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Original Article

Effect of wrist cooling on aerobic and anaerobic performance in elite sportsmen

Lt Col Anup Krishnan [a,*], *Lt Col Krishan Singh* [b], *Col Deep Sharma* [c], *Lt Col Vivekanand Upadhyay* [d], *Maj Amit Singh* [e]

[a] *Medical Officer (Sports Medicine), Army Sports Institute, Pune 411040, India*
[b] *Graded Specialist (Physiology), Command Hospital (Southern Command), Pune 411040, India*
[c] *Head of Dept, Sports Medicine, Armed Forces Medical College, Pune 411040, India*
[d] *Medical Officer (Sports Medicine), Armed Forces Medical College, Pune 411040, India*
[e] *Resident, Dept of Sports Medicine, Armed Forces Medical College, Pune 411040, India*

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ABSTRACT

Background: Body cooling has been used to increase sporting performance and enhance recovery. Several studies have reported improvement in exercise capacities using forearm and hand cooling or only hand cooling. Wrist cooling has emerged as a portable light weight solution for precooling prior to sporting activity. The Astrand test for aerobic performance and the Wingate test for anaerobic performance are reliable and accurate tests for performance assessment. This study conducted on elite Indian athletes analyses the effects of wrist precooling on aerobic and anaerobic performance as tested by the Astrand test and the Wingate test before and after wrist precooling.

Methods: 67 elite sportsmen were administered Wingate and Astrand test under standardised conditions with and without wrist precooling using a wrist cooling device (dhamaSPORT). Paired *t*-test was applied to study effect on aerobic [VO_2 (ml/min/kg)] and anaerobic performance [peak power (W/kg) and average power (W/kg)] and Cohen's *d* was used to calculate effect size of wrist precooling.

Results: After wrist precooling, significant increase of 0.22 ($p = 0.014$, 95% CI: 0.047, 0.398) in peak power (W/kg) and 0.22 ($p < 0.0001$, 95% CI: 0.142, 0.291) was observed in average power (W/kg). Although, an increase of 1.38 ($p = 0.097$, 95% CI: −0.225, 3.012) was observed in VO_2 (ml/min/kg), wrist precooling was not significantly effective in aerobic performance. Wrist cooling effect size was smaller in VO_2 (Cohen's $d = 0.21$), peak power (Cohen's $d = 0.31$) and it was larger in average power (Cohen's $d = 0.71$).

Conclusion: Results show wrist precooling significantly improves anaerobic than aerobic performance of elite sportsmen.

* *Corresponding author:*.
E-mail address: faujidoc@rediffmail.com (A. Krishnan).
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Introduction

Human beings are homoeothermic with core temperatures between 36.1 and 37.8 °C.[1] 21–28 °C represents the comfort zone for a large majority of individuals[2] where the core temperature is easily maintained. The body maintains core temperature by initiating various heat loss or heat gain responses (thermoregulation).

Humans can tolerate a decline in core body temperature of 10 °C but a body temperature increase of only 5 °C.[1] At Core temperature above 40.5 °C metabolic enzyme functions start to deteriorate.[4] Heat stress illnesses such as heat cramp, heat syncope, heat exhaustion, heat stroke and dehydration are a major cause of morbidity and mortality during activity in heat[1,3] especially in sportsmen and active duty military personnel.

During sporting activity in heat, there occurs a definite decline in performance with increase in core temperature beyond a critical level (40–40.5 °C).[1,4–6] Cardiovascular strain (increased heart rate and decreased stroke volume) caused by redistribution of blood to the skin rather than to the exercising muscles, early utilization of glycogen stores and dehydration are the main reasons postulated for decline in performance.[1,5,6] "Central governor model for the limits of performance" which states that in response to various inputs (one of those being high core temperature), the brain regulates the number of motor units that can be recruited in the exercising limbs on a moment to moment basis, reducing the number that can be recruited when their continued recruitment, necessary to maintain the exercise intensity, threatens whole body homeostasis. The reduced recruitment of motor units thus decreases the intensity of exercise causing decline in performance.[8]

