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Differential Effects of Cold-Water Immersion on Simple and Complex Cognitive Processing in Football Players

M. Said Zainuddin[1A-E]*, Awaluddin[2B-D], Ahmad Zakaria[3B-C]

[1,2,3] Universitas Negeri Makassar, Sulawesi Selatan, Indonesia

saidzainuddin@unm.ac.id[1]*, awaluddin@unm.ac.id[2], ahmad.zakaria@unm.ac.id[3]

ABSTRACT

This study aimed to analyze the differential effects of short-duration cold-water immersion (CWI) on simple and complex cognitive processing among university football players, hypothesizing that CWI would significantly enhance executive and psychomotor functions compared to standard recovery. Conducted as a quasi-experimental study with a nonequivalent control group pretest-posttest design, 30 male athletes aged 19–21 years were divided into intervention (n=15) and control (n=15) groups using purposive sampling. The intervention group underwent CWI (10°C, progressive durations of 10s, 30s, and 1 min, 2x/week for 2 weeks), while cognitive performance was measured before and after using validated instruments: Trail Making Test A (TMT-A) for simple processing speed, Trail Making Test B (TMT-B) for executive function, and Psychomotor Vigilance Test (PVT) for psychomotor alertness. Statistical analyses included paired and independent t-tests, Wilcoxon, and Mann-Whitney U. CWI resulted in significant improvements in executive function (TMT-B, p=0.033) and psychomotor vigilance (PVT, p=0.034) compared to controls, while improvements in simple processing speed (TMT-A) were significant only within the intervention group, not between groups. These findings demonstrate that short-duration CWI effectively enhances key cognitive domains crucial for football performance. Implications suggest that integrating CWI into recovery protocols may optimize both physical and cognitive readiness in athletes, recommending further research using larger, more diverse samples and extended interventions.

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AUTHORS' CONTRIBUTION

A. Conception and design of the study;
B. Acquisition of data;
C. Analysis and interpretation of data;
D. Manuscript preparation;
E. Obtaining funding

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INTRODUCTION

Football is a high-intensity competitive sport that demands not only peak physical ability but also advanced mental and cognitive maturity to maintain optimal performance throughout matches and training sessions. Over the ninety-minute duration of game, players must sustain concentration, respond rapidly to external stimuli, and make precise decisions under high-pressure conditions. The intense activity levels lead to both physical and mental fatigue and increase the risk of injury (Zainuddin et al., 2021).

M. Said Zainuddin[1A-E*], Awaluddin[2B-D], Ahmad Zakaria[3B-C]
saidzainuddin@unm.ac.id[1*]

Therefore, comprehensive recovery efforts are essential for athletes to optimize their physical and cognitive potential on the field.

Athlete recovery in football has evolved into a multidimensional approach, now considering not only physical aspects but also psychological well-being and neurocognitive function (S et al., 2025). As the paradigm has shifted in sports science, interventions that were once focused solely on muscle recovery and physical endurance now also prioritize strengthening executive function, mental flexibility, sustained attention, and decision-making processes. One widely adopted recovery method is cold-water immersion (CWI), a technique physiologically proven to reduce inflammation, speed up muscle regeneration, and improve sleep quality (Dewangga, 2024).

However, research specifically investigating the effects of CWI on cognitive domains in football athletes remains limited. Yet, optimizing executive and psychomotor functions is crucial for athlete performance, especially given the growing emphasis on rapid adaptation and decision-making in modern sports (Hizbulloh & Resita, 2023). Recent studies show that exposure to cold can trigger the sympathetic nervous system response, elevating levels of norepinephrine which directly influence focus and mental readiness (Rahmawati, 2025). Acute cold exposure and structured CWI protocols have empirically demonstrated significant potential in enhancing complex cognitive domains such as attentional switching, information processing speed, and cognitive inhibition.

Previous literature has mostly examined CWI as a physiological recovery strategy, especially for post-exercise muscle recovery and reduction of tissue irritation (KKK, 2025). The application of CWI as an intervention to optimize cognitive function remains a novel field, highlighting a significant research gap concerning CWI's neurocognitive effects on football athletes. This underscores the urgency for comprehensive studies to validate CWI's effectiveness as a holistic recovery strategy, benefiting not only physical but also mental performance in athletes.

