

The effects of external load-based circuit training on endurance performance in long-distance runners

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ABSTRACT

This study aimed to analyze the effect of external load-based circuit training on muscular endurance performance in long-distance runners from the Indonesian Athletics Association (PASI) Balikpapan. A quasi-experimental one-group pretest-posttest design was used. The sample included seven senior male athletes aged 21–28 years who competed in the 5000-meter and 10,000-meter events. The training intervention lasted eight months and consisted of 66 sessions, held 2–3 times per week. Athletes performed circuit-based resistance exercises using 40%–60% of one-repetition maximum (1RM), with 6–9 sets, 8–12 repetitions, and 15–30 seconds of rest between stations. The results indicated a statistically significant improvement ($p=0.002$) between pre- and post-training scores. The average performance increased by 18%, and the N-Gain score was 0.42, categorized as moderate effectiveness. The greatest improvements were observed in lower body strength endurance (squat test). Although direct race performance data were not collected, the functional tests used reflect the physiological demands of long-distance running, particularly in the 5000m and 10,000m events. In conclusion, circuit training with moderate external loads had a positive effect on enhancing muscular endurance among long-distance runners. Future studies should adopt randomized controlled designs with larger and more diverse athlete populations to validate these findings.

KEYWORDS

Circuit Training; External Load; Muscular Endurance; Long-Distance Running; Performance

1. INTRODUCTION

Athletics is one of the oldest sports and is included in popular sports today. The level of popularity of athletics leads to the number of long-distance running, all elements of society participate in the Indonesian Athletics Association (PASI) in long-distance running races. Of course, it is not surprising that many young people are interested in becoming long-distance runners. Ideally, achievement sports can be achieved optimally if physical factors are fulfilled to support the performance of runners, according to Dikdik et. al. (2019, 81) explained that physical condition is a complete unit of components that cannot be separated just like that, both in terms of improvement and maintenance. The components of physical condition are described as follows: speed (SAQ), endurance, strength, flexibility, power, stamina, strength endurance and power endurance.

As for the research that mentions long-distance running, it is not only about endurance and endurance of speed but must have strength endurance, meaning strength training using the weight training method with the aim of increasing strength endurance so that muscles can be used for a long time. This is in line with the findings reported by Bazylar et al. (2015); Karp (2024), who stated that strength training can improve performance by increasing muscle strength and enhancing anaerobic and/or neuromuscular factors associated with long-distance running. It can also help prevent injuries by strengthening weak muscles and tendons and has been shown to have a positive effect on endurance performance.

The results of an optimal strength training program are not limited to weight training alone; they should also incorporate circuit training. According to Vadivel (2022); Lagos et al. (2024), circuit training consists of exercises performed at multiple stations and can be tailored to the specific demands of long-distance running. It combines various strength training methods, which can be adapted by manipulating factors such as intensity, volume, rest intervals between sets, training frequency, exercise type and sequence, and movement speed.

In fact, while in the field, the author conducted direct observation research in July 2023 in Balikpapan. The provision of strength training programs for long-distance runners is still not optimal, this is because the coaches still use the system if long-distance runners do not require strength training and only focus on training, development and endurance improvement (VO₂max), while Bazylar et al. (2015) in their research revealed that strength and endurance training carried out simultaneously can improve performance endurance in high-level athletes is greater than endurance

training alone. This means that strength and endurance training if done simultaneously can improve the endurance performance of athletes' strength.

The strength-endurance capacity of long-distance runners has not yet been developed to an optimal level, which may limit athletes' ability to maintain running performance over prolonged periods. Current training practices tend to focus primarily on aerobic exercise, while the development of muscular strength is often overlooked. This imbalance may contribute to muscle imbalances, reduced running efficiency, and an increased risk of injury. In addition, it can be seen when runners cannot maintain their muscle work for long periods of time during the 5000m and 10000m races. Therefore, Yamamoto et. al. (2008) showed that the combination of weight training with running training improves running efficiency and strength endurance compared to running training alone, with the conclusion that weight training can improve running economy, which is important for long-distance runners.

Strength in the author's hypothesis is one of the supporting factors to increase endurance work so that later runners can show their best results in the race and muscles are able to maintain their work longer. This finding is in line with the results reported by Lagos et al. (2024), who found that high-load strength training can improve performance, including time-to-fatigue outcomes, in middle- and long-distance runners. Greater improvements can be obtained when two or more strength training methods (e.g., high-weight training, submaximal weight training and/or plyometric training) are combined, albeit with insignificant effects on VO₂max, vVO₂max, MMSS, or running speed capacity.

