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Ice Bath more effective than Proprioceptive Neuromuscular Facilitation on Blood Lactate Reduction and Heart Rate Recovery in Rock Climbing Athletes in Denpasar

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ABSTRACT

Sport is a structured and planned physical activity designed to improve physical fitness and overall health. One rapidly growing discipline in the field of sport is rock climbing, particularly in the speed climbing category. This activity involves high-intensity anaerobic effort that may lead to muscle fatigue, elevated blood lactate levels, and increased heart rate post-exercise. Excessive blood lactate accumulation can disrupt recovery processes and negatively affect short-term and long-term athletic performance. Therefore, it is crucial to apply effective recovery methods to accelerate lactate clearance and restore heart rate to resting levels. Two commonly used recovery techniques are *Proprioceptive Neuromuscular Facilitation* (PNF) stretching and cold water immersion, commonly known as an *ice bath*. This study aimed to compare the effectiveness of PNF stretching and ice bath immersion in reducing blood lactate levels and recovery heart rate in rock climbing athletes in Denpasar City. A quasi-experimental pre-test and post-test design was applied to three groups: PNF stretching (n=6), ice bath (n=6), and a control group (n=6). Interventions were administered twice a week for two weeks. Blood lactate levels were measured using the Lactate Scout device, and recovery heart rate was recorded manually at one and five minutes post-exercise. The results showed that both PNF stretching and ice bath methods significantly reduced blood lactate levels ($p<0.05$) when compared to the control group. However, the ice bath method produced a greater and more consistent reduction. In terms of recovery heart rate, there were no statistically significant differences between the three groups ($p>0.05$), although the ice bath group exhibited a more favorable downward trend in heart rate recovery. PNF stretching did not show significant effects on reducing recovery heart rate compared to the ice bath and control groups but still demonstrated a positive physiological recovery response. In conclusion, the ice bath method was more effective than PNF stretching in reducing blood lactate levels in speed climbing athletes. It is recommended as a primary method for accelerating metabolic recovery following high-intensity exercise. On the other hand, PNF stretching remains a useful alternative recovery technique, especially for enhancing muscle flexibility and reducing muscular tension. It is suggested that PNF stretching be combined with active cooling or other recovery methods to achieve more optimal results. Future research should explore the long-term effects of these recovery methods, variations in ice bath temperature and immersion duration, and involve larger and more diverse athlete populations to improve the generalizability of the findings.

Keywords:

Rock Climbing, Blood Lactate, Recovery Heart Rate, Ice Bath, PNF Stretching, Physiological Recovery.

1. INTRODUCTION

Exercise is a planned and structured physical activity that involves repetitive body movements to improve physical fitness. This activity is important in daily life, as it can enhance endurance and can be practiced from a young age to old age, even on a daily basis. Regular exercise can increase muscle mass, because training stimulates muscle cell growth and activates inactive muscle cells (Janpurba, 2011).

Anaerobic exercise is a type of high-intensity physical activity of very short duration in which muscles use energy sources stored within the contracting muscles without requiring inhaled oxygen as an energy source (Akbar, 2021). This process produces adenosine triphosphate (ATP) through glycolysis and fermentation, which generates less ATP than aerobic processes and leads to the accumulation of lactic acid. Types of exercises typically considered anaerobic include those involving fast-twitch muscle fibers, such as sprinting, high-intensity interval training (HIIT), and weightlifting. Sustained anaerobic metabolism or anaerobic exercise results in a continuous increase in lactic acid and metabolic acidosis, with this transition point referred to as the anaerobic threshold (AT). AT can be directly measured using periodic blood samples to determine blood lactate levels during incremental exercise protocols. Once the blood lactate levels are plotted, the point at which the curve shows a sudden sharp rise represents AT. Other methods include portable lactate analysis and mathematical formulas involving the heart rate (HR) (Akinci, 2019).

