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Review

The Effects of Pre-Exercise Ice-Slurry Ingestion on Thermoregulation and Exercise Performance of Highly Trained Athletes: A Scoping Review

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ABSTRACT

International Journal of Exercise Science 16(2): 1398-1412, 2023. Ice-slurry prepared from plain ice, crushed ice, or sports drink has been used as a cooling strategy before exercise to regulate body temperature and improve exercise performance. However, consensus regarding the benefit is unclear. Therefore, the present review aimed to study the effects of pre-exercise ice-slurry ingestion on thermoregulation and exercise performance of highly trained athletes. The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was used. The data extraction was done using the search engine Google Scholar, and digital repositories such as Cochrane, Scopus, Medline, Ebsco, Proquest and Pubmed. The keywords 'Pre-cooling', 'Ice-slurry', 'Ice Slush' 'Thermoregulation' 'Heat Loss' 'Heat Stress' 'Body Temperature' 'Athletes', 'Sports Persons' 'Exercise Performance' were used. Among the identified records (n = 151), 11 articles which met the inclusion criteria were examined. Out of the eleven studies, six studies reported a significant decrease in core/rectal/GI/skin/body temperature, and six studies reported a significant increase, or positive influence on exercise performance, and three studies both on thermoregulation and exercise performance. Ingestion of pre-exercise ice-slurry (30 min BE; -1°C to +1°C) in the dosage range of 7-14g/kg/BM has a significant beneficial effect on thermoregulation and exercise performance. Ice-slurry prepared from plain crushed ice, or sports drink, or carbohydrate and electrolyte drinks may have a similar effect on thermoregulation and exercise performance.

KEY WORDS: Pre-cooling Strategies, ice-slurry, thermoregulation, exercise performance, athletes

INTRODUCTION

Exercising in hot and humid environments for long durations can increase the skin and core temperature of the athletes; this can result in the early onset of fatigue and impair athletic performance (28). To compete with metabolic heat production coupled with environmental heat stress (air temperature, humidity, wind speed, and solar radiation), intensity and duration of exercise; the parallel need for heat transfer from the body is essential to maintain thermal equilibrium. An increase in the blood flow to the peripheral skin, and the concomitant sweating responses are progressively, and proportionally amplified to achieve thermal equilibrium (3).

Dehydration compromises the thermoregulation during exercise, thus resulting in heat accumulation and thermoregulatory strain/stress in the body which further can lead to hyperthermia-induced fatigue (3, 28). Loss of > 2% of body mass from total body water can impair the nervous system and cardiovascular system functioning, physiological adaptations, thermoregulation, and thereby, fitness and athletic performance (14). Total body water with a minimal variation of +1% to -1% can optimally thermoregulate the athlete's body (37.5^{o}C) during training and competition (14, 16). To maintain euhydration and thermoregulation during training, or competition, athletes use different strategies to reduce the thermal strain. One among them is the use of pre-cooling strategies to reduce body temperature before exercise, thereby reducing the metabolic heat production and increasing the maximum exercise time, or performance (13, 21).

Athletes use pre-cooling strategies such as cold air exposure, cold water immersion (2-20^{o}C) (whole-body immersion, part-body immersion), exposure to ice, or ice products (iced towels, iced garments like ice vests and/or neck cooling collars), and air inhalation. But these are not convenient to use all the time in the field. The most convenient alternative ways are internal pre-cooling strategies like consumption of cool beverage/slush. Ice-slurry is used to lower the core temperature before exercise, and to increase the heat storage capacity during exercise to delay, or prevent the attainment of critical core temperature (12, 13, 21, 24, 25).

Ice-slurry ingestion acts as an ergogenic aid for endurance athletes in improving aerobic performance in hot environments (18). However, the attainment of benefits by athletes from ice-slurry is not always consistent as this depends on the temperature, amount, and duration of consumption of ice-slurry and acclimatisation. The previous systematic reviews focused on different pre-cooling strategies (12, 19), pre and per-cooling across different exercise and environmental conditions (8, 20), with inclusion studies conducted on untrained athletes (20), or comparison with other cooling techniques (7). Keeping the above factors in view, the present review is aimed to collate the information from various studies on strategies and effects of pre-exercise ice-slurry ingestion on thermoregulatory responses and exercise performance of highly trained athletes (many hours of sports training regularly and competition as the major professional activity) in heat stress conditions.

