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Original Research Article

Comparison of the Effectiveness of Cold and Warm Water Immersion on the Intensity of Delayed Onset Muscle Soreness in Calf Muscles after Weight Training

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Abstract: ***Introduction*:** Exercise is essential for maintaining physical fitness, and weight training is a popular form that can cause delayed onset muscle soreness (DOMS). Although cold and warm water immersion are known to reduce DOMS, direct comparative studies are limited. This study compares their effectiveness in reducing calf muscle DOMS after weight training. ***Aims*:** This study aims to determine the comparative effectiveness of cold water immersion and warm water immersion on the intensity of delayed onset muscle soreness in the calf muscles following weight training. ***Method*:** This study employed a quantitative quasi-experimental design with a posttest-only three-group approach. A total of 36 participants were selected using total sampling. DOMS intensity was measured using the Visual Analogue Scale (VAS) on the left calf at 24, 48, and 72 hours after weight training. ***Results*:** This study showed that warm water immersion significantly reduced VAS scores compared to cold water immersion ($p = 0.006$) and the control group ($p = 0.032$), while no significant difference was observed between cold water immersion and the control group ($p = 0.605$), indicating the superior effectiveness of warm water immersion. ***Conclusion*:** Warm water immersion is significantly more effective than cold water immersion and the control group in reducing calf muscle DOMS after weight training.

Keywords: Cold Water Immersion, Warm Water Immersion, Delayed Onset Muscle Soreness, Calf Muscle, Weight Training, Universitas Nusa Cendana.

INTRODUCTION

Delayed onset muscle soreness (DOMS) is a sensation of pain and discomfort in muscles that is commonly experienced after performing unaccustomed exercise or exercise movements involving high muscle force, most frequently occurring during activities that involve eccentric muscle contractions. (Delcour *et al.*, 2014) This sensation typically increases in intensity within the first 24–48 hours after exercise, reaches its peak between 24–72 hours, and then gradually subsides and resolves within 5–7 days after exercise. (Wang *et al.*, 2022) Several theories have been proposed to explain the mechanisms underlying DOMS, including lactic acid accumulation, muscle spasm, connective tissue damage, mechanical muscle damage, cellular inflammation, and enzyme efflux theories. (Zondi *et al.*, 2015)

DOMS is the most common form of mild exercise-induced pain, particularly following unaccustomed physical activity. A study by Yanuar and Rachmah (2018) involving 60 members of a university sports student activity unit at Universitas Negeri Yogyakarta reported that 100% of participants had experienced DOMS after exercise. (Prihantoro & Ambardini, 2018) DOMS is also a major cause of decreased physical performance, particularly affecting muscle strength and range of motion in both athletes and non-athletes. (Kantanista *et al.*, 2016) In the lower extremities, DOMS commonly affects the quadriceps, gastrocnemius, hamstrings, and tibialis anterior muscles. (Prihantoro & Ambardini, 2018) DOMS in the calf muscles contributes to reduced performance in sports involving lower limb movements such as running and jumping and may interfere with daily activities, as the calf muscles play an essential role in basic human functions such as standing and walking. (Lalchhuanawma & Andrew, 2020)

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DOMS can be prevented and managed. Currently, various therapeutic modalities are available to prevent or reduce the symptoms of DOMS. (Heiss *et al*., 2019) Hydrotherapy is one such modality that utilizes the physical properties and advantages of water and is considered to have beneficial therapeutic effects in both clinical and alternative treatments, with minimal side effects. The health benefits of hydrotherapy are generally mediated through thermal effects induced by warm or cold water exposure. (An *et al*., 2019) Warm water therapy has analgesic effects by stimulating the activation of transient receptor potential vanilloid-1 (TRPV1) receptors and also enhances blood flow and tissue metabolism, thereby accelerating tissue healing processes. (Malanga *et al*., 2015) In contrast, cold water therapy induces vasoconstriction, which slows the inflammatory mediator response and reduces inflammation in the treated area. Cold water therapy also produces a local anesthetic effect by lowering the activation threshold of tissue nociceptors and reducing the conduction velocity of nerve signals that transmit pain sensations. (An *et al*., 2019; Malanga *et al*., 2015)