Rock climbing, a sport that is gaining attention, is becoming increasingly popular in Indonesia, particularly among youth. This phenomenon is reflected in the growing number of rockclimbing sports clubs in various cities and regions. These clubs are part of the Indonesian Rock Climbing Federation (FPTI) alongside outdoor enthusiasts and climbing clubs.

Rock climbing plays an important role in the evolution of sports in Indonesia. The activity was divided into two types: climbing on natural rock outdoors and wall climbing in artificial settings. In particular, indoor wall climbing has gained popularity among teenagers in recent years, as evidenced by the frequent organization of wall-climbing competitions, ranging from local to national and international levels.

Rock climbing has become a challenging choice for the younger generations. Its demands for courage and skill make it a competitive sport that focuses on achievement. For this reason, this sport must be optimally developed to achieve the best results.

To improve athletice performance, physical conditioning training is crucial for maintaining muscle fitness. Saputra (2021) explained that such training must consider aspects such as strength, speed, agility, coordination, explosive power, flexibility, and endurance.

Rock climbing requires significant finger and arm strength to overcome the body weight resistance during ascent. High upper-body strength is essential because of the nearly continuous intermittent and sustained isometric contractions of arm muscles (MacDonald, 2018). When athletes engage in training with high volume or very high intensity, fitness may improve, but fatigue tends to increase (Bompa in Widiyanto, 2016).

Rock climbing comprises three different disciplines: speed climbing, bouldering, and lead climbing, each with its own motor demands. Lead climbing is generally categorized as a mixed endurance and strength sport that requires sustained effort and high muscle power. Bouldering, on the other hand, emphasizes maximum strength, development of dynamic power, and quick recovery. Speed climbing is the most dynamic discipline and is characterized by high anaerobic power, fast movements, and short completion times. Elite speed climbers achieved remarkable ascent times, relying primarily on the phosphagen system for ATP synthesis during intense supramaximal efforts lasting up to 5 s. Although anaerobic glycolysis becomes increasingly important over longer durations, good techniques play a key role in enhancing the locomotor speed (Ozimek, 2018).

The limited number of studies on sport-specific strength in speed-climbing indicates the need for further research in this area. Guo et al. (2019) reported that high blood lactate concentrations after climbing a 15-meter speed route (7.6 ± 1.9 mmol/L) reflect significant muscle metabolic activity, given that rapid body movements during climbing are powered by large muscles in both limbs. The positive correlation between the blood lactate concentration and climbing time also showed that slower athletes tended to have higher lactate levels. Female athletes in this study tended to be slower and produced more lactate than male athletes did. Conversely, faster male athletes showed lower lactate levels. Speed climbing is a high-intensity activity performed in the shortest possible time. Therefore, after high-energy phosphates are depleted via the ATP-CP system, the glycolytic system is used, resulting in high blood lactate levels, which can lead to relatively slower muscle contractions and longer climbing times.

Blood lactate formation resulting from high-intensity and prolonged exercise. In short-duration, high-intensity exercise, energy demands increase dramatically. Although the body struggles to produce large amounts of energy in a short time, the phosphagen system and anaerobic glycolysis are its primary energy sources (Cole et al., 2017).

The phosphagen system can only supply energy for activities lasting less than ten seconds. Therefore, anaerobic glycolysis is the main metabolic pathway that occurs during high-intensity exercise. Blood lactate is formed as the end product of anaerobic glycolysis owing to incomplete glucose breakdown (Fox in Widiyanto, 2016). However, lactate accumulation can occur when its production exceeds its clearance (Brooks in Widiyanto, 2016).

High-intensity activity without adequate recovery, relying on anaerobic glycolysis as the main energy source, can lead to the buildup of lactate in the blood. This inhibits aerobic energy supply to the muscles and results in fatigue (Dewilestari, 2019).