METHODS

The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was used for the present review. The following inclusion and exclusion criteria were used in the selection of research articles.

Inclusion Criteria

1) Studies that include the details related to pre-exercise ice-slurry ingestion, thermoregulation and exercise performance of athletes
2) Studies that were conducted in concern of age group 20-35 yrs
3) Peer reviewed Journals
4) Studies published in the English language
5) Free full text intervention studies.

Exclusion Criteria

1) Studies related to moderately, or untrained, or recreational, or diseased, or disordered, or injured, or para-athletes
2) Non peer reviewed research journals
3) Conference papers, white papers, dissertations, or other research documents that include review-based analysis.
4) non-availability of full-text articles

Data Extraction

The data extraction was done between April 2020 to July 2020 and June to November 2022 by using the search engine Google Scholar, and digital repositories such as Cochrane Library, Scopus, Medline, Ebsco, Proquest and Pubmed. The following steps were involved in the extraction of the research journals. The first step of the strategy was to enter the keywords such as 'Pre-cooling', 'Ice-slurry', 'Ice Slush', 'Thermoregulation', 'Heat Loss', 'Heat Stress', 'Body Temperature', 'Athletes', 'Sports Persons' and 'Exercise Performance' in the digital repositories and Boolean terms such as 'AND' or 'OR' were used to extract the number of research journals. The second step of the search strategy was to apply the filter to choose the type of journal because conference papers are not used in this analysis. The third step was the screening of research journals based on the title and then abstract to satisfy all the inclusion criteria such as age and other factors. Finally, the articles that satisfy all the eligibility criteria are selected to answer the research questions. A Microsoft Excel spreadsheet was used to extract the following information: title of the article, author, country, year of publication, gender, age, number of subjects, environmental conditions, experimental design, type, timing, and dosage, effect on thermoregulation, and effect on performance (Table 1).

Table 1. Study Characteristics

S.No	Author	Country	Type of Sport	Gender	No. of Subjects	Age (yrs)	Experimental Design	Environmental Conditions	Type of Exercise	Intervention Groups	Dosage of Ice-Slurry	Time of Ingestion	Type of Ice-Slurry	Effect on Core/Rectal Temperature	Effect on Performance
01	Mejuto et al., 2018	Spain	Road Cycling	Male	07	34.7	RCD PP	32^{0}C 50% RH,	10km time trial on cycle ergometer	TN: No cooling	-	-	-	Significant decrease in RT in PRE, PRE+MID	No significant differences between the three conditions Slight positive effect in
										PRE: Ice-slurry	14g/kg/BM	30 min BE	7.4% CHO electrolyte drink (−1°C)		
										PRE+MID: Ice-slurry +	14g/kg/BM	30 min BE	7.4% CHO electrolyt		

										iced towels			e drink (−1°C)		PRE intervention
02	Stevens et al., 2016	Australia	Runners	Male	11	29	RCD	33°C 46% RH	5-km running on non-motorized treadmill	ICE: Ice-slurry	7.5 g/kg/BM	30 min BE	Sports drink (−1 °C)	Significant decrease in RT in ICE than CON and MEN	Significantly improved in MEN than ICE and CON No difference between CON and ICE
										MEN: Mid-cooling by a menthol mouth rinse	-	-	-		
										CON: No Intervention	-	-	-		
										CON: Water before and during exercise	DE: 100 ml of water every 200 kJ	-	-		
03	Beaven et al., 2018	New Zealand	Rugby	Male	07	21.5	RCD	--	5X40 m maximal running sprints	Control:15 min passive rest	-	After 15 min passive rest	-	Decreased RT COLD> H+C>Control> Heat	H+C significantly improved sprint performance H+C>Control> COLD> Heat
										Heat: Wearing a lower-body survival garment	-	After 15 min passive rest	-		
										Cold: Ice-slushy	500ml	After 15 min passive rest	-		
										H+C: Wearing the survival garment and ice-slushy	500ml	After 15 min passive rest	-		
04	Saldaris et al., 2019	Australia	Endurance athletes	Male	09	24	RCD	34.2°C 52.9 RH	800 kJ cycle time trial	CON: Water	-	-	Crushed Ice (−0.3±0.1°C)	Reduced CT in ICE	Power output improved by 7.8% in ICE
										ICE: Crushed Ice	7g/kg BM	30 min BE	-		