Modern football demands high-level cognitive skills such as focus, decision-making, attentional switching, and reacting to unexpected stimuli (Komarudin M.Pd et al., 2024). Often, crucial moments—such as goal-scoring opportunities or avoiding fouls—are determined by increased information processing speed and mental flexibility, particularly after effective recovery. Thus, protocols that optimize executive and psychomotor functions are considered vital.

Biologically, cold-water immersion activates the sympathetic nervous system and increases the release of adaptive stress hormones (Nugroho, 2022). Exposure to temperatures below 15ºC for specific durations boosts norepinephrine, a neurotransmitter essential for mood regulation, alertness, attention, and unconscious decision-making—all critical factors for athlete performance in intense competition. This process not only speeds up muscle recovery but also strengthens neural networks in the brain responsible for reaction speed, concentration, and mental readiness (Andryan et al., 2025).

Moreover, CWI provides psychological benefits such as reduced negative emotions and improved mood, as well as enhanced sleep quality—an aspect critical to maintaining consistent cognitive performance in athletes (Saba, 2024). Recent studies indicate that short-duration CWI protocols, such as those employed in this research, yield better and more applicable outcomes for athlete populations than extreme, long-duration interventions that often do not fit real training routines.

Earlier studies mainly focused on muscle recovery and injury risk reduction via CWI, while cognitive domains—especially executive and psychomotor aspects—remain underexplored. Recent research highlights CWI as a "game changer" for cognition-based athlete recovery, though results are varied and many studies utilize indirect designs or general cognitive outcomes. Contemporary literature also recommends specific measurement instruments like the Psychomotor Vigilance Test (PVT) and Trail Making Test (TMT-A/B) to pinpoint cognitive changes relevant to football.

Accordingly, recent research focusing on the specific effects of CWI on executive function (TMT-B), cognitive flexibility, and psychomotor vigilance (PVT) in young athletes is essential to fill knowledge gaps and provide scientific foundations for innovative recovery strategies in competitive sports.

This study aims to analyze the effects of short-duration CWI on the cognitive functions of football athletes, specifically in domains of information processing speed, executive flexibility, and psychomotor vigilance (Saputra, 2022). It was conducted using a quasi-experimental design with a control group, employing validated instruments (PVT and TMT-A/B), and targeted outcomes directly related to real match performance.

Measuring cognitive function in athletes undergoing CWI intervention is expected to clarify CWI's contribution to optimizing mental readiness and provide empirical evidence of changes in executive and psychomotor functions relevant to the demands of modern football (Nuril Akbar, 2025).

The findings are expected to offer a scientific basis for integrating CWI into recovery protocols for football and other sports demanding high cognitive performance. A structured and ecologically valid CWI practice can become an innovative strategy for professional athlete recovery, as well as contribute academically to the advancement of sports training and research (Hasyim, 2024). Furthermore, this research opens possibilities for deeper exploration of CWI's neurobiological mechanisms, its effects on neurotransmitters, sleep quality, and athletes' psychological well-being. Subsequent studies with a multidomain approach may strengthen external validity and broaden generalizations of CWI therapy benefits for athletes across various ages and competition levels.

METHODS

This study employed a quasi-experimental design with a nonequivalent control group pretest-posttest approach to measure the effects of cold-water immersion (CWI) on cognitive function using quantitative data analysis. The research was conducted at the Football Field of the Faculty of Sports Science and Health at Makassar State University because this location provided comprehensive facilities for football training, controlled cognitive testing, and access to a swimming pool for CWI interventions.

M. Said Zainuddin[1A-E]*, Awaluddin[2B-D], Ahmad Zakaria[3B-C]
saidzainuddin@unm.ac.id[1]*

The study population comprised university football athletes at Makassar State University (n = 60–80). The sample consisted of 30 male athletes aged 19–21 years, divided into an intervention group (n=15) and a control group (n=15), selected using purposive sampling based on inclusion and exclusion criteria.

Inclusion Criteria: Male, aged 19–21 years, members of a football team for at least one year, competitive experience of at least three years, active athletes, willing to sign informed consent, no cognitive impairment or neurological disease, and in good physical and mental condition.

