

Influence of Beverage Temperature on Exercise Performance in the Heat: A Systematic Review

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Purpose: Increased core temperature (T_c), impaired cardiovascular function, and dehydration contribute to fatigue during prolonged exercise in the heat. Although many studies have examined mechanisms addressing these factors, few have investigated the effect of cold beverage temperature on thermoregulation and exercise performance in the heat. **Methods:** Citations from MEDLINE (Ovid), Sport Discus (EBSCOhost), AUSPORT and AusportMed (Informit), Web of Science, and SCOPUS were identified from the earliest record until September 2008 using the search terms *drink temperature, beverage temperature, fluid temperature, water temperature, and cold fluid* combined with *body temperature and thermoregulation*. To be included, studies needed to assess core or rectal temperature during exercise in moderate or hot environmental conditions. After quality rating was completed by two reviewers, the difference in mean T_c and exercise performance was calculated. **Results:** Ten studies meeting search inclusion criteria were available for analysis. Three were excluded because sufficient detail or statistical data were not reported. A meta-analysis was not performed because the studies were deemed too different to group. Three of the remaining 7 studies found modulated T_c with cold beverage consumption, and from the 4 that conducted exercise performance tests, performance improved by 10% with cold fluids. **Conclusion:** Cold fluid may attenuate T_c rise and improve exercise performance in the heat; however, study findings are mixed. Research using well-trained athletes and fluid-ingestion protocols replicating competition scenarios is required. Potential sensory effects of cold fluid in maintaining motivation also need to be assessed as a mechanism underpinning improved performance.

Keywords: fluid temperature, thermoregulation, endurance performance

It is well documented that exercise performance is decreased in the heat compared with cool environments, and onset of fatigue occurs earlier (Maughan & Shirreffs, 2004). Changes in cardiovascular and central nervous system function in addition to the rise in core temperature (T_c) are all considered contributing factors, but the underpinning mechanisms responsible are yet to be clearly identified (reviewed in Kay & Marino, 2000). Fluid ingestion improves exercise performance in the heat by maintaining cardiovascular function (Sawka, Montain, & Latzka, 2001) and reducing rise in T_c (Montain & Coyle, 1992; Noakes, 1993). Although many studies have been conducted to investigate the influence of hydration status on exercise performance (Cheuvront, Carter, & Sawka, 2003; Judelson et al., 2007), relatively few have considered the influence of beverage temperature, which theoretically has the potential to influence the body's heat-storage capacity. It has also been hypothesized that the sensory effect of regular fluid and carbohydrate ingestion during exercise affects central drive and thus performance (Carter, Jeukendrup, & Jones,

2004; Rollo, Williams, Grant, & Nute, 2008). Beverage temperature may additionally influence central drive through similar sensory mechanisms.

There are a number of identified ways that fluid ingestion maintains performance, but some of the mechanisms are yet to be fully explored. In addition to better maintenance of plasma volume, cardiovascular function, and sweating rate, fluid ingestion may influence performance by delaying the evolution of T_c by acting as a "heat sink." Harrison, Edwards, and Fennessy (1978) exercised 4 participants, replacing fluid intravenously with a 1% saline solution or an equivalent volume of drinking water. Although the saline solution was superior in preventing reductions in blood volume, it was less successful than drinking water in attenuating the rise in T_c . This may be because pooled fluid in the gastrointestinal tract might create a more effective heat sink than solution dispersed throughout the body via the circulatory system. In a review, Kay and Marino (2000) used the effect of the volume and temperature of water consumed during exercise to estimate the theoretical change in T_c . The predicted was close to the actual change, so they concluded that beverage temperature significantly affected T_c during exercise in the heat.

Fluid ingestion is also associated with strong sensory effects that potentially stimulate reward/pleasure centers in the brain, causing increased central drive or motivation for exercise. Carter et al. (2004) examined the effect of

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a carbohydrate mouthwash on time-trial performance in well-trained cyclists. Nine cyclists performed two time trials rinsing and expelling either a placebo or tasteless carbohydrate solution (6.4% maltodextrin). Time-trial performance was significantly faster with carbohydrate (59.57 vs. 61.37 min, respectively), and average power output was higher (259 W vs. 252 W). The mechanism was likely related to sensory stimulation of the reward/pleasure centers in the brain, causing increased central drive or motivation for exercise. This has also been reported by Rollo et al. (2008), in whose study a greater distance was covered and there were increased feelings of pleasure during a 30-min run when a carbohydrate mouth rinse was compared with a placebo. Although Rollo et al.'s study investigated the impact of carbohydrate, it is possible that consuming cool beverages in the heat has a positive sensory effect. A recent functional magnetic resonance imaging (fMRI) study has demonstrated that some of the same areas of the brain that detect pleasant taste are also involved in detecting temperature in the mouth (Guest et al., 2007).

