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Influence of Beverage Temperature on Palatability and Fluid Ingestion During Endurance Exercise: A Systematic Review

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Beverage palatability is known to influence fluid consumption during exercise and may positively influence hydration status and help prevent fatigue, heat illness, and decreased performance. ***Purpose:*** The aims of this review were to evaluate the effect of beverage temperature on fluid intake during exercise and investigate the influence of beverage temperature on palatability. ***Methods:*** Citations from multiple databases were searched from the earliest record to November 2010 using the terms *beverage, fluid,* or *water* and *palatability, preference, feeding,* and *drinking behavior* and *temperature*. Included studies (N = 14) needed to use adult (≥18 yr) human participants, have beverage temperatures ≤50 °C, and measure consumption during exercise and/or palatability. ***Results:*** All studies reporting palatability (n = 10) indicated that cold (0–10 °C) or cool (10–22 °C) beverages were preferred to warmer ones (control, ≥22 °C). A meta-analysis on studies reporting fluid consumption (n = 5) revealed that participants consumed ~50% (effect size = 1.4, 0.75–2.04, 95% CI) more cold/cool beverages than control during exercise. Subanalysis of studies assessing hydration status (n = 4) with consumption of cool/cold vs. warm beverages demonstrated that dehydration during exercise was reduced by 1.3% of body weight (1.6–0.9%, 95% CI; $p < .001$). ***Conclusion:*** Cool beverage temperatures (<22 °C) significantly increased fluid palatability, fluid consumption, and hydration during exercise vs. control (≥22 °C).

Keywords: hydration, drink temperature, drink preference

Adequate fluid replacement during exercise is critical to minimize hypohydration, reduce the risk of heat illness, and optimize endurance performance (Shirreffs, 2005). Endurance-performance decrements may be, but not always, observed with dehydration greater than 2% of body mass (Cheuvront, Carter, & Sawka, 2003). Fluid loss from sweat is greater during exercise in the heat, and limiting dehydration within a reasonable range (<2%) can be challenging for some athletes, particularly when conditions are extreme and exercise is prolonged (Sawka & Montain, 2000). Regular ingestion of water or well-formulated carbohydrate-electrolyte beverages is recommended to optimize fluid intake and gastric emptying (Sawka et al., 2007).

Fluid intake of athletes during exercise is driven by thirst (Greenleaf, 1992; Passe, 2001) but often fails to fully replace sweat loss (known as voluntary dehydration; Armstrong, Hubbard, Szlyk, Matthew, & Sils, 1985; Sawka, 1992), resulting in some degree of dehydration. To encourage fluid consumption in situations where an excessive mismatch between fluid intake and sweat losses is likely, attention should be paid to the palatability of the available beverages. In addition to flavor, the temperature of a beverage has been reported to influence palatability and subsequent ingestion (Boulze, Montastruc, & Cabanac, 1983; Rothstein, Adolph, & Wills, 1947; Sohar, Kaly, & Adar, 1962). Indeed, the position stand on exercise and fluid replacement of the American College of Sports Medicine (Sawka et al., 2007) recommends consumption of fluids at approximately 15–21 °C during exercise based on evidence that this is the range in which drinks are most highly rated for palatability (Boulze et al., 1983). Cool beverages may have additional effects not associated with an increase in palatability that may be of interest to an exercising individual, including a reduction in core body temperature, resulting in improved performance (Burdon, O'Connor, Gifford & Shirreffs, 2010).

The purpose of the current article was to conduct a systematic and unbiased review of the research on beverage temperature and fluid intake during endurance exercise (Cook, Sackett, & Spitzer, 1995; Montori, Swiontkowski, & Cook, 2003; Wright, Brand, Dunn, & Spindler, 2007). It updates a previously conducted summary (Passe, 2001), adding the benefits of the systematic review with meta-analysis in assisting evaluation of evidence, and strengthens the results of individual studies with low power (Cook et al., 1995; Montori et al., 2003). The specific interest was to investigate and quantify the influence of the temperature of beverages consumed in relation to exercise on ratings of palatability, the volume of fluid consumed, and the net change in hydration status estimated from changes in body mass.

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Methods

A systematic search was conducted by one researcher (C.B.) using the following terms: *beverage, fluid,* or *water* and *palatability, preference, feeding behavior, drinking behavior,* and *temperature*. The following databases were searched in November 2009: Medline (Ovid; 1950 to present), SPORTDiscus (Ebsco; 1800 to present), ISI Web of Knowledge (1899 to present), and Scopus (1823 to present). The search was updated in March 2011.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were determined a priori by one researcher (C.B.). To be included, studies needed to be human trials using adult (≥18 yr) participants, in which the effect of a cool/cold beverage was compared with a control beverage that differed only in temperature. Trials did not need to be randomized, but the method of treatment allocation was identified and assessed in the quality analysis of manuscripts. The intervention needed to include ad libitum (voluntary) ingestion of a cold (0–10 °C) or cool (11–21 °C) and control (22–50 °C) beverages with measurement of palatability/preference or volume of fluid consumed during or immediately after (<30 min) exercise. Studies were excluded if they were opinion articles or abstracts or did not quantify the volume of fluid consumption during or immediately after exercise. Studies of fluid consumption outside the context of exercise were excluded, as this would significantly increase heterogeneity and prevent a combined meta-analysis from being conducted.

Data on participants, exercise, environmental conditions, drink type, temperature, palatability/preference ratings, and volume consumed were extracted. If more than one data set was available, any additional data were extracted if applicable. To maintain independence in the meta-analysis, the lowest drink temperature was compared with the beverage (control) closest to body temperature (37 °C). Cohen's explanation of magnitude of effect was used to interpret effect size (ES): 0.2–0.49 small, 0.50–0.79 medium, and >0.8 large (Cohen, 1992). Between-studies variability was examined using the I^2 measure of inconsistency (Higgins, Thompson, Deeks, & Altman, 2003). This statistic, expressed as a percentage of 0–100, provides a measure of how much of the variability between studies is due to heterogeneity rather than chance. Difference in means plus 95% confidence interval (CI; Comprehensive Meta-Analysis, version 2.2, Englewood, NJ) and a percent weighted mean change were calculated. The parameter mean change was multiplied according to number of study participants, and the sum of means was divided by sum of participants from all studies to give the final percent weighted mean. Additional data on body-mass changes, flavoring, and pleasure ratings of beverages were also extracted. Publication bias was not assessed to avoid inappropriate interpretation based on analysis of too few studies (Ioannidis & Trikalinos, 2007).

