.4 km/h every five minutes until volitional exhaustion reached (Sperlich *et al.*, 2015). Each subject's top speed at which volitional tiredness set in was noted.

Five-minute stages were chosen to give blood lactate levels time to stabilized at those stages running speed (Palmer *et al.,* 1999). The amount of lactate buildup affected how long it took to reach a steady lactate state, typically achieved in 2 to 5 minutes and dependent on the workload increase throughout incremental testing (Rabinowitz & Enerbäck, 2020). From the first GXT, subjects started moving at a predetermined speed of 50–60%VO_{2peak}. After that, the treadmill's speed was raised by 0.8 km/h every five minutes. Before doing a blood lactate assay, HR data and perceived exertion (RPE) rating were determined. RPE was measured using a Borg 20-point scale, and HR was calculated via an HR monitor during the final 30 seconds of each interval. The fingertip of each subject was punctured with a tiny lancet to obtain a blood sample after each five-minute stage. Before a blood sample was collected, the fingertip region was cleansed, dried, and wiped with an alcohol swab quickly to minimize stoppage time. Blood was drawn onto the lactate test strips (Lactate Plus Analyzer, Eden, Minnesota, USA), then put into the lactate plus analyzer. In 13 seconds, a number in mmol/L with the date and time appeared on the analyzer screen. A baseline lactate sample from a resting state was collected from the fingertip. The drawing and examination of a blood sample followed each five-minute stage. The subsequent phase started if lactate remained constant, indicated by a one mmol/L rise. Nonetheless, MLSS had been attained and/or exceeded if a measured increase in blood lactate was greater than one mmol/L. This technique was repeated until the results of greater than one mmol/L were reached.

2.4 Training Program

The ET procedure occurred three times per week for six weeks, allowing time for potential physiologic, metabolic, and respiratory adaptations (51); sessions lasted 60–90 minutes *(Paavolainen et al.,* 1999). At the Shannon Center on the SXU campus, training was conducted on the 200-meter indoor track. The control performed the entire training without the WV, while the experiment group wore a WV (Iron Wear Fitness; Pittsburgh, PA; USA). The ET program included a 30-minute running trial three times per week to determine running velocity and HR at LT (McGehee *et al.,* 2005). Subjects were urged by the endurance training to complete a 30-minute time trial at their best time. The average running pace was calculated by dividing the ground traveled (m) by the run duration (seconds). The subject's HR monitor or fitness tracker calculated the distance traveled. Six weeks later, the subjects returned to the SXU Human Performance Laboratory to retake the GXT and MLSS tests.

2.5 Statistical Analysis

Excel data sets and Intellectus Statistics (Clearwater, Florida, USA) were used for the data analyses. Measures of central tendency were determined for continuous demographic data using descriptive statistics, expressed as mean ± standard deviation (Table 2). Absolute VO_2 Max, RE, BL, and RE were examined using partial correlations controlling for body composition (body mass + percentage body fat + fat-free mass) and the corresponding 95% confidence intervals (CI) for baseline and post-six weeks of ET. This strategy avoided any misleading correlations caused by linking two variables with the same divisor and eliminated the impact of body composition on VO_2 Max, BL, and RE (Cronin-Fisher, 2017). Strong correlations were defined as correlation r values > 0.70; good correlations are considered r values between 0.50 and 0.70; moderate correlations are defined as correlation r values between 0.3 and 0.5, and weak correlations are defined as correlation r values < 0.30 (Hazra & Gogtay, 2016). A one-way analysis of covariance (ANCOVA) was performed to determine the longitudinal differences in post- VO_2 Max, BL, and RE after controlling baseline values. Independent variables consisted of vest group, body mass, percentage body fat, and fat-free mass to the dependent variables of VO_2 Max, BL, and RE. The significance level was set at $p \leq 0.05$.

