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Effect of Neck Cooling on Thermal Sensation and Exercise Capacity in University Students under Heat Stress Environment

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Abstract

Training and competition in hot environments impose significant physiological and psychological burdens on athletes, thereby adversely affecting sports performance and increasing the risk of heat-related illnesses (e.g., heatstroke, exertional heatstroke, and sudden death). To mitigate physiological and psychological stress for university students during summer physical activities, ensure optimal performance, and prevent heat-related pathologies, effective physical cooling measures must be implemented during exercise. Given the diversity of cooling methods and their varying efficacy, neck cooling emerges as a practical and flexible intervention from a pragmatic standpoint. This approach reduces the psychological strain induced by high temperature conditions, extends time to exhaustion, and enhances athletic performance. Consequently, accessible neck cooling strategies can significantly benefit university students engaging in physical activities under routine high-temperature conditions. The present study aims to investigate the impact of neck cooling on thermal perception and exercise capacity in university students exposed to elevated ambient temperatures.

Subject Areas

Sports Science

Keywords

Thermal Stress Environment, Neck Cooling, Thermal Perception

1. Introduction

It is well-established that exercise under high-temperature conditions induces significant physiological, immunological, and psychological alterations, leading to adverse reactions such as thermoregulatory imbalance, impaired perceptual capacity, and increased physical fatigue. Excessive heat production and elevated core temperature negatively impact exercise performance. Concurrently, uncompensable heat stress causes varying degrees of physiological strain, compromising health status and increasing the risk of heat-related illnesses (e.g., heatstroke, heat cramps, heat exhaustion). Numerous studies have sought reliable cooling strategies to maintain exercise performance in the heat. Evidence confirms that external physical cooling (e.g., cooling vests, cold air exposure, cold water immersion), internal cooling (e.g., ingesting ice slurry, inhaling cold air), or combined internal-external approaches can effectively mitigate thermal strain during exercise. These techniques are applied as pre-cooling (prior to exercise) or per-cooling (during exercise). From a practical standpoint, employing pre-cooling as a per-cooling strategy to enhance performance is often impractical. Therefore, this study focuses on investigating the effects of head, neck, and facial cooling on exercise performance in the heat [1]. Beyond whole-body or exercising limb-specific cooling, targeting anatomically sensitive regions such as the face, hands, and neck—which possess high thermal sensitivity—may alleviate heat stress and improve physical function with greater feasibility [2]. Neck cooling is a well-researched, convenient, and effective method. Compared to cooling equivalent body surface areas on the torso, neck cooling more effectively alleviates thermal strain, allowing individuals to tolerate higher core temperatures and heart rates before volitional termination [3], improving local perceptual responses, and enhancing endurance performance in the heat. Practically, the neck region offers superior accessibility (e.g., less obstructed by sports equipment) [2] and unique anatomical/physiological advantages: it overlies the carotid arteries supplying the brain and receives afferent signals from numerous deep and peripheral thermoreceptors [4]. This positioning enables indirect brain cooling via carotid blood temperature modulation [5]. For exercise in the heat, neck cooling is preferable to head, facial, or combined head/facial/neck cooling [6]. Consequently, this thesis investigates the impact of neck cooling on thermal perception and exercise performance in university students.

2. Materials and Methods

2.1. Participant

First, confirm that you have the correct template for your paper size. This template has been tailored for output on the custom paper size (21 cm × 28.5 cm). We recruited twelve healthy male participants (aged 18 - 22 years) who met the following criteria: absence of physical diseases, no history of acute sports injuries, no smoking or alcohol consumption habits, and ability to exercise at 50% - 80% of VO_{2max} intensity for at least 30 minutes. All participants completed a General Health Questionnaire (GHQ) and provided written Informed Consent Forms (ICFs). Participant characteristics (mean ± standard deviation) were Age: 20 ±

2 years; Height: 176 ± 5.4 cm; Weight: 69.5 ± 8.5 kg; VO_{2max}: 53.9 ± 4.4 ml/kg/min.

2.2. Methods

2.2.1. Literature Material Method

Search PubMed, Web of Science, and China National Knowledge Infrastructure (CNKI) using the following keywords: "neck cooling", "hot conditions" OR "in the heat", "thermoregulation". Exclude studies on animal models and apply the following inclusion criteria: Participant described as healthy with no diseases impairing exercise performance or thermoregulation; Studies reporting the impact of cooling on core temperature; High-temperature environmental conditions > 30˚C; Exercise duration ≥ 45 minutes in heat. A literature review methodology will be employed to analyze current research advancements and limitations, forming the basis for further investigation.