Based on the findings of previous studies, weight-based strength training and circuit training have been shown to have significant effects on physical performance. Therefore, the present study aims to investigate the effect of external-load-based circuit training on the endurance performance of long-distance runners.

2. METHODS

2.1. Design

In this study, the author used a quantitative descriptive experiment method with a sample of long-distance athletes under the auspices of the Indonesian Athletics Association (PASI) Balikpapan. The preliminary research was conducted over an eight-month period, from January to August. This duration is consistent with the recommendations of Kris et al. (2014, 2016), who emphasized the importance of implementing appropriate strength training programs, including the prescription of

exercises, loads, and movement speeds, over a long-term intervention period of more than six months to optimize the transfer of training adaptations to performance. The data collection technique was carried out through the application of experiments, which consisted of 1 *pre-test* before *treatment*, 66 times of *treatment*, and 1 *post-test* after *treatment*. During the 66 athlete meetings, they will be given external load-based circuit training treatment on the performance of long-distance runners' endurance strength.

2.2. Participants

In sampling, the author used the purposive sampling technique with the intention of taking subjects not based on strata and randomness, but based on the existence of certain objectives (Mustofa et al., 2024). The respondents of this study consisted of 7 senior male athletes in the 5000m and 10000m running numbers with an age range of 21 years to 28 years, who were in the Balikpapan Athletics team. During the implementation of the research, the author upholds the code of ethics of experiments that were carried out for more than 6 months, and among them procedurally the intended respondents have received approval from the sports institution of the Indonesian Athletic Association (PASI) Balikpapan, the respondents are consciously and without coercion willing to be the subject of the research, the respondents know the purpose and purpose of this research.

2.3. Instrument

The research instrument used in this study was an achievement test. According to Arikunto, as cited in Mustofa et al. (2024), an achievement test is a test used to measure an individual's performance after learning or acquiring specific knowledge or skills. The instrument used in this study was the 101 Performance Evaluation Test. Mackenzie (2005) stated that tests should be specific, meaning that they are designed to assess the fitness of athletes for the activity in question; valid, meaning that they measure what they are intended to measure; reliable, meaning that they produce consistent results when repeated; and objective, meaning that they produce consistent results regardless of who administers the test.

Therefore, all tests must be specific (designed to measure an athlete's ability and suitability for the activity in question), valid (test what they want to test), reliable (able to perform repetitions consistently) and objective (produce consistent results in the test). As for the instruments that the author took as follows: a) a push up test to measure the endurance ability of arm strength, this instrument has a validity of 0.94 and a reliability of 0.93 (Rosadi in Faizin et. al., 2019), b) a sit up test to measure the endurance ability of the abdominal muscles, this instrument has a validity of 0.78

(Martin et al., 2016), c) a squat test to measure the endurance ability of the leg strength. This instrument has a reliability of 0.77 (Chiu et. al., 2018).

2.4. Procedures

Internal Validity is the inferential validity of whether the observed covariance between treatment (A) and the impact of treatment (B) reflects a causal relationship from A to B as the variable is manipulated or measured. While External Validity is the inferential validity of whether the cause-effect relationship is valid throughout the variation of people, settings, treatment variables and measurement variables (Shadish et al., in Dicky, 2011). This means that if correlated with this study, the internal validity of the treatment given to the respondents will have an impact on changes in muscle work, while externally in addition to changes in muscle work, the increase in muscle duration in the body is a phase in muscle formation and development so that the use of muscle work in activities can last for a long time.

The provision of treatment is in the form of a systematic, planned and repetitive exercise program with an increasing training load by paying attention to the condition of the respondents. As for the training program in question, the author can explain it in the form of table 1.

Table 1. Load-Based Training Program

No	Month	Rep	Rest/Rep	Set	Rest/Set
1	January	12 (40%)	15 seconds	6	3 minutes
2	February	12 (40%)	15 seconds	6	3 minutes
3	March	10 (50%)	15 seconds	8	3 minutes
4	April	10 (50%)	15 seconds	8	3 minutes
5	May	8 (60%)	30 seconds	9	3 minutes
6	June	8 (60%)	30 seconds	9	3 minutes
7	July	10 (50%)	15 seconds	9	3 minutes
8	August	10 (50%)	15 seconds	9	3 minutes

The table shows that the weight-training program begins with a relatively low number of repetitions. This approach is consistent with Dikdik et al. (2019), who stated that muscle-endurance training should be performed with relatively light loads. To improve muscular endurance, the training load should generally range from 30% to 60% of the maximum load, with a high number of repetitions and controlled movement speed. The administration of strength endurance training has the main methodological variables of intensity, number of sets and reps, rest intervals between sets, sequence of exercises, movement speed and frequency of exercise (Cui et al., 2023). The provision of

training programs is identified according to the needs of long-distance runners, including upper body, middle body and lower body consisting of 12 movements. This is because the method used is circuit training, which consists of multiple exercise stations.