One form of hydrotherapy is water immersion, which is categorized based on water temperature, such as warm water immersion (WWI), cold water immersion (CWI), and other water-based methods. Water immersion therapy has been widely used as a post-exercise recovery intervention, particularly among athletes. However, despite its widespread application, scientific evidence regarding its potential benefits and underlying mechanisms remains limited. (Vaile *et al*., 2008) A meta-analysis by Wang *et al*., (2022), which reviewed 59 articles comparing 10 therapeutic modalities, found that CWI was the most effective method for reducing DOMS-related pain after the first 48 hours. (Wang *et al*., 2022)

Several studies (Machado *et al*., 2016; Roberts *et al*., 2015; Leeder *et al*., 2019) examining the role of CWI following isolated eccentric exercise have demonstrated its effectiveness in reducing post-exercise muscle soreness. (Kwiecien & McHugh, 2021) Conversely, Malanga *et al*., (2015) recommended cold water therapy for acute muscle injury recovery and inflammation reduction, while warm water therapy was recommended for alleviating muscle and joint pain and reducing joint stiffness. Malanga *et al*., (2015) also noted that both warm and cold water immersion therapies can help reduce muscle pain; however, the evidence supporting the effectiveness of warm water therapy is more robust. (Malanga *et al*., 2015)

Therefore, based on the background described above, this study aims to compare the effectiveness of cold water immersion and warm water immersion on the intensity of DOMS in the calf muscles following weight training.

METHODS

This study employed a quasi-experimental design with a posttest-only three-group design. The research was conducted at the Sacred Heart Monastery, Penfui, Kupang City, from 25 to 30 September 2023. The study population consisted of 40 male students of the Sacred Heart Monastery, of whom 36 participants were included as samples. This study was approved by the Health Research Ethics Committee of the Faculty of Medicine and Veterinary Medicine, Universitas Nusa Cendana (approval number: UN01230765). All participants provided informed consent prior to participation.

The inclusion criteria were male participants aged 18–25 years. The exclusion criteria included active athletes; individuals with special needs (diagnosed acute or chronic diseases, physical or intellectual disabilities); a history of extremity fractures; current muscle injuries; a history of cold or warm water allergy; current use of analgesic or anti-inflammatory medications; a history of asthma or heart disease; and the presence of open wounds or skin diseases on the legs. The independent variables of this study were cold water immersion (CWI) and warm water immersion (WWI), while the dependent variable was the intensity of DOMS pain.

Data collected included subject identity, body mass index (BMI), vital signs, and physical readiness screening using the Physical Activity Readiness Questionnaire (PAR-Q). The PAR-Q was used to ensure that participants were physically fit and safe to engage in physical activity. Eligible participants were then allocated into three groups: the cold water immersion group, the warm water immersion group, and the control group, with 12 subjects in each group.

All subjects underwent weight training, intervention according to group allocation, and three DOMS pain assessments. The weight training protocol aimed to induce DOMS in the calf muscles and consisted of standing calf raises and seated dumbbell calf raises. The load used for each subject was 75% of one-repetition maximum (1RM) for each exercise. Both exercises were performed in three sets, with participants instructed to perform as many repetitions as possible in each set. A one-minute rest period was provided between sets.

Following the weight training session, subjects received interventions according to their assigned groups. In the CWI group, participants immersed both legs in a seated position up to the level of the fibular head for 10 minutes at a water temperature of 10°C. Subjects in the WWI group underwent the same immersion position for 30 minutes at a water temperature of 38°C. Participants in the control group did not receive any intervention. After the intervention, subjects were allowed to perform daily activities as usual, with restrictions on exercise and any form of DOMS therapy, including muscle massage or the use of analgesic or anti-inflammatory medications.