3. Results

Twenty subjects participated in the familiarization visit, completed the PAR-Q+ and ePARmed-X+ questionnaires, and were evaluated for inclusion and exclusion criteria. Despite having completed the baseline tests, two participants could not participate in the trial due to scheduling conflicts. Therefore, 18 participants — 10 in the WV and eight in the non-WV group — completed the study and underwent analysis. There was a lack of statistical significance in subject demographic data between the WV and non-WV groups.

The partial correlation analysis indicates a small positive relationship (Table 3, Figure 1a) between baseline- VO_2 Max and RE, $r = 0.33$, $p = 0.226$, and a moderate positive relationship (Table 3, Figure 1b) between baseline- BL and RE, $r = 0.46$, $p = 0.086$.

Table 2. Mean values ± standard deviation

	WV (n = 10)		Non-WV (n = 8)		
	Baseline	**Post**	**Baseline**	**Post**	***p*-value**
VO_2 Peak	1.56 ± 0.3	1.87 ± 0.2	1.45 ± 0.3	1.80 ± 0.2	0.401
VO_2 Max	33.1 ± 4.8	37.7 ± 5.0	34.8 ± 3.0	39.2 ± 2.4	0.423
BL	4.96 ± 0.6	4.21 ± 0.5	4.88 ± 1.0	4.44 ± 1.0	0.553
HR	185.8 ± 11.2	189.8 ± 6.1	191.1 ± 3.2	191.4 ± 4.6	0.554
VO_2	31.4 ± 5.2	27.9 ± 4.1	32.4 ± 3.6	29.1 ± 4.7	0.549
Velocity	10.2 ± 0.8	11.2 ± 1.3	10.7 ± 0.4	11.2 ± 1.0	0.935

VO_2 Peak (L/min); VO_2 Max (mL/min/kg); BL (mmol/L); HR (bpm); VO_2 (mL/kg/min); Velocity (km/h)

Table 3. Partial correlation coefficients (r), 95% confidence intervals, and p-values between maximal oxygen uptake (VO_2 Max), blood lactate (BL), and running economy (RE).

	Baseline			Post		
	RE	**95%CI**	***p*-value**	**RE**	**95%CI**	***p*-value**
VO_2 Max	0.33	-.22 - .72	0.226	0.59	.10 - .84	0.022
BL	0.46	-.07 - .79	0.086	0.85	.59 - .95	< 0.001

VO_2 Max (mL/min/kg); VO_2 (mL/kg/min); BL (mmol/L)

