Cold Drink Attenuates Heat Strain during Work-rest Cycles

Authors J. K. W. Lee[2], Z. W. Yeo[2], A. Q. X. Nio[3], A. C. H. Koh[2], Y. S. Teo[1], L. F. Goh[2], P. M. S. Tan[3], C. Byrne[4]

Affiliations Affiliation addresses are listed at the end of the article

Key words
- thermoregulation
- internal cooling
- military

Abstract

There is limited information on the ingestion of cold drinks after exercise. We investigated the thermoregulatory effects of ingesting drinks at 4 °C (COLD) or 28 °C (WARM) during work-rest cycles in the heat. On 2 separate occasions, 8 healthy males walked on the treadmill for 2 cycles (45 min work; 15 min rest) at 5.5 km/h with 7.5 % gradient. Two aliquots of 400 mL of plain water at either 4 °C or 28 °C were consumed during each rest period. Rectal temperature (T_{re}), skin temperature (T_{sk}), heart rate and subjective ratings were measured. Mean decrease in T_{re} at the end of the final work-rest cycle was greater after the ingestion of COLD drinks (0.5 ± 0.2 °C) than WARM drinks (0.3 ± 0.2 °C; $P < 0.05$). Rate of decrease in T_{sk} was greater after ingestion of COLD drinks during the first rest period ($P < 0.01$). Mean heart rate was lower after ingesting COLD drinks ($P < 0.05$). Ratings of thermal sensation were lower during the second rest phase after ingestion of COLD drinks ($P < 0.05$). The ingestion of COLD drinks after exercise resulted in a lesser than expected reduction of T_{re}. Nevertheless, the reduction in T_{re} implies a potential for improved work tolerance during military and occupational settings in the heat.

Introduction

Endurance performance is compromised in the heat due to a rise of body core temperature (T_c) during exercise [13, 31]. The termination of exercise due to exhaustion has been found to coincide with a T_c of approximately 39.7 °C [30]. Different strategies can be employed before the start of exercise so as to delay the onset of hyperthermia. Some of these methods include cold water immersion [6, 20], exposure to cold air [10, 22], wearing a cooling vest [3, 5] and ingestion of a cold drink or ice slurry [24, 28, 35, 37, 41]. The primary aim of these methods is to lower T_c prior to exercise, thus extending the exercise duration before an individual reaches a state of hyperthermia. This extends the individual's heat storage capacity, delaying the onset of fatigue and prolonging the time to exhaustion.

A recent surge of studies has focused on thermoregulation and exercise performance with the ingestion of cold drinks or ice slurry [24, 35, 37, 41]. Compared to other methods such as cold water immersion and cold air exposure, the ingestion of cold drinks is a practical and convenient method for use in the field. Furthermore, cold drink ingestion promotes fluid consumption to attenuate dehydration [2, 27, 40] and serves as a heat sink to lower T_c [4, 29]. These studies have compared the thermal responses following ingestion of either a cold substance or an ambient temperature fluid during rest and/or exercise. From the available data, ingestion of a cold fluid during rest appears to be effective in reducing T_c and is a practical cooling method to be used prior to exercising in a warm environment [24, 28].

Work-rest cycles are employed as a mitigating strategy to prolong work tolerance, especially in conditions when premature fatigue can occur due to excessive heat load. Resting periods during work-rest cycles allow for the transient recovery of T_c to promote work completion. However, the effects of ingesting a cold fluid during rest periods following exercise cannot be ascertained from the documented effects of pre-exercise ingestion, as there are physiological differences after exercising compared to during rest. Following an acute round of muscular exercise, there is a reduction in mean arterial pressure [19] with elevated oesophageal and active muscle temperatures [21]. Furthermore, persistence of peripheral vasodilation to eliminate excess heat from the body during recovery from exercise supersedes the non-thermal factors (i.e.,

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Correspondence
Dr. Jason KW Lee, PhD
Defence Medical & Environmental Research Institute
DSO National Laboratories
Military Physiology Laboratory
27 Medical Drive
#09-01
Singapore
117510
Tel.: +65/6485 7106
Fax: +65/6485 7127
lkaiwei@dso.org.sg

baroreflex) regulating blood pressure [12]. As such, these differences may affect the decrease in T_c and the extent of cooling following exercise compared to pre-exercise cooling.