DOMS pain intensity was measured using a Visual Analogue Scale (VAS), consisting of a 100 mm horizontal line anchored by "no pain" at the left end and "worst pain imaginable" at the right end. Pain assessments were conducted three times at 24, 48, and 72 hours after the weight training session. During measurement, subjects were seated upright with the hip and knee joints flexed at 90°. To represent passive muscle contraction, the researcher applied pressure to the calf muscle using an aneroid sphygmomanometer cuff inflated to 250 mmHg for 10 seconds. Subjects were then asked to rate the perceived DOMS pain on the VAS, specifically for the left calf muscle.

Data analysis was performed using SPSS software. Univariate analysis was conducted to describe respondent characteristics, including age, BMI, and type of physical activity. Data normality was assessed using the Kolmogorov–Smirnov test, with a significance level of $p > 0.05$ for sample sizes greater than 50. The Tukey HSD test was used to compare the effectiveness of cold water immersion and warm water immersion on the intensity of delayed onset muscle soreness in the calf muscles after weight training.

RESULTS

Univariate Analysis

The total number of participants in this study was 36 subjects. All participants were male and aged between 18 and 25 years. Among the 36 samples, only one subject had a body mass index (BMI) above the normal range according to the BMI classification of the Indonesian Ministry of Health, with a BMI value of 25.9. The characteristics of the study subjects are presented in the table below.

Table 1: Age Distribution of Respondents in Each Intervention Group

	Cold Water Immersion	Warm Water Immersion	Control
Characteristic	**Frequency (n = 12)**	**Frequency (n = 12)**	**Frequency (n = 12)**
Age (Years)			
18	2	2	3
19	1	1	2
20	4	3	3
21	2	2	1
22	1	1	0
23	1	1	1
24	1	1	1
25	1	1	1
Total	**12**	**12**	**12**

Based on the data presented in Table 1, the most common ages among respondents in the control group were 18 and 20 years, with three participants each. In the CWI group, the highest proportion of respondents was 20 years of age, comprising four participants. Similarly, in the WWI group, the most frequent age was 20 years, with three participants.

Table 2: Distribution of Body Mass Index (BMI) of Respondents in Each Intervention Group

	CWI	WWI	Control
BMI	**Frequency (n = 12)**	**Frequency (n = 12)**	**Frequency (n = 12)**
< 17,0	1	1	0
17,0 – 18,4	1	1	1
18,5 – 25	10	10	10
25,1 – 27,0	0	0	1
>27,0	0	0	0

Based on Table 2, it is known that the majority of respondents in all three groups had a Body Mass Index (BMI) within the range of 18.5–25.0, which is classified as normal according to the BMI classification of the Indonesian Ministry of Health (Kemenkes RI), with 10 respondents in each group.

Table 3 : Distribution of Types of Daily Physical Activity of Respondents in Each Intervention Group

Types of Daily Physical Activity	CWI	WWI	Control
Farming	6	4	5
Animal Husbandry	4	4	4
Gardening	2	4	3
Total	**12**	**12**	**12**

Based on Table 3, there were three types of physical activities performed daily by the respondents, namely farming, animal husbandry, and gardening. The most common physical activity among the respondents was farming, which was performed by 15 individuals.

Table 4: Distribution of DOMS Intensity in the Calf Muscles After 24 Hours

Variable	CWI	WWI	Control
Pain Scale			
No Pain	1	1	0
Mild	4	5	2
Moderate	3	4	6
Severe	4	2	4
Total	**12**	**12**	**12**

Table 4 describes the intensity of delayed onset muscle soreness (DOMS) measured 24 hours after weight training and the administration of the interventions. The intensity of DOMS was categorized into four levels: no pain, mild pain, moderate pain, and severe pain. In the three intervention groups, the distribution of DOMS intensity after 24 hours showed variability in pain categories experienced by the respondents according to their respective intervention groups.