Few studies have investigated the role of beverage temperature in the evolution of T_{c} or exercise performance in the heat. Theoretically, cool beverages may confer an advantage by acting as a heat sink or by providing a pleasant sensation that improves central drive. These mechanisms are hypothesized to improve endurance performance. There is also mixed evidence of any influence of beverage temperature on gastric emptying, suggesting that the temperature of an ingested solution has little effect on the overall rate of gastric emptying (reviewed in Leiper, 2001). Because the literature does not specifically suggest that athletes consider or regulate beverage temperature in training or competition, a clearer understanding of whether beverage temperature manipulation during exercise in the heat would offer a competitive advantage. This systematic review aims to determine whether the existing evidence supports a modulation of T_{c} and improved performance with ingestion of cool beverages during exercise in the heat and to identify conditions under which this occurs.

Method

A systematic search on beverage and T_{c} was conducted by one researcher (C.B.). Studies were identified by searching from the earliest record until September 2008 using the MEDLINE (Ovid), SportDiscus (EBSCOhost), AUSPORT and AusportMed (Informit), Web of Science, and SCOPUS databases. The following search terms were used singularly and in combination: *drink temperature*, *beverage temperature*, *fluid temperature*, *water temperature*, *cold fluid*, *body temperature*, and *thermoregulation*. When required to further refine the number of results generated (i.e., >50 results), *exercise* was added.

To be included for analysis, studies needed to be of randomized-control-trial or crossover design, measure and report core or rectal temperature and beverage temperature, and be conducted in moderate (>24 °C) or hot

(>28 °C) environments using either running or cycling exercise. Assessment of exercise performance was desirable but not necessary for inclusion. Articles were excluded if they were abstracts, in a language other than English, or were opinion articles. Information extracted from each study was classified according to the following headings: participant age, fitness and acclimation levels, temperature and type of beverage consumed, beverage and exercise protocol, environmental conditions, and diet control. Fitness was classified from VO_{2peak} given in the studies as good (50–54 ml · kg⁻¹ · min⁻¹), very good (55–60 ml · kg⁻¹ · min⁻¹), or excellent (>60 ml · kg⁻¹ · min⁻¹). Drink protocol was classified as water, flavored water, or 6% maltodextrin. Diet control was categorized as to whether participants repeated a 24-hr recorded diet or were given a standardized breakfast. Study-quality ratings were performed independently by two researchers (C.B. and J.G.) following an adapted version from the works of Downs and Black (1998). When reviewers disagreed, specific criteria were discussed until consensus was reached.

From the studies reporting temperature or performance data, differences in mean T_{c} and performance were calculated using the coldest and control drinks. A meta-analysis was not performed because study designs were too different to pool. A weighted mean change in performance was calculated with the parameter mean (percent change) weighted (multiplied) according to number (N) of study participants. The sum of weighted means is divided by sum of N , giving the weighted mean change.

Results

Initial searches yielded 190 citations, but 182 were found to be irrelevant based on title and abstract. Hand searching of relevant article bibliographies also was conducted, identifying an additional two citations in abstract form not listed in databases. The 10 relevant papers are summarized in Table 1. Gender is not specified because all studies used male participants and measured T_{c} via a rectal probe. Abstracts were removed (Lee, Shirreffs, & Maughan, 2006; Lovell, Pout, & Ryder, 2004), and because of insufficient detail on T_{c} data, the manuscript by Gisolfi and Copping (1974) was also excluded from statistical analysis.

Table 2 summarizes manuscript quality-rating scores for the seven remaining studies included in the statistical analysis. All manuscripts had low external validity because participants were not well trained and could not be blinded to beverage temperature. Participant and researcher bias can therefore not be excluded.

Table 3 summarizes the difference in means analysis of data in the reviewed articles.