1. Exclusion Criteria: History of cold-water allergy, current injury or undergoing medical treatment, cardiovascular disease or hypertension, use of medications affecting cognition, and unwillingness to participate fully.
2. Independent Variable: CWI protocol with the following specifications: water temperature of 10°C, progressive duration (10 seconds, 30 seconds, 1 minute per repetition × 3), 20-second rest intervals between repetitions, frequency of twice weekly for two weeks (total of 4 sessions).
3. Dependent Variables: Cognitive functions measured through (1) simple information processing speed (TMT-A), (2) executive function and cognitive flexibility (TMT-B), and (3) psychomotor vigilance and reaction time (PVT).
4. Control Variables: Age, gender, exercise intensity, measurement time (07:00–09:00 AM), restriction of caffeine and alcohol 24 hours prior, and consistent testing environment conditions.
5. Trail Making Test (TMT-A and TMT-B): A validated cognitive assessment tool. TMT-A measures processing speed by connecting 25 numbers (1–25) in sequential order. TMT-B measures executive function by alternately connecting 25 elements (numbers 1–13 and letters A–L). The score is the completion time in seconds.
6. Psychomotor Vigilance Test (PVT): A standardized instrument measuring reaction time by responding to visual stimuli on a computer screen. Measured parameters include mean reaction time (milliseconds) and the number of lapses (failed responses).
7. Supporting Materials: Temperature-controlled immersion tanks, digital thermometers, stopwatches, personal protective equipment, informed consent and demographic forms, laptops for PVT and TMT software implementation, and data recording forms.

The intervention group received CWI at 10°C, maintained consistently using a cooling device. Immersion duration was progressive: 10 seconds (repetition 1), 30 seconds (repetition 2), and 1 minute (repetition 3) with 20-second rest intervals between each repetition. The immersed body region was the lower area (waist to chest) to ensure safety of vital organs. The intervention was administered twice weekly for two weeks (4 sessions total), delivered 10–15 minutes after high-intensity training when the body remained warm and metabolism was active. The control group followed the standard training program without CWI intervention.

Pretest was conducted prior to intervention to establish baseline cognitive function using TMT-A, TMT-B, and PVT under standardized conditions (morning, after overnight rest, without caffeine). Posttest was conducted on day 14 or 24 hours after the final intervention session using procedures identical to the pretest.

Prerequisite Testing: Normality was tested using Shapiro-Wilk ($p > 0.05$ = normal); homogeneity using Levene's test ($p > 0.05$ = homogeneous). Hypothesis Testing: Paired Sample t-test compared pretest-posttest results within each group; Independent Sample t-test compared delta scores between groups ($\alpha = 0.05$). Results were presented with mean, standard deviation, p-value, and effect size (Cohen's d).

RESULTS AND DISCUSSION

Result

This study aimed to analyze the effects of cold-water immersion (CWI) therapy on cognitive function in football athletes at Makassar State University. Data were collected through cognitive function measurements using the Trail Making Test (TMT-A and TMT-B) and the Psychomotor Vigilance Test (PVT) in two groups: the intervention group (n=15) and the control group (n=15). The following section presents the research results systematically.

The characteristics of the research respondents are presented in Table 1 to provide a profile of the study subjects based on gender, age, football experience, and academic level.

Table 1.
Respondent Characteristics

Variable	Intervention Group (n=15)	Percentage (%)	Control Group (n=15)	Percentage (%)
Gender				
Male	15	100.0	15	100.0
Age				
19 years	6	40.0	7	46.7
20 years	5	33.3	5	33.3
21 years	4	26.7	3	20.0
Playing Experience				
3 years	2	13.3	3	20.0
4 years	3	20.0	2	13.3
≥5 years	10	66.7	10	66.7
Academic Level				
Semesters 1-2	7	46.7	8	53.3
Semesters 3-4	5	33.3	4	26.7
Semesters 5-6	3	20.0	3	20.0

Table 1 demonstrates that all respondents in this study were male (100%), consistent with the established inclusion criteria. Age distribution was relatively balanced, with the majority aged 19 years in both groups (40.0% in the intervention group and 46.7% in the control group). The majority of respondents had football playing experience of five years or more (66.7% in both groups), indicating that the study subjects were experienced athletes with long-term consistent training. Regarding academic level, most respondents were in semesters 1–2 (46.7% in the intervention group and 53.3% in the control group), suggesting that the study subjects were active students in early stages of their academic programs.

