Effect of Cold Water Intake During Exercise in Heat on Cognitive Function

Yunbin Lee MS, Somi Yun PhD, Jaegu Hwang MS, Heejin Lee PhD, Ah Reum Jung PhD, Dae Taek Lee PhD

Department of Exercise Physiology Laboratory, Kookmin University, Seoul, Korea

PURPOSE: The purpose of this study was to examine the effect of cooling treatment by cold water intake before and during exercise in a hot environment on cognitive function.

METHODS: Twelve healthy adult men (26.3 ± 4.4 years, 176.2 ± 5.8 cm, 77.2 ± 14.6 kg, 24.8 ± 3.7 kg/m²) completed 3 exercise tests; with drinking warm water (36.5°C), with drinking cold water (4°C), or without drinking water. Each test was separated at least 3 days. During each test, they ran on a treadmill for 20 minutes at 75% of their maximal heart rate in 40°C with 40% of humidity. For the drinking conditions, the total volume of drinking was set to 1% of the participant's weight. Before the test in each drinking condition, they consume 1/3 of the total volume at once. The remaining 2/3 was consumed separately 3 times at six-min interval during exercise. A neuropsychological test using the Stroop Color and Word Test (SCWT) was conducted before and after the exercise to examine the changes of cognitive abilities. Data were analyzed using a two way repeated measures ANOVA.

RESULTS: Comparing pre- and post-exercise SCWT, the main effects in words, colors, and words and colors were noticed ($p = .000$, $p = .003$, and $p = .008$, respectively). No differences were found between water drinking conditions.

CONCLUSIONS: Overall, a short bout of high-intensity exercise in the hot environment improved cognitive functions, but it was not possible to determine how water temperature and water intake affected cognitive ability. Further research is needed considering the ages and fitness levels of participants.

Key words: Stroop color and word test, Pre-cooling, High temperature exercise

INTRODUCTION

Regular exercise is recommended for most people to improve health, but participation to exercise is often hampered by environmental conditions [1]. In particular, exercise in hot environments increases the skin blood flow and sweating rate for regulation of body temperature leading to a body water depletion and an imbalance of body homeostasis [2]. The increased depletion of body water by sweating also decreases venous return inducing a cardiac performance drift limiting exercise capacities [1,3]. The elevation of body temperature and dehydration caused by heat exposure affect the normal body functioning and mood of the brain, which can adversely affect cognitive function [4,5].

Cognitive function is considered a very important factor during exercises and performing sports which require physical skills and mental judgment. Cognitive function during exercise is known to be affected by dehydration, body temperature elevation, and hypoglycemia [6]. When the body becomes dehydrated for a long time or acutely, the blood flow to the cerebrovascular vessels decreases, and changes in electrolytes such as hypernatremia and hormonal changes such as glucocorticoid and vasopressin can negatively affect the physical function [7].

Cold treatments against body temperature elevation and dehydration is one of the strategy to prevent heat injuries and physical performance declines. Cold treatment refers to a method of cooling body such as drinking cold water, exposure to cold air, and/or wearing an ice vest be-

Corresponding author: DaeTaek Lee **Tel** +82-2-910-4781 **Fax** +82-2-910-4781 **E-mail** dtlee@kookmin.ac.kr

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Received 28 Oct 2020 **Revised** 15 Feb 2021 **Accepted** 26 Feb 2021

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fore, during, and after exercises to leveling the negative effects of the heat stress [8-13]. Pre-cooling can also delay sweating and dehydration by lowering the body temperature before exercise and extend the time of initiation of temperature increment during exercise [8,14,15]. However, an application of external cooling methods to the human body requires facilities, equipments, and time for cooling. As the greater the cold stress, the greater the discomfort of the subject when using the external cooling [16,17].

Complementing the shortcomings of the external cooling method of the human body and lowering the body temperature when exercising in a hot environment, 'cold water drinking before exercise' can be suggested as a simple cooling treatment method for gaining advantage. According to a previous study, a cold water drinking (4°C) during exercise in a hot environment can play as a heat absorber, slowing the rise of the body temperature and reducing the levels of heat stress [18]. When the body temperature was decreased by 0.5°C after drinking 4°C water in a hot and humid environments, the heart rate was lower than after drinking 37°C water [19]. Cold water drinking before exercise reduced sweating [20] and had a positive effect on the ratings of perceived exertion and the thermal sensation [18].