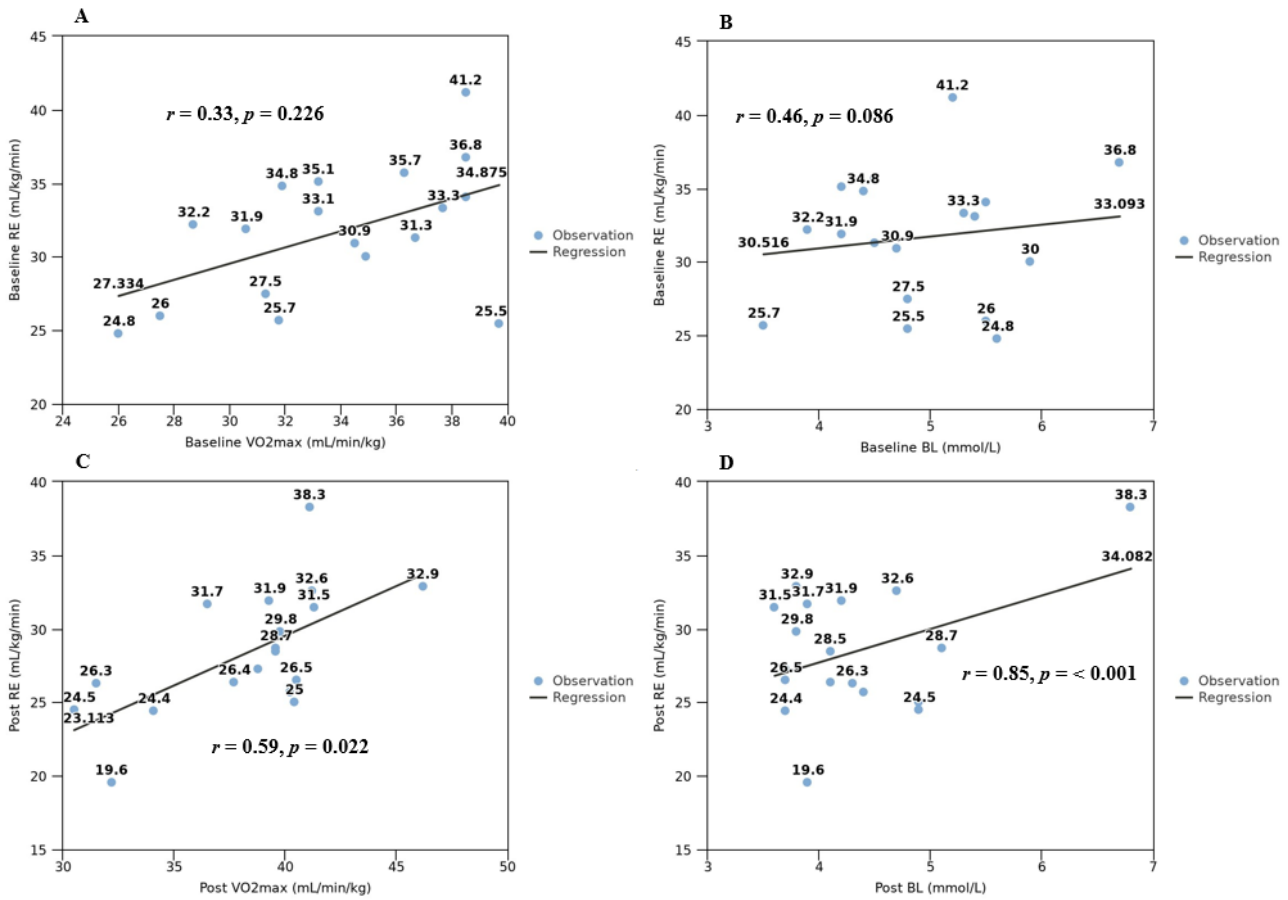

Figure 1. Partial correlation scatterplot. (a) Baseline maximal oxygen uptake (VO_2 Max) and running economy (RE), r = 0.33, (b) Baseline blood lactate (BL) and RE, r = 0.46, (c) Post- VO_2 Max and RE, r = 0.59, (d) Post- BL and RE, r = 0.85.

