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Xiao Feiyan[1], Jiao Lu[2*], A.V. Kabachkova[3], Zhao Huan[4], Tan Li[5]

[1, 2, 3]Tomsk State University, Tomsk, Russia;
[4]Shandong Youth University of Political Science, Jinan, China;
[5]Hunan Agricultural University, Changsha, China
([*]Corresponding author's e–mail: jiaolu0311@gmail.com)

[1]ORCID 0000-0002-1297-8685
[2]ORCID 0000-0001-5012-4974
[3]ORCID 0000-0003-1691-0132
[4]ORCID 0000-0001-5025-7611
[5]ORCID 0009-0003-0936-736X

Fatigue Recovery and Exercise Performance after Contrast Water Therapy- Meta-analysis

Fatigue recovery plays a critical role in athletic performance. Contrast Water Therapy (CWT) has been widely applied, but its effectiveness remains controversial across different exercise types. Methods applied in the study: A systematic review and meta-analysis were conducted using PubMed, Web of Science, and Elsevier databases. Seventeen trials involving 368 participants were included. Two researchers independently screened and extracted data, including subjective indicators (DOMS, RPE) and objective markers (CMJ, sprint, CK, lactate, CRP, IL-6). Results: Meta-analysis showed that CWT significantly alleviated DOMS and RPE, particularly after team-based sports like football. CWT was also effective in reducing lactate levels immediately post-exercise. However, no significant improvements were found in CMJ or sprint performance for most sports. Cold Water Immersion (CWI) showed superior results in reducing CK and lactate at 24–48h post-exercise compared to CWT. Discussion: CWT can reduce perceived muscle soreness and fatigue, especially in team sports, though its impact on objective performance is limited. CWI may be more effective for physiological recovery. Further studies are needed to explore protocol-specific and sport-specific outcomes.

Keywords: contrast water therapy, cold water immersion, fatigue recovery, muscle soreness, ratings of perceived exertion, creatine kinase, lactate, countermovement jump, team sports, recovery strategies.

Introduction

Fatigue recovery is crucial for athletes to sustain performance and reduce injury risks, making effective recovery modalities a key area of sports science research. Contrast Water Therapy (CWT) is a widely used recovery technique involving alternating immersion in cold water (≤20 °C) and hot water (≥36 °C) [1], typically for 1–3 minutes per cycle [2]. This alternating protocol is believed to promote vasoconstriction and vasodilation, thereby enhancing blood circulation and accelerating the removal of metabolic by-products such as lactate. As a result, CWT is popular for its potential to reduce lactic acid accumulation [3], inflammation, edema, pain, and muscle stiffness [1], ultimately alleviating Delayed-Onset Muscle Soreness (DOMS) and improving fatigue recovery.

In contrast, Cold Water Immersion (CWI) involves immersing the body in cold water without alternating temperature changes. CWI is thought to reduce muscle inflammation and edema by inducing vasoconstriction and decreasing tissue temperature. Several studies have directly compared CWT and CWI, yielding mixed results. Some findings indicate that CWI may be more effective in reducing muscle temperature and inflammation due to its ability to sustain vasoconstriction and lower tissue temperature [4–6]. Other studies designate that CWT, due to its alternating vasoconstriction and vasodilation mechanism, may be more effective than CWI in alleviating muscle soreness and reducing creatine kinase levels [7].

While several studies have investigated the effects of CWT and CWI on post-exercise recovery, the findings remain inconsistent. These inconsistencies may stem from variations in experimental designs, exercise protocols, and the lack of systematic integration of key recovery indicators. To comprehensively assess the effects of CWT on fatigue recovery, this review focuses on commonly used subjective indicators, such as DOMS and Rating of Perceived Exertion (RPE), and objective markers [8], including Sprint time, Countermovement Jump (CMJ), Creatine Kinase (CK), lactate, IL-6, and C-reactive protein (CRP) [9, 10]. These indicators are widely recognized for their relevance in evaluating both perceived and physiological recovery after exercise.

By systematically integrating these subjective and objective indicators, this review aims to clarify the effects of CWT on subjects fatigue recovery across different post-exercise time points, providing a more comprehensive understanding of its efficacy.

Based on the available literature, the present study hypothesizes that:

1. CWT can alleviate exercise-induced fatigue and promote subsequent exercise performance.
2. CWT and CWI have similar effects on fatigue recovery and promote subsequent exercise performance.
3. The efficacy of CWT varies depending on immersion depth, exercise types, and experimental designs.

Methods and materials

2.1 Literature Search Strategies

This meta-analysis was conducted from January 2023 to July 2023 according to the guidelines of PRISMA [11]. PubMed, Web of Science, and Elsevier were used as the primary databases for the literature search. The search terms included "Contrast Water Therapy" OR "Contrast water immersion" OR "CWT", "Exercise performance" OR "Sports performance" OR "Athletic performance", and "Fatigue" OR "Recovery". Only articles published in English between 2002 and 2022 were considered. This timeframe was chosen to focus on studies conducted within the past two decades, as it reflects the evolution of contemporary practices, methodologies, and technologies in Contrast Water Therapy (CWT), ensuring the inclusion of recent and up-to-date research. All searches were conducted by two researchers (XFY, JL), with a third researcher (ZH) performing a review for accuracy and completeness.

2.2 Literature inclusion and exclusion criteria

Following the PICOS criteria outlined in Cochrane systematic reviews, the inclusion criteria for the literature were as follows: (1) Participants: General population without specific gender restrictions and free from any diseases. The inclusion criteria did not specifically limit participants to athletes, nor did it impose restrictions on age range, as the focus was on the intervention outcomes rather than participant characteristics; (2) Intervention: Post-exercise CWT intervention, with cold water temperature ≤20 °C and hot water temperature ≥36 °C, this temperature was selected based on prior studies [12]. The inclusion criteria did not impose specific restrictions on the duration of immersion cycles in CWT interventions, as the focus of this review was on the overall effects of CWT rather than the optimization of immersion time. The immersion depth included whole-body immersion up to the umbilicus or shoulders, while studies involving partial immersion, such as hot-cold showers, were excluded to maintain consistency in the intervention protocols; (3) Experimental Design: Both independent samples (between-group designs) and repeated measures (within-group designs) were included, provided they met the inclusion criteria. To ensure valid comparisons, all studies were required to have a clearly defined control group, which performed either passive recovery or low-intensity active recovery. Studies without a control group or those using inappropriate comparison groups (e.g., partial immersion or alternative recovery methods) were excluded; (4) Exercise Type: No specific restrictions were imposed on the type of prior exercise performed by participants; (5) Outcome Measures: Subjective recovery characteristics (DOMS, RPE) and/or objective recovery features (Sprint time, CMJ, CK, lactate, CRP, and IL-6).

The following studies were excluded from consideration: (1) Participants with specific major illnesses affecting exercise performance; (2) Studies with inadequate experimental design; (3) Duplicate publications; (4) Animal experiments; (5) Articles published in languages other than English.

2.3 Variable Selection

The primary outcome measures included subjective recovery characteristics (DOMS, RPE) and objective recovery features (Sprint time, CMJ, CK, lactate, CRP, and IL-6). DOMS and RPE were assessed using validated scales, while Sprint time and CMJ were used to evaluate physical performance. Biochemical markers, such as CK and lactate were included to assess muscle damage and metabolic recovery, respectively. Measurements were taken at multiple time points post-intervention: immediately (0h), 1 hour (1h), 24 hours (24h), and 48 hours (48h) after CWT intervention. The systematic search strategy and literature selection process are illustrated (Fig. 1).

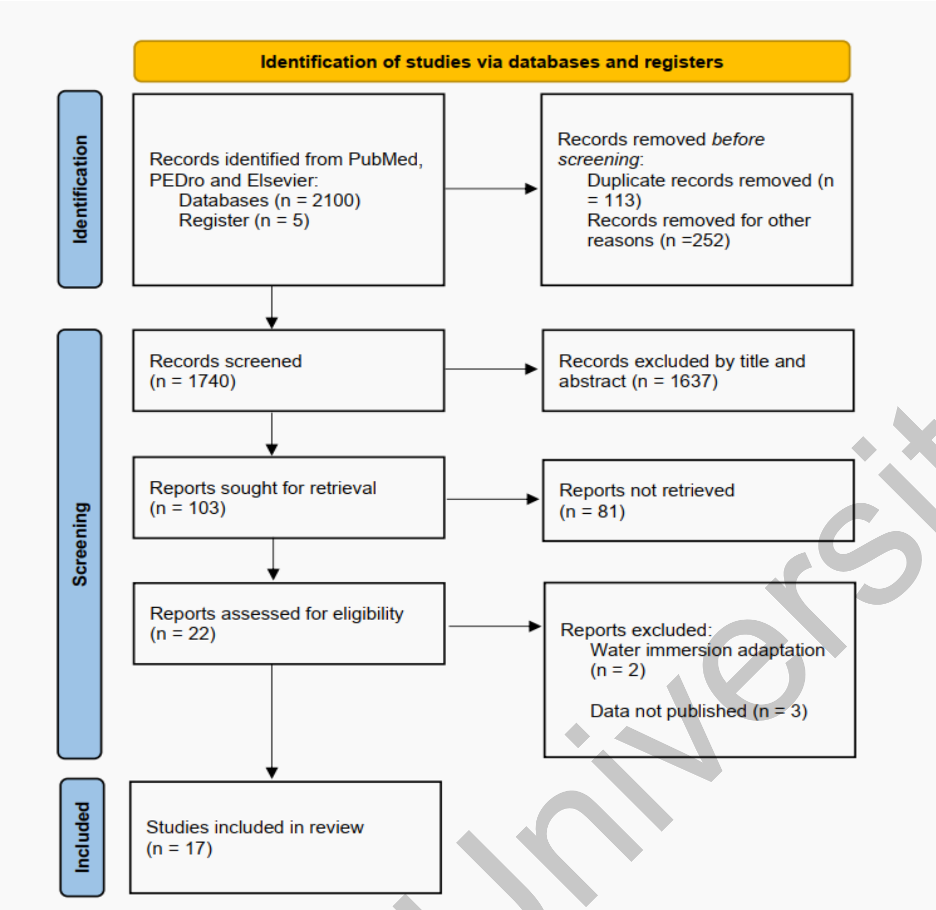

Figure 1. Systematic review procedure

2.4 Data Extraction

Basic information from the literature was extracted by two researchers and subsequently cross-verified. A secondary verification of the extracted data was performed. The included literature underwent a quality risk assessment. In case of discrepancies, a third researcher intervened, and a consensus was reached among all researchers regarding the accuracy of the data extraction. The primary contents extracted included the first author of the literature, publication year, sample size, age, and gender of the study participants, experimental design, post-exercise intervention methods, outcome assessment indicators, and corresponding data.

2.5 Statistical processing

The heterogeneity analysis, data synthesis, subgroup analysis, forest plot generation, and publication bias analysis were conducted using RevMan 5.4 software. When the units were consistent, the Mean Difference (MD) was selected for statistical analysis. When there were variations in measurement units or methods, the Standardized Mean Difference (SMD) was chosen. The I^2 statistic was utilized to assess heterogeneity among studies, where I^2 values of 0 %, ≥25 %, ≥50 %, and ≥75 % represent no heterogeneity, low, moderate, and high heterogeneity, respectively. In the presence of moderate to high heterogeneity ($I^2 \geq 50$ %), a random-effects model was applied; otherwise, a fixed-effects model was used. If heterogeneity was observed, subgroup and sensitivity analyses were performed. After excluding studies with abnormal results, the analyses were repeated to observe whether heterogeneity persisted.

2.6 Risk of bias

The Cochrane risk of bias tool was used to assess all included articles independently by two authors. Each article was scored in the following aspects: random sequence generation, allocation concealment, blinding participants, blinding personnel, blinding outcome assessors, incomplete outcome data, and other sources of bias. Each item was classified as either high risk, unclear risk or low risk [13]. Any disagreements were discussed with a third reviewer (ZH).

2.7 Subgroup analysis

Subgroup analyses were conducted based on different body parts (shoulders, umbilicus), different experimental types (randomized controlled trials (RCTs), cross-over Trials, and other types of Trials) and different types of exercise when performing CWT intervention.

Results

3.1 Risk of bias of the included literature

The risk of bias assessment for the included studies is shown in Figures 2 and 3.