Various cooling modalities have been employed before, during and after the exercise to enhance performance and recovery.[1,3–7,9–11] Cold water immersion, ice slurry ingestion, cooling garments, cold towels, cold air blow, cold water shower, ice pack, rapid thermal exchanger device (RTX) are used either singly or in combination. The basis for precooling and during exercise cooling, is the creation of a larger thermal sink i.e. the sportsman starts exercise with a lower core temperature enabling him to exercise for a longer duration and at higher intensity before reaching the critical temperature.[5,9,10]

Over the last decade, there have been various studies employing forearm and hand or only hand cooling as a modality for precooling, cooling during exercise and after exercise.[12–18] The basis for using forearm and the hand is the presence of a large number of superficial vessels and dense arteriovenous anastomosis in this region.[2,15] Even during resting conditions under extreme thermal stress there occurs increase in blood flow to the skin from 5% of cardiac output under thermoneutral condition to approximately 15–25% of cardiac output and simultaneously there occurs six fold increases in blood flow in respect of forearm.[1,9] Therefore forearm and hand form an important source of heat loss.

Many of these studies have shown improvement in exercise capacity (endurance, strength and recovery time).[6,9,12–18] Some studies have employed direct immersion of hand and forearm[12] or only hand in cold water[13,14] others have used the rapid thermal exchange device (RTX)[6,9,15–18] which consists of a hand rest surface cooled by running water at approximately 16 °C and a vacuum source with pressure sensor to create slight sub atmospheric pressure (40 mm Hg).[9] However this device is cumbersome, costly and lacks portability.

There has been a felt need for a portable light weight technology for wrist cooling once the positive effects of cooling of the wrist with ice cubes packed in a wrist band during exercise in heat were noted. Over the last few years this technology has been under intensive research and clinical trials.[19]

There is a lack of large scale clinical trials regarding efficacy of wrist precooling and during exercise cooling on aerobic and anaerobic performance parameters in sportsmen. Hence we conducted a study to evaluate the effectiveness of a wrist cooling device on aerobic and anaerobic performance in elite sportsmen. Anaerobic performance was tested by the Wingate test[20] and aerobic performance was tested by the Astrand test[21] and, both of which are widely used for the purpose.

Materials and methods

Based on the knowledge about pre cooling effect and lack of information in Indian settings, effect size was considered as 0.35 for calculation of sample size. Level of significance at 0.05 (two-tailed), an effect size of 0.35 with 80% power, using *t*-test for same groups gave a sample size of 67 athletes to be enrolled in the study. Therefore 67 elite athletes were randomly selected for the study after Institute ethics committee approval. The inclusion criteria of the study were male athletes, 6 months of regular training and services/national level participation. The exclusion criteria were a history of hospitalization for more than 2 weeks in last 3 months due to any reason, any acute illness/injury during the study and break in training in preceding 3 weeks.

The potential risk and benefits were explained to the participants. All the participants were then given opportunity to ask questions about the tests. Written consent was taken from the randomly selected participants who fulfilled the inclusion and exclusion criteria.

dhamaSPORT wrist cooling device

Photo 1

This is a wrist cooling device designed and produced in India. It has a ceramic cooling area with dimensions of

Photo 1 – The dhamaSPORT wrist cooling device.

Photo 2 – Wearing technique.

30 × 30 mm (900 mm^2). A thermoelectric system accompanied with high heat transfer coefficients of the heat sink provides consistent cooling of ~7 °C in all ambient conditions. It is powered by a 3.7 V, 3000 mAh rechargeable lithium polymer battery pack. The wristband weighs around 60 gm and Battery pack weighs around 65 gm. Before running the system, around 20–25 ml water need to be evenly spread on the top wetting area (4540 mm^2) of the product. In every 30–40 minutes, the area has to be refueled again with the same quantity of water.

