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REVIEW PAPER

Optimizing Ice Slurry Ingestion for Endurance Performance in the Heat: A Meta-Analysis

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Abstract

Ice slurry ingestion is a simple cooling intervention purported to improve endurance performance. Despite its popularity in the field, a recent meta-analysis suggested this intervention has no performance effect. The aim of the present meta-analysis was to determine the effect of ice slurry ingestion on endurance performance in the heat. Data for this meta-analysis were retrieved from the PubMed. Effect sizes were calculated as the standardized mean difference (Hedges' g), and meta-analyses were completed using a random-effects model. A method-of-moments meta-regression was used to determined confounding factors. Sixteen studies using randomized controlled trials with a total of 152 subjects were included. Improvement in endurance performance in the heat was moderate: g=0.54 (95% confidence interval, 0.30-0.77, p<0.001). There was a significant dose effect associated with the endurance performance (p=0.024); moreover, the performance effects of ice slurry ingestion were not influenced by the timing of ingestion or environmental conditions. These data support the ingestion of ice slurry during endurance events in the heat. To optimize this simple cooling strategy in the field, it is recommended to ingest no more than 10 g • kg^{-1} before or during exercise.

Key words: *Cooling, Thermoregulation, Time to Exhaustion, Systemic Review*

Introduction

Environmental heat has been well documented to impact negatively athletes during high-intensity, long duration competitions. Exercising in high temperature and/or high humidity decreases time to exhaustion, increases heat storage, and reduces endurance performance (Nybo, Rasmussen, & Sawka, 2014). For elite endurance athletes competing at the highest level, performance in the heat has been shown to be impaired by ~3% compared to thermoneutral competition conditions (Guy, Deakin, Edwards, Miller, & Pyne, 2015). Considering the smallest worthwhile variation in elite endurance runners is less than 2.5% (Hopkins & Hewson, 2001), strategies that could effectively mitigate the negative influences of heat are highly relevant to the medal perspective for elite athletes competing in hot and humid environments.

Not surprisingly, there is an ever-increasing interest in active cooling strategies for high-intensity sports that are of a long duration in challenging environments. Successful interventions include cold water immersion, cooling vests, cold/ice drinks that can be applied as pre-cooling and/or during exercise (Bongers, Thijssen, Veltmeijer, Hopman, & Eijsvogels, 2015). Active cooling strategies are recognized by both practitioners and sports scientists for the successful participation in endurance exercise in the heat. Interestingly, ice slurry ingestion has been reported to be the most prevalent cooling strategy amongst elite athletes preparing for the 2015 World Athletics Championships (Periard et al., 2017). While the specific reason for the popularity of ice slurry ingestion amongst elite athletes is not known, one of the possible reasons could be that ice slurry ingestion represents an effective yet practical intervention for field applications. When employed as a pre-cooling intervention, ice slurry ingestion could effectively reduce core temperature at the commencement of exercise and, such effect could be carried over during the early stage of exercise, thus acting as a heat sink in challenging environments (Naito, Iribe, & Ogaki, 2017; Siegel et al., 2010). It has been reported

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that manipulating core temperature by lowering 0.4°C at the commencement of exercise reduced the sweat rate by 20.3% and subsequently increased endurance capacity by 6.8% in a thermoneutral environment (Hessemer, Langusch, Bruck, Bodeker, & Breidenbach, 1984). Increasing the body's heat storage capacity is a primary mechanism that enables ice slurry ingestion to improve endurance performance in the heat. As importantly, logistical issues associated with active cooling strategies prior to and/or during elite competition in the field also favor the adoption of this simple intervention.

Given that environmental heat and humidity can severely limit performance, hence medal chances, in elite competition, optimizing ice slurry ingestion is of interests to elite athletes participating in endurance events. Currently, there is no consensus regarding the dose-response relationship, timing strategy, and influences of different environmental temperature and humidity conditions (Bongers et al., 2015; Choo, Nosaka, Peiffer, Ihsan, & Abbiss, 2018). Accordingly, this meta-analysis explored up-to-date evidence on how effective ice slurry ingestion could enhance endurance performance in the heat, and in particular, highlighted key intervention strategies that could influence its effect.

