Original Article

Effects of post-exercise recovery methods on exercise-induced hormones and blood fatigue factors: a systematic review and meta-analysis

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Background: High-intensity exercise consumes a large amount of energy and tends to induce post-exercise fatigue. Promoting physical and psychological recovery after exercise can enable individuals to perform better in subsequent training or competitions and reduce the risk of injury. This study aims to investigate the effects of post-exercise recovery methods on exercise-induced hormones and blood fatigue factors.

Methods: PubMed, Embase and Web of Science databases were queried to collect literature on the correlation between post-exercise recovery methods and the expression of exercise-induced hormones and blood fatigue factors. The search time ranged between inception to July 2020. Stata (version 15.0) was used for meta-analysis.

Results: A total of 10 studies were included, involving the data of 278 cases. Among these, 148 people were placed in the study group and assigned active post-exercise recovery measures while 130 people were placed in the control group and assigned no post-exercise recovery measures. The results of this meta-analysis showed that there was significant difference between the study group and the control group [relative risk (RR) =15.62, 95% confidence interval (CI): 3.25, 75.06, $P<0.05$]. The subgroup analysis on the effect of active and passive recovery on the blood lactate concentration (BLC) and creatine kinase (CK) concentration revealed that the CK concentration [standardized mean difference (SMD) =−0.76, 95% CI: −1.47, −0.04] and BLC (SMD =−1.16, 95% CI: −2.30, −0.02) were significantly lower in the study group compared with the control group. Further analysis on the effect of different post-exercise recovery methods on the BLC and CK concentrations indicated that BLC (SMD =−1.16, 95% CI: −2.30, −0.02) was significantly lower in the group with cold water immersion compared with the control group, while there was no significant difference in the changes of CK concentration. Additionally, food supplementation was shown to reduce CK concentration (SMD =−1.16, 95% CI: −4.69, 2.36).

Conclusions: Recovery measures after high-intensity exercise can accelerate the reduction of BLC and the activity and concentration of CK, thus helping the body quickly return to a pre-exercise state.

Keywords: Exercise recovery; cold water immersion; creatine kinase (CK); blood lactate concentration (BLC)

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Introduction

The improvement of living standards has afforded people the time and energy to pay more attention to their health. Physical exercise can improve health in a variety of and interesting ways. However, high-intensity exercise consumes a large amount of energy and tends to induce post-exercise fatigue. Maximizing the benefits of exercise performance depends on the optimal balance between training and recovery, so as to prevent psychological and physical maladjustment caused by load training (1,2). It is generally believed that promoting physical and psychological recovery after exercise can enable individuals to perform better in subsequent training or competitions and reduce the risk of injury. Therefore, various rehabilitation interventions have been used to promote post-exercise recovery.

Exercise releases factors, such as creatine kinase (CK), that are related to energy production and metabolism. CK is an enzyme that catalyzes the transfer of high-energy phosphate bonds between adenosine triphosphate and phosphocreatine; it is one of the key enzymes of energy metabolism in skeletal muscle cells (3) and has become one of the most studied enzymes in the current research on exercise biochemistry. The concentration of CK in the blood increases after high- or low-intensity exercise, which can lead to skeletal muscle injury and soreness (4). Meanwhile, a decrease in CK concentration in the blood can reflect a reduction in muscle injury and faster post-exercise recovery (5). In addition, after intense exercise, quick and effective restoration of blood lactate concentration (BLC) to a resting level is also critical for athletes to maintain good physical strength. Active post-exercise recovery can increase metabolic rate and systemic blood flow, thus promoting the clearance of BLC and accelerating lactate metabolism through oxidation and gluconeogenesis (6-8). It has been shown that a significant difference exists in the post-recovery situation between individuals who perform active recovery to eliminate BLA and those whose recovery is passive (9). For the recovery period after a competition, researchers have focused on how to apply effective methods to eliminate BLA to achieve rapid recovery of the body. These include active recovery measures, such as relaxation activities after exercise and active rest with moderate-intensity exercise (10,11).