Before conducting further statistical analysis, normality testing was performed using the Shapiro-Wilk test to determine whether the data were normally distributed. The results of the normality test are presented in Table 2.

Table 2.

Normality Testing(Shapiro-Wilk)

Variable	Intervention Group		Control Group	
	Pretest (p-value)	**Posttest (p-value)**	**Pretest (p-value)**	**Posttest (p-value)**
TMT-A	0.412	0.089	0.356	0.624
TMT-B	0.108	0.082	0.071	0.198
PVT	0.124	0.002	0.042	0.018

Based on Table 2, TMT-A and TMT-B data in both groups showed normal distribution (p > 0.05), so subsequent analysis employed parametric tests: Paired Sample t-test and Independent Sample t-test. However, PVT data were not normally distributed in the intervention group posttest (p = 0.002) and in the control group pretest and posttest (p < 0.05), so nonparametric tests (Wilcoxon and Mann-Whitney U) were used for PVT analysis.

TMT-A was used to measure simple cognitive processing speed. The results of pretest-posttest analysis within each group using Paired Sample t-test are presented in Table 3.

Table 3.

Results of Paired Sample t-Test for TMT-A

Group	Mean Pretest (seconds)	Mean Posttest (seconds)	Mean Difference	SD	t	p-value
Intervention	34.22	23.18	11.04	9.38	4.563	0.001
Control	29.14	25.72	3.42	7.62	1.738	0.104

The analysis in Table 3 shows that the intervention group experienced a significant reduction in TMT-A completion time from pretest to posttest (p = 0.001; p < 0.05), with an average decrease of 11.04 seconds. This indicates an improvement in simple cognitive processing speed following CWI therapy. Conversely, the control group showed no significant difference between pretest and posttest (p = 0.104; p > 0.05), although a time reduction of 3.42 seconds was observed, likely due to the practice effect of repeated testing.

Subsequently, an Independent Sample t-test was performed to compare score changes (delta) between the two groups, with results presented in Table 4.

Table 4.

Results of Independent Sample t-Test for Delta TMT-A

Variable	Mean Difference	t	df	p-value
Delta TMT-A	7.62	1.986	28	0.057

Table 4 demonstrates that although there was an average delta difference of 7.62 seconds between the intervention and control groups, this difference did not achieve

M. Said Zainuddin[1A-E*], Awaluddin[2B-D], Ahmad Zakaria[3B-C]
saidzainuddin@unm.ac.id[1*]

statistical significance (p = 0.057; p > 0.05). This finding indicates that CWI has an effect on simple cognitive processing speed, but the effect is not sufficiently strong statistically to significantly differentiate it from the control group.

TMT-B measures more complex executive functions, including cognitive flexibility, attentional switching, and cognitive inhibition. The analysis results are presented in Table 5.

Table 5.
Results of Independent Sample t-Test for TMT-B

Group	Mean Pretest (seconds)	Mean Posttest (seconds)	Mean Difference	SD	t	p-value
Intervention	68.42	42.26	26.16	23.14	4.380	<0.001
Control	61.38	53.64	7.74	17.22	1.742	0.103

Table 5 demonstrates that the intervention group experienced a highly significant improvement in executive function and cognitive flexibility, as evidenced by a reduction in TMT-B completion time of 26.16 seconds (p < 0.001). By contrast, the control group showed no significant change (p = 0.103; p > 0.05), although a time reduction of 7.74 seconds was observed.

An Independent Sample t-test comparing delta TMT-B between the two groups is presented in Table 6.

Table 6.
Results of Independent Sample t-Test for Delta TMT-B

Variable	Mean Difference	t	df	p-value
Delta TMT-B	18.42	2.241	28	0.033

Results in Table 6 show a significant difference in delta TMT-B between the intervention and control groups (p = 0.033; p < 0.05). This finding confirms that CWI has a significant effect in enhancing executive function and cognitive flexibility in football athletes, which are critical aspects for rapid decision-making and situational adaptation on the field.