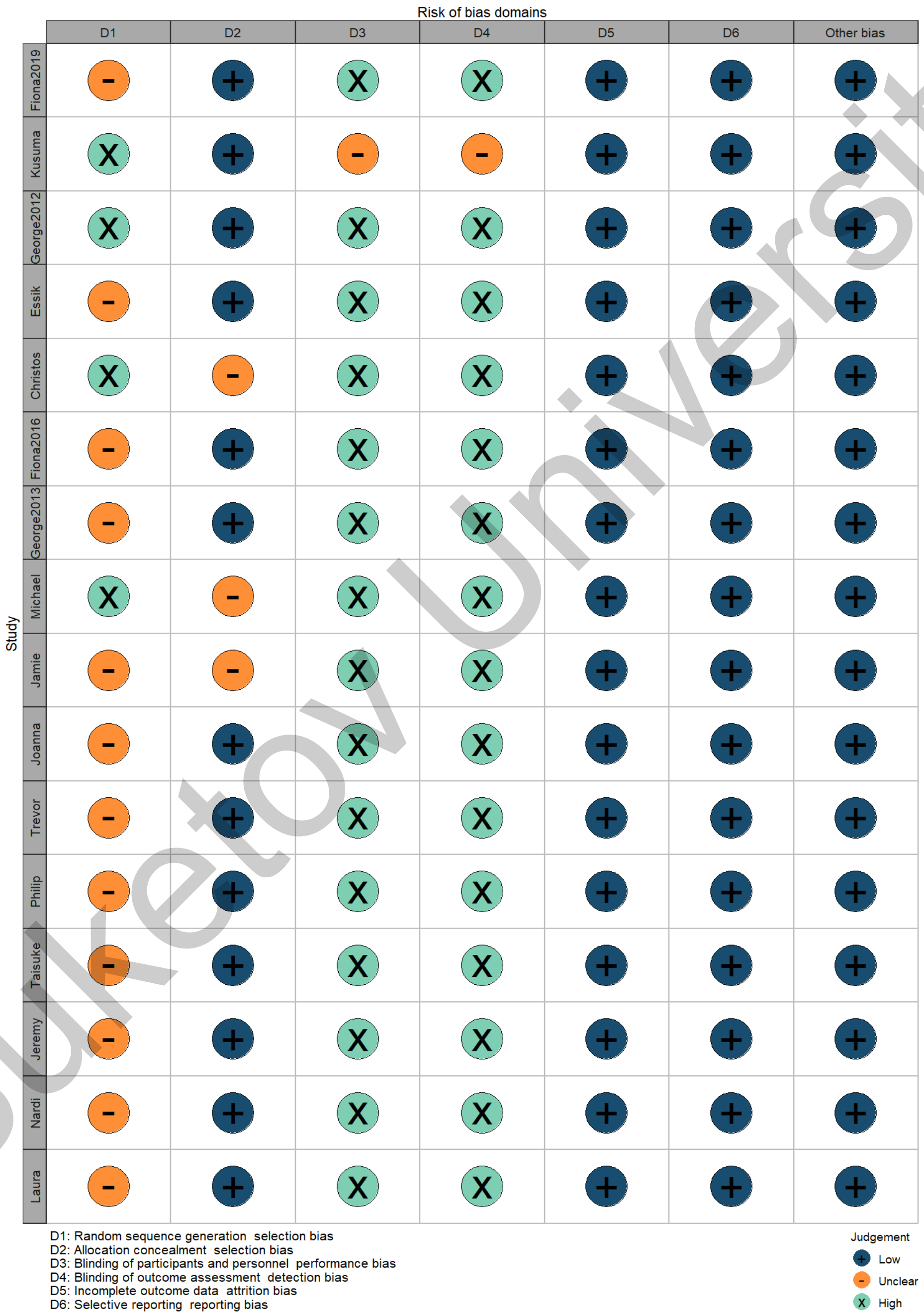

Figure 2. Risk of bias graph for all included studies

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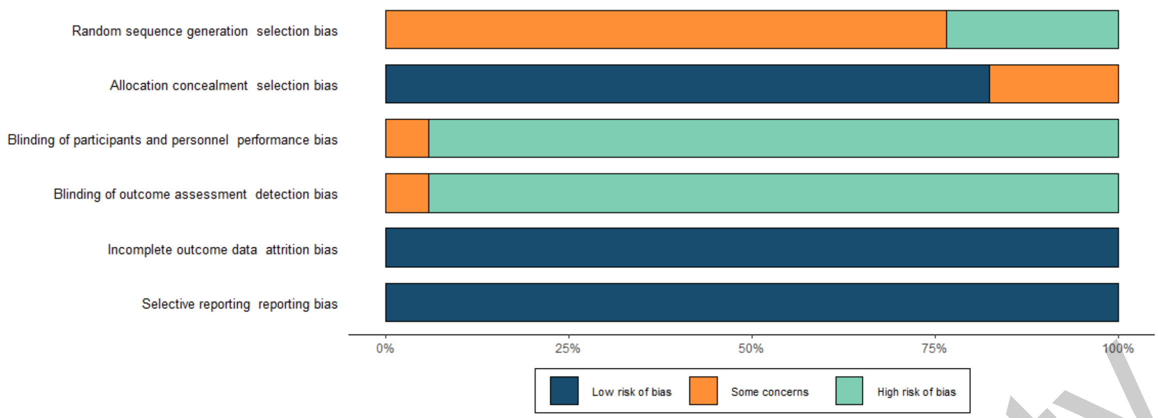

Figure 3. Risk of bias summary for all included studies

3.2 Basic characteristics of the included literature

In this review, a total of 17 studies were included, providing the primary data source for this analysis [6, 12, 14–28]. These trials initially recruited 368 healthy participants (338 males and 30 females). However, due to individual dropouts (e.g., personal reasons or inability to complete the intervention), only 338 participants completed the trials and were included in the final analysis (Table 1).

Table 1

Summary of the included studies

Study, year	**Characteristics of participants (training status, sex (m: f), age)**	**Enviroment condition (Tm±S; RHm±S)**	**Exercise protocol**	**Classification of the exercise**	**[CWT duration and temperature] ×number**	**Control group**	**Outcome variables and time of measurement post exercise(h)**
1	2	3	4	5	6	7	8
Fiona A Crowther et al., 2019	Recreational avtive healthy males (14:0); 26±6 yrs	24.3-25.8°C; 56.7-61.0 %RH	Simulated ruby tournament	High intensity	[1 min at 15°C+1 min at38°C]×7	14 min passive recovery	DOMS (0;1); CMJ(0;1); Sprint time(0;1)
Kusuma, M. Nanang et al., 2021	Elite athletes(30:0); 18.23±1.17 yrs		Sub-maximal intensity of circuit training	Sub-maximal intensity	15°C&38°C total 15 min	15 min static stretching	Lactate (0); DOMS(0)
George P. Elias et al., 2012	Australian Footballers(14:0); 20.9±3.3 yrs		AF training	High intensity	[1 min at 12°C+1 min at 38°C]×7	14 min passive recovery	DOMS (0;1;24;48); Fatigue(0;1;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Essi K. Ahokas et al., 2019	Physically active men(9:0); 26±3.7 yrs		Short term exercise with maximal effort		[1 min at 10°C + 1 min at 38°C]×5	10 min active recovery	Lactate (0); DOMS(1;24;48); CK(24;48)
Christos K. Argus et al., 2016	Healthy males(13:0); 26±5 yrs		Single full-body resistance training session	High intensity	[1 min at 15°C + 1 min at 38°C]×7	14 min passive recovery	DOMS(0;1); Fatigue(0;1)
Fiona Crowther et al., 2017	Recreational avtive healthy males(34:0); 27±6 yrs	22.6-23.9°C; 71.9-73.9 %RH	Simulated team-game circuit	High intensity	[1 min at 15°C + 1 min at 38°C]×7	14 min passive recovery	DOMS (1;24;48); CMJ(1;24;48); Sprint time(1;24;48); TQR(1;24;48)
George P. Elias et al., 2013	Elite footballers (24:0); 19.9±2.8 yrs	25.8°C; 63 %RH	AF match	High-intensity	[1 min at 12°C+1 min at 38°C]×7	14 min passive recovery	DOMS (0;1;24;48); Fatigue(0;1;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Michael J. Hamlin et al., 2007	Junior representative rugby players(17:3); 19 ± 1 yrs		Repeated sprint test	High-intensity	[1 min at 8-10°C+1 min at 38°C]×3	6 min slow jogging	Lactate(0)

Continuation of Table 1

1	2	3	4	5	6	7	8
Jamie Stanley et al., 2012	Well-trained cyclists(18:0); 27±7 yrs	25.1±0.8℃	60 min high intensity cycling	High-intensity	[1 min at 14.2±0.6℃+2 min at 35.5±1.1℃]×3	10 min passive recovery	DOMS(0); Fatigue(0)
Joanna M. Vaile et al., 2007	Recreational athletes(4:9); 26.2±5.8 yrs		5 sets of 10 eccentric bilateral leg press contractions	High-intensity	[1 min at 8-10℃+2 min at 40-42℃]×5	15 min passive recovery	DOMS(0;24;48); CK(0;24;48)
Trevor Higgins et al., 2012	Well-trained rugby players(24:0); 19.5 ± 0.8 yrs		Simulated game of rugby union	High-intensity	[1 min at 10-12℃+1 min at 38-40℃]×5	15 min passive recovery	Fatigue(48)
Philip D. Glasgow et al., 2014	Healthy participants(32:18); 18-35 yrs		Eccentric hamstring contractions to fatigue	High-intensity	[1 min at 10℃+1 min at 38℃]×3	10 min passive recovery	DOMS(24;48;72); CK(24;48;72)
Taisuke Kinugasa et al., 2009	28 young soccer players; 14.3±0.7 yrs		90 min soocer match	High-intensity	[1 min at 12℃+2 min at 38℃]×3	9 min active recovery	TQR(0;24)
Joanna Vaile et al., 2008	Strength trained males(38:0)		5 sets of 10 eccentric bilateral leg press contractions	High-intensity	[1 min at 15℃+1 min at 38℃]×7	14 min passive recovery	Lactate(0;24;48); CK(0;24;48); IL-6(0;24)
Jeremy Ingram et al., 2009	Athletes(11:0); 27.5±6.0 yrs	19.8±1.5℃; 41±12 %RH	Simulated team sports exercise	High-intensity	[2 min at 10℃+2 min at 40℃]×3	15 min passive recovery	DOMS(0;24;48); CK(0;24;48) CRP(0;24;48)
M. De Nardi et al., 2011	18 young soccer players 15.5±1.0 yrs	31.9±1.7℃; 87.5±2.9 %RH	140 min low intensity training	Low-intensity	[2 min at 15±0.5℃+2 min at 28±0.5℃]×2	8 min passive recovery	Fatigue(0;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Laura E. Juliff et al., 2014	Elite netball athletes(0:10); 20±0.6 yrs		Netball specific circuit	High-intensity	[1 min at 15℃+1 min at 38℃]×7	14 min passive recovery	Fatigue(0;24)

3.2.1 Type of literature

The types of literature include single-group pre-post comparison studies [12, 15, 16, 21], cross-sectional studies [24], randomized controlled trials [14, 17, 18, 20, 25], and cross-over studies [6, 19, 22, 23, 26–28].

3.2.2 Type of exercise

Type of exercise included team sports such as simulated rugby matches [16, 29], soccer training [6] and matches [17, 23], netball-specific circuit training [22], simulated team-game circuit training [15, 21], high-intensity cycling [26], sub-maximal intensity exercise [24], low-intensity training [25], short-term exercise [12, 19], and eccentric exercise [18, 27, 28] (Table 1).

3.2.3 Characteristics of CWT

During CWT interventions, the immersion depth varied, including water reaching the level of the navel or below [18–21, 24, 25, 28], as well as water reaching the level of the shoulders or below [6, 12, 14–17, 22, 23, 26, 27]. The temperature of the hot water during CWT interventions ranged from 28±0.5 °C to 42 °C, and the cold water temperature ranged from 8 °C to 15±0.5 °C, with immersion durations of 6 to 15 minutes per session (Table 1).

3.2.4 Characteristics of CON

The common control (CON) methods include passive recovery, typically lasting 8–15 minutes [6, 15–18, 26, 28–33], as well as static stretching [24], jogging [19], and active recovery [12, 23], with varying durations of 6−15 minutes. The reason for choosing these forms as control groups is that subjects during rest periods in competitions are not just passively waiting [34], but also engage in low-intensity warm-up activities to maintain body temperature. Therefore, low-intensity active recovery has also been included in this review (Table 1).

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3.3 CWT versus CON

3.3.1 DOMS

CWT significantly reduced DOMS at 1h, 24h, and 48h post-exercise compared to CON (1h: SMD -0.59, 95 %CL -0.89 to -0.29, 6 trials); (24h: SMD -0.56, 95 %CL -0.86 to -0.27, 7 trials); (48h: SMD -0.39, 95 %CL -0.68 to -0.10, 7 trials). Heterogeneity was observed at 24h and 48h, but the use of a random-effects model did not change the significance of the results (Fig. 4).