Figure 1 graphically displays the mean difference in T_{c} between cool and control beverages (with 95% confidence interval [CI]). A pooled mean was not calculated because study designs were too varied. The data were calculated from either post- T_{c} or change from pre- to post- T_{c} .

Table 1 Detailed Summary of Relevant Studies

Reference	N	Age, years	Accl	Fitness level	Diet control	Drink	Drink temperature	Drink protocol (amount/frequency)	Exercise protocol	Environmental conditions
Armstrong, Hubbard, Szlyk, Matthew, & Sils, 1985	12	23 ± 6.9	N	—	B	W	6 °C, 22 °C	ad libitum	6 hr intermittent (30 min:30 min) treadmill (1.34 m/s, 5% grade)	40 °C dry bulb, 29% RH, 8.1 wind speed
Gisolfi & Copping, 1974	6	26 ± 6.7	—	E	—	W	10 °C, 37 °C	200 ml/20 min or 1 L pre or 1 L pre + 200 ml/20 min	19–29 km (1.5–25 hr) at 75% VO _{2peak}	35.5 °C/21.5 °C db/wb
Lee, Shirreffs, & Maughan, 2008	8	22 ± 4	N	V	R	W	4 °C, 37 °C	3 × 300 ml pre EX and 100 ml/10 min	65% VO _{2peak} TTE	35 °C, 60% RH
Lee, Maughan, & Shirreffs, 2008	8	27 ± 4	N	G	R	F	10 °C, 37 °C	400 ml at 30, 45, 60, 75 min	90 min 50% + TTE	25 °C, 60% RH
Lee & Shirreffs, 2007	9	26 ± 6	N	G	R	F	10 °C, 37 °C	1 L at 50–60 min	95% VO _{2peak} TTE	25.4 °C, 61% RH
Lee et al., 2006 ^a	8	—	—	—	—	F	4 °C, 50 °C	300 ml/15 min	95% VO _{2peak}	25.3 °C, 56% RH
Lovell et al., 2004 ^a	6	—	—	—	—	M	4 °C, 50 °C	ml calculated from fluid loss × 6/15 min	60% VO _{2peak}	24 °C, 37% RH
Mundel, King, Collacott, & Jones, 2006	8	26 ± 7	N	—	R	F	4 °C, 19 °C	ad libitum + 300 ml/15 min	90 min 60% VO _{2peak}	34 °C, 28% RH
Szlyk, Sils, Francesconi, Hubbard, & Armstrong, 1989	14	21–33	N	—	B	W, F	15 °C, 40 °C	ad libitum	65% peak aerobic power TTE	40 °C dry bulb, 42% RH, 8.1 km/hr wind speed
Wimer, Lamb, Sherman, & Swanson, 1997	7	26 ± 13	—	G	—	W	0.5 °C, 19 °C, 38 °C	10 ml/kg at 62 min + 4 ml/kg at 80 and 100 min	120 min 50% VO _{2peak}	26 °C, 40% RH + cold water at 31 °C

Note. Accl = acclimatized; RH = relative humidity; TTE = time to exhaustion. All studies used male participants. Age is given as $M \pm SD$. Fitness classified as good (G; VO₂ 50–54 ml · kg⁻¹ · min⁻¹), very good (V; VO₂ 55–60 ml · kg⁻¹ · min⁻¹), or excellent (E; VO₂ > 60 ml · kg⁻¹ · min⁻¹). Drink protocol classified as water (W), flavored water (F), or 6% maltodextrin (M). Diet control was categorized as repeating a 24-hr recorded diet (R) or given a standardized breakfast (B).

^aAbstract excluded from review.

Table 2 Quality Ratings of Studies

Study	Hypothesis stated	Main outcomes	Participant description	Intervention described	Confounder distribution	Main findings described	Variability estimates	Adverse events reported	Patients lost to follow-up	Actual p value reported	Representative participants	Participants blinded	Researcher blinded	Statistical tests	Accurate measures	Same population recruited	Same time recruitment	Randomized to groups	Concealed randomization	Total (of 19)
Armstrong et al., 1984	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	Y	N	N	Y	N	9
Lee, Shirreffs, et al., 2008	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	11
Lee, Maughan, et al., 2008	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	11
Lee et al., 2007	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	11
Mundell et al., 2006	Y	Y	N	Y	N	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	N	N	11
Szylk et al., 1989	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	N	Y	Y	Y	N	10
Wimer et al., 1997	Y	Y	N	Y	N	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	11