Photo 2

Testing procedure

All the participants had to visit the laboratory twice with minimum gap of 48 h between the 2 visits for adequate recovery between tests. On the day prior to the performance tests the participants were advised to abstain from high intensity exercise. Aerobic capacity expressed as VO_2max (ml/kg/min) and anaerobic capacity expressed as peak power (W/kg) and average power (W/kg) were measured along with anthropometric measurements for each sportsmen.

On day 1, participants were given overview of the study and Astrand and Wingate cycle ergometer tests were done on the participants in a temperature controlled centrally air-conditioned room with the temperature set at 24 °C.

Day 1: Astrand cycle ergometer test without precooling

The subject pedaled against initial resistance to increase his heart rate (HR) up to 120 beats per minute (bpm) in the initial 3 min after which they continued to pedal for a minimum of 6 min at 60 revolutions per minute (rpm) and against fixed resistance. The average of the last 2 min HR and the fixed load was taken as the sub maximal HR and work rate. The software then predicted the VO_2max by plotting the HR and work rate on the nomogram. In case the subject's HR over the last 2 min varied by more than 5 bpm the test was automatically continued till the variation between the HR in the last 2 min was less than or equal to 5 bpm.

Day 1: Wingate cycle ergometer test without precooling

Warm up was given for 5 min in an intermittent manner (alternating 30 s exercise with 30 s rest). The warm up was done on a cycle ergometer to promote more specific physiological and motor adaptation.

On the command "Start" the subject pedaled as fast as possible without any resistance. It takes 3–4 s to reach maximum speed. Once the maximum speed was achieved, a predetermined load 7.5% of body weight in kg was applied and the participant was encouraged to pedal as fast as possible for next 30 s. Any attempt to conserve energy during the last few seconds was discouraged.

Day 2: The Astrand and Wingate test were repeated after 30 min of precooling with dhamaSPORT. The cooling was continued through both the tests.

Statistical analysis

Statistical analysis was done in SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL). Summary statistics including mean and standard deviation (SD) were calculated for age (years), aerobic capacity i.e. VO_2 (ml/min/kg), and an anaerobic capacity i.e. peak power (W/kg) and average power (W/kg). Kolmogorov–Smirnov test was applied to test the normality of these variables. Paired samples *t*-test was used to study effect of wrist cooling on VO2 (ml/min/kg), peak power (W/kg) and average power (W/kg) for all athletes. Statistical significance was set at $p \leq 0.05$. Mean difference along with 95% confidence interval (95% CI) before and after wrist cooling was calculated for aerobic and anaerobic capacities of all athletes. Cohen's *d* was calculated to measure the effect size for the comparison between two means before and after wrist cooling as ratio of mean difference to the standard deviation (Table 1).

Results

Mean age of male athletes was 21.3 years (SD = 3.62 years). Among all athletes, mean VO_{2max} was 49.03 ml/min/kg which increased to 50.68 ml/min/kg after wrist cooling. Difference of 1.38 ml/min/kg was observed in VO_2 after wrist cooling which was not statistically significant ($p = 0.097$, 95% CI: −0.225, 3.012). Mean peak power was 10.13 W/kg which increased to

Table 1 – Summary statistics of VO_2 (ml/min/kg), peak power (W/kg) and average power (W/kg) before and after wrist cooling among athletes.

Aerobic and anaerobic capacity of athletes (*n* = 67)	Wrist cooling Mean (SD)		Difference Mean (95% CI)	Paired *t*-test *p*-Value	Effect size Cohen's *d*
	Before	After	After–before		
VO_2 (ml/min/kg)	49.30 (10.29)	50.68 (10.73)	1.38 (−0.225, 3.012)	0.097	0.21
Peak power (W/kg)	10.13 (1.50)	10.35 (1.36)	0.22 (0.047, 0.398)	0.014	0.31
Average power (W/kg)	7.55 (0.81)	7.77 (0.76)	0.22 (0.142, 0.291)	<0.0001	0.71

Table 2 – Kolmogorov–Smirnov test results.