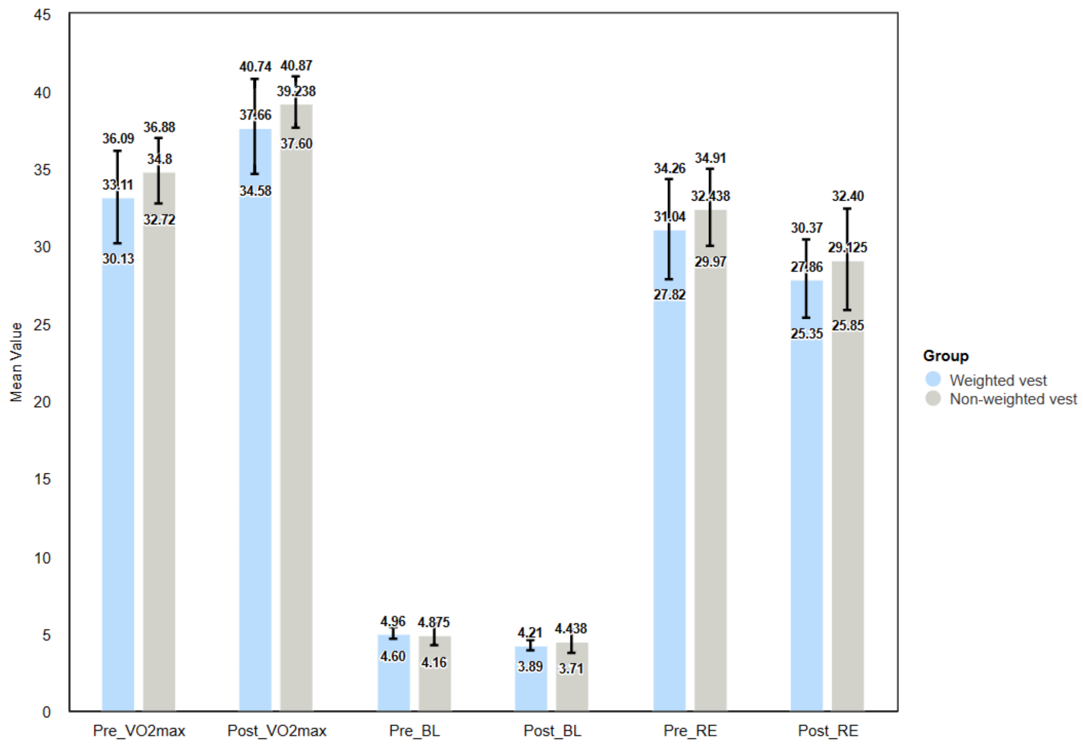

Figure 2. Profile plot. Post-endurance training values of weighted vest (WV) and non-WV maximal oxygen uptake (VO_2 Max), blood lactate (BL), and running economy (RE).

The partial correlation analysis suggests a strong positive relationship (Table 3, Figure 1c) between post- VO_2 Max and RE, $r = 0.59$, $p = 0.022$, and a strong positive relationship (Table 3, Figure 1d) between post- BL and RE, $r = 0.85$, $p < 0.001$. A coefficient of 0.59 and 0.85 represent large effect sizes for post- VO_2 Max, RE, and BL.

The one-way ANCOVA suggested that baseline-VO_2 Max, statistically impacted post-VO_2 Max, $p = 0.016$, but differences were not observed between the WV or non-WV groups, $p = 0.742$. The covariate, baseline-BL, significantly affected post-BL, $p < 0.001$, but without differences in the WV and non-WV groups, $p = 0.224$. Lastly, baseline-RE significantly influences post-RE, $p = 0.018$, but differences among the WV and non-WV groups were not observed, $p = 0.807$ (Figure 2).

4. Discussion

Evidence obtained from male athletes or their surroundings for the development of male talent frequently serves as the foundation for current sports performance and player well-being methods in female sports. While some beneficial practices can be extrapolated from a male setting, often there is a neglect to take the needs of female athletes into account (Zhu *et al.,* 2021). The first step in developing applied sport science methods, choosing an evidence-based strategy, or starting new research is to assess and evaluate the present body of knowledge (Emmonds *et al.,* 2019). Given that fewer investigations have examined female athletes than male athlete cohorts, doing so may just result in selecting the strongest evidence that is currently available (Lebel *et al.,* 2021). This may imply to the coach or practitioner that the data is helpful in supporting decision-making or, conversely, that the results may not be suitable for application to practice because of intrinsic differences (Emmonds *et al.,* 2019). As such, VO_2 Max, BL, and RE are commonly utilized markers of endurance performance (Billat *et al.,* 2001; Goodwin *et al.,* 2007; Morgan & Daniels, 1994). Therefore, the current study investigated a counterbalance and longitudinal analysis between VO_2 Max, RE, and BL and RE in young females.