Before the enactment of this study, athletes had passed the maximum strength program, because without intervention from the stages of anatomical adaptation and maximum strength as well as maximum rep data (1 RM), the author did not dare to conduct research on endurance, this is like what was conveyed by Faizal (2012) as for the periodization of strength training consisting of: 1) the anatomical adaptation phase, 2) the maximum strength phase, 3) conversion phase, 4) maintenance phase, and 5) transition phase. So, it can be known that athletes are currently in the phase of forming and developing endurance strength.

In order for this study to get objective results, the author needs and must avoid errors in the implementation of the test. The data was obtained using the experimental method at the beginning of the test as the initial data and the end of the test as the final data of the experiment. The goal is to be able to determine the effect of the treatment results that have been given. To determine the endurance ability of the arms, abdomen and legs, push-ups, sit ups and squats were used before and after treatment.

To obtain valid data in this study, the author needs to make an exercise program plan that is in accordance with the purpose of the exercise. In the implementation of the research, the author will provide a weight training program with the circuit training method to athletes of the Indonesian Athletic Association (PASI) Balikpapan long-distance running number. The procedure for implementing the test is carried out as follows: a) the push up test is carried out for 1 minute, the equipment needed is a mat, stopwatch, and an assistant. b) the sit up test is carried out for 2 minutes, the equipment needed is a mat, stopwatch, and an assistant. c) the squat test is carried out for 1 minute, the equipment needed is a mat, stopwatch, and assistants. The purpose of each of these tests is to measure the durability of the force.

2.5. Statistical Analyses

The data analysis technique was calculated using average, percentage, t-test sampling calculations to see the success of the exercise method on the physical aspects of strength endurance, descriptive statistics, inferential statistics homogeneity, normality, prerequisite test, and gene score. The design steps of this study will show the order of research activities, namely the initial test (Y1),

treatment (X), and final test (Y2). The difference between the initial test and the final test (*gain*) will later be used as an assumption as the effect of the treatment.

3. RESULTS

Diagram 1 shows the difference between the average preliminary-test (pre-test) and final-test (post-test) scores following the external-load-based circuit training program, specifically in relation to the athletes' strength endurance.

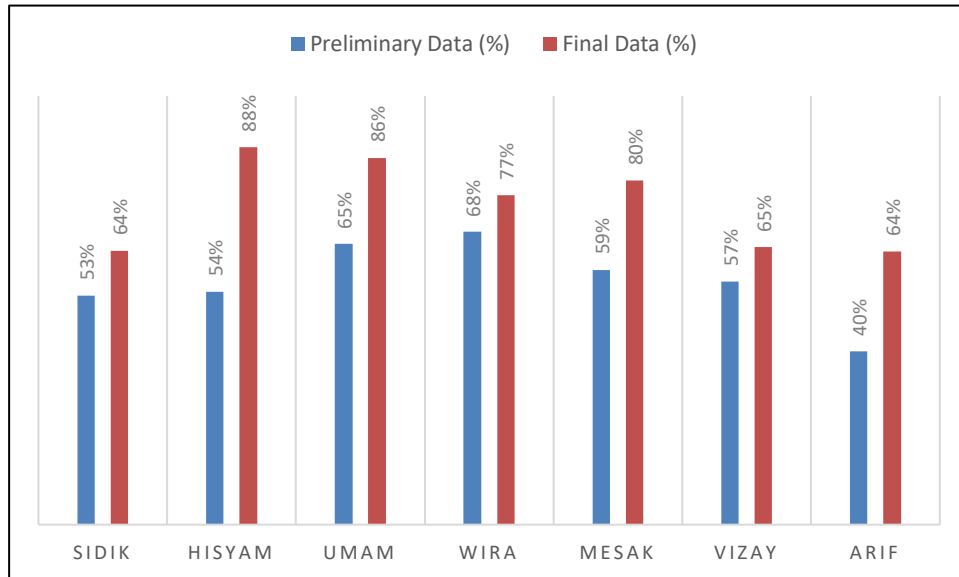


Diagram 1. Pre-test and post-test strength-endurance scores after circuit training