Methods

Literature search

A computer-based systematic search (EndNote, ver. X9, Clarivate Analytics, USA) was performed in the PubMed database to identify potentially relevant studies. The keywords used were Ice slu* (slurry, slushy, slush) ingestion, which yielded 201 initial records. Searches were made in December 2018 and last updated in December 2018.

The initial screening consisted of title and abstract review. The general inclusion criteria for studies in this first screening were: full-length experimental articles, reporting healthy human subjects, with ice slurry ingestion, and exercising in the heat. Thus, 40 full texts studies were assessed for further eligibility. The specific exclusion criteria were as follows: no measurement of endurance performance (n= 9); measurement of uncompensable work performance, that is, firefighters (n=4); existence of additional cooling strategies that the main effect of ice slurry ingestion cannot be isolated (n=3); outcome assessed by power outputs, repeated sprints, intermittent exercise, or graded exercise to predict endurance performance (n=8); and core temperature at the end of endurance performance test was below 38°C (n=1). One additional study (Riera, Trong, Sinnapah, & Hue, 2014) was identified through cross-referencing eligible studies. Therefore, a total of 16 eligible studies were included in the meta-analysis (Burdon, Hoon, Johnson, Chapman, & O'Connor, 2013; Ihsan, Landers, Brearley, & Peeling, 2010; Jeffries, Goldsmith, & Waldron, 2018; Maunder, Laursen, & Kilding, 2017; Naito et al., 2017; Naito & Ogaki, 2017; Riera et al., 2014; Siegel et al., 2010; Siegel, Mate, Watson, Nosaka, & Laursen, 2012; Stanley, Leveritt, & Peake, 2010; Stevens, Dascombe, Boyko, Sculley, & Callister, 2013; Stevens et al., 2016; Takeshima, Onitsuka, Xinyan, & Hasegawa, 2017; Tran Trong, Riera, Rinaldi, Briki, & Hue, 2015; Yeo, Fan, Nio, Byrne, & Lee, 2012; Zimmermann, Landers, & Wallman, 2017).

Data extraction

Using a standardized sheet, the following information was extracted from each of the included studies: total number of subjects, demographics, environmental conditions, intervention strategies, exercise protocols, and comparisons in outcome measures of endurance performance test. The ice dose was standardized as ice slurry ingestion relative to the body mass (i.e., g·kg-1). Four studies did not report this value directly and the doses were estimated using the total fluid consumption divided by the mean body mass reported in each study (Maunder et al., 2017; Riera et al., 2014; Stanley et al., 2010; Tran Trong et al., 2015). For one study (Riera et al., 2014), the ice dose was determined by combining the ice/fluid ingestion during warm-up, immediately at the beginning of the performance trial, at the 1st, 2nd and 3rd 5-km of the 20-km time trial. For one study (Tran Trong et al., 2015), the ice dose was determined based on during one block of 4-km cycling and 1.5-km running. Studies that employed ice slurry ingestion prior to the endurance performance test only, were coded for subgroup analysis.

The assessment of risk of bias for each study was completed by using the Physiotherapy Evidence-Based Database Scale (PEDro) (Moseley, Herbert, Sherrington, & Maher, 2002). The scale assesses bias for each study from 11 evidence-based criteria. However, due to blinding of the ice slurry ingestion was not practical, the highest score that could be obtained from the scale was adjusted to 8.

Meta-analysis

Since a post-analyses of the results suggest the temperature gradient of the ice and fluid ingestion does not affect the effect size, the trial results based on two different control fluid temperatures (Tran Trong et al., 2015) were combined (Julian PT Higgins & Green, 2008) to avoid the unit-of-analysis error. Studies that investigated the temporal effect of ice slurry ingestion were treated as independent data points (Naito et al., 2017; Takeshima et al., 2017). For one study (Yeo et al., 2012), the environmental condition was estimated (ambient temperature as 32°C, and relative humidity as 55%) based on general information from that article. Sensitivity analysis checked how this imputation of missing data would have influenced the precision of the results.