When considering the facts that body temperature elevation and dehydration can adversely affect cognitive function, a proper cold water consumption in a hot environment not only prevents dehydration but also improves the exercise performance with affecting on cognitive function. However, most of the existing studies have focused on the effect of cold water intake on body temperature, and it is still unclear how it affects cognitive function. In addition, despite the fact that water temperature can affect the absorption rate of water in the body, most of the preceding studies have only been studied with a specific temperature, and the water temperature of ingested water has not been standardized [21-23]. Therefore, it is necessary to identify how important the variables related to the temperature of ingested water are for the cognitive function in a hot environment. The purpose of this study is to investigate the effect of water intake at various water temperatures before and during exercise on cognitive function in a hot environment.

METHODS

1. Participants

Twelve healthy young men with no known cardiovascular diseases and/or other illnesses were recruited as participants (Table 1). They re-

Table 1. Physical characteristics of the subjects (M±SD)

	Age (yr)	Height (cm)	Weight (kg)	BMI (kg/m ²)	BF (%)
Man (n=12)	26.3±4.4	176.2±5.8	77.2±14.6	24.8±3.7	22.2±5.3

Values are mean ± SD.

BMI, body mass index; BF, body fat content.

ceived an explanation of the purpose, procedures, and risks associated with the study and filled out the consent form for the study. The study was approved by the Institutional Research Ethics Committee and all research procedures were carried out in accordance with the Declaration of Helsinki and the Ethical Guidelines of the American College of Sports Medicine (ACSM).

2. Experimental design

Participants were randomly assigned and completed 3 test sessions; with drinking warm water (36.5°C), with drinking cold water (4°C), or without drinking water. In each session, they ran on a treadmill for 20 min at their 75% of maximal heart rate (154.4±5.6, 157.8±10.3, 152.8±7.9 bpm in cold water, warm water, and no water conditions, respectively) in 39.2±2.1°C and 41.4±8.6% of relatively heat environment.

The hydration group, in order to minimize the difference in the amount of dehydration, the individual's water intake and exercise intensity were managed to be the same. For the drinking conditions, the total volume of drinking was set to 1% of the participant's weight [19]. Before the test in each drinking condition, they consume 1/3 of the total volume at once. The remaining 2/3 was consumed separately 3 times at six-min interval during exercise. Before and after their exercise bouts, their cognitive function was tested using the Stroop Color and Word Test (SCWT) [25]. At rest and during exercise their heart rate by electronic monitor (H7 Bluetooth Heart Rate Sensor, Polar, Finland) and 3 skin temperatures (pectoral muscle, brachial triceps, and quadriceps) using thermocouples were monitored and recorded (Thermocouple Scanner, Barnant Company, USA). Tests were conducted at a same time of the day and each subject completed all tests within 2 weeks.

3. Measurements

Before the experiments, their body composition was measured. Vigorous physical activity was restrained before each test session. The SCWT is a neuropsychological test used for clinical and experimental purposes. It was performed to evaluate the ability to suppress cognitive interference that occurs when processing different properties of the same stimulus si-

multaneously. When the subject undertook the SCWT, they were asked to read aloud the words (W), color symbols (C), and color words (CW) arranged in random order for as long as 45 seconds. W read the words spoken in accordance with the order in which they were arranged in black, while C marked the 'XXXX' symbol with red, blue, and green and guided subjects to read words out in the order in which they were arranged. Finally, CW is a word in a color different from the meaning of the word (for example, the word 'blue' is printed in red), and the method is the same as the above method [24]. The interference score (IF) of the SCWT was calculated using the regression equation with $IG = CW - [(W \times C)/(W+C)]$ [25]. The total volume of sweat was calculated by weighing nude weight before and after the exercise bout after drying body surface.

4. Statistical analysis

Measured variables were expressed as mean $\pm$ standard deviation (M $\pm$ SD). The SPSS/PC Ver. 25 (IBM, NEW YORK, AMERICA) statistical

package was used. One-way ANOVA and Scheffé were used to compare sweating verify the main effects. Two-way repeated measures of ANOVA were utilized for Skin temperature, RPE, SCWT comparing conditions. Scheffé was used as a post-hoc. The statistical significance level was set at $\alpha = .05$.

RESULTS

1. Construction of the prediction models

The sweat volume in each condition was shown in Table 2. Sweat volume was the highest in warm water condition, but it was not statistically significant.

Skin temperature responses during exercise was shown in Table 3. No time and conditions interaction was noticed.

Ratings of perceived exertion was shown in Table 4, and no statistical differences were noticed between conditions.