Study Quality Assessment

Study quality was independently rated by two reviewers (H.O. and P.C.) using an adapted version of Downs and Black (1998). Since the source population was healthy adults, Items 11 (people asked to participate representative of source population) and 12 (actual participants representative of population) were combined, and studies were only required to report the source of the population. Item 13 (representative staff/facilities) was eliminated as it is not required for healthy-population interventions. Items 17 (adjust for length of follow-up) and 26 (losses of patients) were removed as they are not required for single-visit or repeated short-intervention study designs. Power was calculated on the main outcome and given a score of 1 for adequate power or 0 for inadequate power or if it could not be calculated. Where reviewers disagreed, specific criteria were discussed with a third reviewer (C.B.) until consensus was reached. If an item was unable to be determined, a "no" was given. No studies were excluded based on scoring of quality (Higgins & Green, 2011).

Results

The search yielded 500 citations, 15 were found to be relevant from title and abstract searching, and bibliography, journal, and author searching yielded an additional five references. One of these references contained two sets of incomplete data published in a book (Passe, 2001), so we contacted that author, who supplied further information to allow inclusion in our manuscript. After inclusion and exclusion criteria were applied, six papers were removed due to failure to involve exercise conditions (n = 3), nonadult populations (n = 1), or no control condition or beverage >50 °C (n = 3; Figure 1). Data were extracted from 14 remaining studies. Seven papers were published from 1984 to 1989, two in 1997, and four in 2006 or 2007. The unpublished data were obtained from a book chapter published in 2001. Four papers studied the effect of beverage temperature on fluid consumption during or immediately after exercise. Six studied beverage temperature and palatability and four studied both. Exercise modalities were walking (n = 6), cycling (n = 1), and circuit training (n = 1), with exercise duration of 30 min to 3 hr in temperate to hot conditions (22.9–33.9 °C).

The eight studies assessing the effect of beverage temperature on fluid consumption during and after exercise are summarized in Table 1. Due to significant differences in study design where some studies measured postexercise rehydration (Boulze et al., 1983; Passe, 2001; Sandick, Engell, & Maller, 1984), the results were analyzed separately. The meta-analysis of beverage consumption during exercise revealed significant methodological heterogeneity (89%), so a random-effects model was used (Cook el at., 1995). A large ES of 1.4 (0.75–2.04, 95% CI) was found, equating to an 867-ml (442–1,292 ml, 95% CI) difference in mean fluid inges-

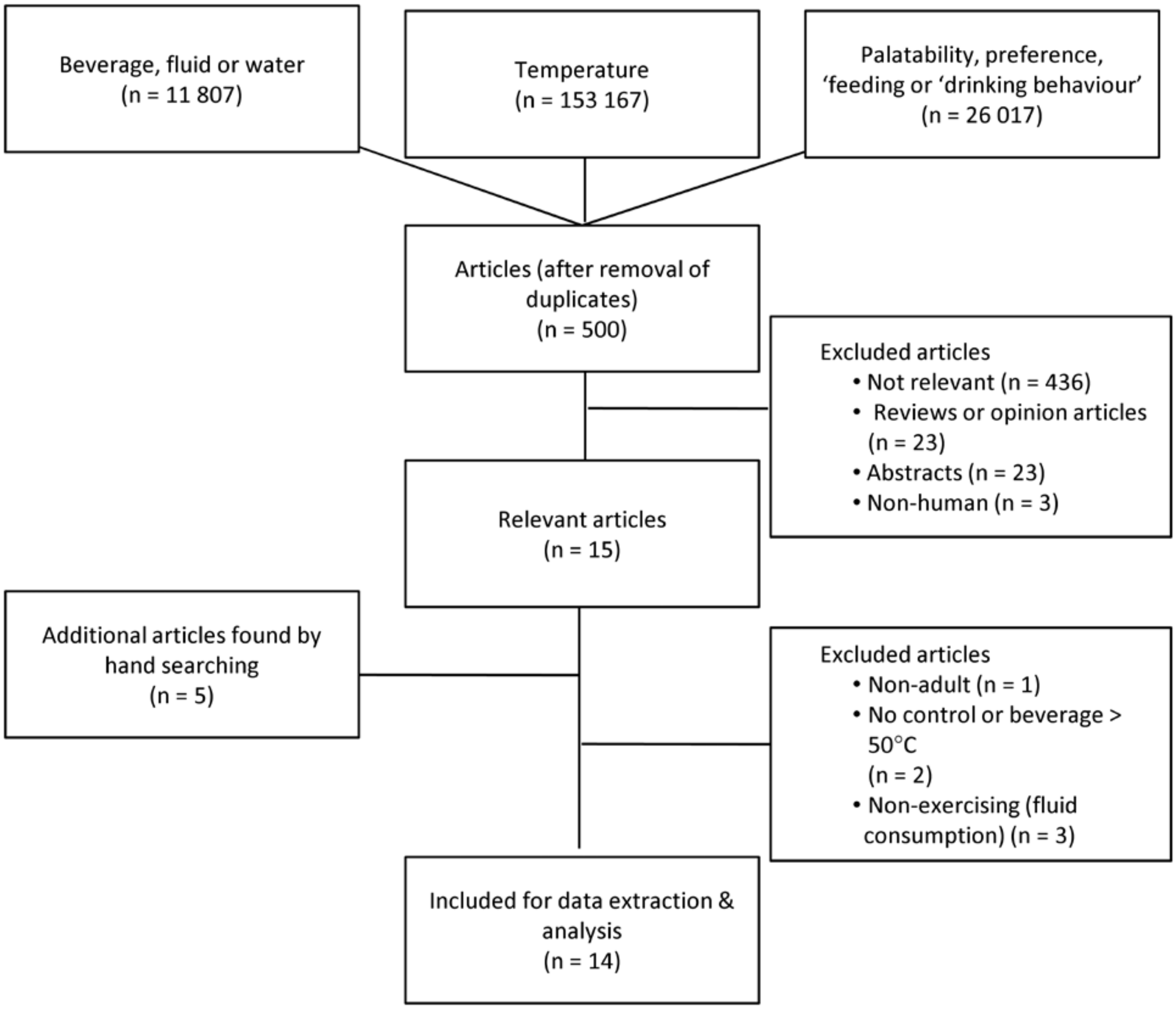

Figure 1 — Flow diagram of search strategy and results.

tion favoring cooler beverages (Figure 2, Table 2). A weighted mean difference found that participants consumed 50% greater volumes of cooler fluids than control drinks. The volume of fluid consumed postexercise increased significantly (ES 0.9, 95% CI 0.20–1.61) by 92 ml (31–154 ml, 95% CI) with cooler versus control-temperature beverages (Figure 3, Table 2). A weighted mean difference of 314% was found.