The correlational analysis revealed a strong positive between subject relationships between VO_2 Max, BL, and O_2 uptake during submaximal running speed, quantified as RE, $r = .59$ and BL, $r = 0.85$, respectively. The current results support previous findings with a comparable correlation ($r = 0.29$) among submaximal RE and VO_2 Max (Pate *et al.,* 1992). The relationship between submaximal RE and VO_2 Max, on the other hand, is more robust and somewhat favorable in smaller cohorts of top distance runners, $r = 0.59$ (Morgan & Daniels, 1994), and physically active, $r = 0.48$ (Sawyer *et al.,* 2010). However, all prior research should be interpreted carefully since it contains statistical artifacts caused by the correlation of two variables with similar divisors (Cronin-Fisher, 2017). By reducing the impact of body composition with partial correlations in the current study, misleading correlations between RE, VO_2 Max, and BL were avoided, allowing the actual link between these variables to be investigated. This relationship exists because a runner with a lower metabolic expenditure is more economical, as supported by the current findings in which RE improved from 31.7mL/kg/min after six weeks to 28.4mL/kg/min.

As mentioned, VO_2 Max uptake, BL, and RE are among the physiological factors influencing endurance running and have been well-documented (Billat *et al.,* 2001; Goodwin *et al.*, 2007; Morgan & Daniels, 1994). More than 70% of the performance variance between subjects can be attributed to these three variables (di Prampero, 1985). Although genetics and training are related to athletic performance (Hawley, 2002; Rupert, 2003), the former is typically a fixed component. On the other hand, training may have a significant impact on physiologic, metabolic, and respiratory adaptation and performance (Priest & Hagan, 1987). With top athletes, where the pace of adaptation and performance improvement may have plateaued, endurance runners frequently look for the most efficient training methods to boost performance (Midgley *et al.,* 2006). Effective long-distance running training regimens should concentrate on VO_2 Max, lactate threshold, and running economy improvement because these factors have been identified as the most significant physiological predictors of long-distance running performance. The current study provides an additional training modality that should be considered in developing an ET program.

When evaluating the results, it is crucial to consider the current investigation's limits. To begin with, the age range was less diverse than anticipated. City and university policies were in place as participant recruitment began because of the COVID-19 pandemic. Using strict mitigation procedures, participants and the lead investigator's exposure to COVID-19 was significantly reduced. Future conversations should consider a range of ages.

5. Conclusion

The study's findings show that WV ET enhances running performance. It is safe, efficient, and quick for coaches and people to use weighted vests during training. Therefore, a planned endurance training program with at least three 30-minute sessions over six weeks is sufficient to induce metabolic, respiratory, and physiologic qualities. A 10% body mass WV worn during endurance exercise may be beneficial as an ergogenic aid for those seeking alternative training methods for improved performance. There is a strong influence aerobic training exerts on endurance performance markers of VO_2 Max, BL, and RE. As demonstrated by this study, baseline measurements of previously indicated performance characteristics may not relate to each other. However, six weeks of ET is sufficient to elicit alterations in endurance markers and enhance performance.

References

Barnes, K.R., & Kilding, A.E. (2015). Running economy: measurement, norms, and determining factors. *Sports Medicine - Open*, 1(1), 8. [DOI] [PubMed]

Barnes, K.R., Hopkins, W.G., McGuigan, M.R., & Kilding, A.E. (2015). Warm-up with a weighted vest improves running performance via leg stiffness and running economy. *Journal of Science and Medicine in Sport,* 18(1), 103-108. [DOI] [PubMed]

Billat, V.L., Demarle, A., Slawinski, J., Paiva, M., & Koralsztein, J.P. (2001). Physical and training characteristics of top-class marathon runners. *Medicine & Science in Sports & Exercise*, 33(12), 2089-2097. [DOI] [PubMed]

Brooks, G.A. (1985). Anaerobic threshold: review of the concept and directions for future research. *Medicine & Science in Sports & Exercise,* 17(1), 22-34. [DOI] [PubMed]

Brooks, G.A. (2020). Lactate as a fulcrum of metabolism. *Redox Biology,* 35, 101454. [DOI] [PubMed]

Costello, J.T., Bieuzen, F., & Bleakley, C.M. (2014). Where are all the female participants in Sports and Exercise Medicine research?. *European Journal of Sport Sciences,* 14(8), 847-851. [DOI] [PubMed]