Hypothesis test summary

	Null hypothesis	Test	Sig.	Decision
1	The distribution of VO_2 (ml/min/kg) (Astrand)_before is normal with mean 49.30 and standard deviation 10.29	One-sample Kolmogorov–Smirnov test	.845	Retain the null hypothesis.
2	The distribution of VO_2 (ml/min/kg) (Astrand)_After is normal with mean 50.68 and standard deviation 10.73	One-sample Kolmogorov–Smirnov test	.990	Retain the null hypothesis.
3	The distribution of peak power (W/kg) (Wingate)_Before is normal with mean 10.13 and standard deviation 1.50.	One-sample Kolmogorov–Smirnov test	.986	Retain the null hypothesis.
4	The distribution of average power (W/kg) (Wingate)_Before is normal with mean 7.55 and standard deviation 0.81.	One-sample Kolmogorov–Smirnov test	.756	Retain the null hypothesis.
5	The distribution of peak power (W/kg) (Wingate)_Post is normal with mean 10.35 and standard deviation 1.36.	One-sample Kolmogorov–Smirnov test	.988	Retain the null hypothesis.
6	The distribution of Average power (W/kg) (Wingate)_Post is normal with mean 7.77 and standard deviation 0.76.	One-sample Kolmogorov–Smirnov test	.982	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.5.

10.35 W/kg after wrist cooling. Mean average power was 7.55 W/kg which increased to 7.77 W/kg after wrist cooling. After wrist cooling, significant increase of 0.22 W/kg ($p = 0.014$, 95% CI: 0.047, 0.398) in peak power and 0.22 W/kg ($p < 0.0001$, 95% CI: 0.142, 0.291) in average power was observed in athletes. Wrist cooling was significantly effective in increase of peak and average power among all athletes. Standardized difference between the mean values of VO_2 before and after wrist cooling or effect size was smaller (Cohen's $d = 0.21$) indicates that wrist cooling is less effective in improving aerobic capacity of athletes, while larger effect size in average power (Cohen's $d = 0.71$) shows that wrist cooling is highly effective in improving anaerobic capacity of athletes (Table 2).

Discussion

In the present study, when we compared the effect of precooling by wrist cooling device in elite sportsmen of mixed disciplines, we found that there was a significant increase in the VO_2 max as well as the power output. We have found that wrist cooling device has increased both VO_2 max as well as power output as compared to previous studies.

Endurance performance is improved by precooling by increasing pace during race, delaying time to exhaustion at a set pace or increasing measured VO_2 max. Our study showed an increase in the measured VO_2 max of the sportsmen.

VO_2 max changes after precooling studies have reported conflicting reports. Febbraio et al.,[18] found lower VO_2 during exercise in the heat, while Hargreaves et al.,[22] found slight increase in VO_2. Febbraio et al.,[23] reports no difference in mean VO_2 in cyclists in heat. This could be explained by the active muscles getting low oxygen supply due to the heat, but did not measure direct leg VO_2 and hence did not report any definite conclusions. Several studies propose no change in oxygen consumption with precooling after exercise duration of 10 min and that there is any relation between oxygen consumption and performance. Some studies propose that precooling enhances performance by reduction in the metabolic changes which occur when body and muscle temperature increases.[24–26]

No similar study has been found in a detailed literature search but some studies have reported improved performance in endurance sports but the measured parameters were different. Precooling improves heat storage reserve before core temperatures rise and allows faster race pace during time trials[27] or increases the time to exhaustion at a set pace.[28] Improvement in run distance from 7250 m to 7550 m (+4%) in 30 min all out run at 32° centigrade and 60% relative humidity[28] after precooling were also reported.

There are several studies which used hand cooling as a precooling method and have shown performance improvements during work or exercise. Hand and/or foot cooling,[16,29] has been tried in various sportsmen ***and military personnel*** recently. Military personnel working in hot environments ***with or without chemical suits*** have reported shortened rest periods and improved work periods after hand/***foot*** cooling.[29,30] Grahn et al.,[16] postulated that that heat removal through the hand is effective in improving performance in heat stress conditions. Hsu et al.,[31] reported lowered temperature, lactate concentration and oxygen uptake in cyclists and improved timings during a 30-km time trial.