Post-exercise cooling via cold water immersion has shown to be effective in reducing thermal strain and improving performance in subsequent rounds of exercise [9,17,38]. However, data pertaining to post-exercise cooling via ingestion of ice or fluid remains limited [8]. Stanley et al. [37] had previously determined that ice slurry was more effective than cold water in lowering T_c when given to cyclists during rest between 2 rounds of exercise. However, the results of the study were limited by the differences in volume ingested between the ice slurry and the cold water trials.

Therefore, the aim of the present study was to investigate the effects of ingesting cold drinks during work-rest cycles in a warm and humid environment. We hypothesized that the ingestion of cold drinks (4 °C) compared to ingesting a similar volume of drinks at room temperature (28 °C) during a rest period would reduce the physiological strain (rectal temperature (T_{re}) and heart rate (HR)) in a subsequent round of exercise in the heat, implying a potential for improved work tolerance during military and occupational work-rest cycles in the heat.

Methods

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Participants

8 healthy males volunteered to participate in this study. Ethical approval was granted by the Institutional Review Board and conformed to the international standards and as required by the journal [15]. Their age and physical characteristics are shown in ▸ **Table 1**. The participants gave their informed consent to participate after being briefed on the nature, benefits and risks of the study. They retained their right to withdraw from the study at any time. All participants were required to pass a health history questionnaire and a medical screening for anaemia, renal impairment, abnormal cardiac rhythms, chamber enlargement and ischemia.

Table 1 Physical characteristics of the participants.

Description	Mean ± SD	Range
age (yr)	24 ± 0	23–24
body mass (kg)	62.8 ± 7.0	50.4–72.7
height (m)	1.69 ± 0.08	1.60–1.80
body mass index (kg/m^2)	21.9 ± 2.1	19.1–24.9
body fat (%)	13.3 ± 3.2	9.4–19.5

Preliminary measurements

Anthropometric measurements were taken during a session separate from the 3 laboratory trials. Height was measured to the nearest 0.005 m using a stadiometer (Seca, Brooklyn, N.Y., USA). Body mass was measured to the nearest 0.001 kg using an industrial weighing scale (KCC150, Mettler-Toledo, Germany). Skinfold thickness measurements were made at 4 sites (biceps, triceps, subscapular and suprailiac) in duplicate using skinfold callipers (HSK-BI, British Indicators, UK), with the mean value being used to calculate total skinfolds. Body density was calculated according to the estimation of Durnin and Womersley [11], with body fat percentage being estimated based on the equation of Siri [34].

Experimental design

Participants performed a series of 3 trials. The first was a familiarisation trial in which they ingested a thermoneutral fluid (38 °C) so as to avoid possible learning effects for each of the test drinks. This was followed by 2 experimental trials: ingestion of COLD (4 °C) or WARM (28 °C) drinks in a randomized order using a Latin Square design. Trials were separated by a minimum of 7 days and a maximum of 14 days. Participants were asked to record their diet for 48 h before the familiarization trial and to repeat this same diet for subsequent experimental trials. They were requested to avoid strenuous activity and to refrain from alcohol in the 24 h prior to each trial. All trials commenced in the morning at approximately 10:00 a.m. to control for circadian variations in T_c.

For each experimental trial, participants reported to the laboratory after fasting overnight. Upon arrival to the laboratory, a standard breakfast consisting of an instant chocolate beverage (Milo Fuze 3 in 1, Nestle Pte Ltd, Singapore), a packet of cream crackers (Hup Seng Perusahaan Makanan (M) Sdn. Bhd, Malaysia) and 500 mL of water were provided 90 min before the commencement of the trial. A pre-exercise urine sample was collected before the participant's nude body mass was recorded. Urine osmolality was measured using freezing point depression (Osmomat 030-D, Gonotec, Germany). A probe (YSI Precision 4400 series temperature probe, YSI temperature, USA) marked by an improvised bead made from porous adhesive tape (3 M micropore tape, 3 M Corporation, USA) was inserted 10 cm beyond the anal sphincter for the measurement of T_{re}. Skin thermistors (Grants Instruments, Cambridge, UK) were attached to the chest, triceps, thigh and calf on the right-hand side of the body using the same porous adhesive tape (3 M transpore tape, 3 M Corporation, USA). Finally, a chest strap and heart rate monitor (Polar Vantage, Polar Electro Oy, Kempele, Finland) were worn on the participant. Weightings for skin temperature at

