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Comparison of The Effectiveness of Active Recovery and Cold-Water Immersion on Fatigue Recovery in Recreational Runners

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Abstract

This study examines the effectiveness of Active Recovery (AR) and Cold-Water Immersion (CWI) in reducing blood lactate as an indicator of fatigue recovery in recreational runners after completing a 5-kilometer run. Using a pretest–posttest crossover design, seven recreational runners participated in two recovery conditions AR and CWI with a one-day washout period between treatments. Lactate levels were measured before and after each recovery session. The analysis showed that AR lowered lactate levels from 8.286 mmol/L to 6.257 mmol/L ($p = 0.106$), while CWI reduced levels from 5.243 mmol/L to 3.300 mmol/L ($p = 0.057$). While neither method showed statistically significant differences, CWI revealed a more noticeable trend in accelerating lactate reduction toward OBLA values compared to AR. These findings indicate that CWI could provide faster metabolic recovery for recreational runners needing shorter recovery periods, whereas AR remains appropriate for gentler recovery focused on sustaining movement ease. Due to the limited sample size, additional studies with a larger population are advised to provide stronger support for these recovery strategies.

How to Cite

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INTRODUCTION

The 5-kilometer run is becoming increasingly popular among people worldwide (Aprilo et al., 2024). Besides being a competitive event, this activity is also popular because people use it to stay healthy, lower their chance of getting long-term illnesses, and build stronger friendships through running groups. The numbers show that more people are joining in as recreational runners every year, which matches the growing trend of people choosing more active ways to live (Varela-Sanz et al., 2024). Running more often and harder can make you feel tired, which can lower how well you perform, make you more likely to get hurt, and slow down how your body and mind recover.(Rahmani et al., 2025). Fatigue in runners can be split into two parts. One type is central fatigue, which involves the brain and nervous system. The other is peripheral fatigue, which is connected to how the muscles work and how they use energy (Domenico & Raiola, 2021). Therefore, an effective recovery process is essential for recreational runners to return to optimal condition, minimize the risk of overtraining, and be ready for the next training session or race.

International research has highlighted various aspects of fatigue and recovery in non-professional runners (Restrepo-Villamizar et al., 2020). A systematic review found that intensive running can alter biomechanical parameters, such as leg stiffness and ground reaction forces, which impact injury risk (Anderson et al., 2022). Other studies show that recreational runners who run 5 km generally experience neuromuscular dysfunction. This condition is characterized by increased fatigue, decreased leg muscle strength, and reduced body stability, which can ultimately affect your running stride. A pilot study on trail runners even showed a shift in autonomic nervous system function after the race, characterized by decreased heart rate variability and increased sympathetic dominance (Faiqah & Puspitasari, 2022). Some muscle functions do recover relatively quickly, but signs of fatigue were already apparent before the race began. One common approach to recovery is active recovery, where runners keep moving with light activities such as leisurely walking or slow jogging to help improve blood flow. This method is considered capable of reducing lactate buildup while also reducing muscle soreness after intensive exercise (Menzies et al., 2010). On the other hand, cold-water immersion is also quite popular as a recovery strategy, which involves immersing the body in low-temperature water to reduce inflammation and provide a refreshing effect on the muscles. This method is believed to accelerate physiological recovery, especially after high-intensity strenuous activity (Roberts et al., 2014). However, literature specifically examining recreational runners at the 5K distance is still limited, particularly in examining the relationship between central and peripheral fatigue and the dynamics of recovery within hours to a day after the race (Pastor, 2022). Thus, there is room for research to gain a deeper understanding of how the recovery process takes place in this population.

One of the main indicators of physiological fatigue is the accumulation of lactate in muscles and blood, which is a product of anaerobic metabolism when the body is working at high intensity (Immanuel et al., 2017). Accumulated lactate can cause muscle fatigue, pain, and decreased performance, making lactate level monitoring important in assessing the effectiveness of recovery methods (Yamaguchi et al., n.d.). A study of fatigue mechanisms and recovery strategies in recreational runners is also important from the perspective of sports science and public health (Paley & Johnson, 2025). Fatigue in middle-distance sports such as 5km running can be interpreted as a reduction in the body›s capacity to maintain a stable intensity of work, which arises from a combination of factors from both the central and peripheral systems. (Sanchez et al., 2025). A good understanding of the body›s response to physical stress can support more effective exercise program planning, prevent overuse injuries, and maintain long-term exercise motivation (Liu et al., 2023). In addition, research in this field can contribute to the development of evidence-based interventions, such as active and passive recovery methods, that are appropriate for the characteristics of non-elite runners (Kelemen et al., 2025). To date, there has been little research that systematically compares the effectiveness of Active Recovery and Cold-Water Immersion in reducing physiological fatigue and subjective perception, as well as mapping central and peripheral fatigue in recreational 5 km runners during short-term recovery periods. herefore, the results of this study are not only theoretically relevant, but also have practical implications that can be directly felt by runners, coaches, and the running community.