Hydrotherapy is another effective method that can shorten recovery time, and has been increasingly used in the global field of competitive training. Cold water immersion after exercise can reduce muscle fatigue and pain, so it is frequently used for post-exercise recovery (12). Intermittent pneumatic compression (IPC) is another common method; it has the advantage of not requiring muscle tension while still being able to produce sufficient pressure for increasing venous and lymphatic drainage, thereby reducing swelling (13). Food supplementation, with items such as milk, carbohydrates, lipids, vitamins, and minerals, is another easy and effective way to achieve post-exercise recovery. Among these, milk contains whey and casein, which can increase muscle protein synthesis after exercise (14) while a high concentration of electrolytes can promote the recovery of body fluid after exercise (15).

To a certain extent, the above methods may increase heart rate, blood pressure, respiration, metabolism and cardiac output during exercise. Furthermore, they can reduce the activity and concentration of serum CK, thus reducing the fatigue of athletes after training. Additionally, lactate metabolism can be accelerated, thus improving delayed muscle soreness after training, and preventing exercise-induced muscle injury. The aim of this meta-analysis was to investigate the effects of post-exercise recovery methods on exercise-induced hormones and blood fatigue factors, and to compare the effects of different post-exercise recovery methods on CK concentration and BLC.

We present the following article in accordance with the PRISMA reporting checklist (available at http://dx.doi.org/10.21037/apm-20-2409).

Methods

Literature retrieval strategy

PubMed, Web of Science, and Embase databases were queried to collect randomized controlled trials of post-exercise recovery methods between the inception and July 2020. The search terms were as follows: ("post-exercise recovery" and "exercise recovery" and "after exercise") or ("exercise-induced hormone") or ("fatigue factor" and "perceived fatigue"). The references of the included literature were then reviewed to supplement the studies.

Screening criteria

The inclusion criteria were as follows: (I) randomized controlled studies on post-exercise recovery methods published in the English language; (II) healthy subjects receiving a recovery method to restore motor function after exercise; (III) at least one outcome measure of exercise-induced hormone (CK or other) reported; (IV) at least one outcome indicator of fatigue factor (lactate or other) reported.

The exclusion criteria were as follows: (I) semi-randomized controlled trials or non-randomized controlled trials, animal experiments, studies on mechanism, case reports, reviews; (II) repeated literature or literature with insufficient data; (III) reports with no outcome measures; (IV) subjects with cardiovascular diseases such as coronary heart disease and hypertension or genetic diseases, which could affect the outcome.

Interventions and outcome measures

The interventions were as follows: in the study group, cold water immersion, food supplementation, or IPC were applied as active post-exercise recovery methods; in the control group, passive post-exercise recovery, with no active measures, was applied.

The outcome measures were as follows: BLC and CK concentration in blood during post-exercise recovery.

Data extraction

Two investigators independently screened literature and extracted the data according to the screening criteria. Disagreements were resolved through discussion or consultation with a third party. The following data were extracted: name of the first author, year of publication, study location, interventions in the experiments, and main outcome measures.

Quality evaluation

Methodological quality of the included literature was evaluated using the method recommended by the Cochrane Handbook for Systematic Reviews of Interventions (16). The evaluation criteria for study quality included the following: whether random allocation was applied, whether the allocation scheme was concealed, whether a blind method was used, whether withdrawal and loss to follow-up were recorded, and whether intention-to-treat analysis was performed in cases of withdrawal and loss to follow-up. If all the quality evaluation criteria were fully met (i.e., yes), the study had the least risk for bias (level A); if one or more of the quality evaluation criteria were partially met (i.e., unclear), the study had a moderate risk for bias (level B); if one or more of the quality evaluation criteria were not met at all (i.e., no), the study had a high risk for bias (level C).