Several studies report increased performance in sports, but some studies do not advocate precooling for performance improvement. Bolster et al. do not advocate body cooling before triathlons.[32] They achieved precooling by water immersion at 25.5 °C and made the subjects swim for 15 min or cycle for 45 min at 75% of peak VO_2. They did not report any exercise performance gains and based this on the minimal thermoregulatory and metabolic responses between precooling and control trials. Drust et al. reported no benefits of precooling on physiological responses during intermittent exercises in soccer players (90 min soccer specific intermittent exercise protocol).[33] Another study found that work rate and VO_2 were increased for a given heart rate after precooling.[34]

The negative effects of precooling may be due to extreme vasoconstriction and/or reduction in muscle temperature which may impact performance as optimum muscle performance requires an optimal temperature range.

We have used wrist cooling method of precooling which differed from the other studies and to see the effect of wrist precooling on the anaerobic performance, we evaluated their average and peak power which showed significant increase in these parameters.

Literature search revealed studies favoring as well as contradicting our results. Marsh et al[36] reported a small positive effect ($d = 0.39$) of pre-cooling prior to a 70 s sprint in elevated temperatures. It is postulated that a moderate elevation in body temperature by improving mechanical and metabolic processes, may be beneficial for high-intensity exercise.[37]

Castle et al.,[38] showed a peak power output increase of 4% in conditions of ~34 °C and 52% relative humidity after precooling with ice packs on upper legs, as compared to no precooling.

Performance enhancement in short duration events may be explained by the following mechanism. Precooling reduces systemic and local temperature causing vasoconstriction which increases blood volume centrally. This improves blood flow to the exercising muscles which improves oxygen delivery and metabolic by products removal. Cold exposure also increases circulating catecholamine levels which are beneficial in high intensity exercise. Hence Marsh et al[39] using a 70 second high intensity cycling trial which requires a mix of aerobic and anaerobic energy supply in warm (29 °C) and humid conditions (80% RH), with 30 min precooling, reported improved performance by 3.3% compared with controls.

In contraindication to this fact, fatigue develops without any reduction of skeletal muscle blood flow.[40] It is therefore questionable that performance is enhanced by increase in muscle blood flow caused due to vasoconstriction even in short duration exercise. This is corroborated by Ball et al.[41] who showed more improvement in short duration sprints performed in hot conditions (30 °C) as compared to moderate (18.7 °C) conditions.

However studies contradicting the above findings are also available. Sleivert et al.,[35] reported negative effects on 45 s performance like those observed in temperate weather conditions.[42] Duffield et al.,[43] used ice jackets for cooling before and during exercise in 30 °C and 60% RH and reported no significant benefits and postulated that the negative effects of peripheral hypothermia is impairing muscular performance. Hence Crowley et al.[44] found lower peak and average power output, and cumulated work to the point of fatigue, due to cooling, with a low fatigue index.

The reduced performance could be due to the fact that in short duration sprints, muscle temperature, contractibility and/or efficiency of anaerobic metabolism is more relevant than cardiovascular or thermoregulatory factors. Time-to-peak tensions, decreased voluntary power output[45] are increased in cooler muscles which also show decreased anaerobic metabolic rate during high intensity exercise.[23,35] The reduction in surface temperature due to cooling may reduce the mean power frequency of the EMG[46] which could indicate slower recruitment of fast twitch motor units or a slow muscle fiber conduction velocity.[47]

Conclusion

Wrist cooling device applied before exercise is a promising precooling device. It leads to improvement in the aerobic and anaerobic performance in sportsmen with anaerobic performance gains being slightly on the higher side. This has got implications in improving endurance and anaerobic performance in sports and military training and combat activities where use of this small handy device may improve physical performance. More research with an increased sample size, using sportsmen of varied disciplines/military personnel in field conditions, is indicated to corroborate/negate our findings.

Conflicts of interest

The authors have none to declare.

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