2.2.2. Experimental Method

All participants underwent maximal oxygen uptake (VO_{2max}) assessment using the COSMED K5 portable metabolic analyzer. Testing was performed on a professional-grade motorized treadmill according to the Bruce protocol, which is regarded as the standard method for VO_{2max} determination due to its established role in evaluating cardiorespiratory fitness. A minimum of three testing personnel were present during each test to ensure participant safety. Exercise intensities for the subsequent experiment were prescribed based on the individually measured VO_{2max} values. This study employed a randomized, cross-over design with two conditions: a Neck Cooling Group (NCG) and a No Cooling Control Group (CG). Twelve participants completed both conditions in a counterbalanced order. Experiments were conducted in an environmental chamber maintained at 35˚C and 30% relative humidity. On the experimental day, participants first provided a urine sample to assess Urine Specific Gravity (USG). A USG value < 1.020 was required to ensure euhydration. Body Weight (BW) was then measured. Participants exhibiting USG > 1.020, indicating hypohydration, were provided with water 60 minutes prior to exercise. If USG remained > 1.020 after this period, the session was rescheduled. The initial weight of the water bottle provided was recorded. Pre-exercise resting Heart Rate (HR) was recorded via a chest-worn Polar HR monitor. Tympanic temperature (ear canal) and posterior neck skin temperature were measured using an infrared thermometer and tympanic thermometer, respectively. The exercise protocol comprised two phases (Figure 1): Phase 1: Participants ran on a treadmill for 30 minutes at an intensity progressively increasing from 55% to 80% of their individual VO_{2max} (5% increase every 5 minutes). HR, tympanic temperature, posterior neck skin temperature, Thermal Sensation (TS), Thermal Comfort (TC), Thermal Acceptability (TA), and Rating of Perceived Exertion (RPE; Borg 6 - 20 scale) were recorded every 5 minutes. Water intake was permitted upon request. A 5-minute rest period followed. Phase 2: Participants immediately commenced running at 70% VO_{2max} until volitional exhaustion. Participants in the NCG wore a commercially available neck cooling device (Black Ice LLC; dimensions: 375 mm L × 60 mm W × 15 mm T; mass: 155 g) covering the posterior and lateral neck throughout this phase. The CG performed the task without cooling. HR, tympanic temperature, posterior neck skin temperature, TS, TC, TA, and RPE were recorded every 5 minutes. Water intake was permitted upon request. Time to Exhaustion (TTE) served as the primary performance measure. Throughout the test, participants wore the Polar HR monitor. Subjective thermal perception and psychological fatigue were assessed using validated Likert scales: Thermal Sensation (TS): Scale: +3 (Very Hot), +2 (Hot), +1 (Warm), 0 (Neutral), −1 (Slightly Cool), −2 (Cool), −3 (Cold); Thermal Comfort (TC): Scale: +3 (Very Comfortable), +2 (Comfortable), +1 (Slightly Comfortable), −1 (Slightly Uncomfortable), −2 (Uncomfortable), −3 (Very Uncomfortable); Thermal Acceptability (TA): Scale: +3 (Very Acceptable), +2 (Acceptable), +1 (Slightly Acceptable), −1 (Slightly Unacceptable), −2 (Unacceptable), −3 (Very Unacceptable). The test was terminated immediately if participants reached their age-predicted maximum HR, exhibited excessive core temperature elevation, reported severe fatigue (RPE), or experienced gastrointestinal distress. Post-exercise, the HR monitor was removed. Participants voided their bladder and were re-weighed wearing the same clothing as pre-test. Performance metrics for both groups included TTE and change in body weight (pre- vs. post-exercise).

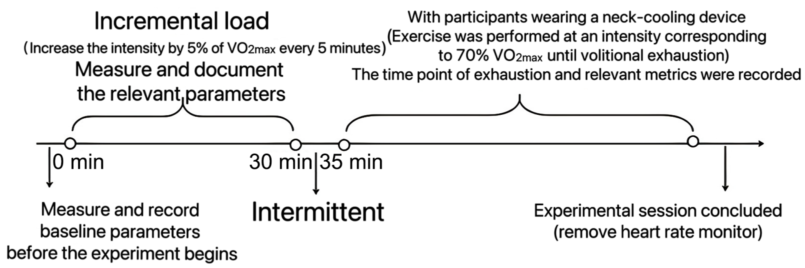

Figure 1. Flow diagram of neck cooling.