The drinks provided in studies assessing fluid consumption during or immediately after exercise were water only ($n = 3$), water and a flavored drink ($n = 3$), or flavored drink only ($n = 2$). Of the studies providing flavored drinks, four used carbohydrate solutions of varying concentrations and one failed to provide details of drink composition. Carbohydrate concentrations varied from minimal (0.2 g/100 ml: Mundel, King, Collacott, & Jones, 2006; 0.9 g/100 ml: Szlyk, Sils, Francesconi, Hubbard, & Armstrong, 1989) to moderate (3 g/100 ml: Hubbard et al., 1984; 6 g/100 ml: Passe, 2001). Weighted mean differences (Figure 4, Table 2) indicated that flavoring increased consumption of cooler fluids by 12% (range 3–19%) and control beverages by 33% (–8% to 79%). In the study of Szlyk et al. (1989), where a subgroup of subjects was identified as high drinkers (body-mass change <1%), fluid consumption was less affected by palatability. When this group is removed, the increase in consumption of flavored warm beverages over warm water was 38% (27–79%).

Four studies (Armstrong et al., 1985; Hubbard et al., 1984; Jung, Dale, & Bishop, 2007; Szlyk et al., 1989) reported changes in body mass related to exercise, allowing a measurement of the net mismatch between fluid intake and sweat losses with beverages of different temperatures. Warm-fluid consumption resulted in fluid mismatch greater than 2% of body mass in six of nine data sets reported (Table 1). However, with cold/cool fluid consumption, only one study reported exceeding 2% fluid mismatch, which was in a subgroup of "reluctant

Table 1 Summary of Exercise Studies That Compared the Effect of a Cooler Versus Control Beverage on Fluid Consumption

Reference	*N*	Gender	Age (years)	Fitness	Drink type	Environment (°C)	Activity	Exercise duration (hr)	Time of consumption	Cooler (°C)	Control (°C)	Body-mass change >2%: cool	Body-mass change >2%: control
Armstrong et al., 1985	12	M	23 ± 6.9	NR	W	30	4.8-km/hr, 5%-grade walk, 30:30 intervals	6.0	During	6	46	N	Y
										22	46	N	
										6	22	N	N
Boulze et al., 1983	40	NR	NR	Mod	W	NR	Mountain climbing	2.55	15 s post	15	40	NA	NA
										0	40		
										0	15		
Hubbard et al., 1984	16	M	23 ± 3	NR	F	30.6	4.8-km/hr, 5%-grade walk, 30:30 intervals	6.0	During	15	40	N	N
					W							N	Y
Jung et al., 2007	10	M	23.4 ± 1	Mod	W & F	30.0	4.8-km/hr walk	3.0	During	7	25	N	N
Mundel et al., 2006	8	M	26 ± 7	Mod	F	24.2	65% VO_{2peak} cycle	0.91–1.0	During	3.6	19	NR	NR
Passe, 2001	58	35 M, 23 F	23–55	NR	SD	NR	70–85% HR_{max} circuit	0.5	Post till full (<10 min)	2, 7, 15	22	NA	NA
Passe, 2001	57	NR	NR	NR	SD vs. W	NR	70–85% HR_{max} circuit	0.5	Post	NA	32	NA	NA
Sandick et al., 1984	18	16 M, 2 F	24 ± 4.2	Mod	W	23.0	8 min calisthenics + 20-min run	0.46–55	15 min post	5	37	NA	NA
										15	37		
										5	15		
Szlyk et al., 1989	9 (D)	M	21–33	NR	W	32.1	4.8-km/hr, 5%-grade walk, 30:30 intervals	6.0	During	15	40	N	Y
					F							N	Y
	5 (RD)				W							Y	Y
					F							Y	Y

Note. D = drinkers; RD = reluctant drinkers; M = male; F = female; NR = not reported; NA = not applicable; Mod = moderate; W = water; F = flavored water; SD = sports drink; Y = yes; N = no. Age is given as *M* ± *SD* or range.