Due to the nature of sports science studies, the included studies were based on small sample size. Hence, the Hedges' g values were calculated as effect size in this meta-analysis (Comprehensive Meta-Analysis, ver. 3.3, Biostat, USA) and interpreted as small effect (g=0.2), moderate effect (g=0.5), or large effect (g=0.8). Considering populations and experimental protocols vary across studies, a random-effects model was fitted for the meta-analysis. A positive g indicates improved endurance performance following ice slurry ingestion, whereas a negative g indicates null effects following ice slurry ingestion. Confidence intervals (CIs, 95%) not overlapping the null were considered a statistically significant effect.

The inter-study heterogeneity was quantified based on the Cochran's Q statistic, with a cutoff significance level of 10% (J. P. Higgins, Thompson, Deeks, & Altman, 2003). A method-of-moments meta-regression was performed to identify covariates for the dispersion of the main effect size. The publication bias was visually inspected based on the funnel plot method.

Table 1. Characteristics of the 16 Studies Examining the Effect of Ice Slurry Ingestion on Endurance Performance

Citation	Subject characteristics			Ambient environment	Ice slurry ingestion		Endurance performance test
	n^a	Age (yr)	VO_{2max} (ml·kg^{-1}·min^{-1})		Dose (g·kg^{-1})	Ingestion strategy	
Burdon et al., 2013	10	30.1	61.8	32°C, 40% rH	3.5	Pre-TT, ~90 min cycling	TT, 4 kJ·kg^{-1} body mass cycling
Ihsan et al., 2010	7	27.7	-	30°C, 75% rH	6.8	Pre-TT, ~45 min	TT, 40-km cycling
Jeffries et al., 2018	10	33	52.4	35°C, 40% rH	1.25	During TTE, at 85% baseline TTE	TTE, 70% aerobic power cycling
Maunder et al., 2017	7	35.5	63	35°C, 60% rH	10.5	Pre-TT, ~15 min, and during TT	TT, 40-km cycling
Naito et al., 2017	7	25	48.8	35°C, 30% rH	1.25	Pre-TTE, ~35 min *or* ~50 min	TTE, 65% VO_{2max} cycling
Naito & Ogaki, 2017	9	23	47.7	35°C, 30% rH	3.25	Pre-TTE, ~30 min, and during TTE	TTE, 60% VO_{2max} cycling
Riera et al., 2014	12	42	59.9	31°C, 78% rH	12.84	Pre-TT, ~15 min, and during TT	TT, 20-km cycling
Siegel et al., 2010	10	28	56.4	34°C, 55% rH	7.5	Pre-TTE, ~35 min	TTE, running at 1st ventilatory threshold
Siegel et al., 2012	8	26	54.2	34°C, 52% rH	7.5	Pre-TTE, ~40 min	TTE, running at 1st ventilatory threshold
Stanley et al., 2010	10	30	60	34°C, 60% rH	13.1	Pre-TT, ~50 min	TT, 75% peak power × 30 min cycling
Stevens et al., 2013	9	29.1	61.7	33°C, 25% rH	10	Pre-TT, ~60 min cycling	TT, 10-km running
Stevens et al., 2016	11	29	-	33°C, 46% rH	7.5	Pre-TT, ~45 min	TT, 5-km running
Takeshima et al., 2017	10	20.3	-	30°C, 80% rH	7.5	Pre-TTE, ~15 min *or* ~45 min	TTE, 55% peak power cycling
Tran Trong et al., 2015	10	41	59	33°C, 57% rH	5.21	During TT and recovery	TT, 5× of 4-km cycling + 1.5-km running
Yeo et al., 2012	12	23	54.3	28.2°C WBGT	8	Pre-TT, ~50 min	TT, 10-km outdoor running
Zimmermann et al., 2017	10	28	-	35°C, 50% rH	7	Pre-TT, ~38 min	TT, 800 kJ cycling

Note: rH, relative humidity; TT, time trial; TTE, time to exhaustion; VO2max, maximal oxygen uptake; WBGT, wet bulb global temperature , [a] sample size.