The experimental measurement parameters are as follows:

- Tympanic Temperature: Core body temperature is one of the four vital signs. Maintaining a constant core temperature is essential for human health. Tympanic temperature measurement assesses the temperature of the carotid artery blood flow near the tympanic membrane, which exhibits a strong correlation with core body temperature. Therefore, in this study, tympanic temperature measurement will be employed to assess the body temperature of the athletes. Temperature readings will be taken and recorded at five-minute intervals.
- Skin temperature was measured using an infrared thermometer on the neck.
- Body Weight Measurement: Changes in body weight before and after exercise reflect fluid loss during the activity. Body weight is measured using a scale accurate to 0.1 kg (equivalent to 100 grams). The difference between pre- and post-exercise body weight can be used to assess an athlete's hydration status or dehydration level, calculated as follows: Hydration Status (%) = [(Pre-exercise weight − post-exercise weight)/Pre-exercise weight] × 100. Body weight change

measurement is considered one of the simplest and most physiologically sound assessment methods. This approach offers relatively high feasibility, as it imposes minimal requirements on both personnel and equipment.

- Heart Rate Monitoring: Subjects wore chest-worn heart rate monitors (Polar Team System) during exercise for real-time monitoring. The average Heart Rate (HR) and maximum HR throughout the exercise session were recorded. Exercise intensity was expressed as the ratio of average HR to maximum HR. Instantaneous HR was recorded at five-minute intervals to reflect the subject's real-time exercise status.
- Thermal Perception and Subjective Fatigue: Analysis of subjective thermal perception will utilize Likert scales for Thermal Sensation, Thermal Comfort, and Thermal Acceptability. The Thermal Sensation scale ranges from +3 (Hot) to −3 (Cold), with the following descriptors: +3 = Hot, +2 = Warm, +1 = Slightly Warm, 0 = Neutral, −1 = Slightly Cool, −2 = Cool, −3 = Cold. The Thermal Comfort scale ranges from +3 (Very Comfortable) to −3 (Very Uncomfortable), with the following descriptors: +3 = Very Comfortable, +2 = Comfortable, +1 = Slightly Comfortable, −1 = Slightly Uncomfortable, −2 = Uncomfortable, −3 = Very Uncomfortable. The Thermal Acceptability scale ranges from +3 (Very Acceptable) to −3 (Very Unacceptable), with the following descriptors: +3 = Very Acceptable, +2 = Acceptable, +1 = Acceptable (Slightly), −1 = Unacceptable (Slightly), −2 = Unacceptable, −3 = Very Unacceptable. Subjective fatigue level (RPE) will be assessed using the Borg Rating of Perceived Exertion Scale (Borg RPE Scale 6 - 20). Experimenters will verbally ask participants about their perceived exertion, record their responses on the scale, and thereby gauge their fatigue level and tolerance to the ambient temperature and exercise intensity.

2.2.3. Mathematical Statistics Methodology

After concluding the experiment and completing data collection, all raw data were entered into Excel software for storage. Following data entry, the Excel data were imported into JMP Pro 16 (SAS Institute Inc., Cary, NC, USA) for statistical analysis. The statistical analysis primarily included the following components:

- Normality analysis of the data.
- Descriptive statistical analysis of Heart Rate (HR), tympanic temperature, skin temperature, and thermal perception indicators, presented as mean ± standard deviation.
- Paired samples t-test to compare physiological indicators (heart rate, skin temperature, tympanic temperature) and thermal perception between cooling and non-cooling test conditions, investigating the impact of neck cooling on thermal perception and exercise capacity.

3. Results

3.1. Participant Characteristics

This study recruited 12 subjects, all with Body Mass Index (BMI) and body fat percentage within normal ranges (BMI: 22.4 ± 2.6 kg/m^2; body fat percentage: 12.1% ± 3.5%). Their age was 20 ± 2 years, height 176 ± 5.4 cm, weight 69.5 ± 8.5 kg, and maximal oxygen uptake (VO_{2max}) 53.9 ± 4.4 ml/kg/min.

3.2. Alterations in Body Fluid Balance with Neck Cooling during Heat Exposure

Characteristics of Body Weight Changes during Exercise in High-Temperature Environments

Under high-temperature conditions without cooling measures, there was no significant difference between pre-exercise USG (1.013 ± 0.001) and post-exercise USG (1.014 ± 0.001) ($P > 0.05$). Similarly, with neck cooling intervention, no significant difference was observed between pre-exercise USG (1.014 ± 0.001) and post-exercise USG (1.016 ± 0.001) ($P > 0.05$). Additionally, the differences in USG before and after exercise were not significant between cooling and non-cooling conditions. This indicates that neck cooling in high-temperature environments minimally affects body fluid balance and does not significantly enhance exercise capacity. Compared to weight changes after exercise without cooling, neck cooling showed no notable increase or decrease in body weight changes before and after exercise (Figure 2). This further confirms that neck cooling does not interfere with body fluid regulation and has a minimal impact on physiological changes during exercise.