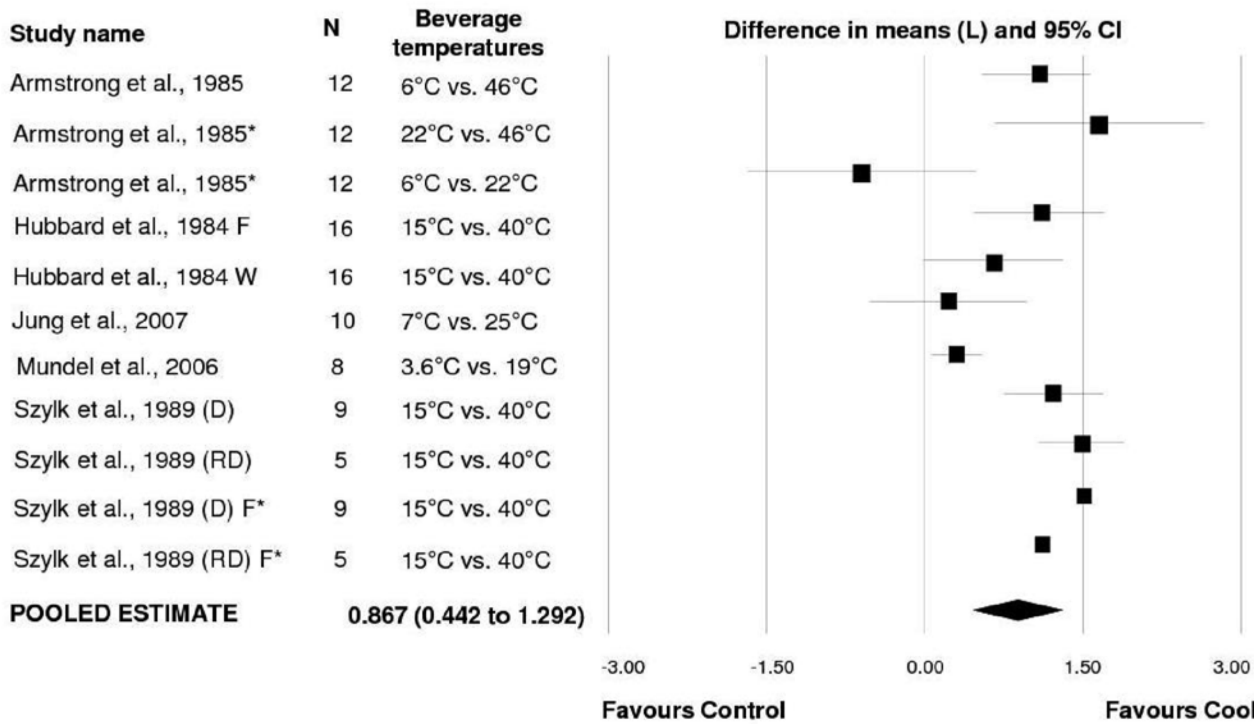

Figure 2 — Meta-analysis of five trials of beverage temperature and fluid consumption during exercise. F = flavored; W = water. Szlyk et al.'s groups are drinkers (D) and reluctant drinkers (RD). *Removed from meta-analysis to maintain independent comparison.

drinkers." In a subanalysis of the four studies, cold/cool beverages were associated with a smaller change in body mass (i.e., smaller fluid mismatch) than trials with warmer beverages, with a mean improvement in hydration status equivalent to 1.3% of body mass (1.6–0.9%, 95% CI; Figure 5, Table 2).

Ten studies assessed palatability or preference for beverages at different temperatures (Table 3). A quantitative summary analysis was not possible, as few papers ($n = 5$) provided numerical data or statistical analysis between temperatures and negative and positive descriptors of preference/palatability were varied. However, the available data were plotted and demonstrate increased liking/preference with cooler beverages (Figure 6). Data from studies without statistical analysis additionally suggest that most conditions and studies found a positive descriptor associated with cooler beverage temperatures (Table 3). Outcome data from all studies were used to calculate a weighted mean change, revealing a 79% greater preference for cooler beverages over the control beverages.

The quality rating of the studies revealed common shortcomings (Table 4). Descriptions of participant characteristics were often inadequate, and studies did not identify the source population represented. Few reported an actual p value for main outcomes, and, where applicable, many studies did not report potential or actual adverse events. None were blind to beverage temperature, since masking the temperature of ingested fluids is not possible. Only one study was not randomized (Boulze et al., 1983).

Discussion

This systematic review of the literature on fluid intake during and after exercise demonstrates that cooler beverages (0–22 °C) tend to be more palatable and are associated with higher ratings of pleasure and reduction of thirst than warmer beverages (22–46 °C). These beneficial characteristics of cold beverages are evident across a wide variety of conditions including differences in hydration status, a range of ambient temperatures, and both the exercise and postexercise situation. In studies conducted in temperate to warm conditions, the increased palatability of cooler beverages translated to a 50% and 314% increase in consumption during and immediately after exercise, respectively.

The studies investigated a range of different exercise and fluid protocols, with five studies involving the consumption of beverages during exercise and three studies examining fluid consumption on the completion of exercise (Boulze et al., 1983; Passe, 2001; Sandick et al., 1984). Most studies were of crossover design and assigned participants to a beverage temperature on separate visits. However, one study allowed participants to access beverages at different temperatures simultaneously (Sandick et al., 1984), and another (Boulze et al., 1983) assigned groups to different beverage temperatures while

Table 2 Mean Difference for the Influence of Beverage Temperature and Flavor on Fluid Consumption and Body-Mass Change

Reference	Drink type	Cooler (°C)	Control (°C)	Beverage consumption (dif. in means for temperature; L; 95% CI)	Cooler vs. control, $p < .05$	Body-mass change (dif. in means; kg; 95% CI)	Cooler vs. control, $p < .05$	Beverage consumption (dif. in means for flavoring; L; 95% CI)	Flavor vs. water, $p < .05$
Armstrong et al., 1985	W	6	46	1.050 (0.522–1.578)	Y	–1.6 (–2.2 to –1.0)	Y		
		22	46	1.650 (0.651–2.649)	Y	–1.10 (–1.7 to –0.5)	Y	NA	
		6	22	–0.600 (–1.696 to 0.496)[a]	N	–0.5 (–1.1–0.1)	N		
Boulze et al., 1983	W	15	40	0.075 (0.053–0.097)	Y	NA		NA	
		0	40	0.192 (0.157–0.227)	Y				
		0	15	–0.117 (–0.156 to 0.078)[a]	N				
Hubbard et al., 1984	F	15	40	1.079 (0.451–1.707)	Y	–1.3 (–1.8 to –0.7)	Y	0.584 (–0.29 to 1.46) α	N
	W			0.640 (–0.037 to 1.317)	Y	–1.1 (–1.9 to –0.2)	Y	0.494 (–0.04 to 1.03) β	N
Jung et al., 2007	W & F	7	25	0.220 (–0.534 to 0.974)	N	–0.1 (–0.9–0.7)	N	0.16 (–0.08 to 0.4) α	N
Mundel et al., 2006	F	3.6	19	0.300 (0.050–0.550)	Y	NR		NA	
Passe, 2001	SD & W	2	22	0.003 (–0.05 to 0.06)	N	NA		NA	
		2	15	–0.026 (–0.08 to 0.03)[a]	N				
		15	22	0.029 (–0.02 to 0.08)	N				
		2	32	0.07 (0.02–0.13)	NR				
		15	32	0.10 (0.05–0.15)	NR				
		NA	32	NA	N			0.049 (0.04–0.06) α	Y
Sandick et al., 1984	W	5	37	0.242 (0.142–0.342)	NR	NA		NA	
		15	37	0.112 (0.059–0.165)	NR				
		5	15	0.130 (0.020–0.240)	NR				
Szlyk et al., 1989	W & F	15	40	1.217 (0.734–1.701) D	Y	–1.37 (–1.7 to –1.0) D	Y	0.11 (NR) β –0.172 (NR) α	
				1.481 (1.065–1.897) RD	Y	–1.53 (–1.8 to –1.3) D	Y	0.29 (–0.1 to 0.68) β 0.811 (0.57–1.05) α	N Y

Note. W = water; F = flavored water; SD = sports drink; D = drinkers; RD = reluctant drinkers; Y = yes; N = no; NA = not applicable; NR = not reported. α is control and β is cooler drink temperature comparison.

[a]Control fluid consumed more than cold. For flavoring vs. water, a positive number favors flavoring.