Statistical analysis

Stata (version 15.0) software was used for statistical analysis. For quantitative data, the combined effect size estimates were the standardized mean difference (SMD) and its 95% confidence interval (CI). For dichotomous data, combined estimates were relative risk (RR) and its 95% CI. The study group (active post-exercise recovery) was compared to the control group (passive post-exercise recovery). Heterogeneity of the included studies were assessed using the Cochrane's Q test and I^2 statistics. If homogeneity was significant ($P>0.1$, $I^2<50\%$), the fixed effects model (FEM) was used for meta-analysis; otherwise, the random effects model was used ($P<0.05$, $I^2>50\%$). Potential publication bias was evaluated using funnel plots, and sensitivity analysis of the study results was performed to assess the robustness of the conclusions.

Results

Literature retrieval results and basic characteristics of the included literature

A total of 488 potentially relevant studies were initially retrieved, and 401 were excluded according to titles and abstracts. After further filtering, 12 animal experiments, 54 unrelated studies, and 11 case reports were excluded. Finally, 10 trials (17-26) were included in this meta-analysis (*Figure 1*). In the study group, athletes received cold water immersion, food supplementation, and IPC as recovery measures after exercise. Among the included literature, seven articles carried out the comparison of cold water immersion and passive recovery, two articles compared food supplementation and passive recovery, and one article compared IPC and passive recovery. A total of 278 cases were involved in the 10 studies, of which 148 were assigned as the test group and 130 as the control group. The basic characteristics of all included literature are shown in *Table 1*. In general, the included trials were classified as low to moderate quality. The risk of bias of each trial is summarized in *Figure 2*.

Meta-analysis results

Effect of active and passive recovery on post-exercise recovery

Among the included literature, seven studies used cold

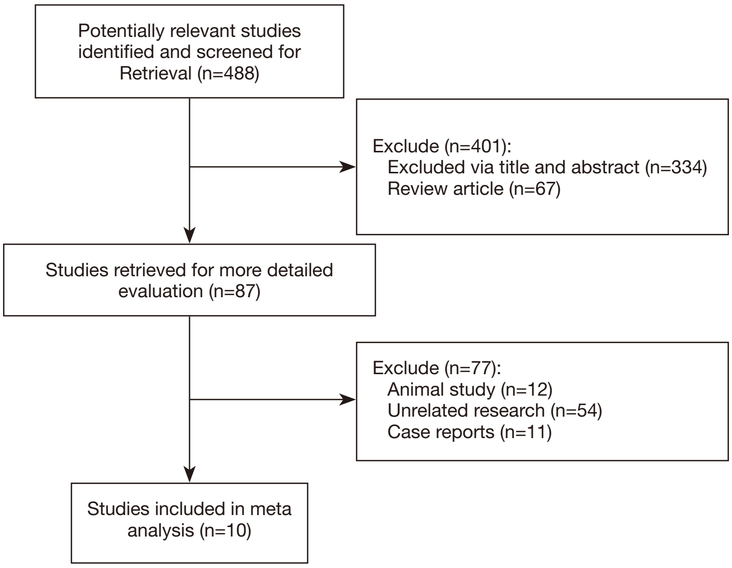


Figure 1 Literature screening process.