Results

A detailed summary of the main characteristics of the 16 studies is presented in Table 1. This meta-analysis represents data synthesized from 152 subjects, varying in sample size from 7 to 12. All subjects included in these studies were defined as healthy, physically active, recreational athletes or moderately trained athletes. Of the 16 studies, 11 studies investigated the effects of pre-exercise cooling, 3 studies investigated pre- and mid-exercise cooling, and 2 studies investigated mid-exercise cooling. The risk of bias of the studies assessed as PEDro scores ranged from 6-8 out of a possible 8 points, qualifying as high quality.

After data pooling (Figure 2), this meta-analysis revealed that ice slurry ingestion improved endurance performance in the heat (g, 0.54; 95% CI, 0.30-0.77; p<0.001) compared with control group (fluid temperature ranging from 3.1°C to 37°C).

Figure 3 shows meta-regression investigating the dispersion of the effect size that could be explained by the study's characteristics. There was a significant association of ice dose with the effect size (p=0.024). There were no significant association between either time from ice slurry ingestion leading to the endurance performance (p=0.751) or environmental temperature and humidity (p=0.505), and the effect size. By removing the one study with imputed ambient temperature and humidity from the meta-regression, the regression coefficient remained insignificant (QModel=1.70, p=0.428), suggesting there is minimal impact of imputation on the results.

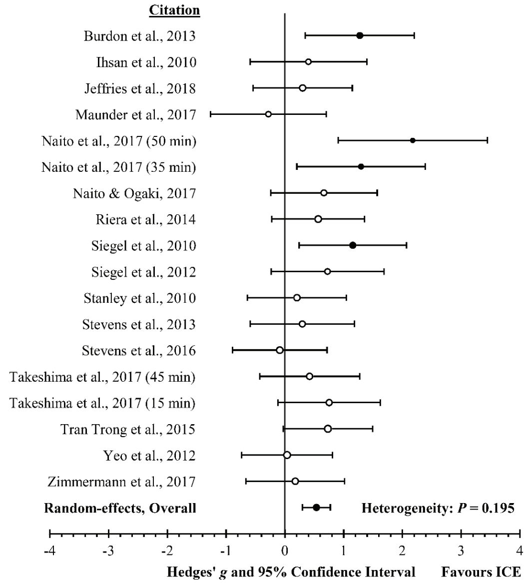

Figure 1. Forest plot of effect size from 16 studies that assessed the effect of ice slurry ingestion on endurance performance in the heat. A circle represents the effect size of a study, and the circle size is proportional to the study's weighting in a random-effects meta-analysis. The horizontal line depicts the 95% confidence interval for each effect. Open circle represents insignificant effect while filled circle represents significant effect.