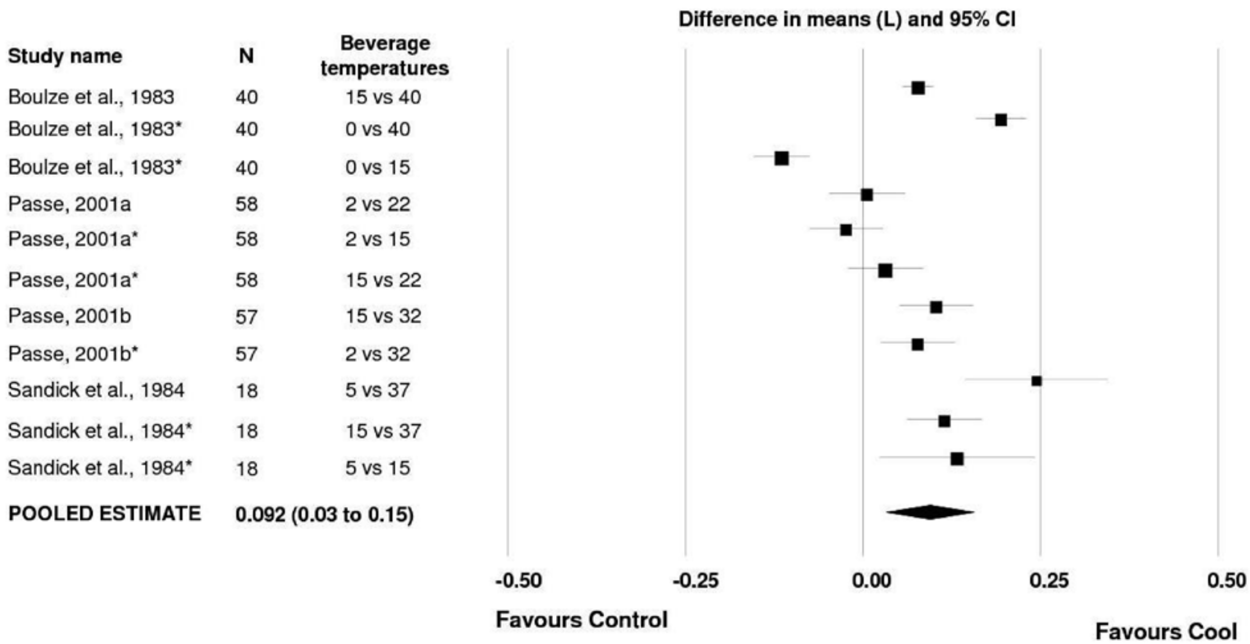

Figure 3 — Meta-analysis of four trials of beverage temperature and fluid consumption immediately postexercise. F = flavored; W = water. *Removed from meta-analysis to maintain independent comparison.

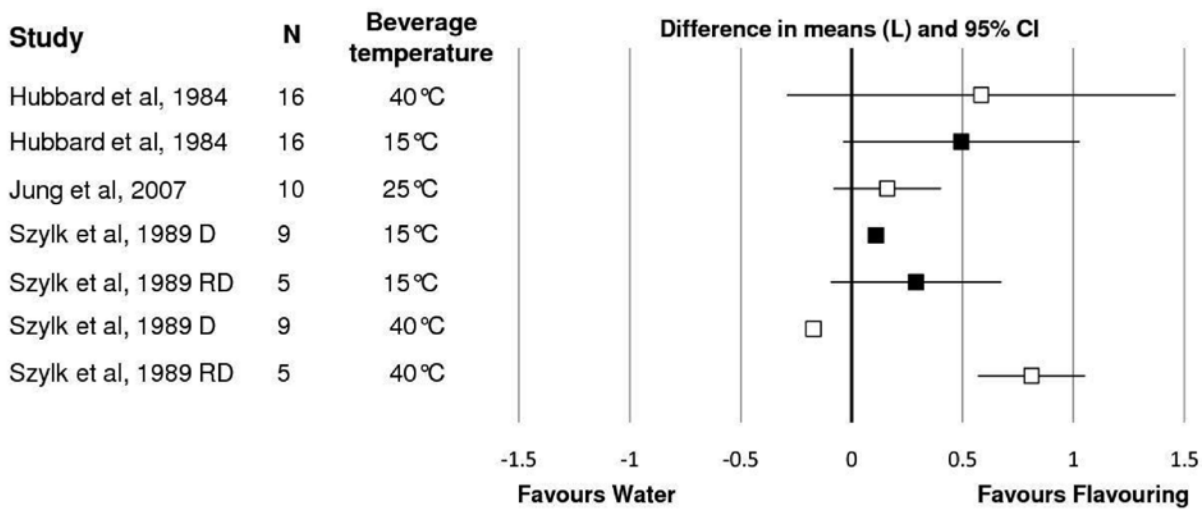

Figure 4 — Effect of flavoring on volume consumption of cold (fill) and control (no fill) beverages. Szlyk et al.'s groups are drinkers (D) and reluctant drinkers (RD).

allowing participants in one experiment to mix beverages to create their preferred temperature.

The mechanism behind sensations of pleasure elicited by cold versus warm beverages remains unclear. Early rodent-based research showed that saliva production was increased in rats with cold (0 °C) versus warm (22 and 37 °C) beverage ingestion (Pangborn, Chrisp, & Bertolero, 1970). Furthermore, fluid consumption in rats was not different when ambient (skin) temperature was cold (5 °C) or warm (40 °C), but when both mouth and skin temperature were altered together, cold-fluid consumption was reduced (Carlisle, 1977). These findings were interpreted as evidence for an orolingual-receptor mechanism that influences fluid consumption by feedback from temperature-sensitive receptors in the mouth rather than skin. The suggestion for a direct orolingual mechanism in humans is supported by evidence that cold beverages are associated with increased saliva production (Brunstrom & Macrae, 1997) and reduced negative sensations of thirst and dry mouth (Brunstrom