Glycolysis can occur both aerobically and anaerobically depending on the availability of oxygen in the cell. Anaerobic glycolysis is divided into two pathways: alactic anaerobic and lactic anaerobic glycolysis. Alactic anaerobic conditions occur continuously with increasing muscle tension. However, excessive blood lactate formation in athletes can lead to muscle injury (Janssen, 2012).

One way to accelerate blood lactate recovery is to enhance the oxidation and gluconeogenesis processes, as well as accelerate lactate distribution to the liver (Widiyanto, 2016). Potential physiotherapy interventions to accelerate lactic acid recovery based on their physiological effects include Proprioceptive Neuromuscular Facilitation (PNF) and cryotherapy.

PNF is a stretching method that is used to improve muscle elasticity. Hindle et al. (2012) explained that this technique has positive effects on both active and passive stretching. In athletic and clinical settings, PNF is used to increase range of motion (ROM) both actively and passively to optimize motor performance and rehabilitation. The mechanism of PNF involves proprioceptive impulses generated by stimulation of proprioceptive sensory organs in the muscles, tendons, and joints. This sensory information informs body position and movement and affects the muscle-tendon system and manual pressure. When a muscle is stretched, signals from muscle spindle receptors are sent to the spinal cord, which then triggers muscle contraction during stretching (Long et al., 2013; Ylien, 2008). Overall, the PNF stretching techniques improved ROM, muscle strength, and athletic performance. Regular and consistent application is necessary to achieve positive effects of this technique. PNF also helps maintain muscle elasticity, reducing the risk of injury (Hindle et al., 2012).

Cryotherapy can be used as a physical recovery method in athletes after intense training. This technique can help relieve pain and inflammation in soft tissues. The application of cold to the skin, subcutaneous tissue, intramuscular areas, and joints can cause temperature changes that stimulate muscle inflammatory responses (Arovah, 2016). Cryotherapy can induce local vasoconstriction, reduce swelling, and lower metabolic activity in the body. This technique aids in recovery from conditions such as sores or tense muscles (Airaksinen et al., 2013). Cryotherapy has analgesic effects, reduces pain, and increases blood flow, oxygenation, and muscle metabolism. Applying this technique immediately after exercise, particularly in the form of an ice bath, can help relieve soreness and reduce muscle damage (Noorah, 2016).

Meyer (2013) found that using an ice bath or cold-water immersion after intense training can significantly lower blood lactate levels. Several studies have shown that this procedure accelerates recovery by reducing inflammation and facilitating lactate removal from muscles. Ice baths can reduce blood lactate levels by approximately 1 to 2 mmol/L after 15 to 20 min of treatment. However, individual responses to ice baths may vary depending on factors such as treatment duration, water temperature, and the physical condition of the athlete prior to treatment.

It is important to note that ice bath use should follow guidelines, such as proper timing and duration, and take into account the skin condition. Contraindications should also be considered, particularly in athletes with cold allergies or certain health conditions. Properly managing ice bath recovery according to athletes' needs after intense exercise is essential to maximize benefits and reduce muscle inflammation (Noorah, 2016).

Cryotherapy after intense physical activity, such as full-body immersion in ice baths or alternating between cold and warm water, has become a common practice among athletes, particularly at the elite level. This practice is believed to reduce muscle soreness and fatigue after training or competitions. Several mechanisms have been proposed to explain the potential benefits of this therapy, including the stimulation of muscle cell activity, narrowing of blood vessels to clear waste products, reduced metabolism, decreased swelling, and lactic acid breakdown. However, despite its popularity among athletes, cold-water therapy is not always strongly supported by scientific evidence, and several studies have produced inconclusive or even ineffective findings. Therefore, it is important to further explore whether this practice truly provides significant benefits or is related to placebo effects.

pulse is a palpable vibration in the arterial blood vessel walls that occurs during heart contraction and relaxation (systole and diastole). Heart rate, or pulse rate, is the number of beats felt in one minute due to blood flow through the heart. The pulse is most easily palpated where the arteries pass close to the skin surface. The recovery pulse is the time required to return to the normal heart rate after completing exercise. This measurement is important for observing how quickly a person can recover from strenuous physical activity (Kusuma, 2020).