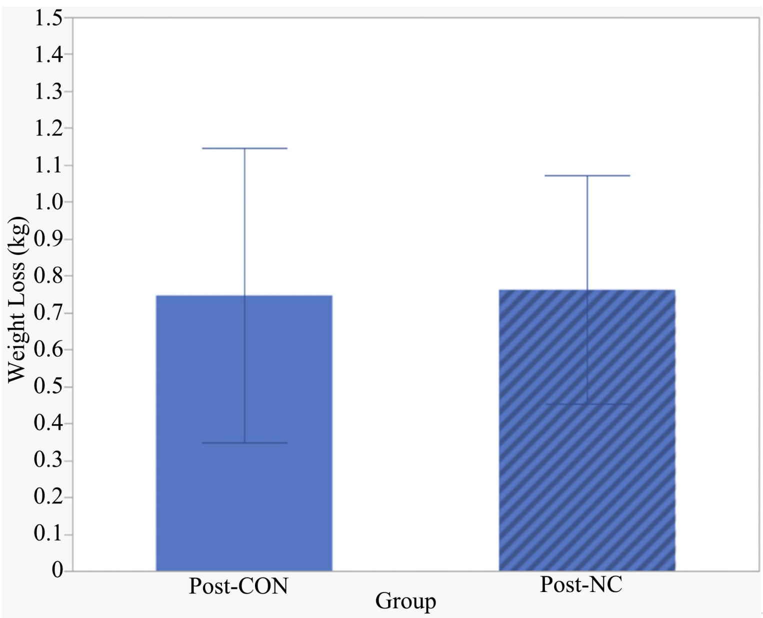

Figure 2. Weight change.

3.3. Physiological Changes during Cervical Cooling in High-Temperature Environments

3.3.1. Characteristics of Tympanic and Nuchal Temperatures during Exercise in a Hot Environment

As illustrated in Figure 3, post-exercise neck cooling in high-temperature environments resulted in a significantly lower cochlear temperature compared to no cooling measures (P < 0.05). Although exercise in high-temperature environments progressively increased cochlear temperature in college students, the post-exercise cochlear temperature with neck cooling (37.1˚C ± 0.1˚C) was markedly reduced relative to the no cooling condition (37.3˚C ± 0.1˚C).

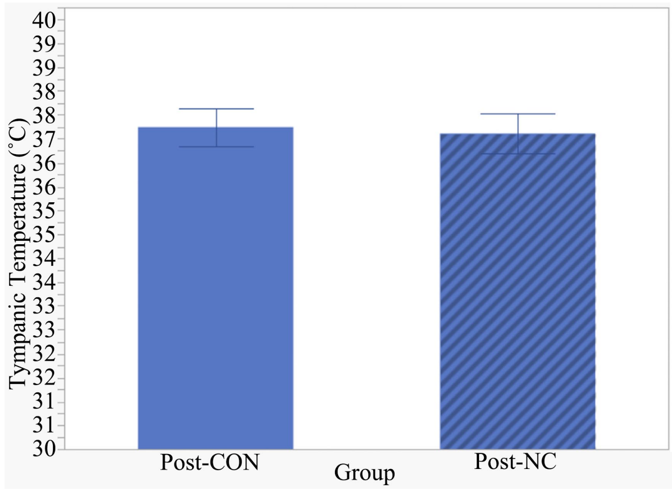

Figure 3. Tympanic temperature.

Figure 4 demonstrates that posterior neck temperature exhibited a very significant decrease after neck cooling during high-temperature exercise (P < 0.01). The posterior neck temperature declined from 33.2˚C ± 0.2˚C (without cooling) to 30.9˚C ± 0.1˚C (with cooling). Compared to the control group's posterior neck temperature changes, this indicates that neck cooling directly reduces posterior neck temperature and indirectly influences the thermoregulatory center, subsequently lowering brain temperature. By maintaining appropriate body temperature during exercise, this strategy enhances athletic performance.

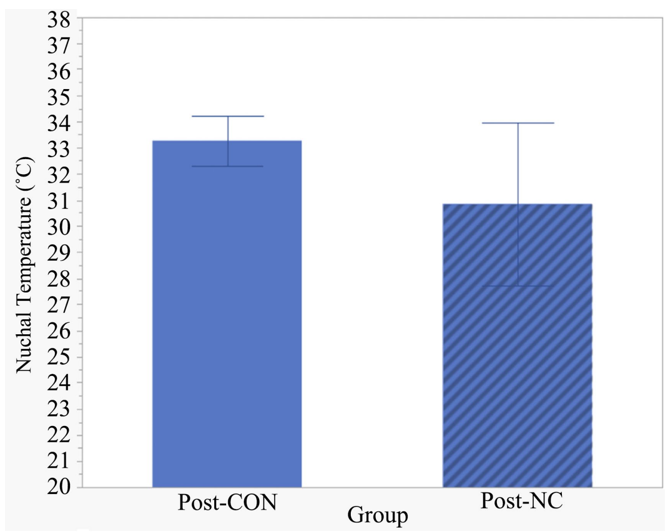

Figure 4. Nuchal temperature.