Table 1 The basic characteristics of inclusion in the literature

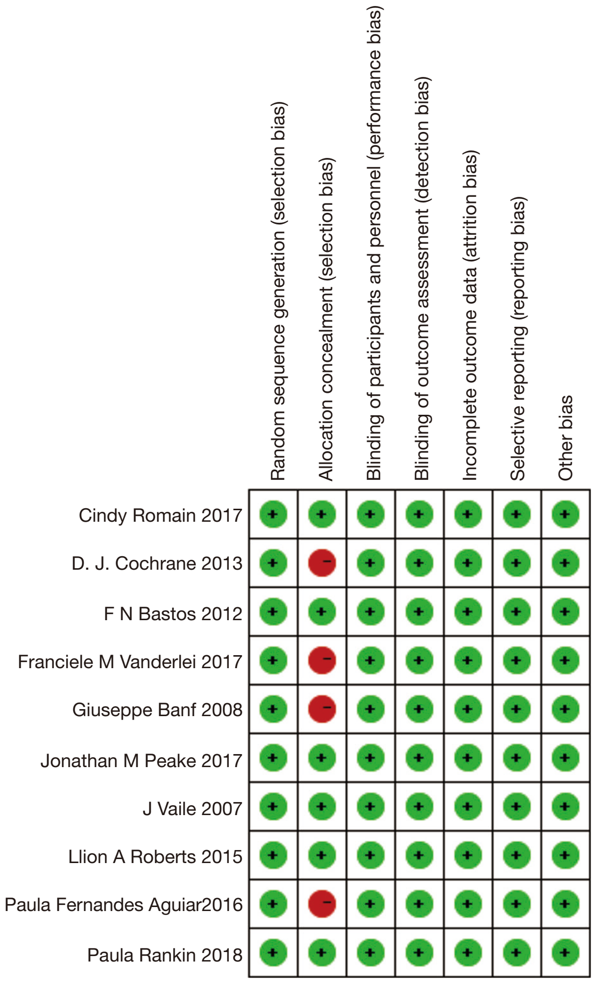
First author	Year	Sex	Age	Sample size/case	Intervention measures	Outcome
Llion A. Roberts	2015	Man	21.2±2.2	24	CWI	CK
Giuseppe Banfi	2008	Man	26±2.5	20	CWI	BLC
J. Vaile	2007	Man	32.2±4.3	24	CWI	CK
F. N. Bastos	2012	Man	21±2	40	CWI	BLC
Franciele M. Vanderlei	2017	Man	21.77±2.99	63	CWI	CK
Paula Fernandes Aguiar	2016	Man	23±3	17	CWI	BLC
Jonathan M. Peake	2017	Man	22.1±2.2	18	CWI	CK
D. J. Cochrane	2013	Man	21.0±1.7	20	IPC	CK
Cindy Romain	2017	Man	20	16	Food	CK
Paula Rankin	2018	Woman	21.6±3.4	36	Food	CK

CWI, cold water immersion; IPC, intermittent pneumatic compression; CK, creatine kinase; BLC, blood lactate concentration.

water immersion as the post-exercise recovery method; Random effects models (REM) (I^2=83.6%, P<0.001) was used for analysis, and a significant difference was identified between cold water immersion and passive recovery (RR =13.79; 95% CI: 1.80, 105.53, P<0.001). In two studies, food supplementation was used as the post-exercise recovery method, REM was used for analysis, and no significant difference between food supplementation and passive recovery was found (RR =23.52; 95% CI: 3.41, 162.15, P>0.05). In one study, IPC was compared with passive recovery (RR =21.00, 95% CI: 1.40, 315.98). These results reveal that cold water immersion has a positive effect on post-exercise recovery compared with passive recovery (*Figure 3*).

Effect of active and passive post-exercise recovery on CK concentration and BLC

A total of seven articles explored the effect of post-exercise recovery methods on CK; REM (I^2=80.5%, P<0.001) was used for analysis, and the results showed that within



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Cindy Romain 2017	+	+	+	+	+	+	+
D. J. Cochrane 2013	+	−	+	+	+	+	+
F N Bastos 2012	+	+	+	+	+	+	+
Franciele M Vanderlei 2017	+	−	+	+	+	+	+
Giuseppe Banf 2008	+	−	+	+	+	+	+
Jonathan M Peake 2017	+	+	+	+	+	+	+
J Vaile 2007	+	+	+	+	+	+	+
Llion A Roberts 2015	+	+	+	+	+	+	+
Paula Fernandes Aguiar2016	+	−	+	+	+	+	+
Paula Rankin 2018	+	+	+	+	+	+	+