Table 3 Difference in Means Analysis of Data in Reviewed Articles

Reference	Beverage temperatures	Core temperature °C, difference in means (95% CI)	Performance, min (95% CI)	Difference with cold drink
Armstrong et al., 1985	6 °C vs. 22 °C	0.22 (-0.842 to 1.282)	11.8 (8.9 to 14.7) ^{*a}	22.7%
Lee, Shirreffs, & Maughan, 2008	4 °C vs. 37 °C	0.3 (0.023 to 0.577) [*]	-0.13 (-1.1 to 0.82) ^b	-3.8%
Lee, Maughan, & Shirreffs, 2008	10 °C vs. 37 °C	-0.01 (-0.229 to 0.209)	0.34 (-0.332 to 1.012) ^b	9.4%
Lee & Shirreffs, 2007	10 °C vs. 37 °C	0.0 (-0.196 to 0.196)	7.0 (4.23 to 9.78) ^{*a}	12.7%
Mundel et al., 2006	4 °C vs. 19 °C	0.26 (-0.101 to 0.621)		
Szylk et al., 1989	15 °C vs. 40 °C	0.38 (0.183 to 0.577) [*]		
Wimer et al., 1997 ^c	0.5 °C vs. 38 °C	0.138 (0.091 to 0.185) [*]		

Note. CI = confidence interval; weighted mean change = 10%.

^aTime to exhaustion; ^bSubmaximal load + high-intensity time to exhaustion; ^cCold versus warm drinks in 26 °C environmental conditions.

*Statistically significant.

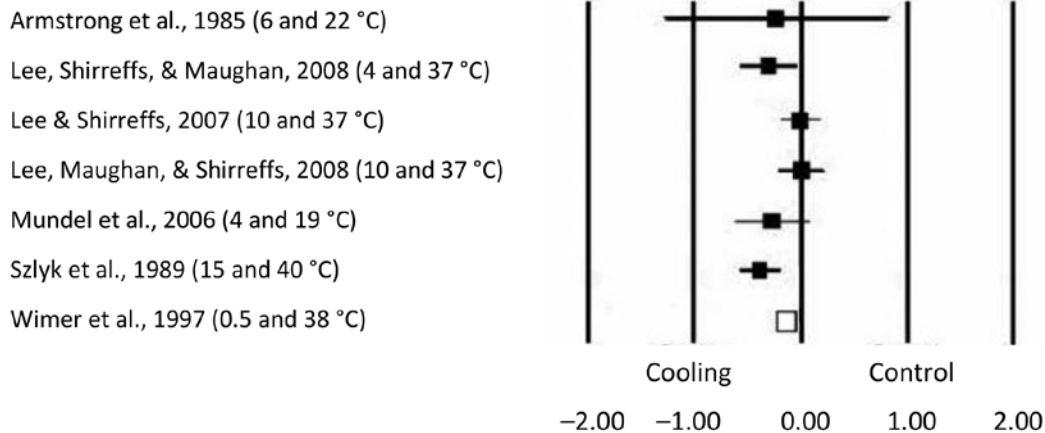


Figure 1 — Influence of beverage temperature on core temperature (°C). Core temperature (difference in means and 95% confidence interval) measured at end of exercise (black) and core temperature change from pre- to postexercise (white).

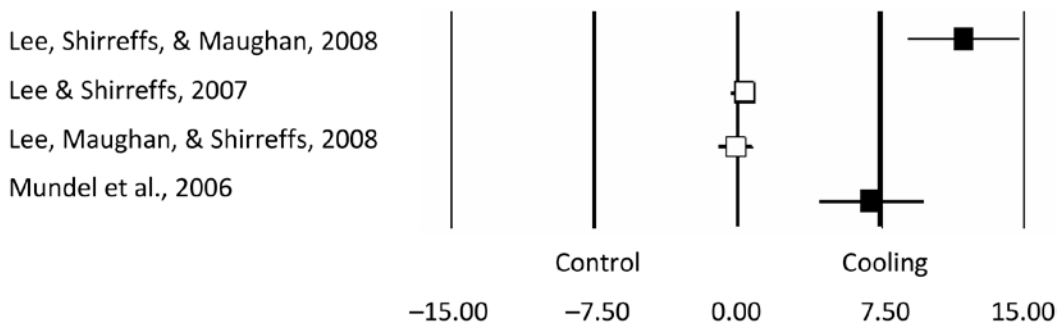


Figure 2 — Influence of beverage temperature on performance (min; difference in means and 95% confidence interval). Time to exhaustion (black) and submaximal + high-intensity time to exhaustion (white).