3.3.2. Heart Rate Characteristics during Exercise in a Hot Environment

As illustrated in Figure 5, compared to continuing exercise in a high-temperature environment without any cooling measures after initial heat exposure, neck cooling intervention resulted in minimal alteration in heart rate dynamics. During the cooling-assisted exercise phase, the heart rate (149.1 ± 3.3 beats/min) showed no significant difference (P = 0.39) compared to the non-cooling exercise phase (145.9 ± 3.5 beats/min). This indicates that while heart rate progressively increased during sustained exercise in heat, the implementation of neck cooling had a limited effect on moderating the magnitude of this increase. Consequently, it conferred minimal cardiovascular benefits during exercise and did not substantially enhance athletic performance.

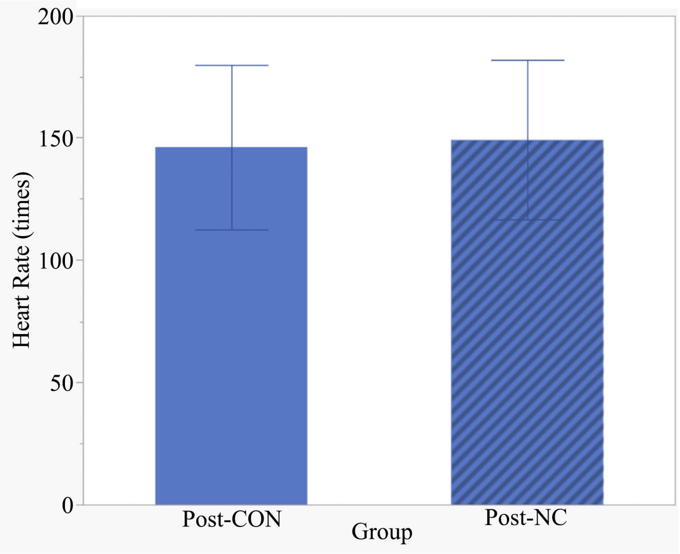

Figure 5. Exercise heart rate characteristics.

3.4. Changes in the Subjective Perception of Localized Neck Cooling under Hot Conditions

3.4.1. Neck Cooling and Thermal Perception

As shown in Figure 6, neck cooling during exercise in high-temperature environments significantly improved thermal acceptance compared to no cooling. The thermal acceptance without cooling (−0.8 ± 0.2) showed a statistically significant difference from that with cooling (−0.5 ± 0.2).

Figure 7 and Figure 8 indicate that thermal sensitivity increased progressively under no cooling conditions, with a substantially larger magnitude of increase compared to cooling conditions. Post-cooling thermal sensitivity (1.1 ± 0.1) differed significantly from no cooling conditions (1.7 ± 0.1). Thermal adaptability also improved markedly after cooling, with post-cooling thermal adaptability (−0.5 ± 0.2) demonstrating significant enhancement over no cooling conditions. This reflects an increased tolerance to heat stress in high-temperature environments, indicating a subjectively more comfortable state during exercise with cooling interventions.

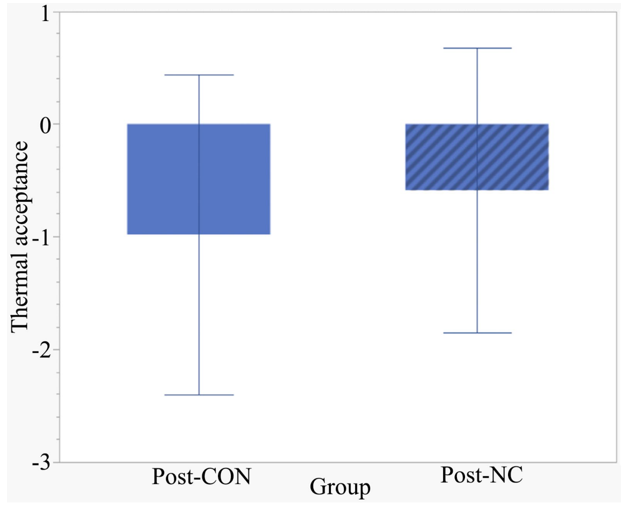

Figure 6. Thermal acceptance.