Table 5: Distribution of DOMS Intensity in the Calf Muscles after 48 Hours

Variable	CWI	WWI	Control
Pain Scale			
No Pain	0	1	0
Mild	2	5	3
Moderate	5	5	4
Severe	5	1	5
Total	**12**	**12**	**12**

Table 5 shows the distribution of DOMS intensity changes from day 1 (24 hours). Changes in pain levels among respondents indicated both progressive worsening of pain and reduction in pain intensity in some individuals. For example, in the warm water immersion (WWI) group, the number of respondents experiencing severe pain on day 1, which was two individuals, decreased to one individual on day 2. In contrast, in the cold water immersion (CWI) group, the number of respondents experiencing severe pain increased from four individuals on day 1 to five individuals on day 2. Both the CWI and WWI groups also demonstrated an increase in pain intensity among some respondents, shifting from mild pain on the first day to moderate pain on the second day.

Table 6: Distribution of DOMS Intensity in the Calf Muscles after 72 Hours

Variable	CWI	WWI	Control
Pain Scale			
No Pain	0	3	2
Mild	6	8	6
Moderate	4	0	3
Severe	2	1	1
Total	**12**	**12**	**12**

Table 6 presents the pain intensity on day 3 (72 hours) after weight training. In the WWI group, several respondents experienced a reduction in pain intensity, with up to three individuals reporting no pain. Meanwhile, in the CWI group, all respondents still experienced pain; however, the intensity of pain reported began to decrease.

Bivariate Analysis

Bivariate analysis was conducted to determine differences in effectiveness and statistical significance among the cold water immersion (CWI), warm water immersion (WWI), and control groups at 24, 48, and 72 hours after DOMS measurement. The analysis was performed using a one-way ANOVA with a 95% confidence level ($\alpha \leq 0.05$) for normally distributed data, while non-normally distributed data were analyzed using the Kruskal–Wallis test. If the bivariate analysis demonstrated statistically significant differences, further evaluation of the effectiveness between intervention groups for each day was performed using the Independent t-test or the Mann–Whitney U test.

The results of the bivariate analysis are as follows. On the first day, bivariate analysis was performed using a one-way ANOVA to compare the treatment groups, followed by Tukey's HSD test to assess effectiveness. The one-way ANOVA revealed no significant differences among the CWI, WWI, and control groups on the first day after intervention ($p = 0.435$; $p > 0.05$). This non-significant result indicated that further effectiveness testing between interventions was not required.

Bivariate analysis of the second-day data was also conducted using a one-way ANOVA to compare the treatment groups, followed by the Independent t-test or Mann–Whitney U test if significance was observed. The one-way ANOVA results showed no statistically significant differences among the intervention groups on the second day after treatment ($p = 0.069$; $p > 0.05$). Therefore, further effectiveness testing was deemed unnecessary.

For the third day, bivariate analysis was performed using the Kruskal–Wallis test to compare the treatment groups, with the Mann–Whitney U test planned for post hoc analysis if significant differences were found. The Kruskal–Wallis test demonstrated no statistically significant differences among the intervention groups on the third day ($p = 0.107$; $p > 0.05$), indicating that further effectiveness analysis was not required.

Multivariate Analysis

Multivariate analysis was conducted to evaluate differences in intervention effectiveness across the three days of VAS measurements using a two-way ANOVA. This analysis aimed to assess changes in VAS scores from the first to the last day of measurement, followed by Tukey and LSD post hoc tests to identify differences in effectiveness among the intervention groups.

Table 7: One Way Anova Test

Source	Type III Sum of Squares	f	Mean Square	F	P Value
Corrected Model	21254.336a	8	2656.792	3.231	.003
Intercept	172933.503	1	172933.503	210.319	.000
Days	12639.777	2	6319.889	7.686	.001
KLPK	7281.903	2	3640.951	4.428	.015
Days * KLPK	1657.590	4	414.398	.504	.733
Error	76468.683	3	822.244		
Total	270006.000	02			
Corrected Total	97723.020	101			

The results of the two-way ANOVA indicated a statistically significant decrease in VAS scores over time, suggesting a reduction in pain intensity experienced by the respondents. Significant differences were observed among the intervention groups, necessitating further assessment of intervention effectiveness using Tukey's HSD or LSD tests.