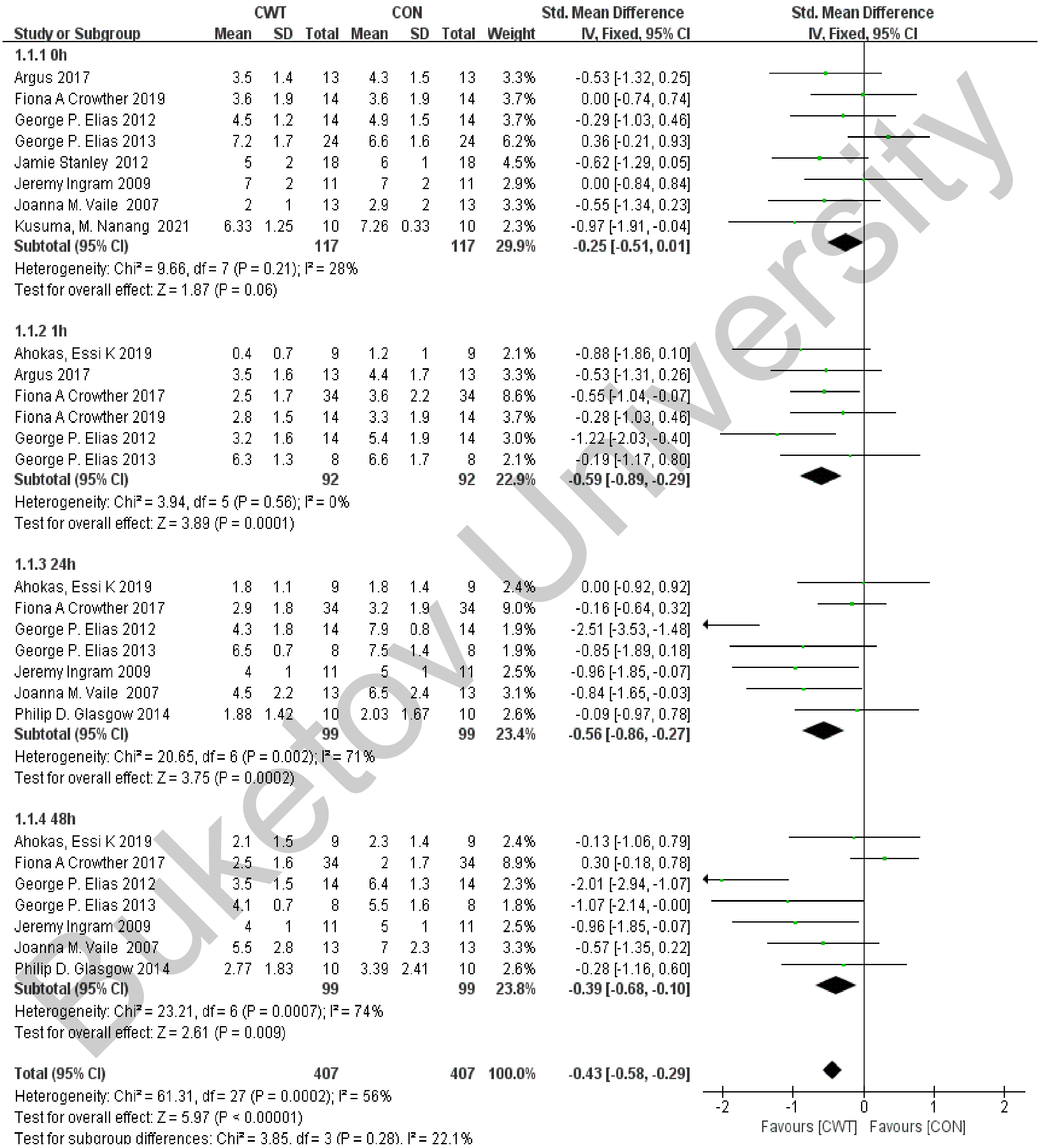

Figure 4. Forest plot of the comparison of CWT versus CON for measurement of DOMS
CWT=Contrast water therapy, CON= Control, DOMS= Delayed-onset muscle soreness.

Sensitivity analyses were conducted to investigate whether heterogeneity was caused by individual studies. Heterogeneity decreased when George et al. [6] was excluded at 24h (Chi² = 5.57, df = 5 (P= 0.35); I² = 10 %), suggesting that this literature may be responsible for the heterogeneity.

CWT subgroup analysis was performed based on different immersion depth to further explore potential sources of heterogeneity. There was no significance between the subgroups of the shoulder and umbilical immersion groups (24h Test for subgroup differences: Chi2=0.11, df=1(P=0.74); I^2=0 %); (48h Test for subgroup differences: Chi2=0.02, df=1(P=0.89); I^2=0 %), indicating that the difference immersion depth of CWT was not responsible for the heterogeneity. Subgroup analyses were performed according to the type of experiment, but no statistically significant difference was observed (Test for subgroup differences: 24h: Chi2=2.33, df=2(P=0.31); I^2=14.0 %; 48h: Chi2=1.83, df=2(P=0.40); I^2=0 %).

3.3.2 Perceived fatigue

Perceived fatigue was significantly reduced at 0h, 1h, 24h, and 48h after CWT compared to CON (0h: SMD -0.43, 95 %CL -0.77 to -0.08, 6 trials); (1h: SMD -0.81, 95 %CL -1.30 to -0.31, 3 trials); (24h: SMD -0.71, 95 %CL -1.18 to -0.24, 4 trials); (48h: SMD -0.48, 95 %CL -0.96 to -0.00, 4 trials) (Fig. 5). Heterogeneity was low across time points, and sensitivity analysis confirmed the stability of the results.

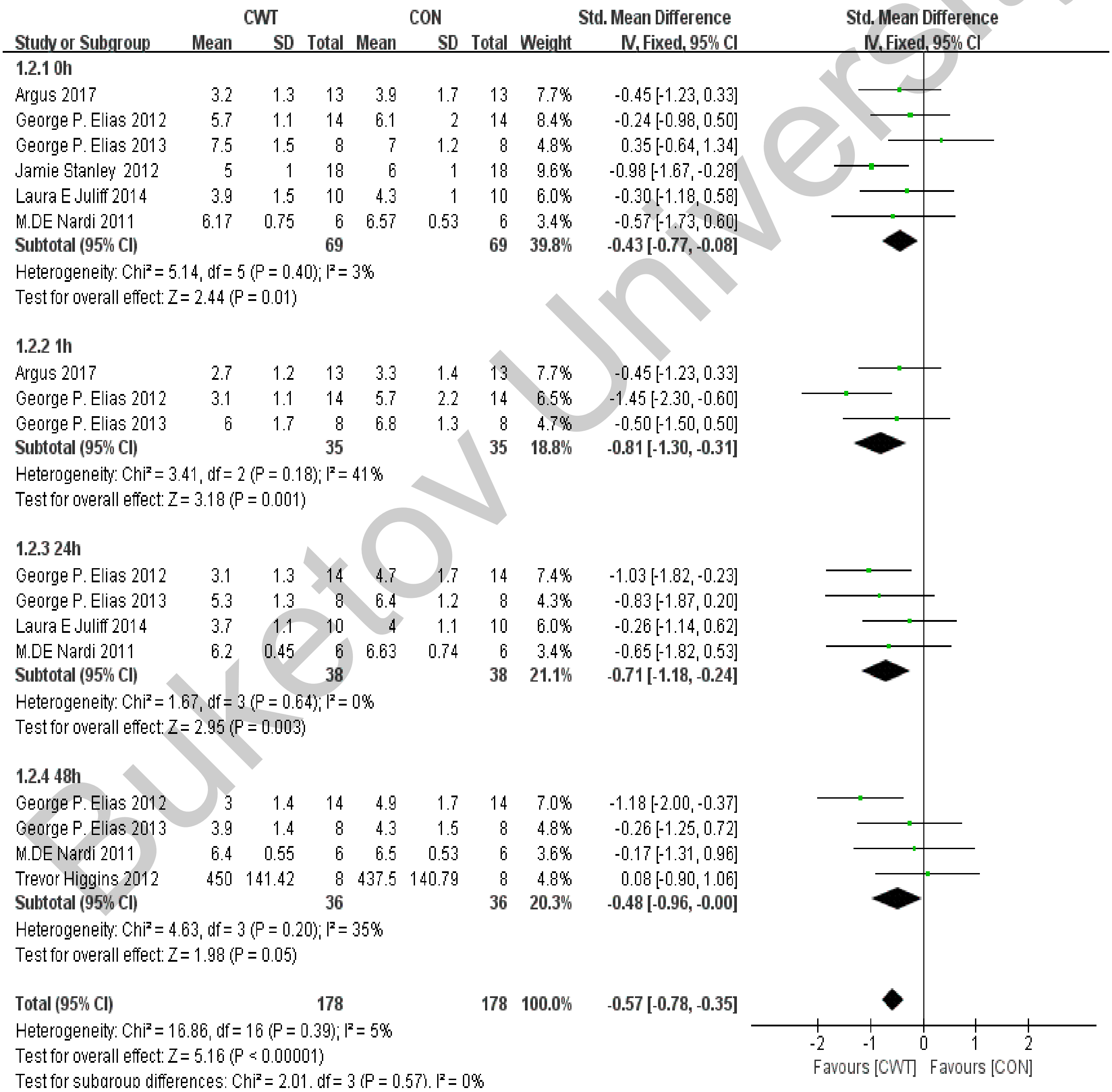

Figure 5. Forest plot of the comparison of CWT versus CON for measurement of Fatigue
CWT=Contrast water therapy, CON= Control, Fatigue= Perceived fatigue.

3.3.3 CMJ

No significant difference in CMJ were observed at any time point post CWT in comparison to the CON (0h: SMD -0.02, 95 %CL -0.44 to 0.41, 4 trials); (1h: SMD -0.15, 95 %CL -0.55 to 0.25, 2 trials); (24h: SMD -0.03, 95 %CL -0.38 to 0.32, 4 trials); (48h: SMD -0.01, 95 %CL -0.41 to 0.39, 3 trials). The results indicate that the CWT intervention did not enhance CMJ immediately after exercise or at the 1h, 24h, and 48h post-exercise (Fig. 6).

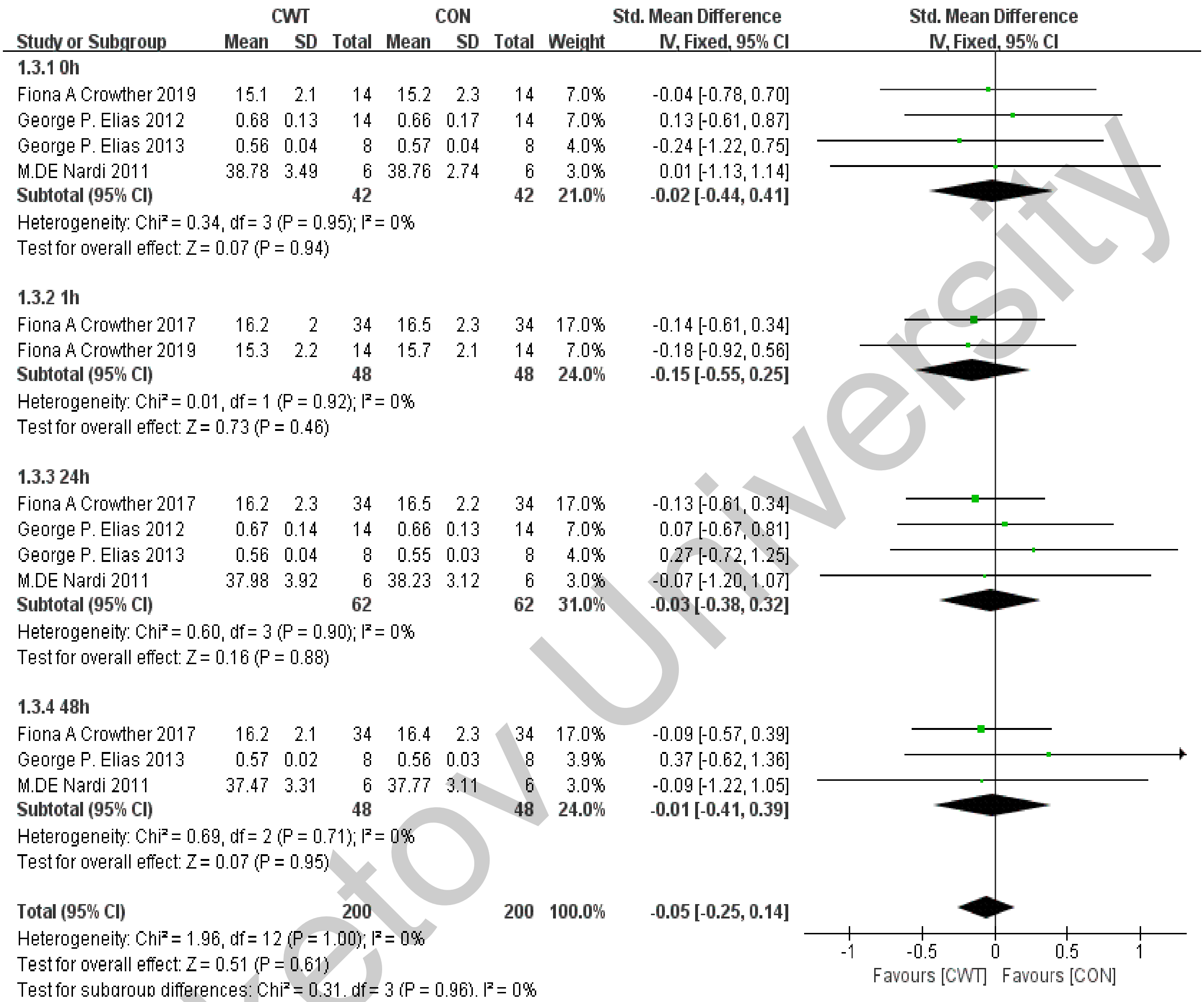

Figure 6. Forest plot of the comparison of CWT versus CON for measurement of CMJ
CWT=Contrast water therapy, CON= Control, CMJ=Countermovement jump.

3.3.4 Sprint time

As the figure shows, the sprint time after CWT intervention was not significantly different from the CON group at 0h, 1h, 24h, and 48h (0h: SMD 0.13, 95 %CL -0.30 to 0.56, 4 trials); (1h: SMD 0.10, 95 %CL -0.30 to 0.50, 2 trials); (24h: SMD -0.20, 95 %CL -0.56 to 0.16, 4 trials); (48h: SMD -0.04, 95 %CL -0.39 to 0.32, 4 trials). However, the data showed heterogeneity at 24h (I^2=62 %). There was still no significant difference between the two groups after the random effects model was used (24h: SMD -0.30, 95 %CL -0.96 to 0.36, 4 trials) (Fig. 7).