Results of the four studies measuring exercise performance are shown graphically in Figure 2, reported as difference in mean time to exhaustion (TTE; min) with 95% CIs. Studies used either TTE or 90-min submaximal effort followed by high-intensity TTE. A pooled mean was not calculated because study numbers were low and designs too varied to group.

Three of seven studies found a significantly reduced T_{c} ; these tended to employ a larger range in beverage temperature between the cold and control conditions and tended to be conducted in warmer environmental conditions. Of the four studies assessing performance, two reported significant improvement, with an overall weighted mean change of 10% with the cooler beverage. Significant performance improvement was only observed in studies using TTE ($n = 2$), not submaximal exercise followed by high-intensity TTE ($n = 2$).

Discussion

This systematic review clearly demonstrates that few ($n = 10$) studies have investigated the effect of beverage temperature on T_{c} , and even fewer ($n = 4$) have measured its influence on exercise performance. Three of the seven studies found a significant reduction in T_{c} , ranging from 0.14 to 0.38 °C. Reductions of 0.4 (Hessmer, Langusch, Bruck, Bodeker, & Briedenbach, 1984), 0.38 (Lee, Shirreffs, & Maughan, 2008), and 0.25 °C (Mundel et al., 2006) have been demonstrated to be practically significant in improving performance. The overall weighted mean improvement in studies that assessed exercise performance by TTE ($n = 4$) was 10%. These improvements appear substantial, but not all studies were positive. Only two of the four TTE studies (Lee, Shirreffs, & Maughan, 2008; Mundel et al.) reported significant improvement.

Overall, the major shortcomings identified by the quality-rating assessment were inadequate participant description, blinding, randomization (not concealed), and reporting of statistics (no report of actual p values). The wide range of study designs and athletic caliber of participants and different beverage-ingestion protocols led to difficulty in interpreting the results. This made meta-analysis impossible and identifies a need for further research to confirm a benefit of cool beverage ingestion and under what ingestion and exercise protocols this would be expected.

There are a number of reasons why some studies may not have found a benefit of cool beverage ingestion on T_{c} . These include use of unacclimatized participants who were not well trained, resulting in a decreased consistency in performance (Hopkins & Hewson, 2001). The exercise stimulus in some studies may also not have been of sufficient intensity (i.e., $>60\%$ VO_{2peak}) to raise T_{c} to the critical level required for significant effects. Environmental conditions in the studies were also quite varied, from cool (25 °C) to extremely hot (40 °C), with humidity ranging from 28% to 70%. The four studies reporting a significant effect of beverage temperature on either T_{c} or performance tended to use a greater exercise stimulus ($>65\%$ VO_{2peak}) and warmer, more humid conditions (Lee, Shirreffs, & Maughan, 2008; Mundel et al., 2006; Szlyk et al., 1989; Wimer et al., 1997). Studies (Lee, Maughan, & Shirreffs, 2008; Lee & Shirreffs, 2007) conducted in relatively cool, low-humidity environments all failed to show a significant effect of beverage temperature on performance. However, despite this, they all reported positive trends in T_{c} gradient over exercise that may have been significant in warmer, more humid conditions or during more intense exercise. This aspect requires further study.

Fluid-ingestion protocols also varied widely, with some (Lee, Maughan, & Shirreffs, 2008; Lee, Shirreffs, & Maughan, 2008; Lovell et al., 2004) opting for the regular consumption of a standardized bolus (not adjusted for body weight or sweating rate). Other studies (Armstrong et al., 1985; Mundel et al., 2006; Szlyk et al., 1989) allowed participants to drink ad libitum, so differential hydration status may have been a confounder. Two studies (Lee & Shirreffs, 2007; Wimer et al., 1997) gave a large, single bolus (1 L and 10 ml/kg, respectively) at one point during exercise, which is not characteristic of race practice, when athletes are more likely to intermittently drink smaller fluid volumes. No study has used a protocol that controlled fluid ingestion per kilogram of body weight or used fluid replacement to maintain hydration for the participants as is recommended practice (American College of Sports Medicine, 2007).