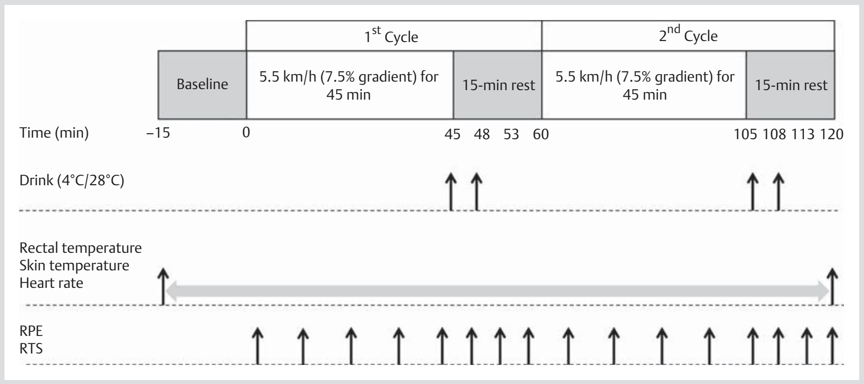

Fig. 1 Schematic representation of the laboratory protocol. Rectal temperature, skin temperature and heart rate were measured continuously and recorded at 5 min intervals, while ratings of perceived exertion and thermal sensation were recorded every 10 min after the first 5 min of each exercise bout and every 5 min during the 15 min rest periods. Prior to the start of exercise, these parameters were measured every 5 min for 15 min. Exercise consisted of 2 work-rest cycles, with a 45 min walk on the treadmill at a speed of 5.5 km/h with a gradient of 7.5 % and a 15 min rest period. Participants ingested either COLD (4 °C) or WARM (28 °C) drinks at the 3rd and 8th min of each rest period.

4 sites were applied as 0.3 × (skin temperatures of chest and triceps) + 0.2 × (skin temperatures of thigh and calf) to compute mean skin temperature using the equation of Ramanathan [33]. Prior to the start of the exercise, baseline measurements were obtained every 5 min as the participant was seated in the environmental simulation chamber (VEKZ10, Vötsch Industrietechnik, Germany) for 15 min at an ambient temperature of 32.0 ± 0.4 °C with relative humidity of 63 ± 1 %. The following biological parameters were measured: T_{re}, skin temperatures (T_{sk}), HR, ratings of perceived exertion (RPE) [7] and modified thermal sensation [18] based on the ASHRAE scale.

Following the collection of baseline measurements, participants walked on the treadmill for 45 min at a speed of 5.5 km/h with a gradient of 7.5 %. This fixed exercise intensity corresponded to 7 metabolic equivalents. It is noteworthy that a military route march is performed at an absolute speed, instead of at a relative exercise intensity of each individual soldier. Biological parameters were recorded at intervals of 5 min during the trial except for RPE and thermal sensation, which were recorded every 10 min after the first 5 min of each exercise bout and every 5 min during the 15 min rest periods (▶ **Fig. 1**). Environmental data was recorded every 15 min using the climatic squirrel logger (Grant Instrument, UK). Premature trial cessation was determined by volitional exhaustion or when $T_{re} \geq 39.5$ °C.

After each 45 min bout of exercise, the participant was seated. Plain water was ingested at the 48th and 53rd min (2 × 400 mL; total 800 mL). Each aliquot was ingested within 2 min. The temperature of the water was maintained in an electrical water bath (Clifton NE4-D, Nickel Electro Ltd, England). After 15 min of seated rest, the same exercise protocol, recovery protocol and hydration regime were repeated for the next 60 min.