PVT was used to measure psychomotor vigilance and reaction time. Because the data were not normally distributed, analysis employed the nonparametric Wilcoxon test. Results are presented in Table 7.

Table 7.
Results of Wilcoxon Test for PVT

Group	Mean Rank Pretest	Mean Rank Posttest	Z	p-value
Intervention	11.20	4.80	-3.182	0.001
Control	9.67	7.33	-1.244	0.214

Table 7 demonstrates that the intervention group experienced a significant reduction in reaction time (p = 0.001; p < 0.05), indicating improved psychomotor vigilance following CWI therapy. The control group showed no significant change (p = 0.214; p > 0.05).

A Mann-Whitney U test was performed to compare posttest PVT scores between the two groups, with results presented in Table 8.

Table 8.
Results of Mann-Whitney U Test for Posttest PVT

Variable	Variable	Mann-Whitney U	Z	Variable
Posttest PVT	64.500	-2.124	0.034	

Results in Table 8 show a significant difference in posttest PVT scores between the intervention and control groups ($p = 0.034$; $p < 0.05$). This finding further strengthens the evidence that CWI is effective in enhancing psychomotor vigilance and accelerating reaction time in football athletes.

Based on the data analysis conducted, it can be concluded that cold-water immersion (CWI) therapy has positive effects on cognitive function in football athletes, particularly in executive function, cognitive flexibility (TMT-B), and psychomotor vigilance (PVT). Although CWI also demonstrated effects on simple cognitive processing speed (TMT-A), the difference from the control group did not achieve strong statistical significance.

Discussion

Effects of CWI on Cognitive Function: A Neurophysiological Perspective

The primary finding of this study is that cold-water immersion (CWI) therapy significantly enhances executive function, cognitive flexibility, and psychomotor vigilance in football athletes. These results align with recent research demonstrating that acute cold exposure can trigger neurobiological responses that support improved cognitive function.

Physiologically, exposure to water at 10°C activates the sympathetic nervous system, triggering substantial norepinephrine (noradrenaline) hormone release. Norepinephrine is a critical neurotransmitter involved in regulating alertness, focus, and response speed to external stimuli. Elevated norepinephrine levels have been shown to strengthen prefrontal cortex activity—the brain region responsible for executive function, decision-making, and cognitive flexibility. Thus, the significant improvements in TMT-B and PVT scores observed in this study can be explained through the sympathetic activation mechanisms and neurotransmitter modulation induced by CWI exposure.

Differential Effects of CWI on Simple versus Complex Cognitive Functions

One notable finding in this study is the differential effect of CWI on simple cognitive function (TMT-A) versus complex cognitive function (TMT-B). Although the intervention group showed improvements in both tests, only TMT-B achieved significant differences compared to the control group. This finding aligns with the hypothesis that CWI is more effective in modulating complex executive cognitive functions than simple information processing.

TMT-A measures basic cognitive processing speed that is largely automatic and does not require complex attentional switching or cognitive inhibition. Conversely, TMT-B demands the ability to alternate between two stimulus sets (numbers and letters), requiring higher-order executive control, mental flexibility, and the capacity to suppress automatic responses. The sympathetic nervous system activation triggered by CWI appears to have greater impact on cognitive aspects requiring top-down prefrontal cortex modulation, as measured in TMT-B.

Enhanced Psychomotor Vigilance and Implications for Football Performance

The study results demonstrate that CWI significantly improves psychomotor vigilance and accelerates reaction time, as measured by the PVT. Psychomotor vigilance is the capacity to sustain attention and respond rapidly to stimuli—an aspect critically important in competitive football.

In football matches, athletes must respond quickly to changing situations, such as opponent movements, ball trajectory, and coach instructions. Optimal reaction speed enables athletes to make tactical decisions instantly and execute technical movements with high precision. The enhanced psychomotor vigilance resulting from CWI can provide a significant competitive advantage, particularly during crucial match moments demanding rapid and accurate responses.

These research findings are consistent with several recent studies exploring CWI's effects on cognitive function. Research by (Siregar, 2024) found that repeated therapeutic cooling can enhance executive function and sleep quality, subsequently supporting cognitive performance. Another study by (Nurhaliza et al., 2024) reported that participants undergoing CWI experienced increased vigilance and reduced negative emotions, supporting this study's findings regarding enhanced psychomotor vigilance.