Based on the background presented above, the researcher aims to analyze the effects of comparing Proprioceptive Neuromuscular Facilitation stretching and ice bath on reducing blood lactate levels and recovery pulse rate in rock climbing athletes in Denpasar City.

2. METHOD

An experimental study was conducted using a quasi-experimental design with a two-group pre-test and post-test design. This study was conducted at the Kompyang Sujana Field in Denpasar from July to August 2024. The research population consisted of all members of the Denpasar City rock-climbing team registered with the Indonesian Rock Climbing Federation (FPTI), totaling 18 athletes. Because the total population met and exceeded the minimum requirement of the Federel formula and the size was less than 100, the total sampling technique was used. Thus, all 18 athletes were included in the study sample and randomly divided into three groups of six participants each. The inclusion criteria were being a member of the Denpasar City rock-climbing team, aged at least 15 years, and willing

to participate by signing informed consent. The exclusion criteria were current injury or injury recovery, while the drop-out criteria were sustaining an injury during the research period or withdrawal from the study.

3. RESULTS AND DISCUSSION

Normality and Homogeneity Test

The results of the normality test for the blood lactate variable in Table 2 show that the data in the three groups during the pre-test had p-values of 0.052, 0.416, and 0.411. All p-values were greater than 0.05, indicating that the pre-test data in the three groups were normally distributed. Similarly, in the post-test, the p-values were 0.866, 0.814 for Group 2, and 0.434 for Groups 1,2, and 3, respectively, indicating that the post-test data were normally distributed. Levene's test results for the homogeneity of the pre-test blood lactate levels showed a p-value of 0.64 ($p > 0.05$), indicating that the variance among the groups was homogeneous.

Table 2. Normality and Homogeneity Tests Using the Shapiro–Wilk Test and Levene's Test on Pre–Post Blood Lactate Levels

Research Data Blood Lactate	*Saphiro-Wilk Test*			*Levene's Test*
	Group 1	Group 2	Group 3	
	p	*p*	*p*	*p*
Pre Test	0,052	0,416	0,411	0,64
Post Test	0,866	0,814	0,434	

Meanwhile, in Table 3, the results of the normality test for the recovery heart rate variable also showed that the pre-test data had a p-value of 0.065 for Group 1, $p = 0.820$ for Group 2, and $p = 0.415$ for Group 3, all of which were greater than 0.05. In the post-test, the p-values were $p = 0.664$ for Group 1, $p = 0.505$ for Group 2, and $p = 0.473$ for Group 3. Based on these results, it can be concluded that the recovered heart rate data were also normally distributed in all groups. The homogeneity test results, using Levene's test on the pre-test data, showed a p-value of 0.201, indicating that the variance among the groups was homogeneous.

Table 3. Normality and Homogeneity Tests Using the Shapiro–Wilk Test and Levene's Test on Pre–Post Recovery Heart Rate Using the Brouha Test

Research Data Recovery Heart Rate	*Saphiro-Wilk Test*			*Levene's Test*
	Group 1	Group 2	Group 3	
	p	*p*	*p*	*p*
Pre Test	0,065	0,820	0,415	0,201
Post Test	0,664	0,505	0,473	

Hypothesis Test on Blood Lactate Reduction Before and After Ice Bath Intervention

Based on the paired sample t-test analysis in the group receiving the Ice Bath intervention, the mean reduction in blood lactate levels was **8.1 ± 4.001 mmol/L**, with a p-value of **0.000**. As $p < 0.05$, this result indicates a statistically significant decrease in blood lactate levels after the Ice Bath intervention. This finding aligns with previous studies that highlight the efficacy of cold-water immersion in accelerating lactate clearance and improving metabolic recovery after high-intensity activities (Meyer, 2013; Hohenauer et al., 2015; Cain et al., 2025).