At the end of the trial, all instrumentation was promptly removed and a post-exercise urine sample was collected. Nude body mass was measured within 5 min upon cessation of trial following the removal of any unevaporated sweat with a towel. Sweat loss was estimated from the differences in body mass before and after each trial, corrected for fluid intake and urine production.

Statistical analyses

All statistical computations were performed using the Statistical Package for Social Sciences version 12.0. Student's paired t-test was used to evaluate differences in the measured physiological variables at a single time point. A 2-factor (i. e., drink temperature and time) repeated measures ANOVA was used to evaluate the changes in the variables over time (the number of time points computed was in accordance with the reported sampling intervals described earlier). All data are presented as mean ± standard deviation. For all statistical analyses, the 0.05 level of significance was used.

Results

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Environmental conditions and hydration status

There were no differences in mean ambient temperature (COLD: 32.4 ± 0.1 vs. WARM: 32.1 ± 0.1 °C; $P = 0.31$) and mean relative humidity (COLD: 63 ± 1 vs. WARM: 62 ± 1 %; $P = 0.65$) between trials. Wet bulb globe temperature was 28.1 °C during exercise and the thermal stress would be classified as 'high risk' (WBGT > 28 °C) [1]. Participants were considered euhydrated prior to each trial as demonstrated by pre-trial urine osmolality (COLD: 278 ± 283 vs. WARM: 312 ± 320 mOsmol · kg^{-1}; $P = 0.37$) and body mass (COLD: 62.81 ± 7.00 vs. WARM: 62.72 ± 6.97 kg; $P = 0.50$).

Rectal temperature (T_{re})

Participants commenced each trial with identical T_{re} (COLD: 37.0 ± 0.3 vs. WARM: 37.0 ± 0.2 °C; $P = 0.71$; ▶ **Fig. 2**) and there was no difference between COLD and WARM up to the 45th min, i. e., the end of the first bout of work (COLD: 37.4 ± 0.3 vs. WARM: 37.5 ± 0.3 °C; $P = 0.73$). After the ingestion of drinks during the first resting period, T_{re} was lowered in the second work cycle (65–85 min) for COLD compared to WARM (COLD: 37.8 ± 0.5 vs. WARM: 38.0 ± 0.4 °C; $P < 0.05$). At the end of the second rest period, T_{re} was lower in COLD (37.5 ± 0.6 °C) than in WARM (37.8 ± 0.4 °C; $P < 0.05$).

The decrease in T_{re} was greater in COLD compared with WARM for the first (COLD: 0.3 ± 0.1 vs. WARM: 0.2 ± 0.1 °C; $P < 0.01$) and second rest period (COLD: 0.5 ± 0.1 vs. WARM: 0.3 ± 0.1 °C;

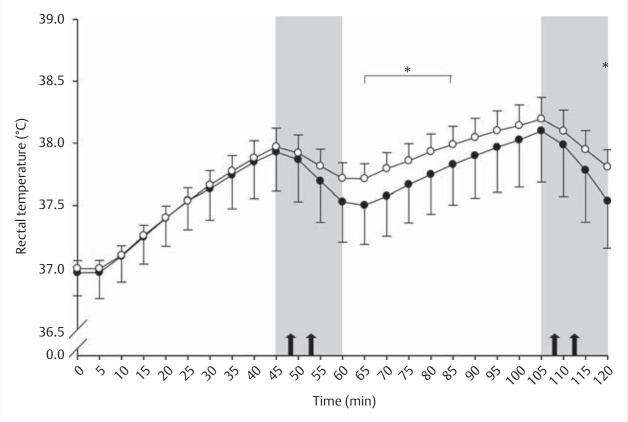

Fig. 2 Rectal temperature (T_{re}) of COLD (4 °C drinks; filled circles) and WARM (28 °C drinks; unfilled circles) during trials. Shaded regions indicate the 15 min seated rest periods. Arrows denote the ingestion of drinks at the 3rd and 8th min of each rest period. Mean T_{re} was lower from 65–85 min and at 120 min in COLD compared to WARM (*; $P < 0.05$).