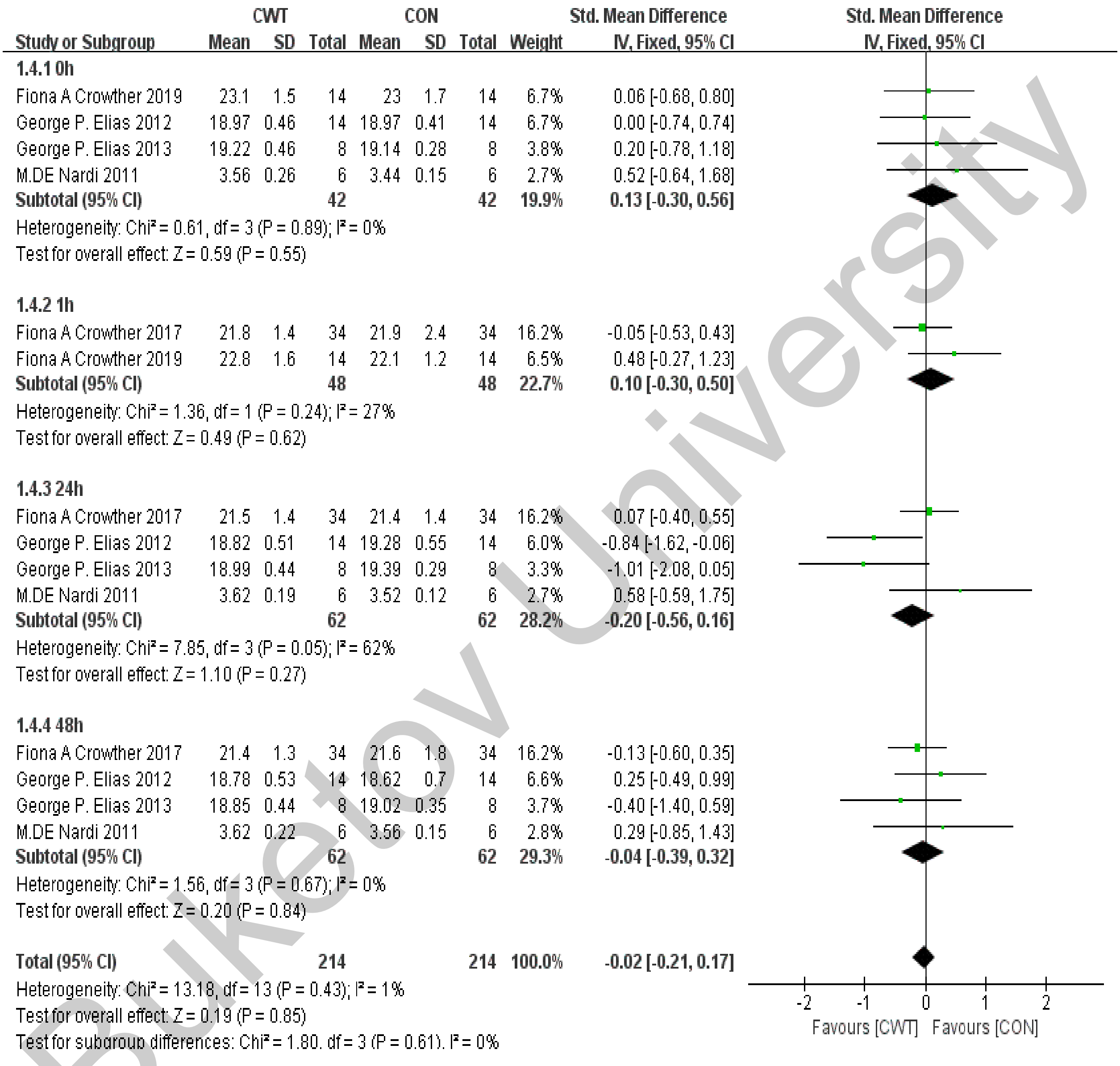

Figure 7. Forest plot of the comparison of CWT versus CON for measurement of Sprint time
CWT=Contrast water therapy, CON= Control.

Sensitivity analyses were conducted to determine the causes of heterogeneity. Eliminating the literature one by one did not change the heterogeneity between the data. To thoroughly examine the heterogeneity, the subgroup analysis was conducted based on the varied water positions during CWT. The results indicate no significant difference between the subgroups (Test for subgroup differences: Chi2=0.36, df=1(P=0.55); I^2=0 %), suggesting that difference in water immersion at either shoulder or umbilical level do not contribute to heterogeneity in sprint times at 24h post-CWT. During the subgroup analysis of various trial types, no significant difference was found (Test for subgroup differences: Chi2=1.16, df=1(P=0.28); I^2=13.7 %), indicating that trial type variations do not have a significant impact on the observed heterogeneity in sprint time outcomes at 24h after CWT.

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3.3.5 Lactate

Compared to CON, there was no significant difference in lactate in the CWT group at 0h, 24h or 48h (0h: SMD -0.20, 95 %CL -0.60 to 0.20, 4 trials); (24h: SMD 0.16, 95 %CL -0.43 to 0.76, 1 trials); (48h: SMD 0.34, 95 %CL -0.26 to 0.94, 1 trials). There was heterogeneity among the data at 0h (I^2=60 %), hence a random effects model was used. However, the results were still not significantly different (0h: SMD -0.34, 95 %CL -0.99 to 0.32, 4 trials), indicating that the results were stable (Fig. 8).

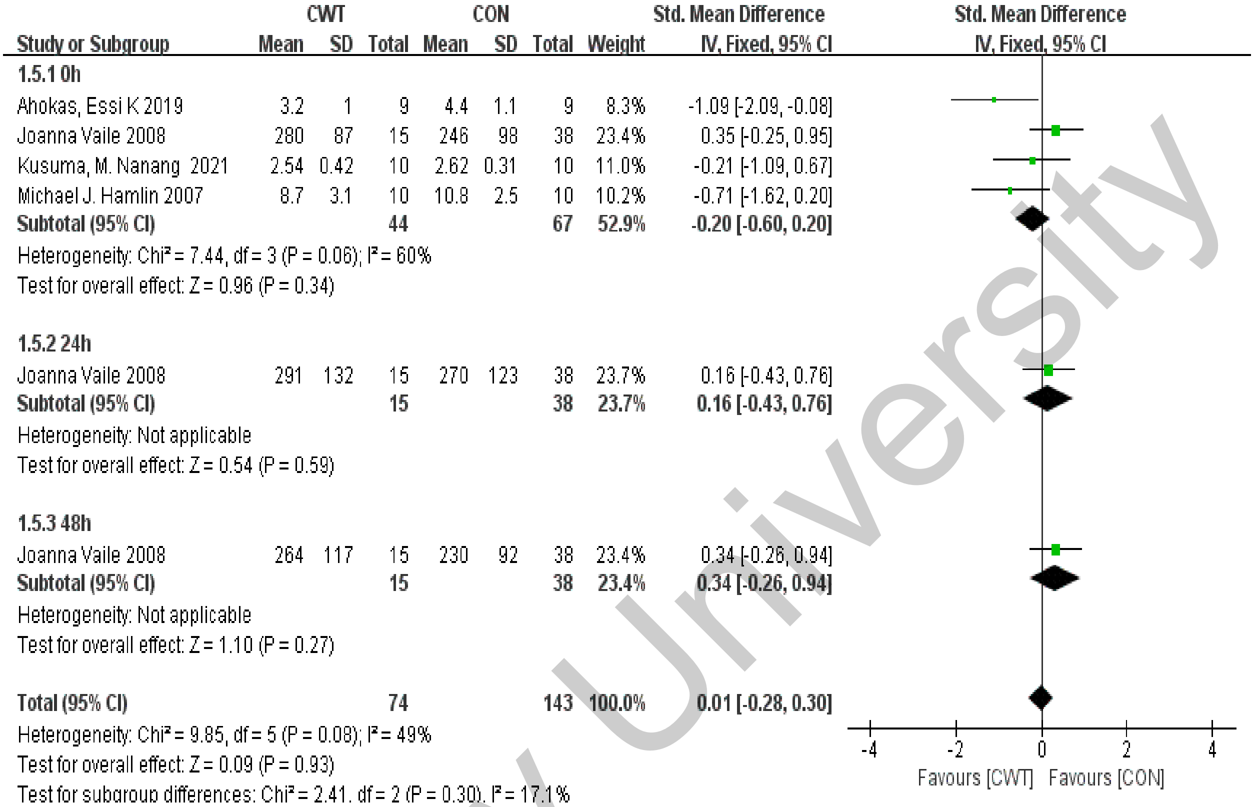

Figure 8. Forest plot of the comparison of CWT versus CON for measurement of Lactate
CWT=Contrast water therapy, CON= Control.

Sensitivity analyses to identify sources of heterogeneity revealed that there was no heterogeneity between the data when the Joanna Vaile, 2008 literature was deleted (Chi2=1.71, df=2(P=0.43); I^2=0 %), so it is probable that this literature was the source of heterogeneity between the data. Meanwhile, after this literature was deleted, significant difference between the CWT group and the CON group was identified (SMD -0.63 95 %CL -1.17 to -0.10, 3 trials). This suggests that the results of the original meta-analysis were susceptible to significant changes due to changes in the number of studies.

In order to investigate the source of heterogeneity in lactate levels at 0h, subgroup analyses were conducted. There has no significant difference between the shoulder and umbilicus subgroups of CWT (Test for subgroup differences: Chi2=0.03, df=1(P=0.86); I^2=0 %), which suggest that alterations in water positions during CWT were not responsible for the variability in lactate levels at 0h. In addition, subgroup analyses were performed based on the type of trials. There was no significant difference among subgroups of varying trial types (Test for subgroup differences: Chi2=0.50, df=1(P=0.48); I^2=0 %), suggesting that difference in type of trials were not a source of 0h lactate heterogeneity.

3.3.6 CK

As shown, there was no significant difference in CK between the CWT group and the CON group at 0h, 24h, and 48h (0h: SMD -0.17, 95 %CL -0.58 to 0.24, 3 trials); (24h: SMD -0.05, 95 %CL -0.40 to 0.29, 5 trials); (48h: SMD 0.00, 95 %CL -0.35 to 0.35, 5 trials). And there was no heterogeneity between the results, suggesting that CWT was not effective in improving CK compared to CON (Fig. 9).

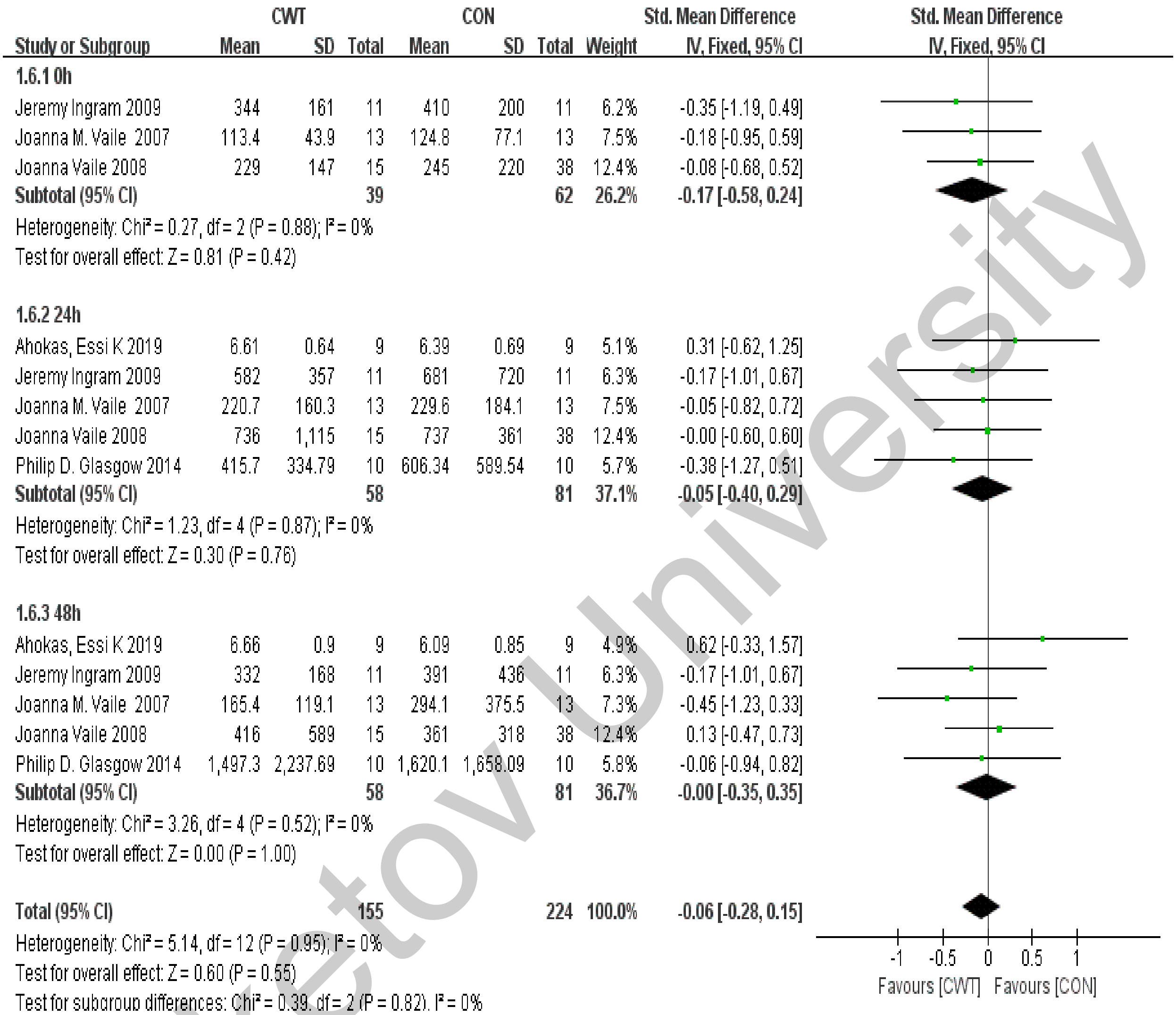

Figure 9. Forest plot of the comparison of CWT versus CON for measurement of CK
CWT=Contrast water therapy, CON= Control, CK=creatine kinase.