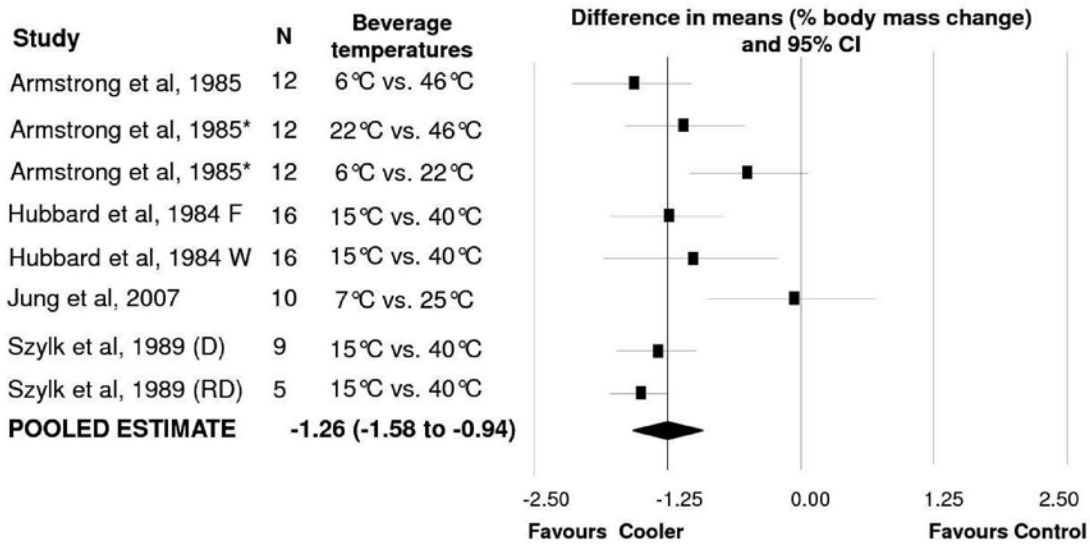

Figure 5 — Effect of beverage temperature on percent body-mass loss during exercise. F = flavored; W = water. Szlyk et al.'s groups are drinkers (D) or reluctant drinkers (RD).*Removed from meta-analysis to maintain independent comparison.

& Macrae, 1997; Brunstrom, 2002; Guest et al., 2006). Furthermore, cold-fluid consumption has been found to increase pleasantness and to stimulate areas of the brain associated with pleasure (Guest et al., 2007).

Studies assessing the reported palatability of drinks consumed during or postexercise determined that pleasure was greatest with cold drinks (0–10 °C) and slowly decreased as beverage temperature rose (Boulze et al., 1983; Passe, 2001; Sandick et al., 1984). The reduction in palatability and pleasure of warm beverages appears to terminate drinking and result in greater dehydration as measured by greater loss of body mass. This relationship is not always clear, however. Although an increase in pleasure with cold-beverage consumption would be expected to result in the greatest fluid ingestion, some studies have found that cold beverages (0–10 °C) were rated as more pleasant than cool drinks (11–22 °C) but were ingested in smaller volumes (Armstrong et al., 1985; Boulze et al., 1983; Passe, 2001 ; Sandick et al., 1984). This finding was replicated by the study of Passe (2001) where assessment of liking was higher with the cold (2 °C) versus cool (15 °C) beverage, yet cool fluids were consumed in ~7% greater volumes. A possible explanation is that drinking may be terminated more rapidly with cold (<10 °C) than with cool (11–22 °C) beverages if the coldest temperatures are "over pleasant" and reduce thirst. The combination of results of palatability, volumes of ingestion, and observed changes in body-mass loss from the currently available studies suggests that 10–20 °C is the temperature range of the drinks that are likely to achieve goals of fluid intake in relation to exercise. Indeed, Boulze et al. observed that beverages were consumed at a higher rate when served at 15 °C than at other temperatures, and when participants were allowed to prepare their own drinks, this was their preferred beverage temperature.

The positive influence of cooler beverages on pleasure, palatability, and fluid consumption appears to be greater during exercise (ES 1.4) when compared with postexercise hydration (ES 0.9). Furthermore, consumption of cooler beverages during exercise has been found to have a direct benefit for endurance performance in the heat (Mundel et al., 2006). Initially, the benefit of cold-beverage consumption was hypothesized to result from a reduction in core body temperature (Burdon et al., 2010) or improved gastric emptying (Bateman, 1982; Costill & Saltin, 1974). The effect on gastric emptying was later deemed negligible after investigation with superior methodology (Lambert & Maughan, 1992) and findings that intragastric temperature recovers quickly (within 5–10 min; Shi, Bartoli, Horn, & Murray, 2000). Aside from thermoregulatory mechanisms, an important benefit of cooler beverages may be an increase in fluid consumption during exercise in the heat. Recent research has investigated whether the sensation of increased pleasure associated with cold fluids can directly affect exercise capacity. One such study found that mouth rinsing with menthol to elicit a cool sensation improved cycling time to exhaustion in the heat compared with a placebo (Mundel & Jones, 2010). In another investigation, the reduction in maximal isometric contraction was ameliorated with consumption of a cold beverage after exhaustive running in the heat (Siegel, Maté, Watson, Nosaka, & Laursen, 2011). Human evidence for an orolingual mechanism whereby cold sensations increase pleasure is strong but requires further investigation.

Given the potential detrimental effect of dehydration on thermoregulation and exercise performance (Cheuvront et al., 2003), it is important to assess whether consumption associated with the palatability of cold or cool beverages improves hydration status compared with warm beverages. From the studies where information on