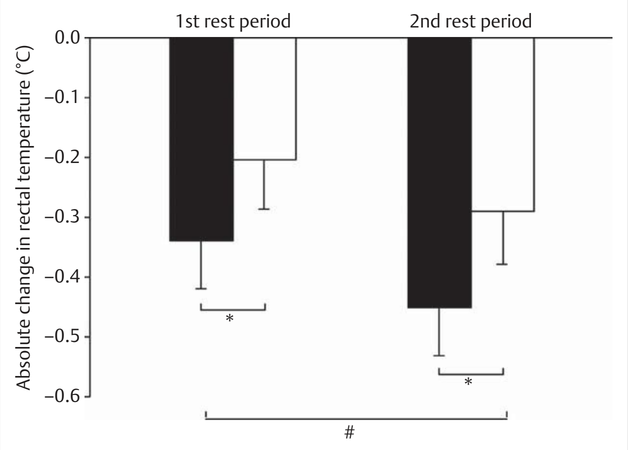

Fig. 3 Decrease in T_{re} during the first (45–60 min) and second (105–120 min) rest period with COLD (black bars) and WARM (white bars). Mean values and SD are shown. The decrease in T_{re} was greater in COLD than WARM for both rest periods (*; $P < 0.05$). The decrease in T_{re} was greater in the second rest period compared to the first for both trials (#; $P < 0.05$).

$P<0.01$; ▶ **Fig. 3**). A smaller difference in T_{re} was observed between the trials in the first (0.1 ± 0.2 °C) than in the second rest period (0.2 ± 0.1 °C; $P<0.05$).

Mean skin temperature (T_{sk})

There was no difference in T_{sk} between trials at all time points. However, the rate of T_{sk} (°C·min^{-1}) decrease was greater ($P<0.01$) with the ingestion of COLD drinks (0.05 ± 0.02 °C·min^{-1}) during the first rest period as compared to WARM drinks (0.03 ± 0.02 °C·min^{-1}). No difference was observed in the rate of T_{sk} decrease for the second rest period between COLD (0.04 ± 0.02 °C·min^{-1}) and WARM (0.03 ± 0.02 °C·min^{-1}; $P=0.52$).

Heart rate (HR)

Participants commenced each trial with similar HR (COLD: 74 ± 9 vs. WARM: 76 ± 7 beats·min^{-1}; $P=0.45$). However, HR was lower with the ingestion of COLD drinks (124 ± 14 beats·min^{-1}) as compared with WARM drinks (130 ± 13 beats·min^{-1}; $P<0.05$) from the 55th min to the 105th min. Mean HR was lower during the second rest period in COLD (97 ± 13 beats·min^{-1}) compared with WARM (103 ± 14 beats·min^{-1}; $P<0.05$). At the end of the trial, HR was lower in COLD (88 ± 11 beats·min^{-1}) than WARM (95 ± 12 beats·min^{-1}; $P<0.05$).

Sweat rate and fluid balance

Post-exercise urine volume was similar for both trials: volume was 190 ± 139 mL in COLD and 273 ± 371 mL in WARM ($P=0.41$). Estimated sweat rate during exercise was similar with the ingestion of COLD drinks compared to WARM drinks, amounting to 0.64 ± 0.15 and 0.63 ± 0.11 L·h^{-1} respectively ($P=0.73$). Net body mass loss during exercise amounted to 0.0 ± 0.4 % with the COLD drinks and 0.1 ± 0.6 % with the WARM drinks ($P=0.55$).

Ratings of perceived exertion (RPE) and thermal sensation (RTS)

Mean RPE between COLD and WARM throughout the work rest cycles were identical (COLD: 10 ± 2 vs. WARM: 10 ± 2; $P=0.73$). Mean RTS were similar between both trials during the first (COLD: 2 ± 1 vs. WARM: 2 ± 1; $P=0.59$) and second bout of work (COLD: 2 ± 1 vs. WARM: 2 ± 1, $P=0.70$). Mean RTS were similar between COLD and WARM during the first rest period (COLD: 0 ± 1 vs. WARM: 1 ± 1; $P=0.42$) but was lower in COLD during the second rest period (COLD: 0 ± 2 vs. WARM: 1 ± 1; $P<0.05$).