BM: Body Mass; BE: Before Exercise; RH: Relative Humidity; RCD: Randomised Crossover Design; RCT: Randomised Control Trial; CHO: Carbohydrate; RT: Rectal Temperature; CT: Core Temperature: GI: Gastrointestinal

S.No	Author	Country	Type of Sport	Gender	No. of Subjects	Age (yrs)	Experimental Design	Environmental Conditions	Type of Exercise	Intervention Groups	Dosage of Ice - Slurry	Time of Ingestion	Type of Ice-Slurry	Effect on Core/Rectal Temperature	Effect on Performance
05	Zimmerman et al., 2017	Australia	Cycling & Triathletes	Female	10	28	RCD	34.9°C 49.8% RH	800 kJ cycle time-trial	ICE: Crushed Ice	BE: 7g/kg BM of ice-slurry + DE: 100 mL of	30 min BE	Crushed ice (0.5°C)	Decreased CT in ICE	No significant difference in perform

											water every 200 kJ				ance time
										CON: Water before and during exercise	DE: 100 mL of water every 200 kJ	-	-		
06	Gerrett et al., 2017	Japan	Trained Athletes	Male	12	30.4	RCD	30.2°C 42.5% RH	Intermittent exercise protocol of walk, jog, run, sprint	Control: CHO solution	-	-	0.23% of CHO (23.4 ± 0.9 °C)	CT was lower in ICE	No Significant difference in distance covered
										ICE: Ice-slurry	7.5 g/kg BM	30 min BE	0.23% of CHO (0.1 ± 0.1 °C)		
07	Zimmermann et al., 2018	Australia	Cyclists/ triathletes	Male	15	24	RCT	35°C 50% RH	800 kJ cycle time trial	PRE: No precooling + water after every 200kJ	-	-	100 ml of water (27.0±2.0°C)	No Change in CT	Both improved cycle time trial 83% Positive benefit for with POST CTT
										POST: Ice-slurry + Heat acclimation	7g/kg BM	30 min BE	Crushed ice (1°C)		
08	Brade et al., 2014	Australia	Team Sports	Male	12	21.8	RCD	35.2°C 57.8 RH	70 min of repeat sprint cycling (30 sprint - 10 recovery period- 30 sprint)	CON: No Intervention	-	-	-	No significant difference in CT	Mean power (Watts) and total work was increased J +Ice Slushy > J > CON > Ice Slushy
										J: Cooling jacket	-	-	-		
										Ice Slushy: Ice slushy	7 g/kg BM (2.3 g/kg/BM every 10 min) and 2.1 g/kg BM during half time	30 min BE and during half time recovery period.	Plain ice (0.6°C)		
										J+Ice Slushy: Jacket + Ice slushy	7 g/kg BM (2.3 g/kg/BM every 10 min) and 2.1 g/kg BM during half time	30 min BE and during half time recovery period.	Plain ice (0.6°C)		

BM: Body Mass; BE: Before Exercise; RH: Relative Humidity; RCD: Randomised Crossover Design; RCT: Randomised Control Trial; CHO: Carbohydrate; RT: Rectal Temperature; CT: Core Temperature: GI: Gastrointestinal

S.No	Author	Country	Type of Sport	Gender	No. of Subjects	Age (yrs)	Experimental Design	Environmental Conditions	Type of Exercise	Intervention Groups	Dosage of Ice-Slurry	Time of Ingestion	Type of Ice-Slurry	Effect on Core/Rectal Temperature	Effect on Performance
09	Ross et al., 2011	Australia	Cyclists	Male	11	33	RCD	32°C–35°C 50%–60% RH	46.4 km cycling on a cycle ergometer	Con: ad libitum consumption of cold water	-	-	Cold water (4°C)	No significant difference in RT	1.3 % increase in performance