Furthermore, recent research indicates that short-duration CWI protocols conducted realistically (such as those used in this study) yield better and more applicable outcomes for athletes compared to extreme long-term interventions. The short-duration CWI protocol (10 seconds, 30 seconds, and 1 minute) employed in this study proved effective in enhancing cognitive function without causing hypothermia risk or excessive discomfort.

Beyond direct sympathetic nervous system effects, CWI also facilitates physical recovery that supports optimal cognitive performance. Cold exposure has been shown to reduce inflammation, lower creatine kinase levels (a marker of muscle damage), and accelerate muscle regeneration following intense exercise. Faster physical recovery correlates with reduced mental fatigue and enhanced cognitive capacity, as prolonged physical fatigue can impair executive function and vigilance (Pago et al., 2025).

Furthermore, CWI is known to improve sleep quality, a critical factor for memory consolidation and cognitive function recovery. Quality sleep allows the brain to conduct detoxification processes, consolidate long-term memories, and facilitate neural tissue repair involved in executive function. Thus, CWI's positive effects on cognitive function are not merely acute but can provide long-term benefits through optimized physical-mental recovery cycles in athletes.

These research findings have significant practical implications for football athlete recovery strategies. CWI can be integrated as part of routine recovery protocols following intense training or competition, not only to accelerate physical recovery but also to optimize athletes' mental readiness and cognitive function. The CWI protocol used in this study (10°C temperature, progressive duration, twice weekly frequency) proved effective and can be readily implemented in various training settings with available facilities. Coaches and medical staff can consider CWI as a holistic recovery strategy supporting athletes' physical and mental performance. Structured and consistent CWI use can help athletes maintain optimal levels of vigilance, cognitive flexibility, and reaction speed throughout the competitive season (Pratama & Utami, 2024).

Although these research results demonstrate positive CWI effects on cognitive function, several limitations warrant consideration. First, the intervention duration in this study was relatively brief (2 weeks with 4 sessions), so long-term CWI effects on cognitive function cannot be confirmed. Further research with longer intervention durations and more extensive follow-up is necessary to confirm the sustainability of observed effects. Second, the sample size was relatively small (n=30), potentially limiting generalization to broader athlete populations. Research involving larger and more heterogeneous samples (including athletes from various sports, ages, and competition levels) would strengthen external validity. Third, this study did not explore biological mechanisms in depth, such as measuring norepinephrine levels, cortisol, or brain electrophysiological activity (using EEG or fMRI). Further research integrating biomarker measurements and neuroimaging will provide more comprehensive understanding of the neurobiological mechanisms underlying CWI effects on cognitive function. Fourth, psychological factors such as motivation, expectation, and placebo effects were not systematically measured. Research shows that positive expectations regarding interventions can contribute to recovery outcomes, so future research should consider these psychological aspects.

Based on these findings and limitations, recommendations for future research include the following. First, explore long-term CWI effects with extended intervention durations (e.g., 8–12 weeks) and follow-up to assess sustainability of cognitive function improvements. Second, involve larger and more diverse samples, including athletes from various sports and competition levels, to enhance external validity. Third, integrate biomarker measurements (such as norepinephrine, cortisol, BDNF) and neuroimaging techniques (EEG, fMRI) to explore the neurobiological mechanisms underlying CWI effects on cognitive function. Fourth, add psychological variable measurements such as motivation, expectation, fatigue perception, and sleep quality to understand non-physiological factors' contribution to cognitive function improvement. Fifth, compare CWI effects with other recovery modalities (such as contrast water therapy, active recovery, or massage) to identify the most effective recovery strategies for optimizing athletes' cognitive function.

CONCLUSION

The research results demonstrate that cold-water immersion (CWI) therapy is effective in enhancing cognitive function in football athletes, particularly in executive function, cognitive flexibility, and psychomotor vigilance. These findings provide empirical evidence that CWI benefits not only physical recovery but also supports optimization of athletes' mental readiness and cognitive capabilities. The practical implications of this research support integrating CWI into athlete recovery protocols as a holistic strategy to simultaneously improve physical and mental performance.

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