Physiologically, cold-water immersion may enhance recovery by reducing muscle temperature, lowering metabolic demand, and promoting vasoconstriction followed by reactive vasodilation, which facilitates metabolite removal (Hegishte & Kumar, 2023; Versey et al., 2013). For climbing athletes who rely heavily on anaerobic metabolism and experience rapid lactate accumulation (Guo et al., 2019; Ozimek, 2018), the significant lactate reduction observed suggests that Ice Bath therapy can be an effective post-exercise recovery strategy. Furthermore, this result supports the practical application of cryotherapy in sports that require repeated bouts of high-intensity effort, contributing to performance maintenance in competitive settings (Arovah, 2016; Noorah, 2016).

Table 4. Pre–Post Test on Blood Lactate Reduction Before and After Intervention

Group	Before-After Treatment Mean ± SD	P-*Value*
Group 1	8,1±4,001	0,000
Group 2	7,5±3,086	0,002
Group 3	5,1±3,053	0,007

Hypothesis Test on Blood Lactate Reduction Before and After PNF Stretching Intervention

Based on the paired sample t-test analysis in the group receiving the PNF Stretching intervention (Group 2), the mean reduction in blood lactate levels was **7.5 ± 3.086 mmol/L**, with a p-value of **0.002**. This result indicates a statistically significant decrease in blood lactate levels following the PNF Stretching intervention ($p < 0.05$). This finding is in line with previous research showing that Proprioceptive Neuromuscular Facilitation stretching can enhance venous return,

increase blood flow to the working muscles, and promote the clearance of metabolic byproducts including lactate (Hindle et al., 2012; Long et al., 2013).
Physiologically, PNF stretching combines passive stretching and isometric contraction, which can improve muscle elasticity, increase capillary perfusion, and stimulate neuromuscular activation, thereby facilitating metabolite removal (Ylinen, 2008; Hindle et al., 2012). In the context of speed climbing, where rapid anaerobic energy turnover leads to substantial lactate accumulation (Guo et al., 2019; Ozimek, 2018), the observed lactate reduction suggests that PNF stretching is a viable recovery method for improving metabolic efficiency and potentially enhancing subsequent performance. Although the magnitude of reduction in this study was slightly lower than that in the Ice Bath group, PNF stretching offers additional benefits in terms of flexibility and joint range of motion, which may contribute to injury prevention and technical performance in climbing athletes (Arovah, 2016; Widiyanto, 2016).

Between-Group Differences in Blood Lactate Reduction After Intervention
Before conducting further analysis to determine differences between groups, an ANOVA test was first performed to examine whether there were overall significant differences among the three treatment groups regarding blood lactate levels after intervention (post-test).

Table 5. Between-Group Differences in Blood Lactate Reduction After Intervention Using ANOVA

Group	difference *Mean*±SD	P-*Value*
Group 1	7,5±3,448	0,017
Group 2	7,5±3,086	
Group 3	7,5±3,086	

Based on the ANOVA results for blood lactate levels after the intervention, the p-value was 0.017. This value was lower than the significance threshold of 0.05, indicating a statistically significant difference among the three treatment groups. Therefore, these results provide the basis for conducting a post hoc test to determine which specific groups showed significant differences in blood lactate reduction.