Table 8: Tukey HSD Test

Tukey HSD	Intervention Group	Intervention Group	Mean Difference	Std. error	P Value	95% CI	
						Lower Bound	Upper Bound
	CWI	WWI	19.0833*	6.75871	.006	5.6619	32.5048
		Control	3.6833	7.08860	.605	-10.3932	17.7599
	WWI	CWI	-19.0833*	6.75871	.006	-32.5048	-5.6619
		Control	-15.4000*	7.08860	.032	-29.4766	-1.3234
	Control	CWI	-3.6833	7.08860	.605	-17.7599	10.3932
		WWI	15.4000*	7.08860	.032	1.3234	29.4766

Based on the post hoc analysis, a comparison between CWI and WWI demonstrated that WWI resulted in a significantly greater reduction in VAS scores ($p = 0.006$; $p < 0.05$). Similarly, the comparison between WWI and the control group showed that WWI was significantly more effective in reducing VAS scores ($p = 0.032$; $p < 0.05$). In contrast, the comparison between the CWI and control groups revealed no statistically significant difference.

Overall, univariate analysis demonstrated comparable baseline characteristics across groups. Bivariate analysis revealed no significant differences in DOMS intensity at individual time points. However, multivariate analysis showed a significant reduction in VAS scores over time and significant differences among intervention groups, with warm water immersion demonstrating the greatest reduction in pain intensity.

DISCUSSION

Based on the results of this study, significant differences were observed among the cold water immersion (CWI), warm water immersion (WWI), and control groups in relation to delayed onset muscle soreness (DOMS). The findings demonstrated a reduction in pain intensity measured using the Visual Analogue Scale (VAS) on day 1, day 2, and day 3. The decrease in VAS scores was particularly pronounced in the moderate and severe pain categories. In the severe pain category, 11 respondents initially experienced severe pain, which decreased substantially to only 4 respondents by day 3. Similarly, the moderate pain category showed a notable reduction from 11 respondents to 6 respondents by day 3. When examining the distribution of DOMS intensity per group from day 1 to day 3, the most significant reduction in pain category was observed in the WWI group. This finding is consistent with the multivariate analysis results, which demonstrated that WWI was significantly more effective in reducing DOMS from day 1 to day 3 compared with CWI and the control group.

In this study, DOMS induction was achieved through passive contraction to measure DOMS-related pain. This method was selected to induce DOMS more efficiently. (Apostolopoulos *et al*., 2018) However, in contrast to that study, measurements in the present study were performed only on the left leg. This decision was based on findings by Isabel *et al*., (2017), who reported that the dominant extremity has greater muscle volume than the non-dominant extremity. (Teo *et al*., 2017) A larger muscle volume is associated with a higher number of muscle fibers, which may reduce the likelihood of micro-muscle damage during resistance training and consequently result in a less pronounced perception of DOMS. (Teo *et al*., 2017)

DOMS occurs as a result of muscle damage that triggers an inflammatory response. Two primary pathways are involved in the induction of DOMS, namely activation of the bradykinin B2 receptor–nerve growth factor (NGF) pathway and activation of the cyclooxygenase-2 (COX-2)–glial cell line-derived neurotrophic factor (GDNF) pathway. (Mizumura & Taguchi, 2016) DOMS causes movement difficulties and pain-related discomfort. The inflammatory nature of DOMS is supported by research conducted by Jonathan M. Peake *et al*., (2017), which demonstrated that exercise induces inflammatory responses in muscle tissue, as evidenced by increased mRNA expression, macrophage infiltration, and neutrophil accumulation in painful muscle areas. The inflammatory response involves vasodilation, plasma extravasation into the interstitial space, leukocyte migration, and tissue repair. (Peake *et al*., 2017)

Cold water immersion induces vasoconstriction of blood vessels due to exposure to low temperatures, which prompts the body to preserve core temperature. This peripheral vasoconstriction can reduce the migration of leukocytes involved in the inflammatory response, thereby attenuating inflammation. (Yeung *et al*., 2016) In contrast, WWI induces vasodilation, which is associated with a more rapid inflammatory response resolution and faster recovery. (An *et al*., 2019)