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3.3.7 CRP

Analysis of the effects of post-exercise CWT and CON on CRP revealed no significant difference at 0h, 24h, and 48h, indicating that no improvement in CRP could be achieved after CWT. Meanwhile, only one piece of literature was included in the CRP group for meta-analysis, which was insufficient literature to adequately explain the results (Fig. 10).

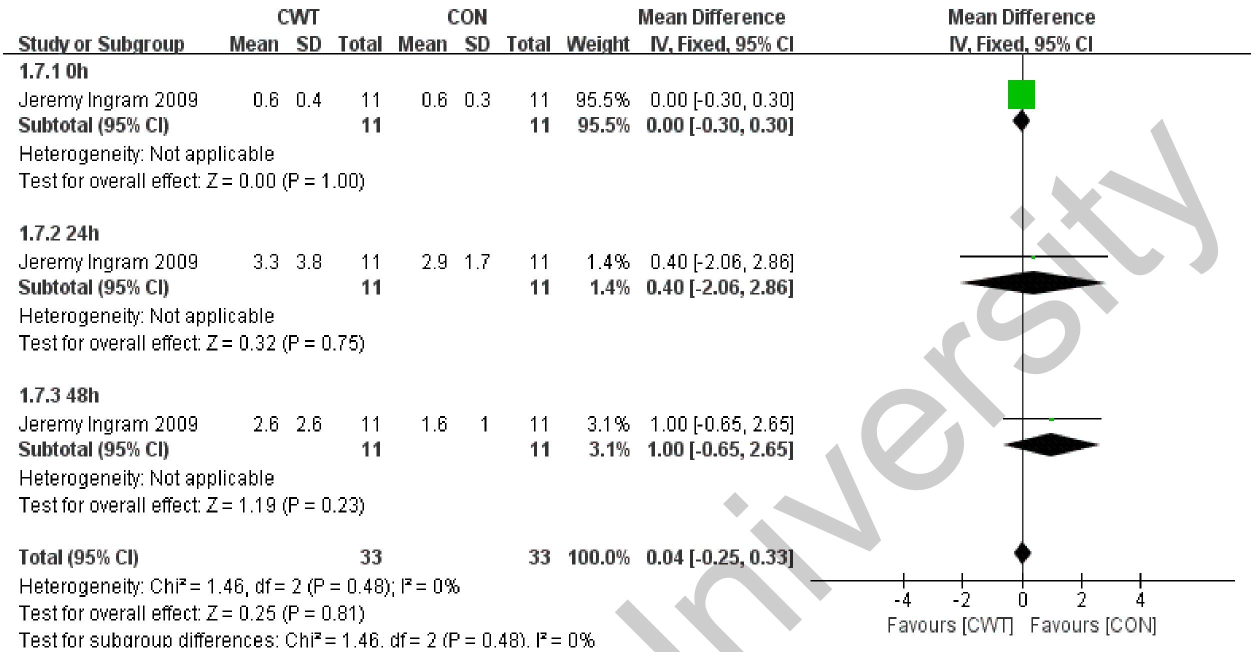

Figure 10. Forest plot of the comparison of CWT versus CON for measurement of CRP
CWT=Contrast water therapy, CON= Control, CRP=C-Reactive Protein.

3.3.8 IL-6

There was no significant difference in IL-6 between the CWT group and the CON group at 0h and 24h, indicating that post-exercise CWT was not able to optimize IL-6 in human blood. Meanwhile, this result is not representative due to the insufficient amount of literature (Fig. 11).

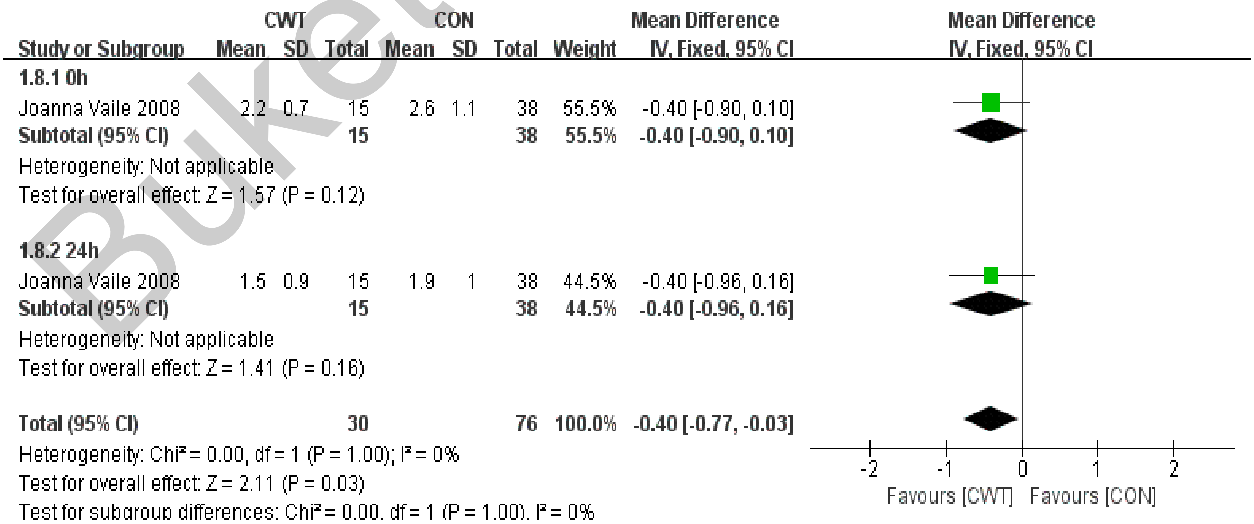

Figure 11. Forest plot of the comparison of CWT versus CON for measurement of IL-6
CWT=Contrast water therapy, CON= Control, IL-6= Interleukin 6.

3.4 CWT versus CWI

3.4.1 DOMS

The data presented in the figure indicates that there was a statistical difference only at 48h (48h: SMD 0.34, 95 %CL 0.03 to 0.65, 6 trials). Heterogeneity present at 1h, 24h, and 48h (1h: I^2=50 %; 24h: I^2=70 %; 48h: I^2=52 %), there was no statistical significance after selecting the random effects model at 1h, 24h, 48h. This result suggesting that the findings at 48h were not stable enough. Meanwhile, there was no difference in the effect of CWT or CWI intervention on post-exercise soreness (Fig. 12).

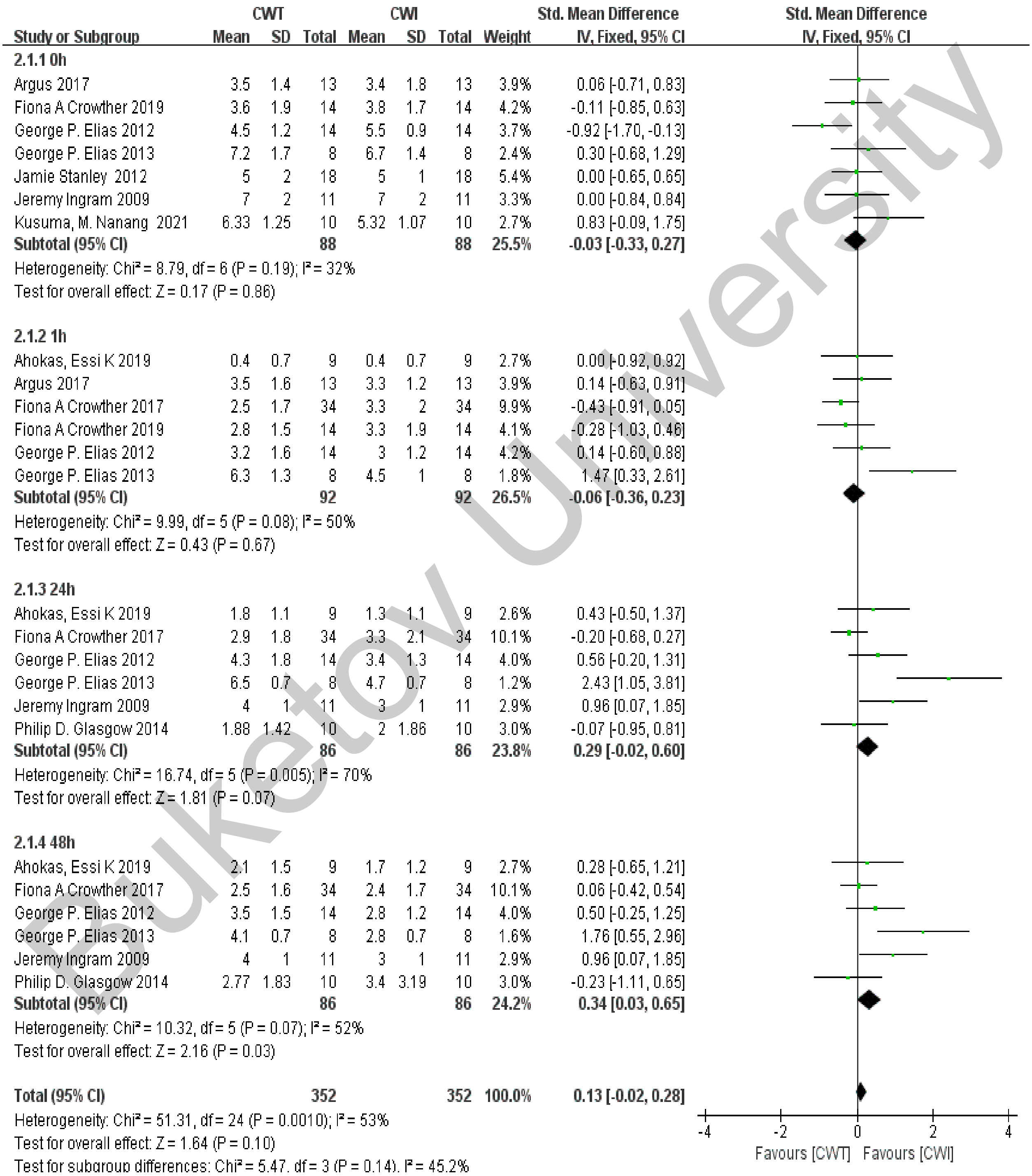

Figure 12. Forest plot of the comparison of CWT versus CWI for measurement of DOMS
CWT=Contrast water therapy, CWI=Cold water immersion, DOMS=delayed-onset muscle soreness.

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3.4.2 Perceived fatigue

No significant difference was found among the perceived fatigue metrics at 0h, 1h, 24h, and 48h post-exercise with either the CWT or CWI interventions (0h: SMD -0.02, 95 %CL -0.39 to 0.34, 5 trials); (1h: SMD -0.14, 95 %CL -0.61 to 0.34, 3 trials); (24h: SMD 0.33, 95 %CL -0.21 to 0.87, 3 trials); (48h: SMD 0.44, 95 %CL -0.03 to 0.91, 4 trials). There was no heterogeneity (0h: I^2=0 %; 1h: I^2=7 %; 24h: I^2=22 %; 48h: I^2=0 %), hence a fixed effects model was used. The results revealed that there was no distinction in the impact of CWT or CWI interventions on perceived fatigue (Fig. 13).