Table 3 Summary of Included Beverage-Palatability Studies

Reference	*N*	Subjects	Condition	Measure	Time posttasting of measure	Volume	Drink type	Cooler temp	Result	Control temp	Result	Pref temp
Boulze et al., 1983	40	NR	Dehydrated, hyperthermic	Pleasure (LS)	Immediate	"Mouthful"	Water	0	1	40	–1	Cold
	40							10	1	40	–1	Cold
Brunstrom & Macrae, 1997	20	F	Rested	Mouth-dryness reduction (VAS; mm)	2.5 min	150 ml	Water	5	34.1 ±20.6	22	9.7 ±11.4	Cold*
		F				400 ml		5	43.6 ±19.3	22	28.8 ±17.7	Cold
	20	M				150 ml	Water	5	22.0 ±21.8	22	20.7 ±13.9	Cold
		M				400 ml		5	38.0 ± 26.9	22	13.2 ±10.4	Cold*
	20	M		Thirst reduction (VAS; mm)		150 ml	Water	5	12.5 ±12.7	22	22.4 ±18.0	Control
		M				400 ml		5	43.5 ±25.6	22	18.4 ±11.4	Cold*
Brunstrom, Macrae, & Roberts, 1997	32	22 M, 10 F	Dry mouth	Pleasantness (LS)	Immediate	"Swill for 5 s"	Water	3	1	33	0	Cold
			Control					3	–1	33	–1	—
			Dry mouth					13	1	33	0	Cold
			Control					13	1	33	–1	Cold
Cabanac & Ferber, 1987	4	M, 18–22 years	Rested	Pleasure (VAS)	Immediate	10 ml	Sweetened water	10	+1	40	0 or –1	Cold
Guest et al., 2006	22	14 M, 8 F, 29.8 years	Rested	Mouth dryness (VAS)	Immediate	1.5 ml	Water	8	0.24 ± 0.11	25	0.20 ± 0.11	Cold
								8	0.24 ± 0.11	16	0.30 ± 0.11	Control
								16	0.30 ± 0.11	25	0.20 ± 0.11	Cool
	22		Dry mouth	Mouth dryness (VAS)	Immediate	1.5 ml	Water	8	0.82 ± 0.21	25	0.68 ± 0.32	Cold
								8	0.82 ± 0.21	16	0.68 ± 0.32	Cold
								16	0.68 ± 0.32	25	0.68 ± 0.32	—
	22	14 M, 8 F, 29.8 years	Rested	Pleasantness (VAS)	Immediate	1.5 ml	Water	8	0.44 ± 0.17	25	0.12 ± 0.28	Cold
								8	0.44 ± 0.17	16	0.32 ± 0.17	Cold
								16	0.32 ± 0.17	25	0.12 ± 0.28	Cool
	22		Dry mouth	Pleasantness (VAS)	Immediate	1.5 ml	Water	8	0.49 ± 0.17	25	0.14 ± 0.22	Cold
								8	0.49 ± 0.17	16	0.35 ± 0.22	Cold
								16	0.35 ± 0.22	25	0.14 ± 0.22	Cool
Guest et al., 2007	5	NR	Rested	Pleasure (VAS)	~10 s	1.5 ml	Artificial saliva	5	2.36 ±2.2	20	1.91 ±1.7	Cold
Passe, 2001	58	NR	Postexercise	Liking (LS)	Immediate	Ad libitum	6% CEB	2	6.96 ± 1.17	22	5.79 ± 1.52	Cold
								2	6.96 ± 1.17	15	6.57 ± 1.17	Cold
								15	6.57 ± 1.17	22	5.79 ± 1.52	Cold
Passe, 2001	58	NR	Postexercise	Liking (LS)	Immediate	Ad libitum	6% CEB	2	6.9 ± 0.18	32	5.09 ± 0.15	Cold
Sandick et al., 1984	18	16 M, 2 F	Exercise	Preference (LS)	Immediate	Ad libitum	Water	5	3.2 ±0.85	38	–2.6 ±1.27	Cold*
	18	24 ± 4.2 years						15	2 ±1.27	38	–2.6 ±1.27	Cool*
Szlyk et al., 1989	9	M	Drinkers	Thirst (LS; % not thirsty)	NR	Ad libitum	Flavored water	15	60	40	43	Cool
	5	21–33 years	Reluctant					15	54	40	46	Cool
Zellner, Rozin, & Brown, 1988	13	NR	Rested	Liking (VAS; cm)	Immediate	NR	Water	2.5	7	22.5	9	Cool

Note. NR = not reported; M = male; F = female; LS = Likert scale; VAS = visual analog scale; CEB = carbohydrate-electrolyte beverage; temp = temperature; Pref = preferred. Included studies used a range of exercise and rested conditions where participants were provided beverages of differing temperature and were required to rate palatability (liking, thirst or pleasure) on a scale.

*$p < .05$.

Study name (N)	Scale		Beverage temperatures	Hedges's g (95% CI)	p-Value
Brunstrom et al., 1997a (20)	Mouth dryness (F)	150mL	5 vs 22°C	1.40 (0.46 to 2.35)	0.004
		400mL	5 vs 22°C	0.77 (-0.11 to 1.64)	0.085
Brunstrom et al., 1997a (20)	Mouth dryness (M)	150mL	5 vs 22°C	0.07 (-0.77 to 0.91)	0.874
		400mL	5 vs 22°C	1.17 (0.25 to 2.08)	0.012
Brunstrom et al., 1997a (20)	Thirst (M)	150mL	5 vs 22°C	-1.34 (-2.28 to -0.41)	0.005
		400mL	5 vs 22°C	0.25 (-0.59 to 1.10)	0.554
Guest et al., 2006 (22)	Mouth dryness	1.5 mL	8 vs 25°C	0.36 (-0.23 to 0.94)	0.232
			8 vs 16°C	-0.54 (-1.13 to 0.06)	0.076
			16 vs 25°C	0.89 (0.28 to 1.50)	0.004
Guest et al., 2006 (22)	Mouth dryness (dried mouth)	1.5 mL	8 vs 25°C	0.51 (-0.08 to 1.10)	0.091
			8 vs 16°C	0.51 (-0.08 to 1.10)	0.091
			16 vs 25°C	0.00 (-0.58 to 0.58)	1.000
Guest et al., 2006 (22)	Pleasantness	1.5 mL	8 vs 25°C	1.36 (0.71 to 2.00)	0.000
			8 vs 16°C	0.69 (0.10 to 1.29)	0.023
			16 vs 25°C	0.85 (0.24 to 1.46)	0.006
Guest et al., 2006 (22)	Pleasantness (dried mouth)	1.5 mL	8 vs 25°C	1.75 (1.06 to 2.43)	0.000
			8 vs 16°C	0.70 (0.10 to 1.30)	0.022
			16 vs 25°C	0.94 (0.33 to 1.55)	0.003
Guest et al., 2007 (5)	Pleasure	1.5 mL	5 vs 20°C	0.21 (-0.92 to 1.33)	0.718
Passe, 2001 (58)	Liking	Ad libitum	2 vs 22°C	0.86 (0.48 to 1.24)	0.000
			2 vs 15°C	0.33 (-0.03 to 0.70)	0.075
			15 vs 22°C	0.57 (0.20 to 0.94)	0.002
Sandick et al., 1984 (18)	Preference	Ad libitum	5 vs 38°C	5.25 (3.88 to 6.62)	0.000
			15 vs 38°C	3.54 (2.50 to 4.58)	0.000