The score of SCWT was shown in Table 5. The main effect of W in Stroop effect was statistically significant ($F = 29.726, p = .001$), but no statistical significance was found in the interaction with water temperature. For the C, the time effect was statistically significant ($F = 13.959, p = .003$), but no interaction was significant. For the CW, the time effect was obvious ($F = 10.236, p = .008$), but no interaction with water temperature was

Table 2. Sweat volume in each condition

	Cold water	Warm water	No water	F	p-values
Sweat volume (g)	470.7 $\pm$ 141.7	488.1 $\pm$ 258.3	416.7 $\pm$ 142	0.467	0.631

Values are mean $\pm$ SD.

Denotes significant difference: $p < .05$.

Table 3. Skin temperature responses during exercise

	Cold water	Warm water	No water	Water Temperature		Time		Interaction effect	
				F	<i>p-values</i>	F	<i>p-values</i>	F	<i>p-values</i>
Triceps Brachii Muscle (°C)									
2 min	34.9±1.8	35.2±1.0	35.0±1.20	.255	.696	.792	.475	1.106	.352
6 min	36.0±3.8	35.1±1.4	34.7±1.1						
10 min	35.9±5.7	34.4±1.2	34.2±1.1						
14 min	33.9±1.9	34.1±1.3	35.0±2.7						
18 min	34.6±1.3	35.0±1.4	35.0±0.8						
Pectoralis Major Muscle (°C)									
2 min	34.8±1.3	35.7±1.0	35.2±0.9	1.945	.167	4.015	.044	1.371	.265
6 min	34.4±0.8	34.9±1.0	34.9±0.9						
10 min	34.6±0.9	35.3±1.0	35.1±0.9						
14 min	34.9±0.9	35.3±0.9	35.5±0.8						
18 min	35.3±0.9	35.6±0.9	35.7±0.8						
Quadriceps Femoris Musculus (°C)									
2 min	34.4±1.8	35.8±1.3	34.7±0.6	.700	.507	1.406	.267	1.824	.148
6 min	34.5±1.5	35.6±1.3	34.7±0.9						
10 min	35.0±2.3	35.4±1.7	34.8±1.0						
14 min	35.0±2.2	35.1±2.4	34.8±1.2						
18 min	35.8±2.9	35.3±1.4	35.3±0.7						

Values are mean $\pm$ SD.

Denotes significant difference: $p < .05$.

Table 4. Ratings of perceived exertion during exercise

	Cold water	Warm water	No water	Water Temperature		Time		Interaction Effect	
				F	p-values	F	p-values	F	p-values
RPE									
6 min	13.6±0.8	13.8±1.0	12.8±1.6	2.950	.073	.015	.942	2.021	.139
10 min	13.3±1.1	13.9±1.0	12.9±1.2						
14 min	13.3±1.3	13.7±0.9	13.1±1.3						

Values are mean ± SD.

RPE, Ratings of perceived exertion.

Denotes significant difference: $p < .05$.

Table 5. Stroop color and word test

	Cold water	Warm water	No water	Water Temperature		Time		Interaction effect	
				F	p-values	F	p-values	F	p-values
W									
Pre	116.1±15.4	112.8±15.2	115.7±11.9	.071	.930	29.726	.001	.762	.48
Post	120.7±15.5	119.3±14.7	119±13.9						
C									
Pre	88.6±19.9	87.8±17.6	91.6±12.0	.069	.930	13.959	.003	2.089	.15
Post	96.3±19.4	92.4±21.1	93.4±13.7						
CW									
Pre	74.7±22.1	71.9±17.7	71.2±12.9	.134	.875	10.236	.008	.283	.756
Post	79.3±21.6	79.4±18.0	75.5±14.2						
IF									
Pre	24.7±15.1	22.7±13.1	20.2±10.2	.420	.662	2.473	.114	.422	.661
Post	26.0±15.6	27.6±9.60	23.2±10.3						

Values are mean ± SD.

W, Word; C, Color; CW, Color+Word; IF, Interference score.

Denotes significant difference: $p < .05$.

noticed. IF did not show any statistically significance.

DISCUSSION

Exercise affects brain plasticity, leading to structural and functional changes that contribute to cognitive function [26]. In previous studies, exercise has helped reduce the risk of developing dementia, improved children's academic achievement, and enhanced memory and attention [27-30]. Genome analysis has shown attenuated stress-induced increases in miR-124, which is involved in nerve production and memory formation [31]. In addition, even in the same exercise, the cognitive response may be affected by various conditions, such as exercise intensity, time, subject, and environmental conditions [18,32].