Figure 2 Risk of bias assessment of the included literature.

the same time, CK concentration was significantly lower after active post-exercise recovery measures than after passive recovery without any measures (SMD =–0.76, 95% CI: –1.47, –0.04, P<0.001). A total of three included articles investigated the effect of post-exercise recovery methods on BLC; REM (I^2=78.0%, P=0.011) was used, and results show that within the same time, BLC was significantly lower after active post-exercise recovery measures than after passive recovery (SMD =–1.16, 95% CI: –2.30, –0.02, P=0.011) (*Figure 4*).

Effect of different post-exercise recovery methods on CK concentration and BLC

The subgroup analysis of different recovery methods with different outcome measures reviewed four studies that explored the effect of cold water immersion on CK concentration; the FEM (I^2=25.6%, P=0.258) was applied, and the results showed no significant differences in CK concentration after receiving cold water immersion after exercise compared with passive recovery (SMD =–0.92, 95% CI: –1.37, –0.47, P=0.258). Two studies investigated the effect of food supplementation on CK concentration; the REM (I^2=94.6%, P<0.001) was used, and the results showed that food supplementation after exercise had some effect on the reduction of CK concentration (SMD =–1.16, 95% CI: –4.69, 2.36, P<0.001). One study investigated the effect of IPC on CK concentration compared with passive recovery. As too few studies were eligible for this analysis, no statistical significance was identified. Cold water immersion was selected as the study group in three studies to observe its effect on BLC blood lactic acid concentration; REM (I^2=78.0%, P=0.011) was used, and the results showed that BLC was significantly decreased after receiving cold water immersion after exercise (SMD =–1.16, 95% CI: –2.30, –0.02, P=0.011) (*Figure 5*).

Publication bias

Funnel plots were used to detect the publication bias in the multivariate meta-analysis. The effects of active passive recovery on CK concentration and BLC were compared (*Figure 6*). The funnel plot of the comparison was almost symmetrical, suggesting no significant publication bias and indicating that our results were stable and reliable.

Sensitivity analysis

The sensitivity analysis of active recovery and passive recovery effects on CK concentration, BLC, and other indicators (*Figure 7*) showed that after excluding one study at a time, the overall effect size of the other studies did not change greatly, indicating that these results were robust.

Discussion

This study investigated the effects of cold water immersion, food supplementation, and IPC as post-exercise recovery methods. The effects of post-exercise recovery methods on blood fatigue factor and exercise-induced hormone concentration, specifically the changes of CK concentration and BLC, were systematically compared. In addition, the effects of different post-exercise recovery methods on CK concentration and BLC were explored. In this study, we determined that taking certain recovery measures after