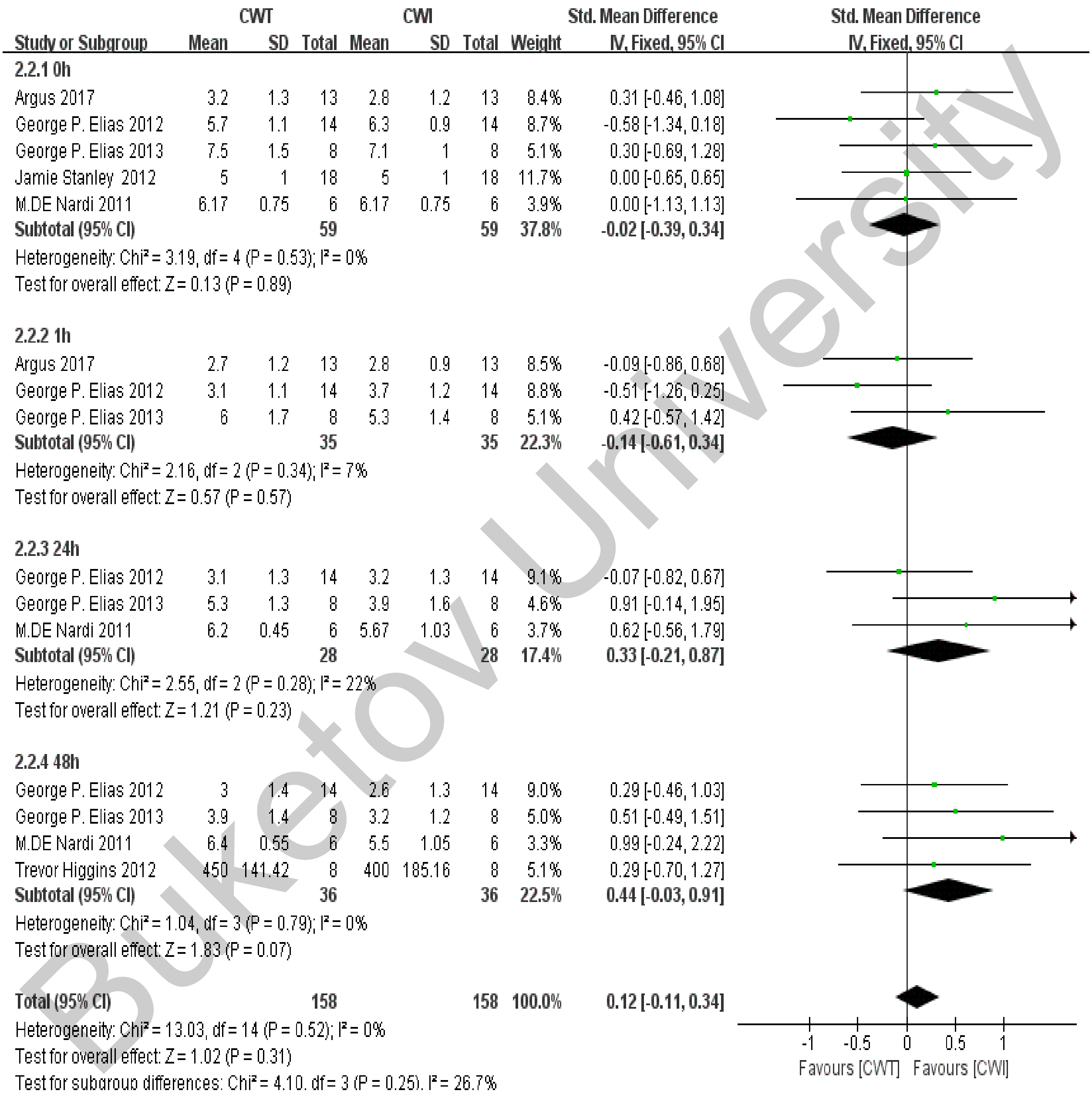

Figure 13. Forest plot of the comparison of CWT versus CWI for measurement of Fatigue
CWT=Contrast water therapy, CWI=Cold water immersion, Fatigue=Perceived fatigue.

3.4.3 CMJ

The results of CMJ at 0h, 1h, 24h, and 48h were not significant after CWT or CWI (0h: SMD -0.16, 95 %CL -0.59 to 0.27, 4 trials); (1h: SMD 0.13, 95 %CL -0.28 to 0.53, 2 trials); (24h: SMD -0.08, 95 %CL -0.43 to 0.27, 4 trials); (48h: SMD -0.14, 95 %CL -0.49 to 0.21, 4 trials), and there was no heterogeneity between any of the results (0h: I^2=0 %; 1h: I^2=0 %; 24h: I^2=0 %; 48h: I^2=0 %), so a fixed effects model was used. These findings demonstrate that there is no difference in the effect of either post-exercise CWT or CWI on CMJ (Fig. 14).

	CWT			CWI				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
2.3.1 0h								
Fiona A Crowther 2019	15.1	2.1	14	15.4	2.5	14	6.6%	-0.13 [-0.87, 0.62]
George P. Elias 2012	0.68	0.13	14	0.69	0.11	14	6.6%	-0.08 [-0.82, 0.66]
George P. Elias 2013	0.56	0.04	8	0.57	0.04	8	3.7%	-0.24 [-1.22, 0.75]
M.DE Nardi 2011	38.78	3.49	6	39.9	2.2	6	2.8%	-0.35 [-1.50, 0.79]
Subtotal (95% CI)			**42**			**42**	**19.6%**	**-0.16 [-0.59, 0.27]**
Heterogeneity: Chi² = 0.19, df = 3 (P = 0.98); I² = 0%								
Test for overall effect: Z = 0.75 (P = 0.45)								
2.3.2 1h								
Fiona A Crowther 2017	16.2	2	34	15.9	2.1	34	15.9%	0.14 [-0.33, 0.62]
Fiona A Crowther 2019	15.3	2.2	14	15.1	2.7	14	6.6%	0.08 [-0.66, 0.82]
Subtotal (95% CI)			**48**			**48**	**22.5%**	**0.13 [-0.28, 0.53]**
Heterogeneity: Chi² = 0.02, df = 1 (P = 0.88); I² = 0%								
Test for overall effect: Z = 0.61 (P = 0.54)								
2.3.3 24h								
Fiona A Crowther 2017	16.2	2.3	34	16.3	2.1	34	16.0%	-0.04 [-0.52, 0.43]
George P. Elias 2012	0.67	0.14	14	0.68	0.09	14	6.6%	-0.08 [-0.82, 0.66]
George P. Elias 2013	0.56	0.04	8	0.57	0.03	8	3.7%	-0.27 [-1.25, 0.72]
M.DE Nardi 2011	37.98	3.92	6	38.08	3.34	6	2.8%	-0.03 [-1.16, 1.11]
Subtotal (95% CI)			**62**			**62**	**29.0%**	**-0.08 [-0.43, 0.27]**
Heterogeneity: Chi² = 0.17, df = 3 (P = 0.98); I² = 0%								
Test for overall effect: Z = 0.44 (P = 0.66)								
2.3.4 48h								
Fiona A Crowther 2017	16.2	2.1	34	16.4	2.4	34	15.9%	-0.09 [-0.56, 0.39]
George P. Elias 2012	0.68	0.15	14	0.68	0.12	14	6.6%	0.00 [-0.74, 0.74]
George P. Elias 2013	0.57	0.02	8	0.58	0.02	8	3.6%	-0.47 [-1.47, 0.53]
M.DE Nardi 2011	37.47	3.31	6	38.62	2.7	6	2.8%	-0.35 [-1.50, 0.79]
Subtotal (95% CI)			**62**			**62**	**28.9%**	**-0.14 [-0.49, 0.21]**
Heterogeneity: Chi² = 0.74, df = 3 (P = 0.86); I² = 0%								
Test for overall effect: Z = 0.78 (P = 0.43)								
Total (95% CI)			**214**			**214**	**100.0%**	**-0.07 [-0.26, 0.12]**
Heterogeneity: Chi² = 2.37, df = 13 (P = 1.00); I² = 0%								
Test for overall effect: Z = 0.70 (P = 0.48)								
Test for subgroup differences: Chi² = 1.26, df = 3 (P = 0.74), I² = 0%								

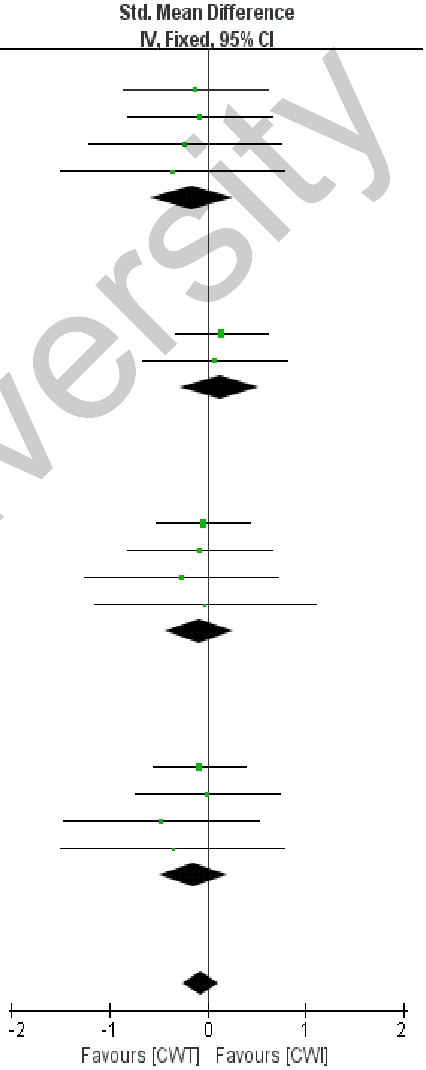

Figure 14. Forest plot of the comparison of CWT versus CWI for measurement of CMJ
CWT=Contrast water therapy, CWI=Cold water immersion, CMJ=Countermovement jump.

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3.4.4 Sprint time

The findings reveal that there was no significant difference in sprint time between the CWT and CWI interventions at 0h, 1h, 24h, and 48h (0h: SMD 0.05, 95 %CL -0.38 to 0.48, 4 trials); (1h: SMD -0.21, 95 %CL -0.61 to 0.19, 2 trials); (24h: SMD 0.22, 95 %CL -0.13 to 0.58, 4 trials); (48h: SMD 0.22, 95 %CL -0.13 to 0.58, 4 trials). The results were not heterogeneous (0h: I^2=0 %; 1h: I^2=0 %; 24h: I^2=3 %; 48h: I^2=0 %), necessitating a fixed-effects model. No evidence of a difference in the effect of either CWT or CWI intervention on exercise performance sprint time was found (Fig. 15).

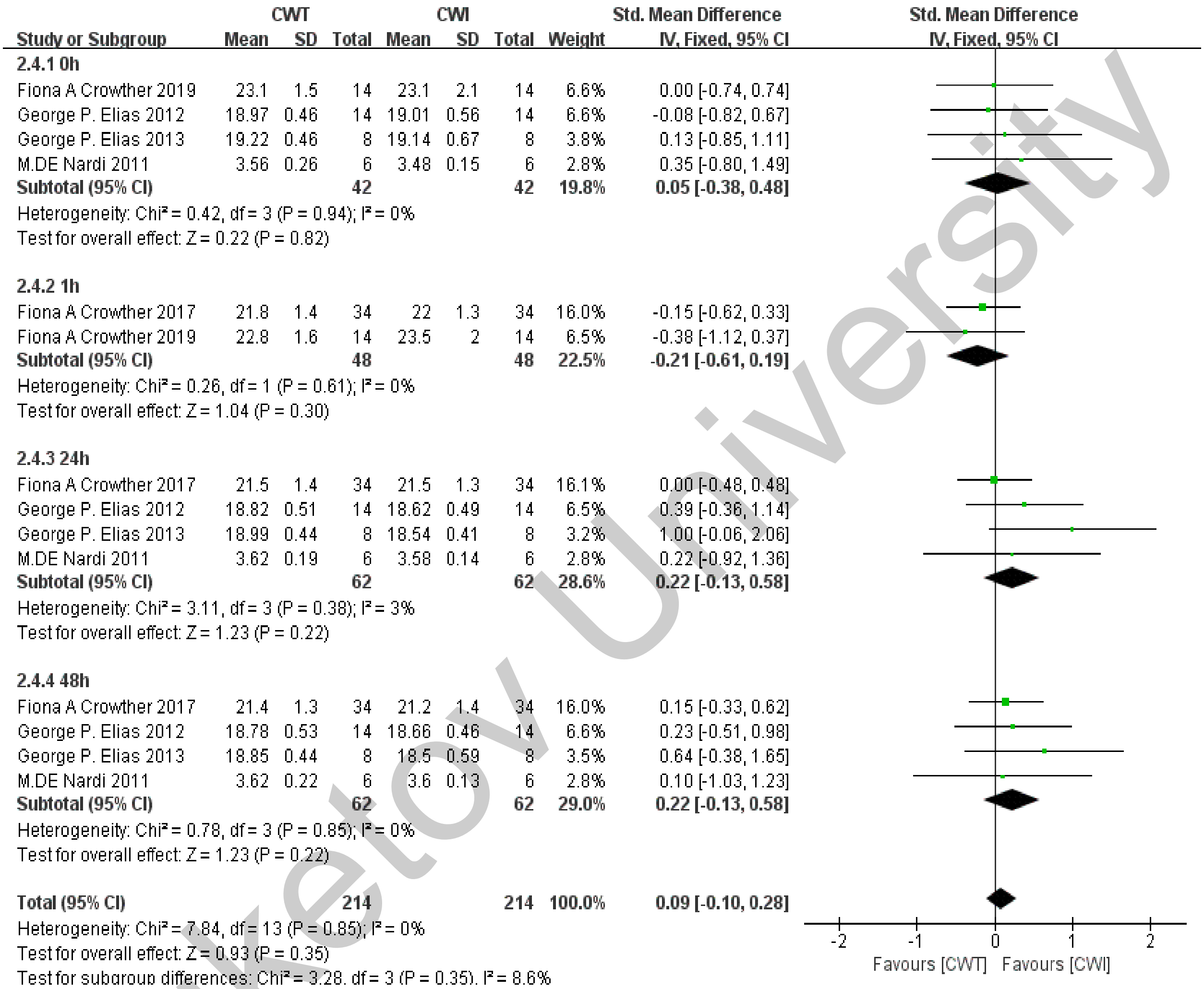

Figure 15. Forest plot of the comparison of CWT versus CWI for measurement of Sprint time
CWT=Contrast water therapy, CWI=Cold water immersion.

3.4.5 Lactate

There was no significant difference between lactate levels at 0h following CWT or CWI (0h: SMD 0.23, 95 %CL -0.27 to 0.73, 3 trials), indicating that the immediate impact on lactate levels is similar when using either CWT or CWI. The results at 24 h and 48 h showed a significant difference (24 h: SMD 0.87, 95 %CL 0.07 to 1.67, 1 trials); (48 h: SMD 0.85, 95 %CL 0.05 to 1.65, 1 trials), indicating that post-exercise with CWI intervention is more effective in removing lactate than CWT at 24 h and 48 h. It should be noted that this result is not representative as only one piece of literature was included (Fig. 16).