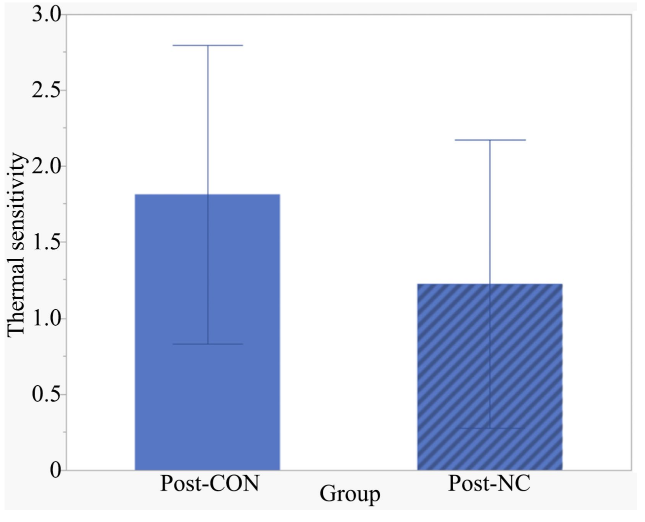

Figure 7. Thermal sensitivity.

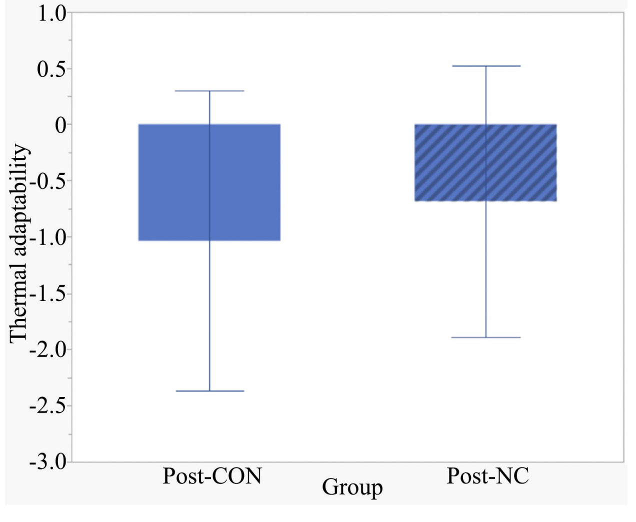

Figure 8. Thermal adaptability.

3.4.2. Characteristics of Perceived Exertion (RPE) during Exercise in High-Temperature Environments

As shown in Figure 9, under high-temperature conditions, the Rating of Perceived Exertion (RPE) gradually increased with the continuation of exercise. After implementing neck cooling measures, the RPE (13.1 ± 0.5) showed no significant difference compared to the RPE without cooling measures (12.9 ± 0.5) (P > 0.05), indicating that neck cooling has a limited effect on the subjective perception of fatigue during exercise in high-temperature environments.

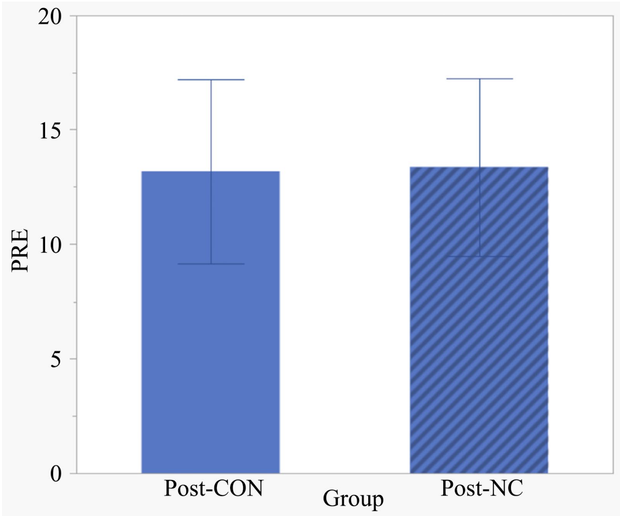

Figure 9. Rating of Perceived Exertion (RPE).

3.5. Effects of Neck Cooling on Exercise Performance in Hot Environments

Time to Exhaustion during Exercise in a Hot Environment

As shown in Table 1, under normal conditions, the time to exhaustion during exercise in a high-temperature environment (13.9 ± 2.5 min) demonstrated a statistically significant difference (P < 0.01) compared to the time after implementing neck cooling (19.9 ± 2.5 min). The application of neck cooling significantly prolonged exercise duration in high-temperature conditions, with the time to exhaustion extended beyond the baseline of no cooling measures. This indicates that neck cooling during high-temperature exercise enhances both exercise performance and exercise capacity.

Table 1. Effects of neck cooling vs. no cooling on perceived exertion and performance during exercise in high heat.