										Std Cool: Whole-body immersion in cold (10°C) water for 10 min followed by wearing a cooling jacket	-	-	-		3.0% increase in power output with New Cool
										New Cool: Combination of ice-slurry + iced towels	14 g/kg BM	30 min BE	Sports drink (Gatorade)		
10	Stevens et al., 2015	Australia	Runners	Male	08	27	RCD	33°C 46% RH	Self-paced 5 km running time trial on a non motorized treadmill	Control	-	-	Tepid fluid (22°C)	No significant difference in RT	No significant difference between control and ice-slurry
										Ice-Slurry: Ice-slurry ingestion in six equal boluses over a30 min	7.5 mL/kg BM	30 min BE	Sports drink (-1°C)		
11	Thomas et al., 2019	UK	Trained Athletes	Male	10	30.5	RCD	34.4°C 36.3% RH	46 min self-paced intermittent exercise	INT: Ice-slurry	7.5 g/kg (3 equal aliquots of 2.5 g/kg/ BM every 10 min)	30 min BE	0.75 g/kg/ BM of CHO Solution (−0.5 ± 0.4°C)	No significant difference in GI, body and Skin temperature	No significant difference in sprint or submaximal performance
										CON: Water	7.5 g/kg of water	30 min BE	0.75 g/kg/ BM of CHO Solution (− 0.5 ± 0.4°C)		
										EXT: Cooling garment + water	7.5 g/kg of water	30 min BE	0.75 g/kg/BM of CHO Solution (− 0.5 ± 0.4°C)		
										MIX: Cooling garment + ice-slurry	7.5 g/kg of ice-slurry (3 equal aliquots of 2.5 g/kg/ BM every 10min)	30 min BE	0.75 g/kg of body mass of CHO Solution (− 0.5 ± 0.4°C)		

BM: Body Mass; BE: Before Exercise; RH: Relative Humidity; RCD: Randomised Crossover Design; RCT: Randomised Control Trial; CHO: Carbohydrate; RT: Rectal Temperature; CT: Core Temperature: GI: Gastrointestinal

RESULTS

After the primary search, 159 records related to the keywords were identified. Based on the title search, duplicate (*n* = 81), and irrelevant records (*n* = 78) were removed. Following this, abstract and full-text screening was carried out, and 11 articles were included based on the eligibility criteria (Fig.1).

Study Characteristics: The characteristics and details of the included studies are presented in Table 1. Most of the studies were done in Australia (*n* = 7) followed by Japan (*n* = 1), Spain (*n* = 1), UK (*n* = 1), and New Zealand (*n* = 1). The studies were conducted on cyclists (*n* = 2), runners (*n* = 2), cyclists and triathletes (*n* = 2), well-trained athletes (*n* = 2), endurance athletes (*n* = 1), team sports (*n* = 1), and rugby (*n* = 1). Studies were randomized counterbalance, (*n* = 10), or randomized control trials (*n* = 1) and the number of participants ranged from 7 to 15. Most of the studies (*n* = 10) were conducted on male athletes and only one study was on female athletes The studies were conducted in controlled conditions in laboratories (Temperature ranged from 30.2^{o}C to 35.2^{o}C and Relative humidity ranged from 42.5 to 60%) either on a treadmill (*n* = 3), or on a cycle ergometer (*n* = 6), or an intermittent protocol (*n* = 1), or indoor sprinting (*n* = 1).

Intervention with Ice-Slurry: Among the studies (*n* = 11), four studies studied the effect of ice-slurry with the control group (9, 23, 26, 31), six studies combined the ice-slurry intervention with an iced towel (15, 22), cool jackets (6, 29), survival garment (2), heat acclimatization (30), and one study with menthol mouth rinse (27). Ten out of 11studies selected for the present review supplemented ice-slurry in the range of 7-14g/kg BM before 30 min of warm-up i.e, during the pre-cooling period. One study provided 500ml of ice slushy after warm-up for 10 min and 15 min passive rest period (2).

Ice-Slurry Intervention on Thermoregulation: In Comparison with Other Study Groups: Rectal and core temperature were studied to understand the thermoregulation (Table 1&2).

At the Start of Exercise: Immediately following ice-slurry ingestion during the pre-cooling period, there was a significant reduction in temperature. Five studies reported a decrease in rectal temperature (2, 15, 22, 26, 27), and five studies focused on core temperature showed a decrease in core temperature within 15-20 min of ice-slurry ingestion (6, 9, 23, 30, 31), and another study showed decreased gastro-intestinal, body and skin temperature (29).

After Exercise: Among the studies, only six studies reported a reduction in core/rectal/body/skin/ temperature post exercise with ice-slurry intervention. Of these, a significant decrease in rectal temperature was found in three studies (2, 15, 27). The other three studies (9, 23, 31) reported a decrease in mean core temperature. The other studies reported that there was no significant effect either on rectal temperature (22, 26), or on core temperature (6, 30), and gastrointestinal, body and skin temperature (29).