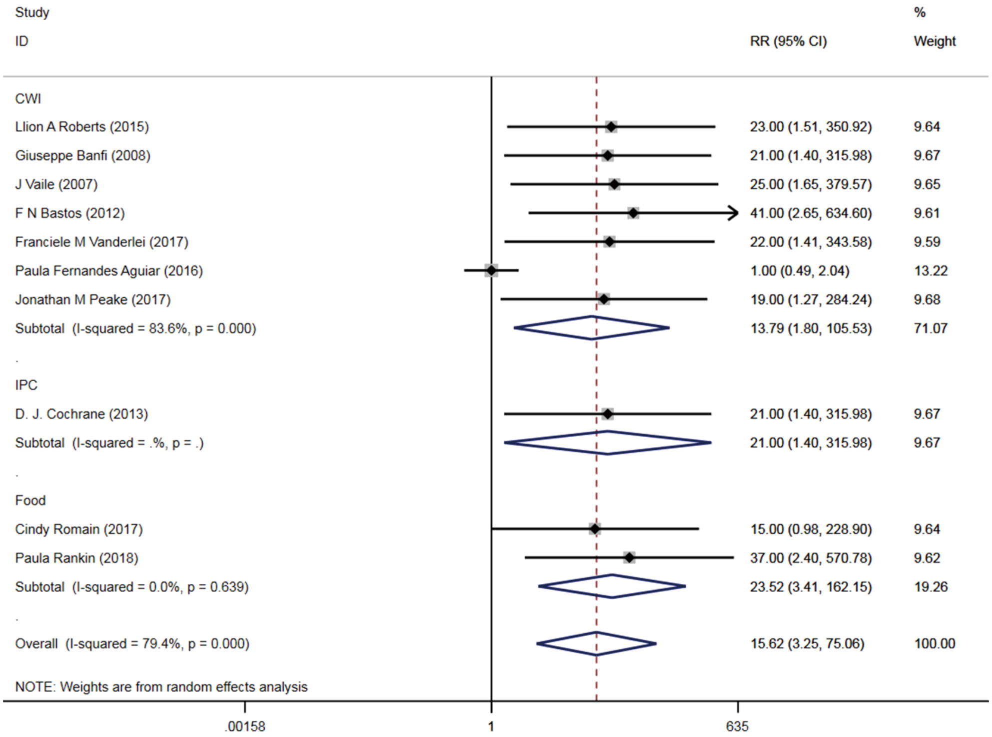


Figure 3 Forest plot of the comparison of active and passive recovery.

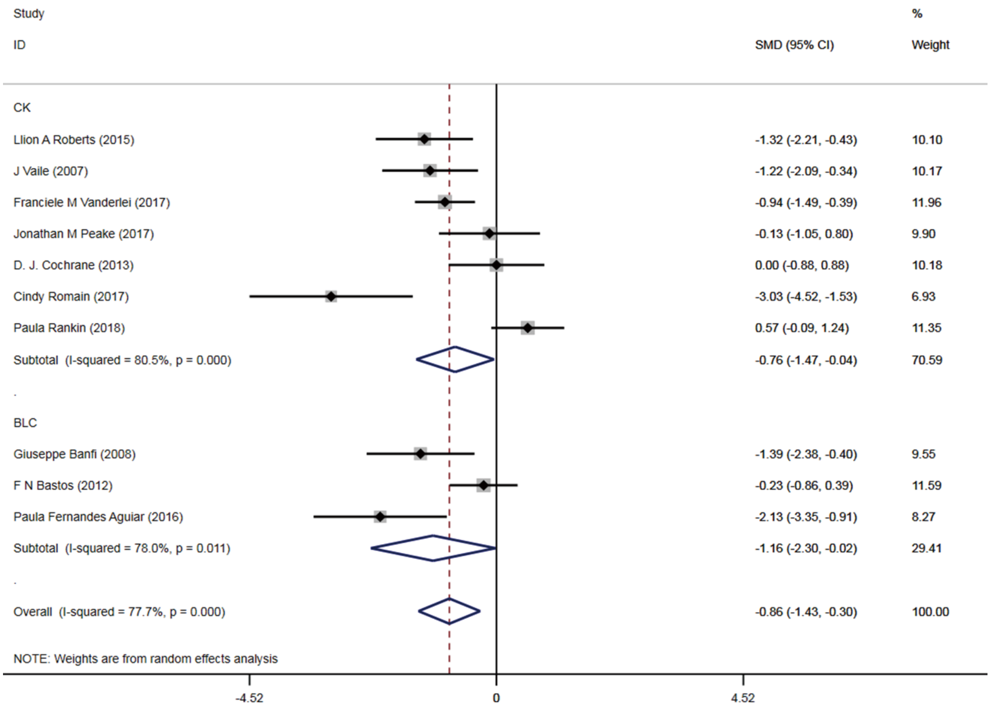


Figure 4 Forest plot of the comparison of the effect of active and passive recovery on CK concentration and BLC. CK, creatine kinase; BLC, blood lactate concentration.