Evaluation Metrics	Group		
	Post-CON	Post-NC	P
Exercise Heart Rate	145.9 ± 3.5	149.1 ± 3.3	P = 0.395
Tympanic Temperature	37.3 ± 0.1	37.1 ± 0.1	P = 0.001
Nuchal Temperature	33.2 ± 0.2	30.9 ± 0.1	P < 0.001

Continued

RPE	12.9 ± 0.5	13.1 ± 0.5	P = 0.662
Thermal Acceptance	−0.8 ± 0.2	−0.5 ± 0.2	P = 0.002
Thermal Sensitivity	1.7 ± 0.1	1.1 ± 0.1	P < 0.001
Thermal Adaptability	−0.9 ± 0.2	−0.5 ± 0.2	P = 0.004
Time to Exhaustion	13.9 ± 2.5	19.9 ± 2.5	P < 0.001
Weight Change	0.7 ± 0.1	0.7 ± 0.1	P = 0.821
Pre-USG	1.013 ± 0.001	1.014 ± 0.001	P = 0.527
Post-USG	1.014 ± 0.001	1.016 ± 0.001	P = 0.422

4. Discussion

4.1. Physiological Effects of Neck Cooling

Through relevant data analysis, the high-temperature cooling group demonstrated significantly decreased tympanic temperature (ear canal temperature) and cervical temperature compared to the high-temperature control group. However, no significant differences were observed in Heart Rate (HR) or fluid balance indicators. Therefore, this study confirms that during exercise in a high-temperature environment, cervical cooling primarily affects thermoregulation in terms of human physiological responses. This aligns with findings by Sunderland *et al.*, whose research showed that cooling the neck region reduces mean cervical skin temperature without impacting HR, core body temperature, mean skin temperature, volitional water intake, sweat loss, or concentrations of lactate, glucose, cortisol, and prolactin [7] [8].

This study found that during exercise, neck cooling effectively reduces tympanic temperature and neck temperature while body temperature rises. Due to the rich vascularization and rapid blood circulation in the neck, cooling interventions can rapidly lower the temperature of blood flowing through this region, thereby significantly reducing neck temperature and potentially affecting whole-body temperature. Research indicates that the neck region may serve as an effective cooling site (e.g., in most exercises, the neck is more accessible than the torso) and an anatomical and perceptual zone (e.g., the neck is proximate to the thermoregulatory center and areas of high thermosensitivity). Huang *et al.* [9] similarly demonstrated that head, neck, and facial cooling reduce local skin temperature in the cooled areas, thereby improving perceptual sensations; the enhanced efficacy of neck cooling may stem from the high thermosensitivity in the neck region and its proximity to the thermoregulatory center. During exercise in hot environments, elevated brain temperature triggers thermosensitive areas in the hypothalamus to release inhibitory signals, impairing exercise performance and altering neural function [10]. Since direct measurement of human brain temperature during exercise is infeasible, alternative data are often referenced. This study observed that the marked decline in tympanic temperature may result from reduced brain temperature, as neck cooling stimulates nerves and blood vessels in the neck, indirectly modulating the thermoregulatory center and cardiovascular functions to enhance exercise performance. However, research by Sunderland *et al.* [8] suggests that surface cooling of the brain may be theoretically possible; yet clinical data failed to confirm a decrease in brain temperature after external cooling of the head and neck regions. Similarly, Tyler *et al.*'s study indicates that neck cooling is unlikely to reduce human brain temperature during exercise and has no effect on core temperature [11]. Theoretically, external cooling could lower brain temperature, but no practical measurements have accurately demonstrated this effect.

As analyzed by Duffield [5], although cooling the head and neck during exercise significantly improves performance, no changes were observed in core temperature or heart rate, which aligns with the findings of this study. Specifically, neck cooling during exercise in a hot environment had a minimal impact on heart rate changes. The observed changes in tympanic temperature (or ear canal temperature), neck temperature, and heart rate during exercise in this study were comparable to those reported in other neck cooling studies. Therefore, although the cooling effect observed in this study was modest, it suggests that neck cooling during exercise exerts a significant influence on local thermoregulation. This may indirectly confer benefits for exercise of longer duration; however, additional data is warranted to substantiate this point.

4.2. Effects of Neck Cooling on Subjective Perception

Through relevant data analysis, this study found that compared to the high temperature control group, the high temperature cooling group exhibited significant changes in thermal acceptability, thermal sensitivity, and heat adaptation. First, neck cooling effectively improved subjects' thermal comfort. Second, it reduced exercisers' fatigue sensation. Simultaneously, neck cooling enhanced subjects' ability to adapt to exercise conditions in high-temperature environments. During exercise in hot environments, elevated body temperature triggers discomfort (e.g., dizziness, fatigue, nausea). The reduction in self-selected work rate under thermal stress may be mediated by thermal perception (including thermal comfort and acceptability) and its influence on RPE (Rating of Perceived Exertion). Cheung's research demonstrated that increased skin temperature directly affects thermal perception by stimulating peripheral thermal sensors [12], aligning with this study's results. Temperature-induced changes in thermal perception impact perceived exertion, as heat-related adverse effects and discomfort impair physiological functions. Neck cooling rapidly reduces local blood temperature, alleviating discomfort from rising body temperature and creating a cooler sensation [13]. It also positively influences subjective perception during exercise in heat, indirectly improving exercise performance. Cheung's research further indicates that local skin cooling (via fan) enhances thermal comfort and reduces warmth perception, thereby attenuating reductions in work rate [12]. Additionally, neck cooling improves exercisers' psychological state. In hot environments, elevated body temperature and fatigue can induce negative emotions (e.g., irritability, anxiety), impairing performance [7]. By mitigating these physical stressors, neck cooling promotes a calmer, more positive mindset [14].