The diagram data above shows the results of the initial test and the final test, which shows that the initial data of athletes/respondents have not been given treatment of weight training programs while the final data of athletes/respondents have been given treatment. Preliminary sidik 53% final 64% increase +11%, Hisyam preliminary 54% final 88% significant increase of +34%, Umam preliminary 65% final 68% increase +3%, Wira preliminary 68% final 77% increase +9%, Mesak preliminary 59% final 80% increase +21%, Vizay preliminary 57% final 65% increase +8%, Arif preliminary 40% final 64% large increase of +24%. The author can conclude that all participants experienced an increase in their scores from the initial (pre-test) to the final (post-test) assessment. The largest increase was observed in Hysam (34%), followed by Arif (24%) and Mesak (21%), while the smallest increase was observed in Umam (3%). These findings indicate that a low initial score does not necessarily result in a poor final outcome. Table 2 shows the descriptive statistics of the participants' preliminary (pre-test) and final (post-test) scores.

Table 2. Descriptive statistics of pre-test and post-test scores

	N	Minimum	Maximum	Mean	SD
Preliminary Data	7	40	68	56.57	9.144
Final Data	7	64	88	74.86	10.495
Valid N (listwise)	7				

From the results of descriptive statistical data, the author can explain, the initial data has the smallest value (min) of 40 and the highest value of 68 (max) with an average value (mean) of 56.57 and a standard deviation (SD) of 9.144 showing a considerable variation/distribution of values. The final data had the smallest value (min) of 64 and the highest value of 88 (max) with an average value (mean) of 74.86 which was a significant increase from the initial data, and the SD of 10.495 showed a slightly larger spread of values than the initial data, but still within reasonable limits. With a provisional conclusion, there was an increase in the average score from 56.57 to 74.86. The minimum score increased drastically from 40 to 64 and the variation in scores increased slightly but was still quite controlled. The next thing the author did was to test homogeneity, it can be seen in table 3.

Table 3. Anova homogeneity statistical test

	Sum of Squares	Df	Mean Square	F	p value
Between Groups	417.214	5	83.443	.987	.640
Within Groups	84.500	1	84.500		
Total	501.714	6			

The results of the homogeneity test statistical data showed that the value of F was 0.987, meaning that the ratio between the variations between groups and the variation in the F group was small, meaning that the differences between groups were not so strong. The significance value (sig.) of 0.640 is the p-value of the Anova test, the interpretation of $0.640 > 0.05$ shows that there is no significant difference between the groups. In other words, the average between groups did not differ statistically. The conclusion of the null hypothesis (H0) that there is no mean difference between groups is accepted and the alternative hypothesis (H1) that there is an average difference is rejected, meaning that although there may be a statistically significant difference in mean numbers the

difference is not strong enough to be considered significant. Furthermore, the author conducted a normality test, the results of which are presented in table 4.

Table 4. Statistical normality test

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistics	Df	<i>p</i> value	Statistics	Df	<i>p</i> value
Preliminary Data	.205	7	.200*	.946	7	.696
Final Data	.255	7	.188	.853	7	.130

From the results of the statistical data of the normality test, because in this study the number of data is 7, the focus of the table above is more on the Shapiro-Wilk test, because the test is more accurate for small samples ($n < 50$). Shapiro-Wilk's interpretation of the initial data of Sig. 0.696 > 0.05 of the normal distribution and the final data of Sig. 0.130 > 0.05 of the normal distribution. The conclusion is that the two data groups are distributed normally, so the normality requirements are met and the parametric t-test can continue. Furthermore, data processing with *a paired sample test*. Furthermore, the author conducted an N Gain Statistical Test with the results can be seen in table 5.

Table 5. N-gain statistical test

	N	Minimum	Maximum	Mean	SD
Ngain_Score	7	.19	.74	.4218	.20481
Ngain_Persen	7	18.60	73.91	42.1809	20.48118
Valid N (listwise)	7				

The results of the n gain statistical data can be explained and the interpretation of N as a sample in the analysis of this study is 7, the N-Gain score (average) is 0.4218 on a scale of 0 – 1, in the medium category meaning that the intervention is quite effective in improving the results of the respondents. N Gain percent (average) 42.18%, is N-Gain converted to percentage, meaning that the effectiveness of the average training results increase by 42% and this corroborates the previous results (medium category). The SD of 0.20481 / 20.48% showed moderate variation between participants and there was a very small (min 0.19) and quite high (max. 0.74) increase. With the final conclusion, the average N-Gain score of 0.4218 is included in the medium category, meaning that the intervention is quite effective in improving athletes' training results, but the increase has not been

evenly seen from the value of 0.19 – 0.74. Finally, the author performed a paired-samples t-test, the results of which are presented in Table 6.