Cronin-Fisher, V. (2017). The SAGE Encyclopedia of Communication Research Methods. *Sage Publications*. [DOI]

di Prampero, P. E. (1985). Metabolic and circulatory limitations to VO2 max at the whole animal level. *Journal of Experimental Biology*, 115(1), 319-331. [DOI] [PubMed]

Emmonds, S., Heyward, O., & Jones, B. (2019). The Challenge of Applying and Undertaking Research in Female Sport. *Sports Medicine - Open*, 5(1), 51. [DOI] [PubMed]

Fink, J.S. (2015). Female athletes, women's sport, and the sport media commercial complex: Have we really "come a long way, baby"?. *Sport Management Review*, 18(3), 331-342. [DOI]

Goodwin, M.L., Harris, J.E., Hernández, A., & Gladden, L.B. (2007). Blood Lactate Measurements and Analysis during Exercise: A Guide for Clinicians. *Journal of Diabetes Science and Technology*, 1(4), 558-569. [DOI] [PubMed]

Hargreaves, M. (2000). Skeletal muscle metabolism during exercise in humans. *Clinical and Experimental Pharmacology and Physiology,* 27(3), 225-228. [DOI] [PubMed]

Hawley, J.A. (2002). Adaptations of skeletal muscle to prolonged, intense endurance training. *Clinical and Experimental Pharmacology and Physiology*, 29(3), 218-222. [DOI] [PubMed]

Hazra, A., & Gogtay, N. (2016). Biostatistics Series Module 6: Correlation and Linear Regression. *Indian Journal of Dermatology*, 61(6), 593-601. [DOI] [PubMed]

Joyner, M.J., & Coyle, E.F. (2008). Endurance exercise performance: the physiology of champions. *The Journal of Physiology*, 586(1), 35-44. [DOI] [PubMed]

Lanferdini, F.J., Silva, E.S., Machado, E., Fischer, G., & Peyré-Tartaruga, L. A. (2020). Physiological Predictors of Maximal Incremental Running Performance. *Frontiers in Physiology*, 11. [DOI] [PubMed]

Lebel, K., Mumcu, C., Pegoraro, A., LaVoi, N.M., Lough, N., & Antunovic, D. (2021). Re-thinking Women's Sport Research: Looking in the Mirror and Reflecting Forward. *Frontiers in Sports and Active Living*, 3. [DOI] [PubMed]

McGehee, J.C., Tanner, C.J., & Houmard, J.A. (2005). A comparison of methods for estimating the lactate threshold. *The Journal of Strength and Conditioning Research,* 19(3), 553-558. [DOI] [PubMed]

McLaughlin, J.E., Howley, E.T., Bassett, D.R., Thompson, D.L., & Fitzhugh, E.C. (2010). Test of the classic model for predicting endurance running performance. *Medicine & Science in Sports & Exercise,* 42(5). 991-997. [DOI] [PubMed]

Midgley, A.W., McNaughton, L.R., & Wilkinson, M. (2006). Is there an optimal training intensity for enhancing the maximal oxygen uptake of distance runners?: empirical research findings, current opinions, physiological rationale and practical recommendations. *Sports Medicine,* 36(2), 117-132. [DOI] [PubMed]

Morgan, D.W., & Daniels, J.T. (1994). Relationship between VO2max and the aerobic demand of running in elite distance runners. *International Journal of Sports Medicine*, 15(7), 426-429. [DOI] [PubMed]

Paavolainen, L., Häkkinen, K., Hamalainen, I., Nummela, A., & Rusko, H. (1999). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Journal of Applied Physiology (1985),* 86(5), 1527-1533. [DOI] [PubMed]

Palmer, A.S., Potteiger, J.A., Nau, K.L., & Tong, R.J. (1999). A 1-day maximal lactate steady-state assessment protocol for trained runners. *Medicine & Science in Sports & Exercise*, 31(9), 1336-1341. [DOI] [PubMed]

