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Effects of environmental temperature on physiological responses during submaximal and maximal exercises in soccer players

*MiHyun No, Hyo-Bum Kwak**

Department of Kinesiology, Inha University, Incheon, Republic of Korea

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ABSTRACT

Background: Although thermoregulation is effective in regulating body temperature under normal conditions, exercise or physical activity in extreme cold or heat exerts heavy stress on the mechanisms that regulate body temperature. The purpose of this study was to investigate the effects of environmental temperature on physiological responses and endurance exercise capacity during submaximal and maximal exercises in healthy adults.
Methods: Nine male soccer players participated in this study. In this study, three environmental temperatures were set at 10 ± 1°C, 22 ± 1°C, and 35 ± 1°C with the same humidity (60 ± 10%). The participants cycled for 20 minutes at 60% maximum oxygen uptake (60% VO_2max), and then exercise intensity was increased at a rate of 0.5 kp/2 min until exhaustion at three different environmental conditions.
Results: Oxygen uptake and heart rate were lower in a moderate environment (22 ± 1°C) than in a cool (10 ± 1°C) or hot (35 ± 1°C) environment at rest and during submaximal exercise, and were higher during maximal exercise ($p < 0.05$). Minute ventilation was lower at 22 ± 1°C than at 10 ± 1°C or 35 ± 1°C at rest and during submaximal exercise, and no significant differences were observed in minute ventilation during maximal exercise (p < 0.05). Blood lactate concentrations were lower at 22 ± 1°C than at 10 ± 1°C or 35 ± 1°C at rest and during submaximal exercise, and were higher during maximal exercise ($p < 0.05$). Time to exhaustion during exercise was longer at 22 ± 1°C than at 10 ± 1°C or 35 ± 1°C ($p < 0.05$).
Conclusion: It is concluded that physiological responses and endurance exercise capacity are impaired under cool or hot conditions compared with moderate conditions, suggesting that environmental temperature conditions play an important role for exercise performance.

* *Corresponding author*. Department of Kinesiology, Inha University, 100 Inha-ro, Nam-gu, Incheon 22212, South Korea.
E-mail address: kwakhb@inha.ac.kr (H.-B. Kwak).
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1. Introduction

The human body is physiologically regulated to keep it homeostatic when environmental conditions change. Humans produce or lose heat through thermoregulation to maintain the homeostasis of body temperature and protect themselves against excessive heat or cold.[1] In the same way, environmental temperature may affect physiological responses to exercise through thermoregulation. For example, our body minimizes heat dissipation by reducing body surface under cold conditions, promoting heat generation by skeletal muscle contraction (i.e., shivering), and preventing heat loss by contracting skin blood vessels (i.e., vasoconstriction).[2] By contrast, our body promotes heat dissipation by sweat evaporation through increased skin blood vessels (i.e., vasodilation) when exposed to heat.[3]

Exposure to cold causes various physiological responses in the human body. It has been reported that cold exposure results in increased heart rate and systolic blood pressure.[4,5] Cold-induced increase in heart rate may be associated with reduced vagal activation compared with sympathetic response to cold.[6] In addition, exposure to cold causes peripheral vasoconstriction leading to increase in systemic vascular resistance and diastolic blood pressure.[2,7] Various physiological responses are also caused by heat stress. Heat increases the heart rate by activating the sympathetic nervous system, but stroke volume is limited because of less return to the heart.[8] Moreover, dehydration caused by heat was associated with decrease in stroke volume, cardiac output, and blood pressure as well as decline in blood flow to the working skeletal muscles.[9]

Physical exercise is involved in skeletal muscle contraction and cardiovascular changes, which include increases in heart rate and systolic blood pressure by both the activation of sympathetic nervous system and the withdrawal of vagal control.[10] Also, dynamic exercise increases stroke volume and oxygen uptake[11,12] and increases blood flow to the skeletal muscle and skin, thereby promoting body heat loss.[3] However, exercise with prolonged and/or repeated cold or heat exposure may impair thermoregulatory control such as shivering and vasoconstriction responses to cold, and evaporation and vasodilation responses to heat.

Prolonged exercise with elevated body temperatures in the heat markedly influences exercise capacity. For example, there was a progressive impairment of marathon performance as the temperature increased from 5 °C to 25 °C.[13] Similarly, high-intensity running distance during a football game in the heat (approx. 43 °C) declined compared with moderate temperature condition (approx. 21 °C).[14] Thus, both environmental and exercise-induced heat stress may cause hyperthermia and increase core and brain temperature, resulting in impaired performance. However, it has been reported that solar loads were not associated with fast marathon performance.[15] Interestingly, impaired maximal oxygen uptake by hyperthermia-induced cardiovascular dysfunction seems to be associated with during high-intensity exercise,[16] whereas oxygen uptake capacity may be not affected during submaximal exercise.[17]

Similarly, exercise capacity and physiological responses are differentially affected by exercise in the cold. For example, Galloway and Maughan[18] reported that exercise time to fatigue during cycling was higher at 11 °C compared with that at 4 °C, 21 °C, or 31 °C. These results were not consistent with those of Parkin et al,[19] who showed that maximal time to exhaustion at the same intensity was produced after 3 °C, suggesting that environmental temperatures between 3 °C and 11 °C may be beneficial to maximal exercise performance. By contrast, it has been reported that exercise performance was negatively affected by cold ambient temperatures.[2] Moreover, Ball et al[20] showed that cold environmental temperatures leading to lowered skeletal muscle temperatures might be detrimental to exercise. Furthermore, it has been shown that maximum oxygen uptake remained unaffected by the cold environment, and there was no significant difference in aerobic capacity.[21,22]

Previous research regarding the effects of environmental temperature on physiological responses to exercise and endurance exercise capacity has produced inconsistent and conflicting results. Therefore, the purpose of this study was to verify the effects of environmental temperature on physiological responses and endurance exercise capacity during submaximal and maximal exercises in healthy adults.

2. Methods

2.1. Participants

Nine male varsity soccer players voluntarily participated in this study, none of whom had any history of diseases including cardiopulmonary disease. Informed consent was obtained from each participant prior to the experiment. They completed the Physical Activity Readiness Questionnaire and attended an orientation session during which the experimental protocol was explained. The principles outlined in the Declaration of Helsinki were followed in this study. The characteristics of participants are detailed in Table 1.

2.2. Experimental design

All participants were randomly assigned to three groups, and each group ($n = 3$) was set according to a randomized crossover design, as shown in Table 2. There were three environmental conditions: cool temperature (10 ± 1 °C), moderate temperature (22 ± 1 °C), and hot temperature (35 ± 1 °C); the same humidity (60 ± 10%) was used in each chamber. Each

Table 1 – Characteristics of participants

	Participants
n	9
Age (y)	18.56 ± 1.13
Height (cm)	176.89 ± 5.62
Weight (kg)	67.67 ± 5.48
BMI (kg/m^2)	21.38 ± 3.10
VO_2max (L/min)	3.23 ± 0.33
VO_2max (mL/kg/min)	48.20 ± 6.84

BMI, body mass index; VO_2max, maximum oxygen uptake.