This study tries to address a missing part by looking at how tired recreational runners feel and how their bodies recover after a 5 km race. It looks at changes in their body and what they feel like before, right after, and in the days that follow.

The goal is to understand what causes tiredness around the body, see how quickly people recover in the short term, and find out what personal factors might explain why some runners feel different from others. This study›s originality derives from the fact that it directly compares active recovery and cold-water immersion in recreational runners who have adhered to a standardized 5-km running protocol. This study concentrates on community-level runners, whose training characteristics and physiological responses are quite different from those of elite athletes or the various exercise modalities examined in prior research. The research offers fresh proof of the feasibility, efficacy, and practical applicability of these two recovery methods for non-elite running populations by combining physiological indicators with perceived fatigue measures.

METHOD

This study used a pretest-posttest with treatment design. Each participant was asked to run a distance of 5 kilometers, then a blood lactate level test was conducted as pretest data. After that, the subjects underwent one of two recovery methods: active recovery and cold-water immersion. In the active recovery treatment, participants walked around the stadium for 10 minutes, while in the cold-water immersion treatment, participants immersed their lower bodies from the waist down in water and ice cubes for 10 minutes, with the temperature maintained using ice cubes and water. After recovery is complete, blood lactate levels are checked again (posttest) to assess the effectiveness of the method administered. Treatment was performed on the same sample with a 1-day interval between the two methods, so that the subject's body had the opportunity to return to its initial condition before the next treatment.

The research variables consisted of independent variables, namely recovery methods; dependent variables, namely blood lactate levels after treatment; and control variables, which included running distance, activity intensity, data collection time, and research environmental conditions.

The population of this study was members of the recreational running community in the city of Bandung. The sample was selected using purposive sampling with inclusion criteria of runners aged between 18 and 27 years old, who had been active in the community for at least three months, were generally healthy, had no injuries, and were able to complete a 5-kilometer run. The sample size consisted of seven recreational runners who met these criteria.

This study began with a 5-kilometer run by all participants (7 people). After completing the run, blood lactate levels were checked using a portable lactate analyzer as baseline data (pre-test), followed by treatment and another lactate check (post-test). The research design used was crossover, with data collection conducted twice within a period of two days with a one-day interval between sessions to avoid any residual effects from the previous treatment (washout period). At the first meeting, the subjects underwent active recovery in the form of a ten-minute walk. At the second meeting, the treatment continued with the cold-water immersion method by soaking in a pool of water and ice at a temperature of 12–15°C for 10 minutes. After the treatment was completed, blood lactate levels were checked again post-test.

Data collection was done through physical exams, including measuring blood lactate levels, and by recording personal information and details about running activities. The data was analyzed by first checking if the lactate levels fol-