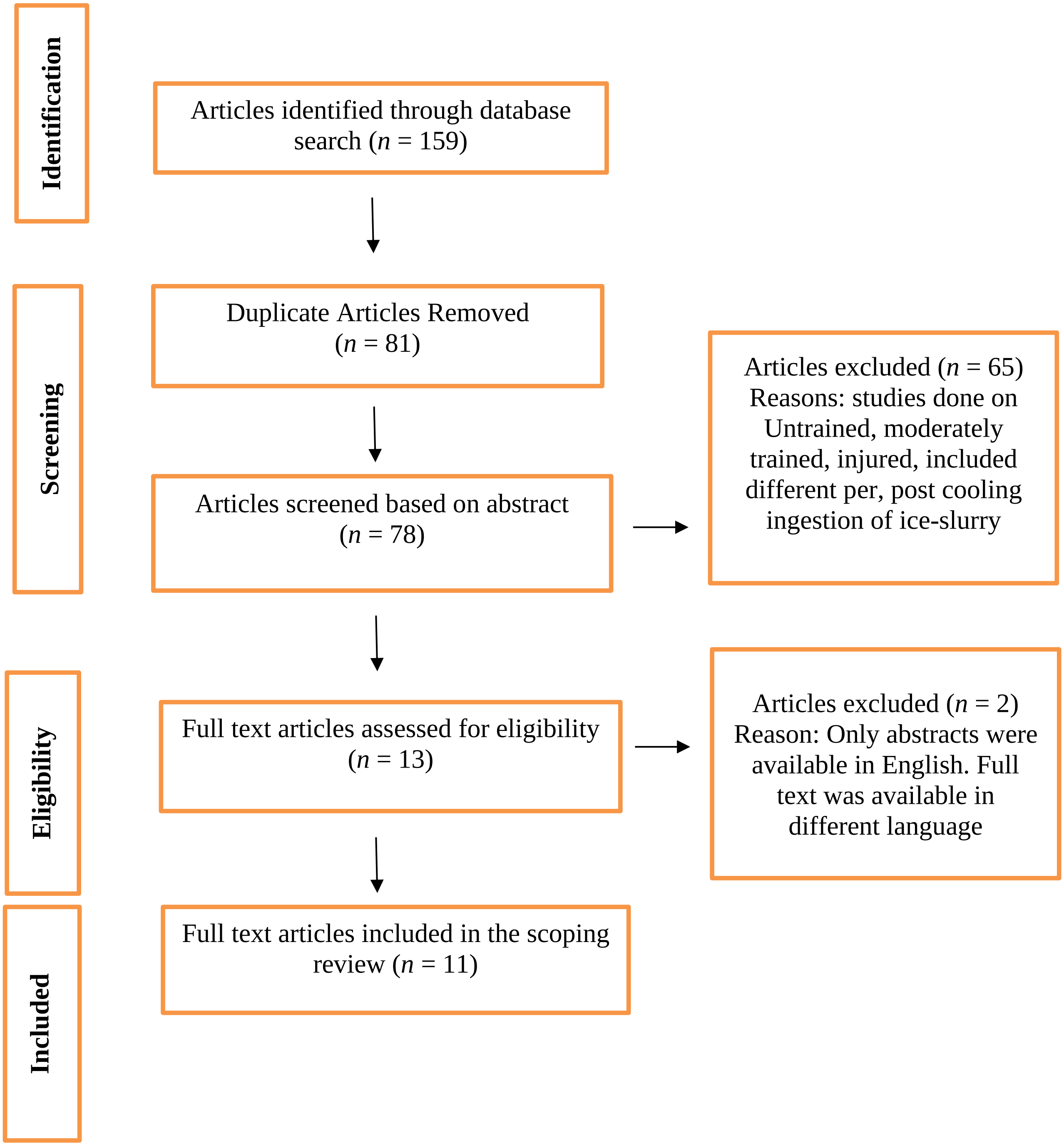

Fig 1. Article Selection Methodology

Ice-Slurry Intervention on Thermoregulation: In comparison with Other Interventions: Ice-slurry supplementation (ICE) was compared with other cooling interventions to see their effect on thermoregulation ($n = 7$). A combination of ice-slurry ingestion with other cooling strategy- iced towel at torso (15), and wearing the survival garment, and consuming the ice slushy showed a significantly positive effect on rectal temperature after exercise (2). Menthol mouth rise (MEN) showed higher rectal temperature over ice-slurry (ICE: 36.9 ± 0.3°C vs MEN 37.2 ± 0.4°C) [25]. On the contrary, a few studies showed no significant effect on thermoregulation (6, 22, 29, 30).