Consuming large amounts of cold fluid is believed to create a heat sink, which should theoretically result in attenuation of the heat accumulated over exercise and reduce the rise of T_{c} . Lower thermal stress may help modify the rise in heart rate and cardiovascular strain observed with exercise in the heat. Skin temperature and blood flow seem to be reduced after consuming a cold fluid (Lee, Shirreffs, & Maughan, 2008; Lee & Shirreffs,

2007; Wimer et al., 1997), which would decrease heat dissipation, but overall heat-storage capacity seems to increase, evidenced by a more gradual evolution of T_{c} .

Gastric emptying, or the rate at which fluid empties from the stomach into the small intestine, can be affected by beverage temperature, osmolality, and volume; stress; dehydration; and beverage carbohydrate concentration (Costill & Saltin, 1974; Leiper, 2001; Rehrer, 1996). If gastric emptying is faster or slower, the rate of rehydration can be significantly affected and hydration status has an impact on T_{c} (Leiper). Any influence of beverage temperature on T_{c} may therefore be exerted or modified by gastric emptying rate. Although Sun, Houghton, Read, Grundy, and Johnson (1988) reported that ingestion of cold (4 °C) orange juice led to slower gastric emptying than thermoneutral juice, other studies suggest that colder (5–12 °C) fluid does result in faster emptying rates (Costill & Saltin; Ritschel & Erni, 1977). Bateman (1982) found a faster emptying rate for 500 ml of cold (12 °C) compared with thermoneutral (37 °C) fluid, but when a smaller fluid volume was consumed (200 ml), the association disappeared. The change in emptying rates is most likely a result of the difference in intragastric temperature, which Shi, Bartoli, Horn, and Murray (2000) found returned close to normal within 5 min of consumption. Most studies show low to moderate effects of temperature on gastric emptying (reviewed in Leiper) and no effect with the smaller volumes more typically consumed intermittently during exercise. Because of the body's ability to return to thermoneutral temperature quickly, any effect would be expected to be small, short lived, and thus unlikely to explain most of the observed benefit of a cool beverage on T_{c} when exercising in the heat.

The purpose of attempting to reduce T_{c} is ultimately to improve athletic performance. However, performance measurement is problematic because it is underpinned by numerous physiological and psychological factors and there is variability resulting from day-to-day biological variation and instrumentation error. The type of exercise protocol and test selected may also influence the range of error and statistical power to detect significant effects of an intervention. Some studies have not found a benefit of consuming cold fluids on endurance performance. The use of TTE, which has a higher coefficient of variation (Laursen, Francis, Abbiss, Newton, & Nosaka, 2007), rather than TT may have also limited the ability of studies to observe a performance effect. The coefficient of variation for TTE performance tests of approximately 1 hr duration has been reported to be 1–2% (Hopkins, Schabort & Hawley, 2001; Paton & Hopkins, 2001). Therefore a weighted mean change of 10% indicates a beneficial improvement. Studies not demonstrating an improvement in performance used a submaximal exercise bout followed by a high-intensity TTE test. This design is a measure of exercise capacity, not endurance performance. Therefore, the two studies using only TTE provide a more appropriate measure of endurance performance.

Mundel et al. (2006) found a positive performance outcome resulting from consuming cold fluid. Participants