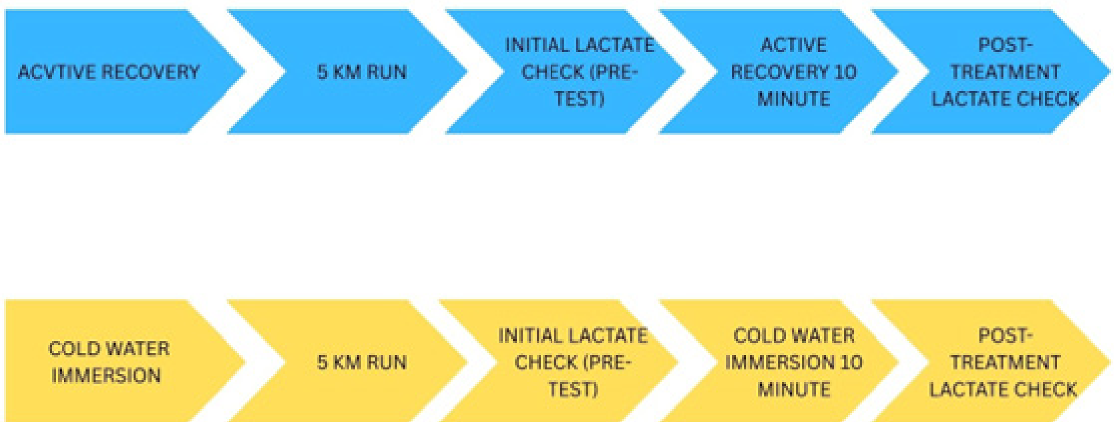

Figure 1. Flowchart of the Active Recovery and Cold Water Immersion Research Procedure.

lowed a normal distribution using the Shapiro–Wilk test. Both groups Active Recovery and Cold Water Immersion had results with significance values above 0.05, meaning they met the requirements for using statistical methods that assume normal distribution. After confirming the data fit the assumptions, a paired sample t-test was used to look at changes in lactate levels before and after treatment within each group. An independent sample t-test was also used to compare how well each recovery method reduced lactate levels after treatment. All data processing steps were carried out systematically to ensure that the results obtained not only described physiological trends but were also statistically reliable. Using this method, the study is expected to provide an empirical description of more effective recovery strategies for reducing lactate levels and accelerating recovery in recreational runners, as well as making a real contribution to community-based sports practices.

RESULTS AND DISCUSSION

Based on the Shapiro-Wilk normality test, lactate level data in the Active Recovery (AR) group (W = 0.978; p = 0.949) and Cold Water Immersion (CWI) group (W = 0.978; p = 0.949) were normally distributed (p > 0.05). This indicates that the data meet the assumptions of parametric statistics. The homogeneity of variance test also shows that the lactate level data in both groups have the same variance, with Levene's Test results of F = 0.883 and p = 0.366 (> 0.05), so the data are declared homogeneous.

Table 1. Homogeneity Test

Variabel	F	Sig	Description
Lactate_Post	.883	.366	Homogeneous

A test of variance homogeneity was performed on **Table 1** to ensure that the lactate level data in the Active Recovery (AR) and Cold Water Immersion (CWI) groups had the same variance before testing for differences between groups. The Levene test results showed an F value of 0.883 with p = 0.366. Since the p value was > 0.05, the data from both groups were declared homogeneous.

The results of the paired sample t-test in **Table 2** active recovery show that the mean lactate level from the overall pre-test was 8.9 mmol/L and the mean post-test lactate level was 6.26 mmol/L (post-test). The mean difference was 2.0286 mmol/L, with a p-value of 0.106. Since p > 0.05, the decrease in lactate levels was not statistically significant, although there was a noticeable downward trend after participants underwent Active Recovery for 10 minutes.

Table 2. Pre-Post Active Recovery Test and Cold Water Immersion

Variabel	Pre-test	Post-test	Sig	Description
Active Recovey	8.286 mmol/L	6,257 mmol/L	.106	No Significant
Cold Water Immersion	5,243 mmol/L	3,300 mmol/L	.057	No Significant

Note:
Pre-test (Average actual lactate check results after exercise)
Post-test (Average actual lactate check results after treatment)

Table 3. Comparison of Active Recovery and Cold Water Immersion

Variabel		Mean	Sig (2-tailed)	Description
Lactate_Post	Active Recovery	6.257	.035*	Singnificant
	Cold Water Immersion	3.300		

The results in **Table 3** show that lactate levels after exercise differ between the recovery methods used. In active recovery, the average lactate level reached 6.257 mmol/L with a significance value of 0.035, indicating a significant decrease in lactate after the intervention. Meanwhile, in cold water immersion, the average lactate level was lower, at 3.300 mmol/L, indicating that this method is more effective in accelerating the removal of lactate from muscles after exercise.