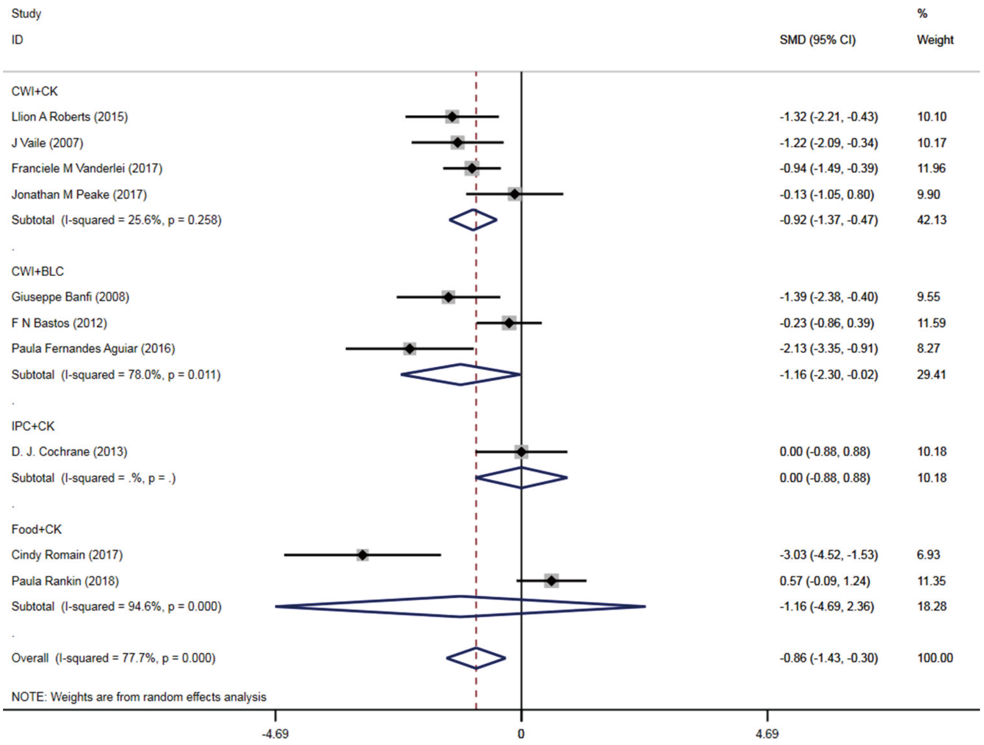


Figure 5 Forest plot of the effect of different recovery methods on CK concentration and BLC. CK, creatine kinase; BLC, blood lactate concentration.

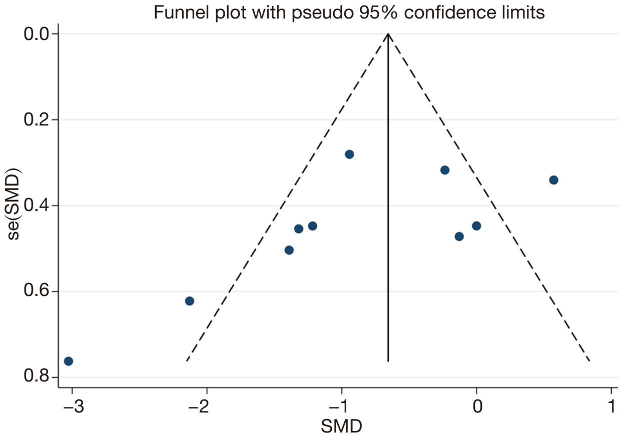


Figure 6 Funnel plot of the comparison of the effect of active and passive recovery on CK concentration and BLC. CK, creatine kinase; BLC, blood lactate concentration.

high-intensity exercise helps to reduce BLC and the activity and concentration of CK, thus accelerating the body's return to a pre-exercise state. Cold water immersion was the most effective among the three post-exercise recovery methods. The results of this meta-analysis showed that active recovery after exercise significantly reduced CK concentration and BLC compared with passive recovery, without significant publication bias. The results of the sensitivity analysis confirmed that these conclusions were also robust. In the analysis of the effects of different recovery methods on CK concentration and BLC, only cold water immersion had a statistically significant effect on the CK concentration, while sample size, food supplementation, and IPC had no effect.