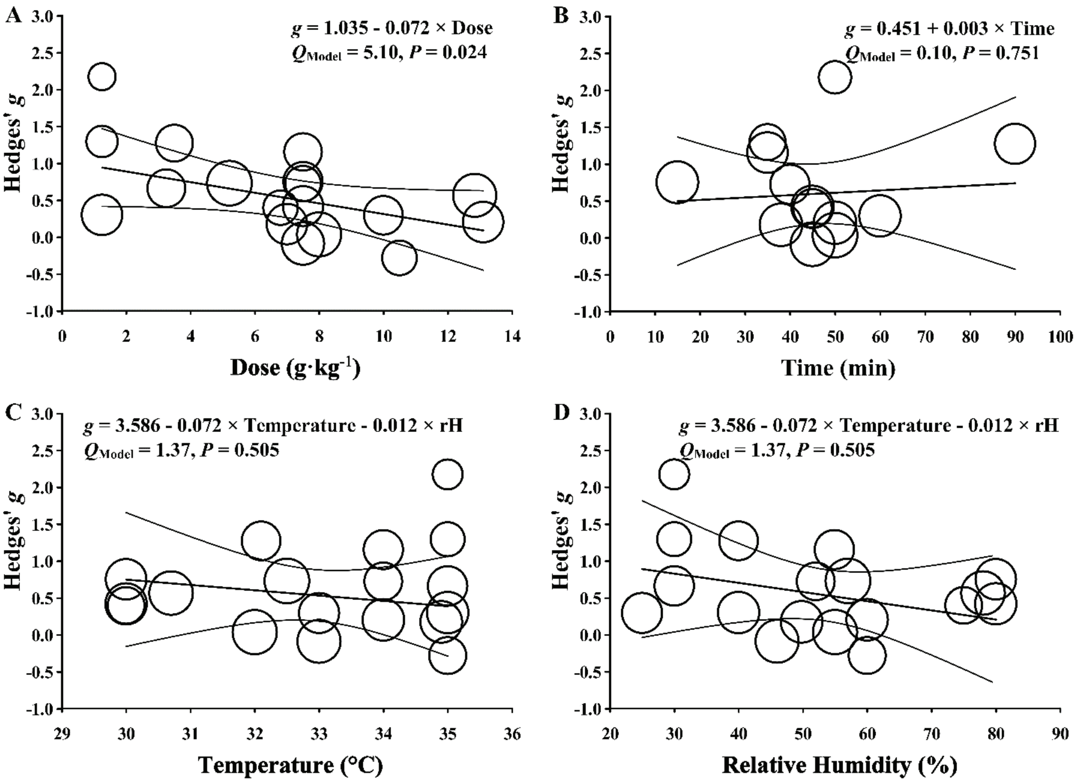

Figure 2. Meta-regression analyses exploring potential heterogeneity as a result of: A. dose of ice slurry ingestion, B. time from ice slurry ingestion to the commencement of performance test, C. ambient temperature, and D. relative humidity (rH). The bubbles are drawn with sizes proportional to the contribution of individual studies towards the method-of-moments linear prediction. The solid line represents linear predictions for the effect size while the curved lines are 95% confidence bands. QModel is the measure of variation explained by the covariates. An alpha level of 0.10 indicates significant variation in the effect size was moderated by the covariate.

The effect size of the 16 studies was plotted against the inverse of the standard errors (Figure 3). There was little evidence of asymmetry in the funnel plot, indicating a considerably equal distribution of the studies along the horizontal line, hence low probability of publication bias.

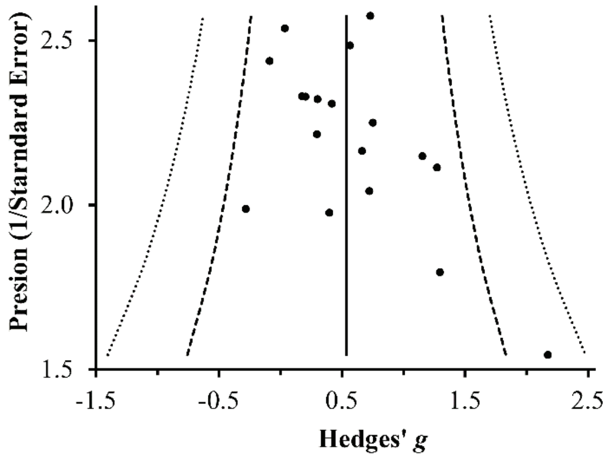

Figure 3. Funnel plot displaying the effect size and the inverse of standard errors in a random-effects meta-analysis. The vertical line marks the weighted effect size and the dashed lines represent 2 and 3 sigma intervals.

Discussion

This meta-analysis focused on the practical aspects of ice slurry ingestion and the major findings show that ice slurry ingestion does improve endurance performance in hot environments, and this benefit is moderate in magnitude (g=0.54). Results from available studies demonstrated that increasing dose of ice slurry ingestion does not add further improvement on endurance performance and the benefit could be diminished with higher dose. Dispersion in the effect size was not significantly associated with timing of ice slurry ingestion or environmental conditions. These findings therefore extend and add new information to the present knowledge regarding ice slurry ingestion on endurance performance in the heat.