Table 6. ANOVA Between Groups on Blood Lactate After Intervention Using Post Hoc Test

Group (Post Blood Lactate)	Mean Difference ± SD	p-Value
Group 1 vs Group 2	5.266 ± 1.854	0.031
Group 1 vs Group 3	5.266 ± 1.854	0.031
Group 2 vs Group 3	0.000 ± 1.854	1.000

Further analysis using the post hoc test was conducted to examine the differences in the mean post-intervention blood lactate levels among the treatment groups. The results revealed that the difference between Group 1 (Ice Bath) and Group 2 (PNF Stretching) had a p-value of **0.031**, while the difference between Group 1 and Group 3 (control) also showed a p-value of **0.031**. Both values were below the significance threshold of 0.05, indicating statistically significant differences between these groups in blood lactate reduction after the intervention. In contrast, the comparison between Groups 2 and 3 yielded a p-value of **1.000**, suggesting no statistically significant difference.
These findings indicate that the Ice Bath intervention (Group 1) produced a significantly greater reduction in blood lactate levels than both PNF Stretching (Group 2) and no treatment (Control, Group 3). This supports existing evidence that cold-water immersion can accelerate lactate clearance through vasoconstriction–vasodilation cycles, which enhance muscle perfusion and waste removal during recovery (Versey et al., 2013; Leeder et al., 2012). Conversely, although PNF Stretching demonstrated some reduction in lactate in the within-group analysis, its effect was not significantly different from that of no treatment when compared between groups. This may suggest that while PNF stretching provides flexibility and range of motion benefits, its role in acute lactate clearance may be less pronounced than that of Ice Bath interventions, particularly following high-intensity anaerobic efforts, such as speed climbing (Menzies et al., 2010; Crowther et al., 2017)

Hypothesis Test on Recovery Heart Rate Before and After Ice Bath Intervention
To analyze changes in recovery heart rate measured using the Brouha method, repeated measures analysis of variance (ANOVA) was applied. This test was chosen because the research design involved repeated measurements of the same subjects at three different time intervals.

Table 7. Hypothesis Test on Recovery Heart Rate Reduction After Ice Bath Intervention

Time Variable	*Mean ± SD* *Ice Bath*	*P-Value*
P1	81,00 ± 2,23	$p = 0.00$
P2	50,66 ± 2,66	
P3	35,66 ± 1,28	

Based on the Repeated Measures ANOVA results for heart rate recovery in the group receiving the Ice Bath intervention, the significance value was **p = 0.000**. Since this value was less than the established significance threshold ($p < 0.05$), it can be concluded that there was a statistically significant difference in the recovery heart rate across the measurement times after the intervention. Therefore, the hypothesis stating that *Ice Bath has an effect on reducing recovery heart rate in rock climbing athletes in Denpasar City* is accepted.

To further identify specific differences between the recovery heart rate measurement times after the Ice Bath intervention, a post hoc analysis using Pairwise Comparisons with Bonferroni adjustment was conducted. The analysis revealed significant differences between Time 1 and Time 2 ($p = 0.003$), between time 1 and Time 3 ($p = 0.000$), and between time 2 and Time 3 ($p = 0.013$). Since all p-values were below 0.05, it can be concluded that the reduction in the recovery heart rate at each time interval was statistically significant.

These findings indicate that Ice Bath intervention provided consistent and progressive improvement in cardiovascular recovery following high-intensity activity. This aligns with previous studies suggesting that cold-water immersion enhances parasympathetic reactivation and reduces sympathetic drive, thereby accelerating post-exercise heart rate recovery (Buchheit et al., 2009; Stanley et al., 2013; Versey et al., 2013). Such physiological responses may be attributed to vasoconstriction, decreased tissue temperature, and reduced cardiac workload, which collectively facilitate a more efficient return to resting cardiovascular functions (Leeder et al., 2012).

Table 8. Comparison Test on Recovery Heart Rate Reduction After Intervention Using Pairwise Comparison – Group 1

Time		Time	Mean	SD	P-Value
P1	vs	P2	30.333	4.455	0.003
P1	vs	P3	45.333	2.578	0.000
P2	vs	P3	15.000	3.055	0.013

Hypothesis Test on Recovery Heart Rate Before and After PNF Stretching Intervention

Based on the Repeated Measures ANOVA results, there was a significant difference in heart rate recovery across measurement times ($p = 0.00 < 0.05$). This result indicates that the PNF Stretching intervention significantly reduced the heart rate progressively after the climbing activity. Therefore, the hypothesis stating that "PNF Stretching has an effect on reducing recovery heart rate in rock climbing athletes in Denpasar City" is statistically accepted.