Cold water immersion, as a common method for exercise recovery, has significant effects on both muscle soreness and perceived fatigue. It has been proven to have significant effects on post-exercise recovery when compared with passive recovery (27). CK concentration and BLC are common indicators in the studies of exercise fatigue (28). In the current meta-analysis, no significant changes were observed in the CK concentration in blood after cold water immersion, but BLC was reduced, which was beneficial to post-exercise recovery. Some related studies have also reported that the perceived fatigue scores were lower after cold water immersion (27). This study provides strong

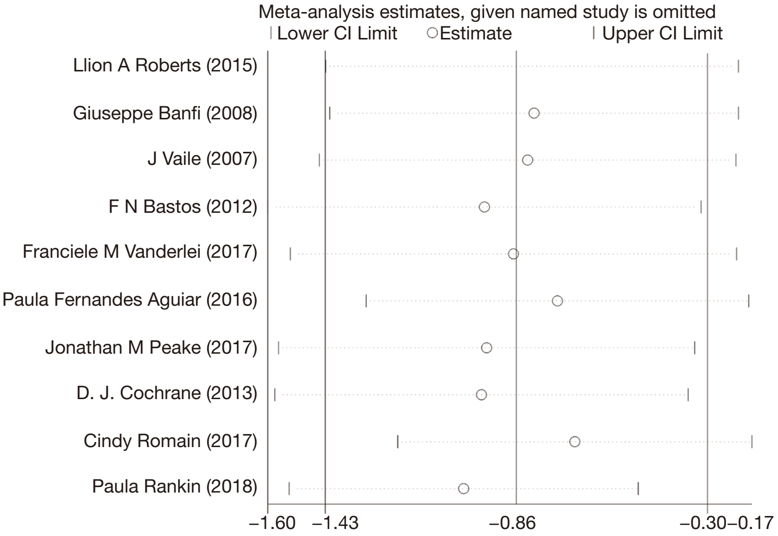


Figure 7 Sensitivity analysis of the comparison of the effect of active and passive recovery on CK concentration and BLC. CK, creatine kinase; BLC, blood lactate concentration.

evidence for the effect of cold water immersion on exercise recovery and BLC. However, the effects of cold water immersion on CK concentration in blood after exercise needs to be confirmed by further studies.

Food supplementation is the most convenient post-exercise recovery method, but few studies have reported its potential to enhance recovery capacity during exercise. Studies have shown that after exercise which induces muscle injury, drinking 500 mL of milk can reduce the decline of muscle function, including peak torque, reactive strength index (RSI), and sprint performance (29,30). This finding is valuable for nutritional prescription of athletes after exercise. In this meta-analysis, food supplementation was found to reduce CK concentration in the blood to some extent, thus accelerating the physical recovery after exercise. Increased levels of myoglobin and CK in the blood circulation are also markers of induced muscle injury after exercise (31). Therefore, the results of this study have potential value to evaluate the effect of food supplementation on injuries after exercise.

Our meta-analysis was limited by the small number of studies included, and only two studies on food supplementation and one study on IPC were eligible.

In summary, active recovery measures after high-intensity exercise can accelerate the body's return to a pre-exercise state, and various recovery measures can change the concentration of CK and lactate in the blood. In this study, cold water immersion was demonstrated to be the best post-exercise recovery method. Considering the limitations, a better research design with a larger range of high-quality randomized controlled trials is still required to confirm the conclusions of this study.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/apm-20-2409). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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