Fatigue in recreational runners is a natural body response that happens when the body's energy system can't keep up with the muscles' need for energy. During a run, especially at moderate to high speeds like in a 5 km race, the body first uses aerobic metabolism to produce energy. But as the pace increases and the demand for energy grows, the body starts relying more on anaerobic metabolism. This process produces lactate as a byproduct, which is a key sign of how much metabolic stress the body is under during the activity (Wahl et al., 2021). The OBLA (Onset of Blood Lactate Accumulation) value set at a range of 4 $mmol \cdot L^{-1}$ is used as a reference for interpreting the runner's condition after exercise, as resting lactate levels are in the range of 1–2 $mmol \cdot L^{-1}$ (María et al., 2013). In this study, after the intervention, the lactate levels show that Cold-

Water Immersion helps bring lactate down close to OBLA levels, while Active Recovery leads to a slower decrease, though there is still a sign of improvement. These results match the idea in physiology that higher lactate during the anaerobic phase is linked to more metabolic fatigue, so how lactate drops after exercise is a good sign of how well the body is recovering (Brooks, 2009). These findings are consistent with the theoretical basis of various studies explaining the dynamics of lactate accumulation and its relevance to the aerobic–anaerobic transition.

How well recreational runners do during moderate to high intensity training depends on how the three main energy systems work together. These systems are phosphagen, anaerobic glycolysis, and oxidative (Sandi, 2019). In the early stages of running, the phosphagen system dominates ATP supply, before shifting to anaerobic glycolysis when energy demand increases sharply and phosphocreatine reserves decline (Hei & Indonesia, 2023). The dominance of the anaerobic pathway contributes to a progressive increase in lactate production, and when oxidative capacity is unable to keep pace, lactate accumulation occurs, correlating with the onset of metabolic fatigue (Patellongi, 1999). The process of lactate disposal after exercise itself is highly dependent on the rate of oxidation in muscle fibers and the lactate shuttle mechanism, whereby lactate is transported to other tissues to be used as an energy substrate (Brooks, 2009). The way lactate levels decrease after Active Recovery and Cold-Water Immersion in this study shows how the body's energy system works. Active Recovery keeps muscles moving a little, which keeps blood flowing well, but keeping up some activity actually makes the sharp drop in lactate slower. On the other hand, Cold-Water Immersion causes blood vessels in the muscles to narrow, which shifts blood flow to areas that can process waste products more efficiently because those areas have a better ability to use oxygen. (Ramskov et al., 2016). so that the decrease in lactate levels towards OBLA values was more pronounced. Muscle fatigue in recreational runners is mainly triggered by the accumulation of metabolites such as hydrogen ions, a decrease in phosphocreatine reserves, and changes in membrane excitability that reduce the ability of muscle fibers to produce optimal tension. Increased anaerobic glycolysis activity during high-intensity phases also increases the production of lactate and other metabolites that contribute to a decrease in muscle contractile performance (Paula et al., 2018). After exercise, how fast your body recovers depends on how well blood flows to the muscles, how much oxygen is used, and how the body initially responds with inflammation. These factors affect how quickly waste products are removed from the muscles and how fast the body returns to its normal state. In this study, Active Recovery kept the muscles slightly active, so the heart rate didn't drop much and stayed at a higher level. This pattern matches earlier research showing that doing light exercise during recovery keeps the heart working steadily, preventing a sudden drop in heart rate (Draper et al., 2006). In contrast, Cold-Water Immersion causes peripheral vasoconstriction, lowers tissue temperature, and suppresses nerve conduction velocity, resulting in a more rapid decrease in cardiovascular response and muscle tension (Moore, Fuller, Buckley, et al., 2022). This response is consistent with recent research showing that CWI reduces delayed muscle soreness and improves perceived recovery through modulation of hemodynamics and early inflammation (Xiao et al., 2023).

The study results show that using cold water immersion leads to a bigger drop in lactate levels compared to active recovery. On average, lactate levels went down from 5.243 mmol/L to 3.300 mmol/L with cold water immersion, while they only dropped from 8.286 mmol/L to 6.257 mmol/L with active recovery. Even though the difference wasn't big enough to be statistically significant because there weren't enough people in the study, it still shows a clear trend of better recovery. Earlier research has found that cold water immersion helps get rid of lactate faster by narrowing blood vessels in the skin, which helps send more blood to areas of the body that use oxygen more efficiently, speeding up the breakdown of lactate (Paula et al., 2018). These findings are consistent with other studies confirming that exposure to cold water increases the efficiency of metabolite clearance and reduces post-exercise physiological stress, as well as bringing lactate levels closer to the OBLA zone, thereby accelerating metabolic recovery (Moore, Fuller, Bellenger, et al., 2022). In contrast, AR maintains light muscle activity, which, although capable of maintaining blood flow, actually slows down the rate of lactate decline because continuous motor activity continues to trigger the production of small amounts of metabolites (Draper et al., 2006). Several other studies have also shown that AR is more effective at maintaining short-term neuromuscular performance but does not always provide lactate reduction as quickly as passive methods or cooling-based methods such as CWI (Katoch et al., 2025). Overall, the pattern of lactate decline in CWI, which was closer to the OBLA value after 10 minutes, indicates that this method provides a faster recovery response for recreational runners compared to AR, although statistical interpretation must still take into account the limited sample size.