Table 9. Hypothesis Test on Recovery Heart Rate Reduction Before and After PNF Stretching Intervention (Group 2)

Time Variable	*Mean ± SD* *Pulse*	*P-Value*
P1	79,00 ± 2,097 bpm	$p = 0.000$
P2	50,33 ± 3,881 bpm	
P3	36,33 ± 1,632 bpm	

Based on the pairwise comparison test results in Group 2 (PNF Stretching), all values were statistically significant ($p < 0.05$). This indicated significant differences between Time 1 and Time 2, Time 1 and Time 3, and Time 2 and Time 3 in the recovery heart rate measurement. Therefore, it can be concluded that the PNF Stretching intervention had a significant effect on reducing the recovery heart rate.

Time		Time	Mean	SD	P-Value
P1	vs	P2	28.667	1.520	0.000
P1	vs	P3	42.667	0.803	0.000
P2	vs	P3	14.000	1.732	0.001

Between-Group Differences in Recovery Heart Rate Reduction After Intervention

This study aimed to evaluate the differences in heart rate recovery among three intervention groups: Group 1 (Ice Bath), Group 2 (PNF Stretching), and Group 3 (control) based on recovery heart rate measurements at three intervals: P1 (0–30 s), P2 (30–60 s), and P3 (60–90 s) using the Brouha method.

Table 10. ANOVA Test on Recovery Heart Rate Among Groups

Heart rate	Group Ice Bath		Group PNF Stretching		Group control		P-*Value*
	Mean	SD	Mean	SD	Mean	SD	
P1	81,00	5,47	79,00	2,09	79,33	3,14	0,609

P2	50,66	2,09	50,33	3,88	54,83	1,63	0,331
P3	35,66	2,42	36,33	6,11	38,66	1,03	0,066

The one-way ANOVA results revealed no statistically significant differences in the recovery heart rate between the groups at P1 (p = 0.609) and P2 (p = 0.331). However, at P3 (90 s post-exercise), the significance value approached the threshold of 0.05 (p = 0.066), indicating a tendency toward more pronounced group differences in recovery heart rate at this later stage of recovery. Further post-hoc analysis using the Bonferroni method supported this observation, showing that the comparison between the Ice Bath group (Group 1) and the control group (Group 3) yielded a p-value of 0.083. Although this value did not reach conventional statistical significance, it was close enough to suggest a potentially meaningful clinical trend. Such borderline results may reflect the physiological time course of post-exercise autonomic recovery, where the benefits of cold-water immersion become more apparent after the initial minute of recovery, as suggested by previous research on the delayed parasympathetic reactivation and thermoregulatory effects of cold therapy (Buchheit et al., 2009; Stanley et al., 2013; Versey et al., 2013)Table 11). Post-hoc test of recovery heart rate between groups before and after intervention

Interval	Group Comparison	SD	p-value
P1	Group 1 vs Group 2	2.115	1,000
P1	Group 1 vs Group 3	2.115	1,000
P1	Group 2 vs Group 3	2.115	1,000
P2	Group 1 vs Group 2	3.251	1,000
P2	Group 1 vs Group 3	3.251	0,658
P2	Group 2 vs Group 3	3.251	0,560
P3	Group 1 vs Group 2	1.229	1,000
P3	Group 1 vs Group 3	1.229	0,083
P3	Group 2 vs Group 3	1.229	0,321