Discussion

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When compared to drinks at 28 °C (WARM), we reported a greater decrease in T_{re} and HR during the work-rest cycles following ingestion of drinks at 4 °C (COLD). The findings demonstrate that the ingestion of cold drinks after exercise, compared with the ingestion of drinks of similar volume at room temperature, can reduce the thermal strain during a subsequent bout of exercise in the heat. The reduction of thermal strain following ingestion of cold drinks was accentuated as the exercise progressed. We did not include an additional trial with no provision of drinks in an attempt to profile the natural recovery of T_c because it is unlikely that drinks will not be consumed under such circumstances. Taken together, these findings imply a potential for improved endurance capacity during military and occupational work-rest cycles in the heat.

Many studies have employed cooling manoeuvres via external or surface cooling methods such as exposure to cold air [10,22], wearing a cooling vest [3,5] and cold water immersion [6,20]. The recent focus has been shifted to internal cooling techniques, namely the ingestion of cold drinks [24,28] and ice slurry [35,37,41]. This form of cooling has shown to be practical, effective in reducing T_c and helps athletes to stay hydrated. Whilst the pre-exercise ingestion of cold drinks or ice slurry has been widely investigated, there is limited information on the effects of ingesting a cold substance after exercise. The present study is novel in demonstrating the efficacy of cold drink ingestion during a military based work-rest cycle in attenuating heat strain. The findings of this study are clearly relevant to athletes competing in multiple events within a single day or team events which are separated by breaks (e.g. halftime/quarter time breaks) or participating in military exercises, such as a route march, which are interspersed with specified work-rest cycles.

Using the assumptions of Nadel and Hovarth [29], the predicted decrease in T_c from ingesting 800 mL of COLD (4 °C) and WARM (28 °C) water is ~0.5 °C and ~0.1 °C, respectively. In the present study, T_{re} reductions of ~0.3 °C and ~0.2 °C were observed with COLD and WARM drinks ingestion respectively, during the first rest period. The difference between the calculated and observed reduction in WARM could be attributed to the normal attenuation of T_c following a bout of exercise, which is separate from the effect of drink ingestion. However, this contradicts the lower-than-predicted T_{re} reduction observed in COLD, as the higher heat debt with a cold drink is expected to evoke a much larger decrease in T_c than what was observed. Thus, we speculate that the need to eliminate heat after the first bout of exercise did not supersede the baroreflex regulating blood pressure in COLD, resulting in vasoconstriction to accumulate heat within the body core. This postulation is further supported by the higher rate of T_{sk} decrease after the ingestion of cold drinks. Furthermore, mean arterial pressure is known to decrease following an acute bout of muscular exercise [19], and this effect can persist for several hours [32], resulting in post-exercise hypotension. Post-exercise hypotension is known to parallel elevated esophageal and active muscle temperatures [21].

During the second rest period, T_{re} reductions of ~0.5 °C and ~0.3 °C in COLD and WARM respectively, were greater than that observed during the first rest period. The elevated amount of heat was exacerbated with the accumulated heat within the body after the first bout of exercise [21]. Gagnon et al. [12] found that a sufficiently high thermal load would supersede the baroreflex, resulting in persistence of vasodilation for up to 10 min and maintenance of sweating up to 50 min following exercise. We hypothesize that the amount of heat within the body had reached a “threshold” to trigger a heat elimination mechanism that supersedes the earlier baroreflex to reduce vasoconstriction when the body is introduced with a heat debt. This was further validated by the no difference observed in rate of T_{sk} change for both WARM and COLD trials. These factors were likely to contribute to the higher reduction in T_{re} observed in both COLD and WARM trials. Nevertheless, it is worth highlighting that the limited number of sites (4 sites) used to estimate mean skin temperature might have prevented the observation of vasoconstriction induced by the cold drinks. Hence placement of skin thermistors nearer to the extremities or direct measurement of skin blood flow would have made the associated mechanisms more definitive.