Ice-Slurry Intervention on Exercise Performance: In Comparison with Other Study Groups: Of all studies (*n* = 11), six studies reported a significant increase, or improvement in exercise performance with pre-exercise ice-slurry ingestion (2, 6, 15, 22, 23, 30). The studies reported a positive effect (15), an increase in running sprint performance (2), mean power output of 7.8% in a cycle time trial (CTT) (23), cycling time trial performance (CTT) (30), power output (6), mean power output of 3.0% (8W), and increased performance time of 1.3% (1.06 min) in a CTT (22). In contrast, five studies showed no difference in performance with ice-slurry (9, 26, 27, 29, 31) (Table 1 & 2).

Ice -Slurry Intervention on Exercise Performance: In Comparison with Other Interventions: Ice-slurry intervention was also compared with ice-slurry along with other cooling strategies, (*n* = 6) and in comparison with mid cooling by mouth wash (*n* = 1). Ice-slurry and a mid-cooling ice towel intervention improved 46.4 km cycling performance, and power output than whole body immersion in cold water followed by wearing a cooling jacket (22). Similarly, wearing a survival garment and ice-slushy/slurry, (2, 6) and heat acclimatisation plus ice-slurry showed significantly improved performance (30). Menthol mouth rinse (MEN) has shown a significant positive improvement in treadmill performance time than ice-slurry (MEN:25.3 ± 3.5 min vs ICE: 26.3 ± 3.2 min) (27). On the contrary, no greater benefits with ice-slurry plus mid cooling with ice towel/cooling garment intervention (15, 29) over ice-slurry (Table 1&2).

Dosage and Timing of Ice-Slurry on Thermoregulation and Exercise Performance: The dosage and timing of supplementation of ice-slurry have an effect on thermoregulation and exercise performance. Supplementation of 7-14 g/kg BM of ice-slurry reported a positive effect (8 out of 11) either on thermoregulation, and exercise performance, or both.

Ice-slurry intervention of 7 g/kg BM (23), and 14g/kg BM (15), and 500ml of ice slushy plus wearing a survival garment after a 10 min warm-up and 15 min passive rest (2) showed an improvement in thermoregulation, and a positive effect on exercise performance.

On the contrary, supplementation of 7g/kg BM (15, 24), 7.5 g/kg BM (17, 22, 25), and 14g/kg BM (22) of ice-slurry showed mixed results showing positive effect on thermoregulation not showing its positive effect on exercise performance, or vice versa. 7.5g/kg BM (26, 29) showed no improvement in thermoregulation, and performance (Table 1&2).

Type of Ice-Slurry: Ice-slurry was prepared using different types of sports drinks, or plain ice, and the temperature ranged from -1°C to +1°C. Observation done on the results reported showed that the influence of ice-slurry on thermoregulation and performance were different even on the consumption of the same amount of dosage and type of ice-slurry (Table 1&2).

Table 2. Summary of Results

S.No	Author	Intervention Groups	Dosage of Ice-Slurry	Pre-Exercise Ice-Slurry Intervention	
				Effect on Temperature	Effect on Performance
01	Mejuto et al., 2018	1. No cooling 2. Ice-slurry 3. Ice-slurry + mid cooling with Iced towels	14g/kg BM	Decreased RT in ice-slurry, ice-slurry + mid cooling with iced towels	Positive effect on 10km cycling time trial in ice-slurry
02	Stevens et.al., 2016	1. Control 2. Ice-slurry 3. Mid-cooling by a menthol mouth rinse	7.5g/kg BM	Decreased RT in ice-slurry	No effect with Ice-slurry Increased running performance with menthol mouth wash
03	Beaven et al., 2018	1. 15-min passive rest 2. Wearing a lower-body survival garment 3. Ice-slushy 4. H+C: Wearing a survival garment & ice slushy	500ml	Decreased RT in ice slushy, H+C	Significantly increased sprinting performance in H+C and ice slushy
04	Saldaris et al., 2019	1. Water 2. Ice-slurry	7g/kg BM	Decreased CT	Significantly power output in 800KJ cycling time trial
05	Zimmermann, et.al., 2017	1. Water 2. Crushed ice	7g/kg BM	Decreased CT	No effect on 800 kJ cycle time-trial
06	Gerrett et al., 2017	1. CHO Solution 2. Ice-slurry	7.5g/kg BM	Decreased CT	No effect on Intermittent exercise performance
07	Zimmermann, et al., 2018	1. Water 2. Ice-slurry+ Heat Acclimatisation	7g/kg BM	No significant difference in CT	Significantly Increased 800KJ cycling time trial
08	Brade et al., 2014	1. Control 2. Cooling jacket 3. Ice-slurry 4. Ice-slurry + Jacket	7g/kg BM and 2.1g/kg BM half time	No significant difference in CT	Positive effect in Ice-slurry + Jacket
09	Ross, et al., 2011	1. Whole-body immersion in cold (10°C) water	14 g/kg BM	No significant difference in RT	Significantly increased 46.4 km cycling