Given that this study involved a relatively small sample size, the differences between the AR and CWI groups that appear to be trends even though they did not reach statistical significance should be interpreted with caution because studies with small samples have a high risk of underpowering, i.e., not being sensitive enough to detect the actual effect if it is small or moderate (Bleakley et al., 2025). Critical literature in the field of sports and rehabilitation shows that many randomized trials are constrained by low statistical power; for example, a recent meta-review found that the median power in RCTs in the musculoskeletal field was only about 42%, and less than a third of RCTs had ≥ 80% power to detect real effects, especially small to moderate effects (Mesquida et al., 2022). In addition, studies with small samples are systematically more prone to large variability, imprecise effect estimates, and false negatives (type II errors), even though clinical or physiological effects may actually exist meaning that the absence of statistical significance does not automatically mean that there are no relevant biological effects (Yamaguchi et al., n.d.). To make the results of studies like this more reliable, future research should use planned power and sample size calculations, report effect sizes and confidence intervals, or use more sensitive methods such as repeated measures or working with multiple centers to get more participants and ensure the group is similar. Even though the current study shows a better trend of lowering lactate with cold water immersion, we should be careful in our conclusions. This is because the study has some methodological limits, like a small group of people, which weakens the statistical conclusions and makes it harder to apply the results to a wider group of recreational runners.

The study found that even though the difference between active Recovery and cold-water immersion wasn't statistically significant, the data showed that cold water immersion helped reduce lactate levels faster, bringing them closer to OBLA levels. This suggests that cold water immersion may support quicker metabolic recovery compared to active recovery. This result matches what other research has shown, which is that cold water immersion can speed up the decrease in lactate, muscle soreness, and how quickly someone feels they've recovered (Sahedi, 2021). For recreational runners who need quick recovery after training or want to train/run again in a short period of time, cold water immersion (water temperature ≤ 15 °C, duration 10–15 minutes) can be a practical and efficient recovery method. On the other hand, active recovery remains relevant when the goal of recovery is to maintain blood flow, prevent muscle stiffness, or when the main priority is not to reduce lactate as quickly as possible for example, when the interval between training sessions is quite long (Parwata, 2015). However, because this study had a small group of participants, the suggestions should be seen as general ideas rather than strict rules. Coaches and runners should think about each person's unique situation, how hard they are training, and what they want to achieve in terms of recovery before deciding on a method. To learn more, future studies should include a bigger group of people, measure lactate levels at several time points like 10, 30, and 60 minutes, and also look at things like muscle function and how people feel about their recovery. This would help create a clearer picture of how the body recovers and make the results apply better to a larger group of people who run for fun.

CONCLUSION

This study shows that Cold-Water Immersion tends to reduce lactate levels more quickly than Active Recovery, although the difference is not statistically significant. Post-treatment lactate values in the cold water immersion group fell close to the physiological OBLA limit, indicating that the metabolic recovery process was more effective during the short recovery period. Meanwhile, AR continues to lower lactate levels, but the rate of decline is slower because light muscle activity during recovery still maintains a small amount of metabolite production. This difference in trends shows that both methods have benefits, but the effects of cold water immersion on metabolic recovery appear to be more pronounced in recreational runners. These results also confirm that the limited sample size affects the power of statistical analysis. The absence of statistically significant differences does not negate the existence of physiologically meaningful differences. Thus, interpretation of the results needs to take these limitations into account so as not to draw exaggerated conclusions or underestimate the actual potential effects.

Based on the limitations of this study, suggestions for future research include considering the use of Cold-Water Immersion for recreational runners who need rapid recovery after high-intensity training, while Active Recovery is more suitable for maintaining muscle flexibility and light activity. Future studies should also involve a larger sample size and add other physiological indicators so that a more complete picture of the recovery process can be obtained.

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