	CWT			CWI				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
2.5.1 0h								
Ahokas, Essi K 2019	3.2	1	9	4.1	1.4	9	15.3%	-0.70 [-1.66, 0.26]
Joanna Vaile 2008	280	87	15	227	95	12	23.3%	0.57 [-0.21, 1.34]
Kusuma, M. Nanang 2021	2.54	0.42	10	2.32	0.27	10	17.3%	0.60 [-0.30, 1.50]
Subtotal (95% CI)			**34**			**31**	**55.9%**	**0.23 [-0.27, 0.73]**
Heterogeneity: Chi² = 5.00, df = 2 (P = 0.08); I² = 60%								
Test for overall effect: Z = 0.90 (P = 0.37)								
2.5.3 24h								
Joanna Vaile 2008	291	132	15	194	65	12	22.0%	0.87 [0.07, 1.67]
Subtotal (95% CI)			**15**			**12**	**22.0%**	**0.87 [0.07, 1.67]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.14 (P = 0.03)								
2.5.4 48h								
Joanna Vaile 2008	264	117	15	177	71	12	22.1%	0.85 [0.05, 1.65]
Subtotal (95% CI)			**15**			**12**	**22.1%**	**0.85 [0.05, 1.65]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.09 (P = 0.04)								
Total (95% CI)			**64**			**55**	**100.0%**	**0.51 [0.13, 0.88]**
Heterogeneity: Chi² = 7.69, df = 4 (P = 0.10); I² = 48%								
Test for overall effect: Z = 2.65 (P = 0.008)								
Test for subgroup differences: Chi² = 2.69, df = 2 (P = 0.26), I² = 25.5%								

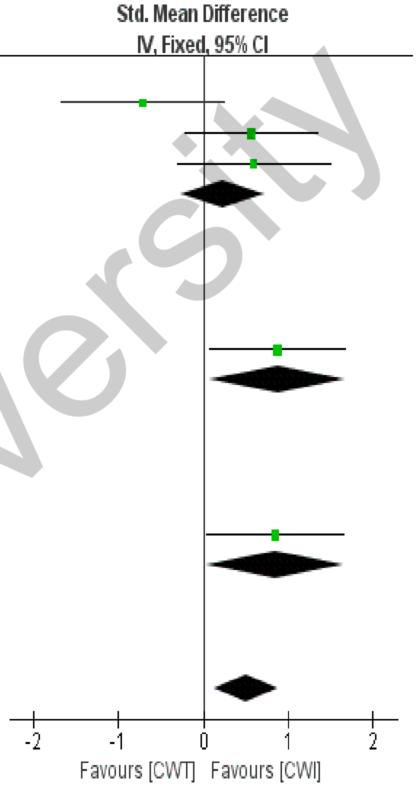

Figure 16. Forest plot of the comparison of CWT versus CWI for measurement of Lactate
CWT=Contrast water therapy, CWI=Cold water immersion.

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3.4.6 CK

Significant difference was observed between the data of CK at 24 h (24 h: SMD 0.48, 95 %CL 0.05 to 0.91, 4 trials). A fixed effects model was utilized due to the absence of heterogeneity amongst the results (0 h: I^2=0 %; 24 h: I^2=0 %; 48 h: I^2=0 %). The findings indicate that the interventions of CWT and CWI had comparable effects on CK at 0 h and 48 h. Conversely, CWI had a greater effect on CK clearance compared to CWT at 24 h (Fig. 17).

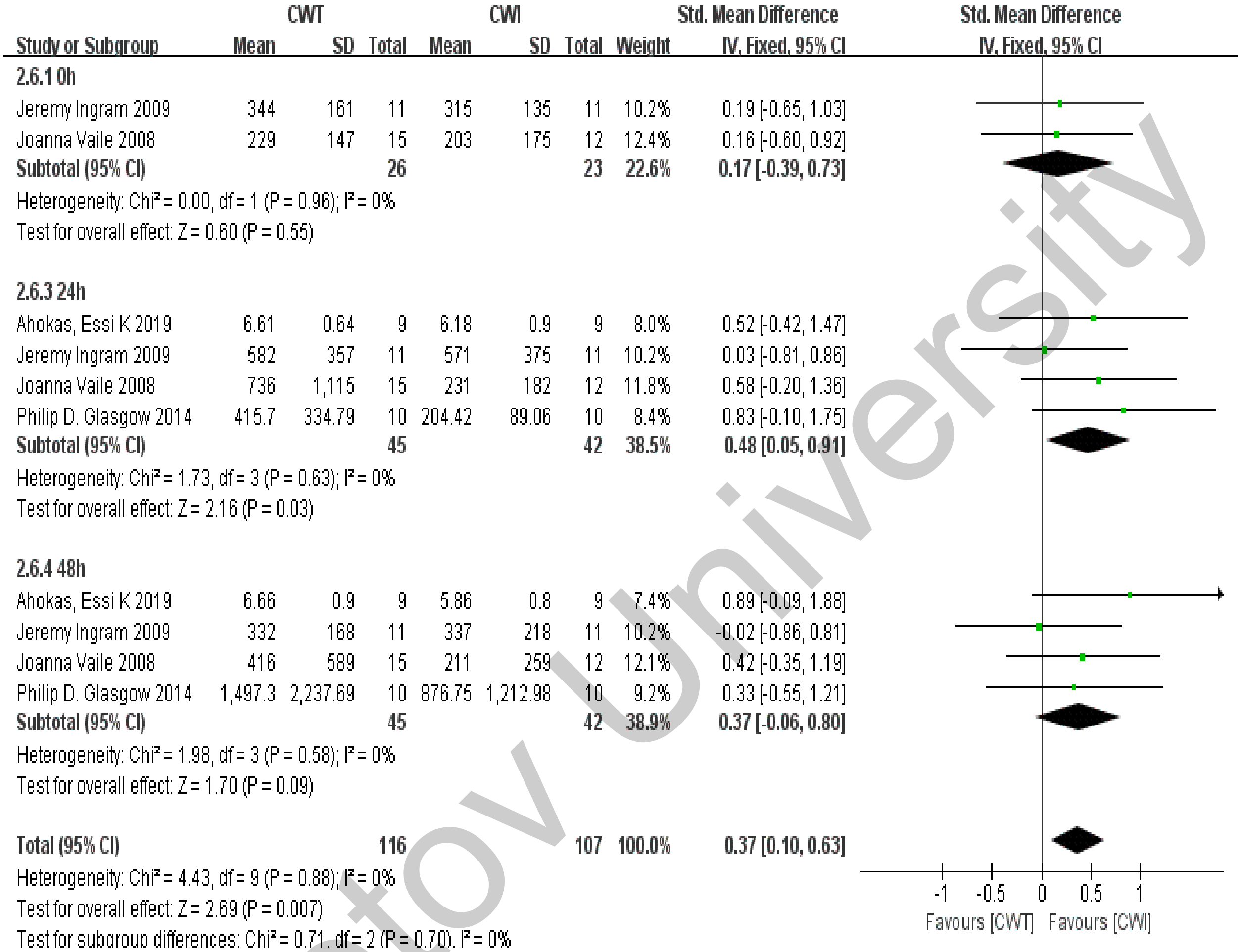

Figure 17. Forest plot of the comparison of CWT versus CWI for measurement of CK
CWT=Contrast water therapy, CWI=Cold water immersion, CK=Creatine kinase.

3.4.7 CRP and IL-6

The analysis presented in the figure reveals no statistically significant difference between the groups subjected to either CWT or CWI interventions in either the CRP or IL-6. However, due to the limited number of sources examined and the inclusion of only one study on indicators of CRP and IL-6, the findings are not representative (Fig. 18, 19).

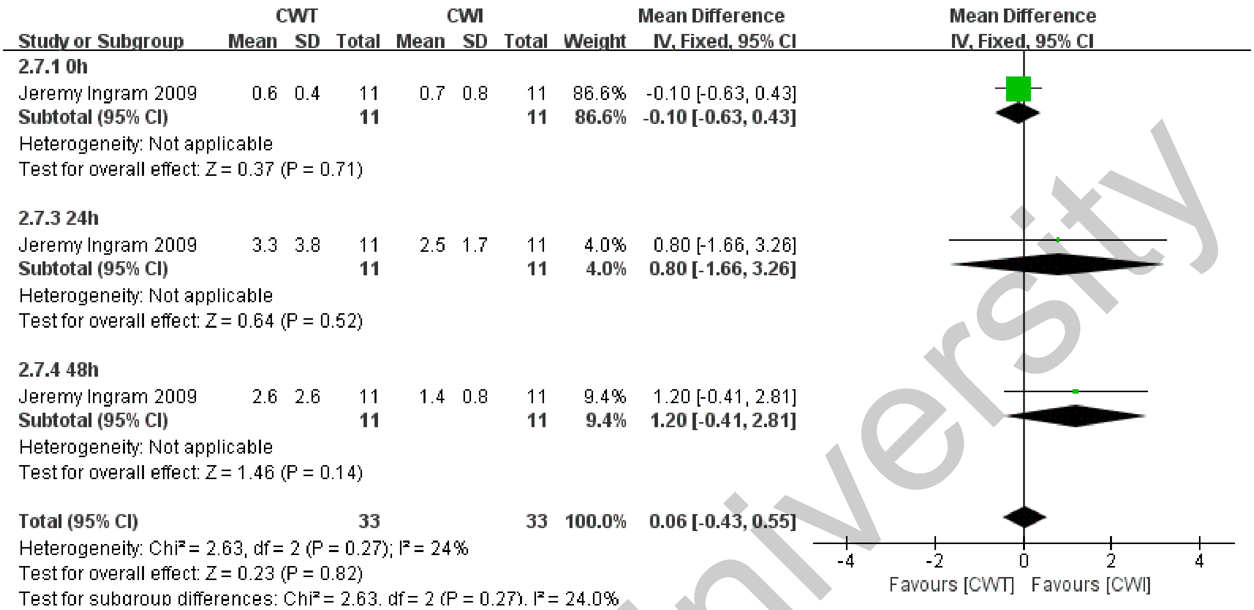

Figure 18. Forest plot of the comparison of CWT versus CWI for measurement of CRP
CWT=Contrast water therapy, CWI= Cold water immersion, CRP=C-Reactive Protein.

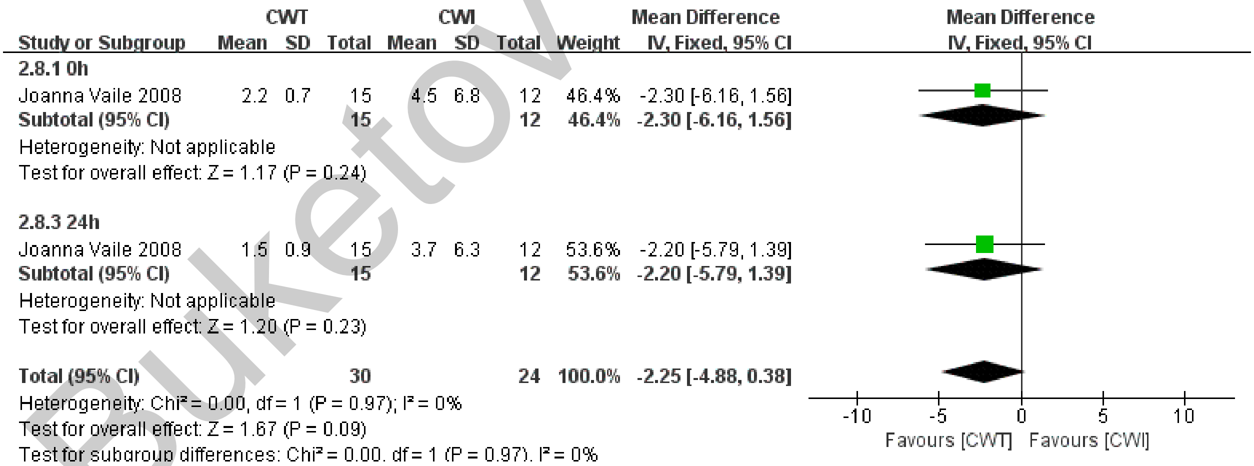

Figure 19. Forest plot of the comparison of CWT versus CWI for measurement of IL-6
CWT=Contrast water therapy, CWI= Cold water immersion, IL-6= Interleukin 6.

3.5 Subgroup analysis

3.5.1 Position of water during CWT

In the subgroup analysis focusing on water immersion depth during CWT, participants were divided into two categories: the umbilical immersion group and the shoulder immersion group. The analysis of DOMS outcomes revealed a statistically significant reduction in the umbilical immersion group at both 24 h and 48 h (24 h: SMD -0.64, 95 %CL -1.13 to -0.15, 3 trials); (48h: SMD -0.60, 95 %CL -1.09 to -0.11, 3 trials) post-CWT. This implies that submerging the body in water up to the umbilical level is effective in reducing muscle soreness. In contrast, no significant difference was observed in the shoulder immersion group at these time intervals, indicating that immersion up to shoulder level did not significantly alter muscle soreness at 24 h and 48 h. Additionally, the shoulder immersion group showed no notable difference in sprint time performance, suggesting that water level reaching the shoulders does not influence sprinting ability 24 hours post-CWT. However, the findings pertaining to the umbilical immersion group were based on a single study, limiting the generalizability of this result. Regarding lactate levels no statistically significant difference was observed in either the umbilical or shoulder immersion groups immediately post-CWT (0 hours). This indicates that the depth of immersion, whether at the umbilicus or shoulder level, does not significantly affect lactate levels at this time point.