Table 6. Paired-samples t-test results

		Paired Differences							
				Std. Error Mean	95% Confidence Interval of the Difference				
		Mean	SD		Lower	Upper	T	Df	p value
Pair 1	Pre Test - Post Test	-18.28571	9.48181	3.58379	-27.05493	-9.51650	-5.102	6	.002

The obtained value of $0.002 < 0.05$ demonstrates a statistically significant effect of weight-based circuit training on strength endurance among pasi Balikpapan athletes in East Kalimantan.

4. DISCUSSION

This study aimed to improve strength endurance in long-distance athletes through pre-test and post-test assessments. The data were analyzed quantitatively using gain scores, descriptive statistics, assumption tests (normality and homogeneity), and a paired-samples t-test. This analysis is supported by recent evidence from the sports literature regarding the effects of external-load-based exercise on endurance and muscular strength. Beattie et al. (2014) reported that long-distance runners who performed weight training twice a week experienced significant improvements in muscle strength and 5-km time-trial performance, concluding that weight training can enhance power output and muscle work efficiency. Rønnestad et al. (2014) found that 8–12 weeks of strength training significantly improved muscular endurance and running performance, suggesting that strength training can provide long-term benefits for long-distance running performance. Bazyler et al. (2015) reported that periodic weight training combined with endurance training improved VO_2max and running performance in long-distance runners, indicating that weight training may enhance not only muscular strength but also cardiovascular adaptations. Based on these previous findings, the authors conclude that weight-based training can improve strength-endurance performance.

In addition to the explanation above, the author also analyzed based on the results of N-Gain which showed an increase in athletes' scores from 40-68% before training to 64-88% after. These findings are consistent with the literature that weight training contributes to increased muscle endurance. This finding is in line with the research of Vikestad et al. (2024), who reported that a combination of strength and endurance training programs can improve endurance performance, with

no significant effect of training sequence (endurance–resistance vs. resistance–endurance). Similarly, Jansson et al. (2022) reported benefits of resistance training for hormonal adaptation and immune function in children and adolescents.

In this study, the author included seven athletes due to the limited number of senior athletes who qualified for long-distance events, particularly in Balikpapan, East Kalimantan. Similarly, Ida et al. (2024), despite using a small sample size, reported significant improvements in muscular endurance and force output, even at light training loads.

Practical implications of external load-based training research with an effective circuit training approach in improving muscle strength endurance in athletes. Based on these findings, there are several practical implications that can be used as a reference in the field of sports training, including the time efficiency and effectiveness of *circuit training* training allows athletes to perform strength training continuously in a relatively short time, with high intensity and minimal rest breaks. This finding is in line with Pillon et al. (2020), who reported that exercise stimulates muscle tissue remodeling, with local inflammation contributing to increases in skeletal muscle mass and changes in muscle fiber composition. The statistically significant difference between the pre-test and post-test results demonstrates the effectiveness of this training model in improving muscular performance, particularly strength endurance. This finding is also consistent with the principles of overload and continuity in sports training.

Encouraging psychological and physiological adaptation such as discipline, consistency and motivation of training due to variations in circuit speed provides a more dynamic stimulus than conventional training. According to Putu (2019), training with heavy loads and short duration provides adaptation in the form of increasing muscle strength, while training with medium loads and long duration will increase muscle endurance.

Broadly speaking, the author must admit that there are many limitations in this study, including the use of small samples that can be used validly in experimental studies if the research design is strong, and in this study the research design used by the author does not have a control group so that it can cause intervention from outside the research. This study was conducted over an eight-month period. Although the results were statistically significant, this does not necessarily exclude the possibility of external factors influencing the outcomes during the intervention period. Differences in participants' activities or conditions between treatment sessions may also have contributed to the observed results.

For future coaches and researchers, it is recommended that studies include larger and more diverse athlete populations. Future research should also compare different strength-training models or methods to provide stronger evidence regarding their effects on strength endurance. In long-term training programs, the role of strength-endurance training in competitive and performance-oriented sports should be further investigated. As noted by Gumelar (2019), a high-quality training system is generally associated with improved athletic achievement.

5. CONCLUSIONS

This study concludes that there is a significant influence of external load-based training with the circuit training method on the performance of the endurance performance of long-distance runners of the Indonesian Athletic Association (PASI) Balikpapan. In terms of intervention, this research can be said to have been successfully carried out in Balikpapan, but it is not necessarily successful in other places due to limitations in the research.

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All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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