Pate, R.R., Macera, C.A., Bailey, S.P., Bartoli, W.P., & Powell, K.E. (1992). Physiological, anthropometric, and training correlates of running economy. *Medicine & Science in Sports & Exercise*, 24(10), 1128-1133. [DOI] [PubMed]

Priest, J.W., & Hagan, R.D. (1987). The effects of maximum steady state pace training on running performance. *British Journal of Sports Medicine*, 21(1), 18-21. [DOI] [PubMed]

Rabinowitz, J.D., & Enerback, S. (2020). Lactate: the ugly duckling of energy metabolism. *Nature Metabolism*, 2(7), 566-571. [DOI] [PubMed]

Rantalainen, T., Ruotsalainen, I., & Virmavirta, M. (2012). Effect of weighted vest suit worn during daily activities on running speed, jumping power, and agility in young men. *The Journal of Strength and Conditioning Research,* 26(11), 3030-3035. [DOI] [PubMed]

Rupert, J.L. (2003). The search for genotypes that underlie human performance phenotypes. *Comparative Biochemistry & Physiology A: Molecular and Integrative Physiology*, 136(1), 191-203. [DOI] [PubMed]

Saunders, P.U., Pyne, D.B., Telford, R.D., & Hawley, J.A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine*, 34(7), 465-485. [DOI] [PubMed]

Sawyer, B.J., Blessinger, J.R., Irving, B.A., Weltman, A., Patrie, J.T., & Gaesser, G.A. (2010). Walking and running economy: inverse association with peak oxygen uptake. *Medicine & Science in Sports & Exercise,* 42(11), 2122-2127. [DOI] [PubMed]

Schaun, G.Z. (2017). The Maximal Oxygen Uptake Verification Phase: a Light at the End of the Tunnel?, *Sports Medicine - Open,* 3(1), 44. [DOI] [PubMed]

Scholz, M.N., Bobbert, M.F., van Soest, A.J., Clark, J.R., & van Heerden, J. (2008). Running biomechanics: shorter heels, better economy. *Journal of Experimental Biology*, 211(20), 3266-3271. [DOI] [PubMed]

Snarr, R., Tolusso, D., & Chrysosferidis, P. (2018). Understanding the physiological factors of VO2max.*Strength and Conditioning Journal*, 5, 16-18. [DOI] [PubMed]

Sperlich, P.F., Holmberg, H.C., Reed, J.L., Zinner, C., Mester, J., & Sperlich, B. (2015). Individual versus Standardized Running Protocols in the Determination of VO2max. *Journal of Sports Science and Medicine,* 14(2), 386-393. [PubMed]

Støa, E.M., Helgerud, J., Rønnestad, B.R., Hansen, J., Ellefsen, S., & Støren, Ø. (2020). Factors Influencing Running Velocity at Lactate Threshold in Male and Female Runners at Different Levels of Performance. *Frontiers in Physiology,* 11. [DOI] [PubMed]

Thompson, M.A. (2017). Physiological and Biomechanical Mechanisms of Distance

Specific Human Running Performance. *Integrative and Comparative Biology,* 57(2), 293-300. [DOI] [PubMed]

van der Zwaard, S., Brocherie, F., & Jaspers, R.T. (2021). Under the Hood: Skeletal Muscle Determinants of Endurance Performance. *Frontiers in Sports and Active Living*, 3. [DOI] [PubMed]

Weston, A.R., Mbambo, Z., & Myburgh, K.H. (2000). Running economy of African and Caucasian distance runners. *Medicine & Science in Sports & Exercise,* 32(6), 1130-1134. [DOI] [PubMed]

Zhu, J.W., Reed, J.L., & Van Spall, H.G.C. (2021). The underrepresentation of female athletes in sports research: considerations for cardiovascular health. *European Heart Journal,* 43(17), 1609-1611. [DOI] [PubMed]

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Informed Consent
All participants provided written consent prior to the start of the study.

Conflict of interest
The author reports there were no conflicts of interest.

Data availability
The contributing data in the current study are available upon request.

Does this article pass screening for similarity?
Yes

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