In addition to the amount and frequency of ingestion, the extent to which ingesting a cold drink is effective in lowering T_c seems to be dependent on the timing at which it is ingested. When cold drinks are ingested before exercise, the observed decrease in T_c is close to the theoretical calculation of ~0.5 °C [24, 35, 36]. For example, after the pre-exercise ingestion of 900 mL of a cold drink, Lee et al. [24] found a 0.5 °C reduction in T_{re}. Similarly, Siegel et al. [35] found a ~0.7 °C decrease in T_{re} after ingesting 600 mL of ice slurry at rest. On the other hand, ingesting cold drinks during exercise does not seem to affect T_c. Only a minimal reduction was observed when a cold drink was ingested in a single large bolus during exercise [23] and the effect diminished when the drinks were ingested serially [25]. In the present study, when the cold drink was ingested during a 15 min rest period, the lower-than-predicted T_{re} reduction observed in COLD lies in between what was observed when a cold drink was ingested before and during exercise. As such, the impact of drink temperature is likely to be dependent on when the drink is ingested and the impact of drink temperature on T_c cannot be assumed to be the same in all situations.

During the first rest period, heart rate was lowered after the ingestion of the cold drink. This effect persisted up to 20 min into the subsequent bout of exercise. This finding is consistent with other precooling studies [14, 22, 24], which reported the attenuation of heart rate compared with the control conditions. However, sweat rate was similar in both trials, which is contrary to the findings of other precooling studies. Previous work have demonstrated a significant delayed onset of sweating after precooling [39] and a decrease in sweat rate during exercise compared with a control treatment [16, 24]. A heat deficit via precooling probably lengthens the time required to reach sweating threshold and delays the onset of heat dissipation mechanisms. The exercise intensity employed in the present study may have been too low to evoke differential responses in sweat rate with COLD and WARM. This is shown by a relatively low mean end RPE of 11 ± 3 in both trials.

During the second rest period, ratings of thermal sensation were lower with the ingestion of cold drinks as compared with WARM drinks. This was not observed during the first rest period. The physiological effects following 2 bouts of exercise and the cumulative effect of several aliquots of cold drink could have resulted in a lower perceived thermal strain during the second rest period compared to the first. Accordingly, end T_{re} was lower in COLD than WARM following the second rest period, but was similar during the first. In any case, dehydration was unlikely to be a contributing factor to the differences in T_{re}, given that the net body mass loss during exercise was minimal for both trials (COLD: 0.0 ± 0.4 %; WARM: 0.1 ± 0.6 %; P = 0.55).

Results showed a T_{re} difference of 0.2 °C between COLD and WARM during the second rest period. A recent study by Lee et al. [26] showed that when 18 male trained soldiers performed a simulated route march on a treadmill in an environmental chamber (32 °C; 70 % RH) for 3 cycles of 60 min, the mean rate of rise of T_c was 0.02 °C.min^{-1}. Assuming heat strain per se is a limiting factor to endurance work capacity under warm conditions [13, 14], a 0.2 °C difference translates to approximately 10 min or 22 % of added work capacity for each work-rest cycle (45 min work; 15 min rest). Furthermore, it should be noted that the present study was limited to 2 work-rest cycles. We hypothesize that an increase in the number of work-rest cycles may further exaggerate this difference as the amount of thermal strain accumulated in subsequent cycles would increase. This would represent a meaningful increase in work endurance capacity for activities that entail many work-rest cycles.

Conclusion

In conclusion, ingestion of cold drinks was found to attenuate heat strain more effectively than warm drinks during work-rest cycles. The effectiveness of a cold drink in reducing T_c is likely to be dependent on the timing at which it is ingested. The results may be of particular benefit for people who are required to perform more than one bout of exercise in warm or hot environments within a short time frame (e. g. military and occupational work-rest cycles, and athletes who have a sufficient break in the activity i. e., halftime), where cooling can enhance subsequent performance. We speculate that the reduction in T_c brought about by the ingestion of a cold drink would be more pronounced should the number of work-rest cycles increase. Future work should be targeted at investigating this hypothesis.

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Affiliations
[1] Defence Medical & Environmental Research Institute, DSO National Laboratories
[2] Department of Physiology, Yong Loo Lin School of Medicine, National University of Singapore, Singapore
[3] Sport Science and Management, Nanyang Technological University, Singapore, Singapore
[4] School of Sport and Health Sciences, University of Exeter, Exeter, United Kingdom

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