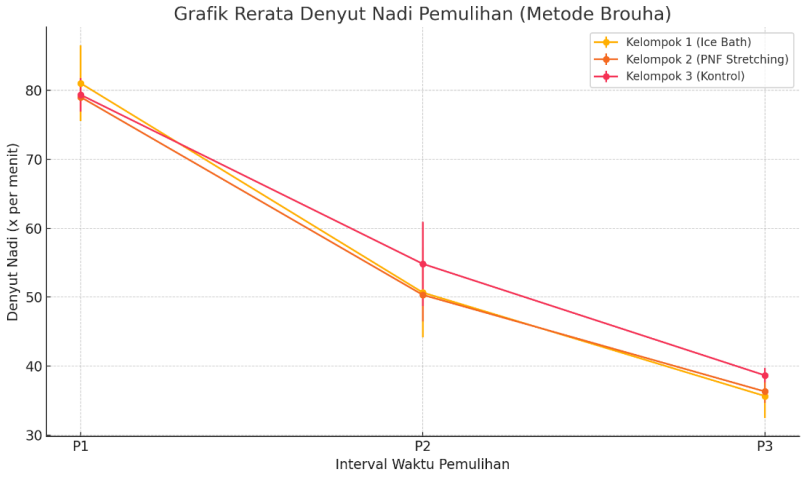

Figure 1. Average recovery heart rate based on time intervals (P1, P2, P3) for each group

The graphical visualization in Figure 1 shows the trend of decreasing heart rate recovery in the three groups (Ice Bath, PNF Stretching, and Control) based on the Brouha time intervals P1 (0–30 s), P2 (30–60 s), and P3 (60–90 s) post-exercise. All three groups experienced a progressive decrease in heart rate from P1 to P3, reflecting the physiological cardiovascular recovery process after exercise load.

The Ice Bath group (Group 1) showed the most consistent decrease in heart rate, followed by the PNF Stretching group (Group 2), while the control group (Group 3) showed a slower decrease. This indicates that cooling with an Ice Bath and stretching with the PNF technique positively influenced the speed of heart rate recovery. Particularly in the P3 phase (60–90 s), the intervention groups showed lower average heart rates than the control group, supporting the statistical findings that differences between groups became more evident in the final recovery phase.

This study involved rock-climbing athletes aged 20–21.5 years with a BMI of 17.32–18.42 kg/m², which falls within the normal range. The uniformity of these characteristics helped maintain the proportional distribution of respondents across treatment groups and control for external variables, thereby ensuring more valid results. Proprioceptive Neuromuscular Facilitation (PNF) stretching effectively reduces blood lactate levels and accelerates heart rate recovery through a mechanism of isometric contraction followed by passive stretching, which increases muscle flexibility, improves blood circulation, and speeds up lactate metabolism in organs such as the liver and skeletal muscles. Its effectiveness increases when performed for more than 15 min or combined with other recovery strategies, such as light aerobic activity or massage. Meanwhile, ice baths work through vasoconstriction caused by cold exposure, which reduces lactate production, followed by vasodilation, which accelerates lactate clearance into the bloodstream for metabolism, while also lowering the metabolic rate, reducing inflammation, and relieving muscle

spasms. The effectiveness of ice baths is high when applied at optimal duration and temperature, and can be further enhanced through methods such as Contrast Water Therapy, which utilizes dynamic vasomotor stimulation to speed up post-exercise recovery.

4. CONCLUSION

Based on the research findings, the following conclusions were drawn: PNF Stretching was effective in significantly reducing blood lactate levels in rock-climbing athletes in Denpasar City; however, the degree of reduction was not superior to that achieved with an Ice Bath. PNF Stretching did not result in a significant decrease in heart rate recovery compared to the Ice Bath and control groups. Ice Bath was proven effective in significantly reducing blood lactate levels in rock-climbing athletes and showed better results than PNF Stretching and the control group. Ice Bath did not produce a significant decrease in the recovery heart rate, although it showed a favorable downward trend. PNF Stretching was not superior to an Ice Bath in reducing either blood lactate levels or heart rater ecovery. There was no significant difference among the three groups (PNF, Ice Bath, and control) in heart rate recovery, although all showed a good physiological recovery response.

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