The results of this study indicate that WWI is more effective than CWI in reducing DOMS. This finding aligns with the 2023 Delphi consensus on musculoskeletal pain, which suggests that heat therapy is more effective than cold therapy for reducing DOMS, as well as with the study conducted by Yutan Wang *et al*., (2021), which demonstrated that WWI effectively reduces DOMS. (Peake *et al*., 2017) The superior effectiveness of WWI may be attributed to the comfort it provides. In addition to psychological effects, WWI promotes vasodilation, which enhances metabolic activity and facilitates the clearance of pro-inflammatory factors. (Wang *et al.,* 2022)

These findings are also consistent with research by Emma Moore *et al*., (2022), which reported that CWI does not have sufficient effectiveness in reducing DOMS, particularly within the first 24 hours. CWI appears to be more effective when applied beyond 24 hours, specifically at 48, 72, and 96 hours. (Moore *et al*., 2022) Conversely, studies by Oliver Dupuy *et al*., (2018) and Feiyan Xiao (2023) reported that CWI has a significant effect on DOMS reduction and is more effective than no intervention. (Xiao *et al*., 2023) The analgesic effect of CWI is attributed to its ability to reduce inflammatory responses by lowering levels of inflammatory markers such as interleukin-6 (IL-6) and C-reactive protein (CRP). Cold-induced vasoconstriction decreases fluid accumulation in the interstitial space, thereby reducing pressure on nociceptors and minimizing pain stimulation. (Dupuy *et al*., 2018)

However, experimental animal studies by Yoshida *et al*., (2022) suggested that immediate cold water therapy following muscle damage may delay muscle regeneration, potentially prolonging pain perception due to delayed tissue repair. Additionally, studies by Gill *et al*., (2006), Sellwood *et al.,* (2007), and Vaile *et al*., (2007) reported that CWI administered after eccentric exercise increased muscle soreness severity when assessed 24 hours post-exercise. (Higgins *et al*., 2013) According to Rafael *et al*., (2019), cold therapy following the RICE protocol remains the first-line treatment for acute muscle injuries, particularly during the early inflammatory phase. (Heiss *et al*., 2019)

The discrepancies among study findings may be influenced by various factors, including exercise type, intervention dosage, and individual characteristics. Research by Siqueira (2018) demonstrated that temperature-regulated water immersion is more effective than no intervention. Additional factors contributing to reduced CWI effectiveness in this study include challenges in maintaining water temperature during outdoor interventions conducted in the afternoon, as ambient conditions caused rapid increases in water temperature, making it difficult to sustain the target temperature of 10°C. Furthermore, variations in DOMS induction may have occurred due to differences in exercise execution, particularly among participants who did not perform resistance exercises to failure. Failure to reach muscular failure may result in less pronounced DOMS, thereby influencing pain perception within the first 24 hours. (Siqueira, 2018)

Additionally, research by Jooyong *et al*., (2021) indicated that individuals with obesity exhibit higher inflammatory marker levels compared with those with normal BMI, suggesting that individuals with higher BMI experience more severe DOMS. (Kim & Yoon, 2021)

Data analysis in this study was conducted across three days based on individual VAS scores. Multivariate analysis using two-way ANOVA revealed a significant decrease in VAS scores from day 1 to day 3. Subsequent Tukey HSD or LSD post hoc tests demonstrated that the WWI group showed significantly greater reductions in VAS scores compared with the CWI and control groups. In conclusion, WWI was found to be significantly effective in reducing DOMS from day 1 to day 3, demonstrating superior effectiveness compared with CWI and no intervention.

Future studies should consider stricter temperature control, larger sample sizes, inclusion of female participants, and objective inflammatory biomarkers to further elucidate the comparative effectiveness of thermal therapies in DOMS management.

Conclusion

Based on the findings of this study, it can be concluded that warm water immersion is more effective than cold water immersion in reducing delayed onset muscle soreness in the calf muscles. Warm water immersion consistently resulted in greater reductions in pain intensity over the observation period, indicating its superior therapeutic potential for post-exercise muscle recovery.

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