		2. Wearing a cooling jacket 3. Ice-slurry + Iced towels			
10	Stevens et al., 2015	1. Tepid fluid 2. Ice-slurry	7.5g/kg BM	No significant difference in RT	No effect on running Time trial
11	Thomas et al., 2019	1. Water 2. Ice-slurry 3. Cooling garment + water 4. Cooling garment + ice-slurry	7.5g/kg/BM	No significant difference in GI, body and skin temperature	No significant difference in sprint or submaximal performance

BM: Body Mass; BE: Before Exercise; CHO: Carbohydrate; RT: Rectal Temperature; CT: Core Temperature: GI: Gastrointestinal; Bolded text denotes findings were significant

DISCUSSION

Exercise capacity and performance is impaired due to thermal strain in hot and humid conditions. To overcome this, athletes use different strategies; one of the most popular is cooling methods, either internal or external. Internal cooling methods are those which are ingested in and act from inside the body like ice-slurry, menthol, etc., and external cooling methods are those that are not ingested and act external on the body, like wearing cooling jackets, whole-body immersion in cold water, or cold air flow (20). Either internal and external cooling methods, or a combination of both, can benefit athletes but have controversial results (6). Ice-slurry intervention is one of the recently used strategies by athletes to thermo-regulate and benefit athletes by helping them perform to their maximum. Ice-slurry intervention can be done at any point of time from before 30 min of exercise (which is called a pre-cooling period) to the recovery period in split doses or at once (26). The present study aimed to collate the information from various studies on strategies, and effects of pre-exercise ice-slurry ingestion on thermo-regulatory responses and exercise performance of highly trained athletes in heat stress conditions.

In the precooling phase, temperature (core/rectal/skin/body/GI) was reduced with ice slurry. Ice-slurry is considered the most effective pre-cooling strategy over cool water ingestion (12, 24). The mechanism behind the ingestion of ice slurry is the enthalpy of the fusion of ice. Ice-slurry ingestion acts as an additional heat sink, and lowers sweating rates, increases internal heat loss, reduces end-exercise core temperatures, increases body heat storage, delays the onset of hyperthermia-induced fatigue, and decreases thermal sensation and improves performance (10). It can also result in core temperature afferent signaling to the brain (17). Though we have observed varied results post-exercise, the thermoregulation was better with ice-slurry intervention (2, 9, 15, 23, 27). Body heat storage on ice-slurry ingestion is highly dependent on sufficient reductions in sweating efficiency. Decrements in sweating efficiency depend on environmental conditions (ambient temperature and humidity) for a given metabolic or physiologic heat production, and rate of airflow across the skin (1). Due to this limitation, the benefit may not be able to sustain the same results per and post-exercise.

Our study found improved exercise performance, i.e., increased cycling time trial (CTT), sprint, power output, or submaximal performance (2, 6, 15, 22, 23, 30) with ice-slurry intervention. Among these studies, five provided intervention with ice-slurry and mid-cooling with iced towels or jackets, wearing the survival garment, or heat acclimatization. Ice-slurry intervention during pre-cooling can help athletes improve repeat sprint cycling performance only for a limited time while doing exercise (6). Pre along with per/mid-exercise cooling (1, 4, 5, 11) and heat acclimatization (1) may be effective in improving exercise performance in hot environments.