Thus, psychological state is a critical factor influencing exercise performance in heat. Neck cooling enhances subjective thermal tolerance, amplifies perceptions of comfort, regulates psychological responses, and ultimately optimizes performance, significantly outperforming no-intervention conditions in high temperature settings.

4.3. Effects of Neck Cooling on Human Athletic Performance

This study analyzed the impact of neck cooling on exercise capacity by recording the time to exhaustion during continuous exercise under high-temperature conditions following cervical cooling treatment. The results demonstrate that the neck cooling group exhibited a significantly prolonged time to exhaustion compared to the control group in a hot environment. This finding aligns with the research by Flouris *et al*. [15], indicating that cold stimulation can induce immediate changes in local Thermal Sensation (TS), thereby reducing the perceived exertion rate [16]. Consequently, this leads to an increase in self-selected pace or time to volitional fatigue. This suggests that neck cooling effectively enhances exercise capacity and prolongs endurance in university students exercising under high-temperature conditions.

Analysis within this study revealed no significant changes in urine specific gravity before and after exercise, regardless of cooling intervention. This indicates that the cooling measure had minimal impact on body weight changes during exercise in the heat. Nevertheless, the results demonstrate that local cooling interventions can improve endurance performance during high-temperature exercise [17]. Firstly, neck cooling aids in reducing tympanic temperature and cervical skin temperature, thereby alleviating the body's thermal load and accelerating heat dissipation. This process delays the onset of exhaustion. Furthermore, neck cooling may exert a positive influence on psychological state. It plays a beneficial role in terms of thermal acceptance, thermal sensitivity, and perceived thermal adaptation, thereby indirectly extending the time to volitional fatigue.

Exercise duration and efficiency are typically reduced in high-temperature environments. Even minor levels of hyperthermia frequently correlate with a decline in voluntary work rate. This voluntary reduction in work rate is partly consciously mediated, representing an action taken to lower the metabolic heat production rate and consequently delay the rise in core temperature [18]. Evidence suggests that the voluntary generation of force and the perception of muscle fatigue may be perceptually limited rather than solely due to physiological constraints [15]. Psychological state likely plays a crucial role in maintaining a given work rate at the point of exercise fatigue. This aligns with the findings of the present study. Data analysis indicated that improvements in psychological aspects—such as a mild sensation of coolness, adaptation to thermal sensation, enhanced adaptability within the heat, and reduced perception of fatigue [19] [20]—contributed more significantly to improved exercise capacity and prolonged time to exhaustion than changes in heart rate or body weight.

4.4. Innovations and Limitations

In this study, building upon previous attempts to identify reliable cooling strategies for enhancing exercise performance in high-temperature environments, we adopted a more accessible, practical, and effective neck cooling method [21]. Furthermore, targeting university students engaged in physical activities such as physical education classes, military training, and sports practice during summer heat, we established a simulated high-temperature environment that closely mimics real-world conditions to achieve superior experimental outcomes. Additionally, to ensure experimental accuracy, we conducted detailed analyses of multiple subjects under fixed-intensity exercise, recording and comparing parameters including exercise duration and Rating of Perceived Exertion (RPE) under conditions with and without neck cooling.

This experiment lacked cardiovascular and neurological data acquisition and analysis following neck cooling. However, substantial related research indicates that neck cooling may enhance exercise performance by influencing the brain and the entire body through numerous blood vessels and nerves in the neck [22]. Additionally, various methods of external physical cooling exist. This study did not account for the effects of cooling other body regions (head, face, and combined head-neck cooling) in high-temperature environments.

5. Conclusion

Compared with no cooling conditions, implementing neck cooling measures in high-temperature environments is more beneficial for university students exercising in the heat. It effectively enhances exercise performance and prolongs time to exhaustion (TTE), thereby delaying the onset of fatigue. Therefore, convenient neck cooling methods should be widely implemented in university sports training and physical education. In high-temperature environments, as fatigue perception progressively increases, subjective perception plays a primary role in improving exercise performance. The cooling sensation and comfort provided by neck cooling improve psychological state, thereby enhancing mental performance during exercise and promoting exercise capacity.

Conflicts of Interest

The author declares no conflicts of interest.

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