Drinking water during exercise is important. Water accounts for the most part of human life maintaining homeostasis. especially during physically active or exposed to heat. In this case, more fluid consumption is necessary over the normal intake. Previous studies suggested a

daily water requirement of 3.0-4.5 liter for those who participate in activities for more than 60 minutes a day, and up to 7 liter a day for highly active people. In addition, since physical activity in a hot environment requires more water, an additional water intake of 2-7 liters are needed over the daily requirement [33].

This study conducted the SCWT, a neuropsychological test, to investigate the effects of exercise on cognitive function even in a hot environment. In order to minimize the performance error of the subject, the preliminary practice time prior to the test was performed identically, and to minimize the learning effect of cognitive ability, different test papers were used for each test. The SCWT can assess cognitive functions. such as learning ability, attention, and thinking judged by the frontal lobe [34]. Therefore, the frontal lobe of the brain was considered to have a cognitive function and effect when exposed to the hot environment. As a result of the SCWT test scores, the results of W, C, and WC before and after exercise were significantly different in all conditions of water temperature and intake ($p < .001$, $p < .01$, and $p < .01$, respectively). Through this,

high intensity exercise showed the cognitive improvement in a hot environment. This supports the findings of previous studies that cognitive improvement through exercise is more effective in high intensity exercise [32,35] and that short term exercise affects cognitive function through aerobic exercise [36,37].

In the case of ingestion of warm and cold water and without drinking water, the difference was not statistically revealed, and the interactions were not observed. In this study, the temperature of drinking water and/or without drinking water during exercise did not influence the cognitive ability. In previous studies, the cooling effects by water intake led to a decrease in skin temperature and the heat accumulation resulting an improvement of endurance performance in a hot environment [19]. Further discussion is needed on the increase of brain plasticity, water intake and temperature due to BDNF changes following aerobic performance for cognitive function. Previous studies measured the body core temperature while only skin temperature was measured in this study, which was the limitation of the study. For the better temperature measurements, the core, skin, and mean body temperature measures are warranted.

For the participants the exercise intensity was assumed to be a moderate intensity as shown in exertion ratings of 12-13. In the previous study, dehydration was affected by 2 % of body weight before and after exercise [38]. However, in this experiment, the sweat loss was 470.7 ± 141.7 , 488.1 ± 258.3 , and 416.7 ± 142.0 g in cold water, warm water, and no water, respectively. These were only 0.6% of the average body weight loss, which seems to be insufficient for affecting cognitive ability. In other words, considering that the difference in the sweat loss according to the temperature and water intake did not show a significant difference, the temperature and water intake did not seem to have an influence on the appropriate level. Even in short-term exercise, children and the elderly are subjects who are more affected by cognition, but in the case of healthy young people, they are less affected by cognition and the influence on the cognitive ability will be lowered according to the fitness level of the subject [39]. By considering the subject's age or fitness level, the results may differ from those of this study.

CONCLUSION

The purpose of this study was to determine whether cold water consumption influenced cognitive response during a high intensity exercise in a hot environment. The subjects underwent the SCWT test, a cogni-

tive test, after high-intensity exercise for 20 minutes at $39.2 \pm 2.1^\circ\text{C}$ and $41.4 \pm 8.6\%$ of humidity with cold water intake, warm water intake, and no intake. The results of W, C, and WC before and after exercise showed significant differences in all three different conditions. However, there was no difference in the cognitive scores in the three conditions. Exercise performance was found to improve cognitive function, but it was not confirmed whether cold water intake at a high temperature could improve cognitive function.

CONFLICT OF INTEREST

This study did not financial supported by any organizations.

AUTHOR CONTRIBUTIONS

Conceptualization, AR Jung; methodology, YB Lee; validation, DT Lee; formal analysis, YB Lee; investigation, JG Hwang; data curation, JG Hwang; writing-original draft preparation, YB Lee, SM Yun; writing-review and editing, HJ Lee; supervision, DT Lee; project administration, SM Yun.

ORCID

Yunbin Lee	https://orcid.org/0000-0001-5927-1540
Somi Yun	https://orcid.org/0000-0001-6659-9499
Jaegu Hwang	https://orcid.org/0000-0002-2082-6294
Heejin Lee	https://orcid.org/0000-0001-5194-0180
Ah Reum Jung	https://orcid.org/0000-0002-5724-5186
Dae Taek Lee	https://orcid.org/0000-0001-7025-8902

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