A menthol mouth rinse, a new intervention to benefit athletes is becoming popular nowadays. Stevens et al. (27) compared ice-slurry intervention with menthol mouth rinse in runners, results showed that ice-slurry intervention can thermoregulate better than menthol, but the 5km running performance was improved in menthol mouth rinse than with ice-slurry. L-menthol and ice-slurry ingestion can expand the overall time of exercise and this extension was witnessed to be around 1% more than baseline performance (11). This shows menthol can improve or sustain running performance in hot and humid conditions.

A majority of the studies provided the intervention 30 min before the exercise. Ice-slurry ingestion of 7.5 g/kg BM in two equal boluses resulted in lower core temperature with no performance benefit in well-trained male athletes (9), similar results were observed in male runners on consumption of same quantity of ice-slurry made from sports drink served in two equal boluses (-1°C) (27). 14 g/kg BM of ice-slurry also resulted in positive thermoregulation (15), and performance in cyclists (15, 22). On the other hand, no benefit on thermoregulation and sprint performance from 3 equal aliquots of 7.5 g/kg/BM of CHO-based ice-slurry intervention (29), or ingestion of 6 equal aliquots 7.5 ml/kg/BM in male runners (26). These contrasting results may be because of differences in serving compared with other interventions i.e., splitting the same dosage into three, or six equal portions whereas others served in two equal portions. The influence of ice-slurry on thermoregulation was from 15 min after ingestion to the rest of the exercise period (9, 29, 31). Zimmermann et al (31) also reported that the ice-slurry effect was only for a short duration up to 20 min after the consumption in a CTT. Similarly, the thermoregulatory effect was up to 2km only in a 5km time trial when consumed in the pre-cooling period (27). These results encourage further exploration of appropriate timing and dosage of ice-slurry ingestion for its ergogenic effect.

Without considering other interventions of the study, and considering only pre-exercise ice-slurry ingestion to identify the role of ice-slurry made from plain crushed ice, sports drinks, carbohydrate and electrolyte solutions showed varied results. Ingestion of 7 g/kg BM of plain ice-slurry (23, 31), or 7.5 g/kg BM (9, 27), or 14 g/kg/BM (15) ice-slurry made from sports drinks or carbohydrate solutions showed improved thermoregulation. But 7.5g/kg BM of ice-slurry made from CHO solution showed no improvement in thermoregulation (26).

Ingestion of 7 g/kg BM of plain ice-slurry showed improved 800 kJ CTT performance (23). But Zimmerman et al. (30) showed no performance benefit during 800kJ CTT performance. Similarly, 14g/kg BM of ice-slurry made from 7.4% carbohydrate-electrolyte sports beverage showed a positive effect 10km CTT performance (15), and 7.5 g/kg/BM sports drink and CHO solutions-based ice-slurry showed no improvement (9, 26, 27). This shows that the dosage from 7-14g/kg/BM may help to maintain thermoregulation and increase exercise performance, and the type of ice-slurry may not influence the effect.

We have found thermoregulatory and exercise performance benefits with ice-slurry alone, or along with other interventions, but need more research evidence as few reported a positive thermoregulatory with no performance benefit, a few vice versa, and some no difference in thermoregulation and performance irrespective of dosage and timing. Nevertheless, ice-slurry ingestion can be most helpful for endurance athletes like runners, cyclists and triathletes. Future research can focus on gender-specific, a combination of cooling methods, type, timing, and dosage of ice-slurry on thermoregulation and exercise performance.

Limitations: The study followed a subjective approach rather than a quantitative analysis. There is a lack of numerical investigation, and the use of real-time analysis. The restricted amount of data that is used in the study can affect the generalizability of the research outcome. Quantitative analysis can be done for exploring the research question. The lack of research in female athletes would be a limitation to apply the practical aspects of ice-slurry in exercise.

Conclusion: Ingestion of pre-exercise ice-slurry (30 min BE; -1°C to +1°C) in the dosage range of 7-14g/kg/BM has a significant beneficial effect on thermoregulation and exercise performance of highly trained athletes. Pre-exercise ice-slurry ingestion along with per/mid-cooling with iced towels/ jackets/ice-slurry, or heat acclimatization, or menthol mouth rinse may be beneficial for maintaining thermoregulation and performance. Ice-slurry prepared from plain crushed ice, or sports drink, or carbohydrate and electrolyte drinks have a similar effect on thermoregulation, and exercise performance. Athletes are encouraged to experiment with a range of ice-slurry strategies during their mock competition settings to determine the performance benefits.

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