This meta-analysis found a comparable effect on endurance performance between ice slurry ingestion (g =0.54) and other cooling strategies. There are a number of choices of pre-cooling interventions for exercise in the heat: palm cooling, foot cooling, neck cooling, forearm immersion, torso cooling via cooling vests, whole-body cold water immersion, iced towel, fan cooling with mist, cold room, cold water ingestion, and more recently L-menthol application. Previous meta-analytic review has summarized common cooling strategies on exercise performance in the heat: mixed method cooling g=0.72, cold water immersion g=0.49, cold water/ice slurry ingestion g=0.40, cooling packs g=0.40, and cooling vests g=0.19 (Bongers et al., 2015). Cooling strategies during elite competitions are practically limited to cold water/ice slurry ingestion and mist cooling. Ice slurry ingestion is effective as a performance enhancement in the heat, and also is very practical. As would be expected, elite athletes consider ice slurry ingestion superior to other cooling strategies (Periard et al., 2017).

The meta-regression of dose effects revealed a significant association with the effect size for endurance performance. The total amount of heat transfer is moderated by the ice volume ingested. Theoretically, a higher dose of pre-cooling ice slurry ingestion yields a higher cooling capacity, which could lead to lower core temperature at the commencement of exercise. None of these 16 studies investigated dose effects and the mechanisms for the present finding cannot be explained. Interestingly, Ihsan and colleagues suggested the maximal tolerable amount of ice consumable within a 30-min period was 6.8 g kg−1 (Ihsan et al., 2010). A review of fluid temperature on palatability and fluid ingestion suggests 10–20°C is the preferred temperature range for beverages used for fluid replacement during endurance exercise in temperate to warm environments (Burdon, Johnson, Chapman, & O'Connor, 2012). Taken together, this might explain a slower time trial performance, when ice (~10.5 g kg−1 or 0.81 kg of fluid) was ingested ad Libitum (Maunder et al., 2017). Nonetheless this meta-analysis summarizing the available data suggests that the ergogenic effect of ice slurry ingestion on endurance performance is not proportional to higher doses.

Given there is a temporally delayed pattern from external cooling to body cooling (Arngrimsson, Petitt, Stueck, Jorgensen, & Cureton, 2004), it is reasonable to assess whether temporal effects associated with ice slurry ingestion could influence the ergogenic effect. The present analysis indicates that the internal cooling effect on endurance performance was not time dependent. Ingestion of ice 15 min prior to the exercise effectively improved (g=0.75) endurance capacity in the heat (Takeshima et al., 2017). As such, ice slurry ingestion can be recommended for cooling an athlete immediately before exercise and during exercise.

Another novel finding of the present review is that the performance effect of ice slurry ingestion is not influenced by the environmental effects. Previous reports have suggested that exercise capacity is progressively impaired as the relative humidity increases (Maughan, Otani, & Watson, 2012). Interestingly, ice slurry ingestion improved (g=0.30) performance in a hot-dry environment (33°C, 25% relative humidity) (Stevens et al., 2013) and the effect does not diminish in a hot-humid environment (g=0.42/0.75; 30°C, 80% relative humidity) (Takeshima et al., 2017). High ambient temperature and relative humidity are of great importance when considering athletic performance. The upcoming Tokyo 2020 Summer Olympics is expected to have a higher wet bulb global temperature than any of previous three Olympics (Kakamu, Wada, Smith, Endo, & Fukushima, 2017) and poses a real challenge to the health and performance of athletes. Ice slurry ingestion can be recommended to elite athletes participating in endurance events, or spinal cord injured athletes with compromised sweating capacity (Price, 2006) as an effective countermeasure in the likely hot-humid environments during Tokyo 2020.

In conclusion, this meta-analysis has provided several novel findings. First, it does not support a recent review (Choo et al., 2018) on this topic. Ice slurry ingestion provides a significant benefit for endurance performance in the heat, and this effect is moderate in magnitude (g=0.54). Second, a specific new insight from the current literature is increasing ingestion of ice slurry may not further improve the performance effect. A dose as low as 1.25 g kg−1 prior to the exercise could be effective. Third, the performance effect is not time dependent and ice slurry can be ingested before and during exercise. Finally, the performance effect is not associated with environmental temperature and humidity. Ice slurry ingestion offers a comparable performance effect compared to other more complex cooling strategies and should be highly recommended for endurance events occurring in the heat.

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Conflict of Interest
The authors declare that there are no conflicts of interest.

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