3.5.2 Types of trial

Subgroup analyses based on trial type were conducted, categorizing studies into RCTs, cross-over trials, and other types of trials. For DOMS, no significant difference was observed in the RCTs group at 24 h or 48h post-CWT. In the cross-over trials group, a significant reduction in DOMS was found at 24 h (SMD -1.64, 95 % CI -3.28 to -0.01, 2 trials), but not at 48 h (SMD -0.61, 95 % CI -1.38 to 0.15, 2 trials). No significant differences were observed in the other types group at either 24 h or 48 h.

Regarding sprint time, results in the RCTs group did not show improvement at 24h post-CWT (SMD: -0.49, 95 % CL: -1.38 to 0.41, across 3 trials). The literature inclusion for both the cross-over group and other types group was deemed insufficient for meta-analysis. In terms of lactate levels immediately post-CWT (0h), non-significant results were observed in both the RCTs group (SMD: -0.12, 95 % CL: -1.16 to 0.92, across 2 trials) and other types group (SMD: -0.59, 95 % CL: -1.25 to 0.07, across 2 trials). These findings indicate that neither RCTs nor other types of trials were effective in altering lactate levels at 0 hours post-CWT.

3.5.3 Types of exercise

Exploring the effects of CWT on subjects after different sport types. The results showed a significant difference in DOMS at 1h and 24h when CWT was performed after team sports (1h: SMD -0.58, 95 %CL -1.06 to -0.10, 3 trials); (24h: SMD -1.07, 95 %CL -2.05 to -0.08, 4 trials), especially following soccer, the DOMS was significant at 24h and 48h (24h: SMD -1.68, 95 %CL -3.31 to -0.06, 2 trials); (48h: SMD -1.60, 95 %CL -2.31 to -0.90, 2 trials). There was insufficient literature to analyze rugby exercise. In team sports, there was significant difference in indicator of perceived fatigue at 1h, 24h, and 48h (1h: SMD -1.01, 95 %CL -1.94 to -0.08, 2 trials); (24h: SMD -0.72, 95 %CL -1.23 to -0.21, 3 trials); (48h: SMD -0.55, 95 %CL -1.08 to -0.02, 3 trials). Additionally, it was also significant difference in the soccer group at 1 h and 24 h (1h: SMD -1.01, 95 %CL -1.94 to -0.08, 2 trials); (24h: SMD -0.95, 95 %CL -1.58 to -0.32, 2 trials). There was also a significant difference in the indicator of sprint time in the soccer group at 24 h (24h: SMD -0.90, 95 %CL -1.53 to -0.28, 2 trials).

For eccentric exercise, no significant differences were observed in DOMS, lactate, and CK at 0h, 1h, 24h, and 48h post-CWT intervention. No available data were reported for perceived fatigue, CMJ, and sprint time in this category. In short-duration exercise, lactate levels significantly decreased at 0h post-CWT intervention (SMD -0.88, 95 % CI -1.56 to -0.21, 2 trials). No significant differences were found in DOMS, perceived fatigue, CMJ, sprint time, and lactate for high-intensity, submaximal intensity, or low-intensity exercise.

Discussion

4.1 CWT versus CON (passive rest and low-intensity active recovery)

All the results of CWT vs. CON are as shown in Table 2.

Table 2

Summary of results of CWT and CON

	0H	**1H**	**24H**	**48H**
DOMS	—	↓	↓† Umbilicus↓; Cross-over↓	↓† Umbilicus↓; Type—
Fatigue	↓	↓	↓	↓
CMJ	—	—	—	—
Sprint time	—	—	—† Part—; Type—	—
Lactate	—† Part—; Type—		—	—
CK	—		—	—
CRP	—		—	—
IL-6	—		—	

Note. ↓= significantly decrease in CWT groups, compared with CON groups; ↑= significantly increase in CWT groups, compared with CON groups; — = unsignificant difference between CWT and CON groups; †= heterogeneity present between CWT and CON groups; Part= CWI of different body parts; Type= different type trial of CWT; CMJ= Countermovement jump; CK= Creatine kinase; CRP= C-Reactive protein; DOMS= Delay of Muscle Soreness; Fatigue= perceived fatigue; IL-6= Interleukin 6.

This meta-analysis demonstrated that CWT significantly alleviates DOMS and perceived fatigue compared to CON, consistent with previous findings by Dupuy et al. [35]. However, unlike the analysis conducted by Dupuy, this review incorporated subgroup and sensitivity analyses to investigate heterogeneity sources, revealing that neither immersion depth nor trial type significantly influenced recovery outcomes. Notably, the study of Dupuy included a broader range of exercise protocols and participant populations, which may explain the differences in outcomes, particularly for biomarkers like CK.

The reduction in DOMS observed with CWT can be attributed to several potential mechanisms. Hydrostatic pressure during immersion likely facilitates fluid redistribution, reducing edema and alleviating muscle soreness. Alternating vasoconstriction and vasodilation during CWT may enhance blood flow, thereby accelerating the clearance of metabolic by-products [28, 36]. Furthermore, cold water immersion reduces skin temperature and sympathetic drive, which can promote recovery by decreasing muscle inflammation and pain perception [37]. However, direct evidence supporting these mechanisms is sparse, and further research is needed to elucidate their precise roles. Additionally, the placebo effect may partly explain subjective improvements, underscoring the importance of conducting future trials with appropriate blinding.

None of the biomarkers exhibited significant changes after CWT as compared to CON. CK is a general biomarker that indirectly responds to muscle damage after strenuous exercise [38]. In contrast to the findings of Dupuy, which reported a significant reduction in CK following CWT [35], the present meta-analysis did not observe a significant effect of CWT on CK levels. The concentration of CK increases maximally when performing multiple sets of moderate to high intensity eccentric exercises [39]. Most of the studies reviewed only utilized a single exercise, which did not generate enough intensity to significantly increase CK. Consequently, there was an insignificant variation in the recovery effect among the different intervention modalities.

Lactate is a metabolite that accumulates during strenuous exercise and has traditionally been associated with muscle fatigue. However, recent evidence suggests that lactate itself may not directly cause fatigue but rather serves as an energy substrate and a buffer against acidosis [40, 41].The results are inconsistent with other studies showing that CWT effectively reduces blood lactate levels at different times. This particular study only found an immediate reduction in blood lactate after short-term exercise. This is because only one

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study about lactate indicators at 24 and 48 hours was included. Additionally, the short duration of CWT included in the literature may also explain the insignificant changes in blood lactate at 0h [19]. Consistent with the findings of Ingram and Vaile et al. that CWT does not affect inflammatory biomarkers [21, 27], this review did not find an effect of CWT on IL-6 and CRP. This might be due to the fact that only a few studies with indicators of IL-6 and CRP were included in the present review and therefore the results were not representative.

CWT did not enhance subsequent exercise performance compared to CON. Blood lactate was not significantly reduced after CWT, and elevated lactate can adversely affect muscle contractile processes [42]. Both CMJ and sprint time, the metrics included in this review to characterize exercise performance, require strong muscle contraction, which may explain why CWT did not improve exercise performance.

4.2 CWT versus CWI

All the results of CWT vs. CWI are as shown in Table 3.

Table 3

Summary of results of CWT and CWI

	0H	**1H**	**24H**	**48H**
DOMS	—	—†	—†	—†
Fatigue	—	—	—	—
CMJ	—	—	—	—
Sprint time	—	—	—	—
Lactate	—†		↓	↓
CK	—		↓	—
CRP	—		—	—
IL-6	—		—	

Note. ↓= significantly decrease in CWI groups, compared with CWT groups; — = unsignificant difference between CWT and CWI groups; †= heterogeneity present between CWT and CWI groups; CMJ= Countermovement jump; CK= Creatine kinase; CRP= C-Reactive protein; DOMS= Delay of Muscle Soreness; Fatigue= perceived fatigue; IL-6= Interleukin 6.

There was few statistically significant difference between CWT and CWI in terms of perceived indicators like DOMS and fatigue, biochemical markers like CRP and IL-6, and exercise performance indicators such as CMJ and sprint time. The study revealed a significant reduction in lactate levels at 24h and 48h as well as a significant reduction in CK levels at 24h with CWI compared to CWT. This suggests that CWI is an effective intervention for relieving body soreness after 24 hours of exercise. However, the long-term use of cold water immersion leads to decreased muscle temperature and impaired exercise performance. Future research aims to explore alternative recovery protocols.

4.3 Characterization of subgroup analysis

4.3.1 Immersion Depth

The recovery efficacy of CWT varied by immersion depth. Subgroup analysis based on immersion depth revealed that immersing the body to the umbilicus was more effective in reducing DOMS at 24h and 48h compared to shoulder-level immersion. This effect can be attributed to hydrostatic pressure differences [36, 43, 44]: when immersed to the umbilicus, hydrostatic pressure facilitates fluid transfer from the lower extremities to the central cavity [36], reducing edema and soreness [44]. In contrast, full-body immersion to the shoulders applies pressure to the thoracic and abdominal cavities, potentially counteracting the beneficial fluid transfer from the lower extremities.

The exercise protocols in the included studies primarily targeted lower extremity muscles, which might explain the more pronounced recovery effects with umbilical immersion. Additionally, the reduced pressure on the upper body during umbilical-level immersion may enhance comfort and relaxation [36, 44], indirectly promoting fatigue recovery.

4.3.2 Trial Type

The effectiveness of CWT in promoting recovery differed across various trial type. Subgroup analysis by trial type showed that cross-over trials were more representative of the effects of CWT on DOMS, demonstrating significant reductions at 24h post-intervention. In contrast, RCTs and other trial types did not show consistent improvements, likely due to variations in study designs and protocols.

The significant heterogeneity observed across different trial types suggests that methodological differences—such as participant selection, intervention timing, and exercise protocols—may influence the reported outcomes. Future research should adopt more standardized trial designs to improve the comparability of results.

4.3.3 Exercise Type

The recovery efficacy of CWT varied by exercise type. CWT was more effective in reducing DOMS and perceived fatigue after team sports, particularly soccer, where significant improvements were observed at 1h, 24h, and 48h post-exercise. This enhanced efficacy may be due to the high physical contact and muscle damage typically associated with team sports, making the alternating hot and cold immersion used in CWT particularly beneficial [20].

In contrast, CWT was less effective in recovery after eccentric exercises, with no significant improvements in DOMS, lactate, or CK at any time point. Additionally, while CWT was effective in reducing lactate immediately post short-duration exercise (0h), it did not show similar benefits for high-intensity, submaximal, or low-intensity exercises.

4.4 Limitations of the study design

It was not possible to blind the different interventions in the study design. Although a RCT design could have been used to try to avoid the placebo effect, RCTs are not enough in this review. When conducting such studies in the future, try to choose the same type of experiment to minimize variability. This study specifically focused on CWT due to its unique alternating hot-cold immersion protocol, which differs fundamentally in mechanism and application from single-modality methods such as Hot Water Immersion (HWI) and Thermoneutral Water Immersion (TWI). As a result, studies solely addressing HWI and TWI were excluded to maintain a targeted scope. While HWI and TWI are recognized as effective recovery modalities, their mechanisms (e.g., sustained vasodilation or neutral hydrostatic effects) are distinct and may warrant a separate systematic review.

This study did not stratify results by gender or exercise protocols, which may influence recovery responses due to physiological and biomechanical differences. Additionally, biomarkers such as lactate dehydrogenase, blood urea nitrogen, and heart rate were not analyzed, limiting a comprehensive understanding of the effects of CWT. Future research should address these limitations to provide a more nuanced understanding of recovery dynamics across different populations and exercise modalities.

The literature search was limited to studies published between 2002 and 2022 to focus on research conducted within the past two decades, reflecting contemporary practices and methodologies in CWT. While this approach ensures the inclusion of relevant and standardized studies, it may exclude earlier pioneering studies or more recent findings beyond 2022. Future reviews may expand this timeframe to incorporate additional evidence

4.5 Future directions for research

In the future, researchers can select the same experimental type for review and analysis. They can also combine multiple recovery methods as a post-exercise intervention for subjects to assess the efficacy of a combined form of these modalities in enhancing subsequent exercise performance. It remains to be seen whether different recovery modalities can be developed for different sports.

Conclusions

Post-exercise CWT interventions were effective in relieving perceived muscle soreness and perceived fatigue. Although CWT did not consistently improve subsequent exercise performance across all conditions, it showed potential benefits after specific types of exercise, such as soccer. Compared to CWT, CWI was more effective in reducing objective soreness, but both interventions demonstrated similar efficacy in overall fatigue recovery. Furthermore, the effectiveness of CWT varied depending on exercise types, with perceptual benefits being more pronounced after team sports. While immersion depth and experimental designs were considered as potential influencing factors, further research is required to confirm their roles in modulating the efficacy of CWT.

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Information about authors

Xiao Feiyan — PhD student, Tomsk State University, Tomsk, Russia; e-mail: xiaofeiyan1223@gmail.com; ORCID ID: 0000-0002-1297-8685

Jiao Lu (contact person) — PhD student, Tomsk State University, Tomsk, Russia; e-mail: jiaolu0311@gmail.com; ORCID ID: 0000-0001-5012-4974

A.V. Kabachkova — Doctor of Biological Sciences, Professor, Tomsk State University, Tomsk, Russia; e-mail: kabachkova.av@yandex.ru; ORCID ID: 0000-0003-1691-0132

Zhao Huan — Lecturer, Shandong Youth University of Political Science, Jinan, China; e-mail: zhaohuan@gmail.com; ORCID ID: 0000-0001-5025-7611

Tan Li — Lecturer, Hunan Agricultural University, Changsha, China; e-mail: tanliaraon@163.com; ORCID ID: 0009-0003-0936-736X