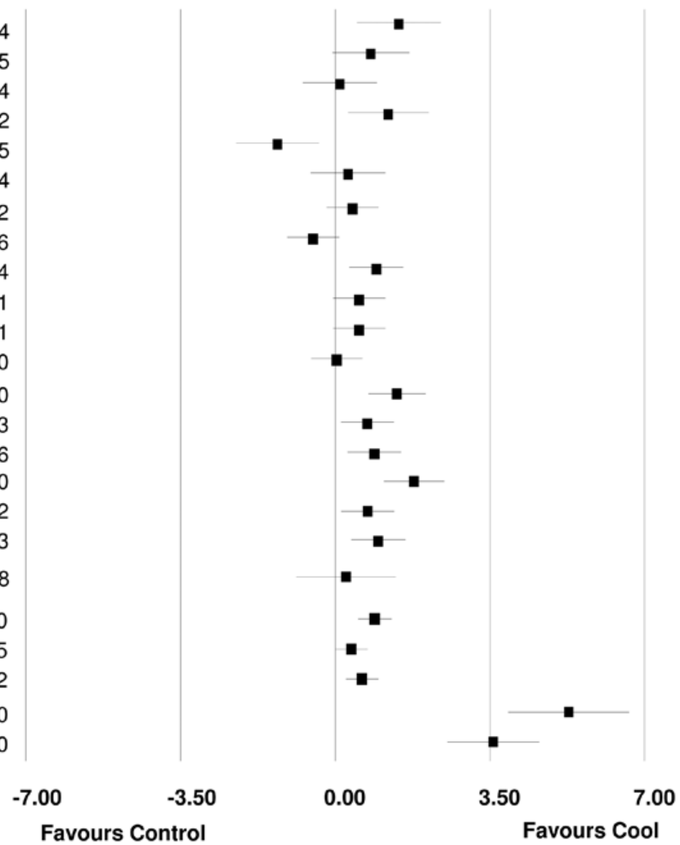

Figure 6 — Effect of beverage temperature on palatability and preference. F = flavored; W = water. Szlyk et al.'s groups are drinkers (D) or reluctant drinkers (RD).

Table 4 Quality Ratings of Included Studies

Studies	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	Data dredging	Statistical tests	Compliance	Accurate measures	Same population recruited	Same time recruitment	Randomized to groups	Concealed randomization	Adjust for confounders	Power	Total (/24)
Armstrong et al., 1985	Y	Y	N	Y	Y	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N	Y	Y	16
Boulze et al., 1983	Y	Y	N	Y	P	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	Y	11
Brunstrom & Macrae, 1997	Y	Y	N	Y	P	N	Y	N/A	Y	N	N	N	N	Y	Y	Y	Y	N	U	Y	N	Y	Y	13
Brunstrom et al., 1997	Y	Y	N	Y	P	N	N	N/A	Y	N	N	N	N	Y	Y	Y	Y	Y	U	Y	N	Y	Y	13
Cabanac et al., 1987	Y	Y	Y	Y	P	N	N	N/A	Y	N	N	N	N	Y	Y	Y	Y	N	U	Y	N	Y	N	12
Guest et al., 2006	Y	Y	N	Y	P	Y	Y	N/A	Y	Y	N	N	N	Y	Y	Y	Y	Y	U	U	N	Y	Y	15
Guest et al., 2007	Y	Y	N	Y	P	Y	Y	N/A	N	Y	N	Y	N	Y	Y	Y	Y	Y	U	Y	Y	Y	N	16
Hubbard et al., 1984	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	U	Y	Y	Y	Y	18
Jung et al., 2007	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N	Y	N	17
Mundel et al., 2006	Y	Y	N	Y	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	18
Passe, 2001	N	Y	N	Y	Y	N	N	N	Y	N	N	N	N	U	U	Y	Y	Y	Y	U	U	Y	Y	10
Sandick et al., 1984	Y	Y	N	Y	P	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	16
Szlyk et al., 1989	Y	Y	N	Y	Y	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	17
Zellner et al., 1988	Y	Y	N	Y	P	Y	N	N/A	Y	N	N	N	N	Y	Y	Y	Y	Y	U	Y	N	Y	Y	15
	Reporting										Ex val	Internal validity (bias)						Internal validity (confounding)						
Total (maximum 14)	13	14	2	14	14	9	9	2	13	3	0	1	0	12	12	14	14	12	5	12	2	13	10	

Note. Y = yes; N = no; P = partial; N/A = not applicable; U = unable to determine; Ex val = external validity. Confounder distribution score: 1 for partial description, 2 for yes.

changes in hydration status was available, cool (6–22 °C) beverages reduced the apparent fluid deficit associated with exercise by the equivalent of 1.3% body mass compared with trials involving warmer (>20 °C) fluids. This reduction in dehydration is meaningful, given that losses of 2% body mass have been associated with performance decrements (Cheuvront et al., 2003). In three studies, the change in fluid volumes associated with altering beverage temperature was found to have a significant effect on net changes in body mass, but one study failed to find an effect of increased beverage consumption on body-mass changes (Jung et al., 2007).

While temperature is an important influence on beverage palatability and preference, beverage flavoring seems to impart an independent effect (Hubbard et al., 1984). Flavoring beverages at cold temperatures has less effect on consumption (12% increase in consumption compared with water; Hubbard et al., 1984; Szlyk et al., 1989) than flavoring warm beverages (which increased consumption by 38% compared with water; Hubbard et al., 1984; Jung et al., 2007; Szlyk et al., 1989). A benefit of flavoring on consumption has been reported by others (Passe, Horn, & Murray, 2000) and may relate to low concentrations (<0.5 M) of warmer sucrose solutions being perceived as sweeter than similar solutions served at cooler temperatures (Bartoshuk, Rennert, Rodin, & Stevens, 1982; Calvino, 1986). Flavoring and the interaction between temperature, flavoring, and palatability deserve further investigation.

Limitations

There are several limitations in the current work that deserve consideration, particularly in relation to the caliber of the literature informing this review. Despite similarities in the design of studies assessing fluid consumption during exercise, there was a large range in exercise duration and environmental conditions. The fluid-ingestion protocols varied substantially, resulting in wide ranges in beverage consumption. Participant description was often poor, and many of the palatability studies gave little or no information on the source population, age, and gender. In addition, data reports were often incomplete, limiting our statistical analysis. Only four of eight palatability studies provided a mean and a measure of variance, restricting our evaluation to observational reporting.

Conclusion

Fluid replacement is recommended to minimize hypohydration during endurance exercise, particularly when performed in hot and humid conditions (Sawka et al., 2007). However, achieving adequate fluid replacement under these conditions is often difficult (Sawka & Montain, 2000; Shirreffs, 2005). By systematic review, we have presented data that suggest that cooler beverages increase palatability and consumption. Due to higher volumes of fluid consumption and decreased levels of body-mass loss associated with beverage served at 10–20 °C, it appears that this is the preferred temperature range for beverages used for fluid replacement during exercise in temperate to warm environments.

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