cycled to exhaustion at 65% peak aerobic capacity and consumed fluid ad libitum. Mundel et al. hypothesized that the improved performance resulted from a fluid-induced heat debt. However, the hydration status of the participants in this study was a potential confounder because they ingested significantly more cold fluid than in the control trial. Therefore this study was unable to delineate whether the improved performance resulted from an induced heat debt or superior hydration. Lee, Shirreffs, and Maughan (2008) also found an improvement in performance, but their protocol included a 30-min rest period with precooling by the ingestion of 900 ml of water at 4 °C. This caused T_{c} to drop 0.5 °C, allowing the participants to cycle 11 min longer because their temperature effectively had farther to rise before reaching a limiting T_{c} . Because motivation and central drive can influence performance it is important to consider whether sensory factors associated with beverage temperature may explain some of the observed performance benefits. Although it was not performed during exercise, Guest et al. (2007) completed an interesting functional MRI study introducing different temperatures of artificial saliva into the mouth and recording activation of brain regions and perceived pleasantness. A cold fluid (5 °C) was rated more pleasant but only significantly when compared with warm (50 °C). It was found that some of the same brain regions involved in detecting temperature were involved in sensing pleasantness. It is possible that a pleasant stimulus helps maintain central drive and increase motivation for exercise. Other studies have investigated the role of sensory mechanisms in the face. Mundel et al. (2007) investigated spraying cold water (~4 °C) on the face during exercise at 65% $\dot{V}O_{2peak}$ for 40 min in the heat (33 °C, 27% humidity). Heart rate was five beats/min lower with facial cooling, and both rating of perceived exertion (RPE) and thermal comfort were also lower. Bradycardia, decreased RPE, and improved thermal comfort at rest and during exercise have also been reported in other studies (Armada-da-Silva, Woods, & Jones, 2004; Kato et al., 2001; Smith, Stephens, Winchester, & Williamson, 1997). However, in a study by Gisolfi and Copping (1974), the effect of beverage temperature was compared with cold face sponging (using a towel soaked in cold water at 10 °C) during prolonged running. This did not attenuate a rise in T_{c} , and although there are no specific details or report of actual measurement, sponging with cold water was stated to give considerable psychological relief.

Marino (2007) proposed that a benefit to performance from a cold beverage would likely be related to a sensory mechanism called anticipatory mechanism of thermal limits. As T_{c} rises, central drive reduces, ultimately resulting in decreased effort in anticipation of reaching a critical T_{c} . With consumption of cold fluid and a decrease in the rate of rise of T_{c} , a feed-forward signal theoretically delays the reduction of central drive associated with fatigue. RPE and thermal comfort were similar at fatigue in Lee, Shirreffs, and Maughan's study (2008), but the consumption of cold fluid decreased RPE and

thermal comfort. This delayed onset of fatigue, allowing participants to exercise for ~11.8 min longer. Although a sensory feed-forward signal may play a part, the role of a heat sink is likely a primary mechanism.

Limitations

This review provides evidence of a possible benefit of cool beverage temperature for exercise in the heat. However, there are limitations in the available literature that informed this review, including few published manuscripts and incomplete reporting of data, only providing change or posttrial indices, making it difficult to pool for more detailed statistical analysis. In addition, study designs were diverse, with variation in environmental exposure, drinking, and exercise protocols. Significant effects may not be observed if the control beverage was below 37 °C. Although race organizers aim to provide cool beverages to athletes during events, the logistics of this are often difficult and anecdotally athletes report that beverages are sometimes too warm.

Future Directions

Future research needs to determine the benefit of beverage temperature under a range of environmental conditions and drinking protocols that emulate typical training and competition situations. Use of well-trained participants is critical to determine whether benefits translate into meaningful performance improvement in this population. Information about the actual temperature of drinks consumed by athletes, particularly in endurance competitions such as marathons and triathlons, would help determine the appropriate temperature for the control beverage.

Conclusion

There is limited evidence of a benefit of consumption of a cold over a thermoneutral beverage for exercise in the heat. Overall the studies identified in this systematic review demonstrate that there may be a modulation of T_{c} when a cold drink (<10 °C) is consumed when compared with a thermoneutral drink (>37 °C). Unfortunately, few studies are available ($n = 10$). In four studies in which the drink was not cold (>6 °C) and closer to the temperature of the control beverage (37 °C) or consumed in a moderate, rather than hot or humid, environment the benefit was not significant. Those reporting a benefit tend to have been conducted in hotter, more humid environments (>28 °C, 30% humidity) with cold beverages less than 5 °C. Available studies unfortunately did not use well-trained participants or designs that emulate typical beverage-consumption conditions adopted by most athletes. A benefit of cool beverage temperature on exercise performance (weighted mean improvement of 10%) was also found in this review. However, not all studies showed a benefit, and only four studies measuring exercise performance are available. The wide range in research designs and limited number of studies meant that meta-analysis would not be

valid and therefore it was not conducted. Additional study is required to confirm a benefit of cool beverage temperature on exercise performance using fluid-ingestion protocols representing typical and feasible competition ingestion patterns. Studies should also aim to determine the mechanism of this benefit and whether it primarily relates to heat attenuation, changes in central drive because of sensory factors, or a combination of the two.

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