EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO COLD-WATER SPRAY STRATEGY: A SCOPING REVIEW

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By

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Dissertation submitted in partial fulfillment

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CERTIFICATE

This is to certify that the dissertation entitled

EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO COLD-WATER SPRAY STRATEGY: A SCOPING REVIEW

is the bona fide record of research work done by:

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during the period from March 2020 until June 2021 under my supervision

I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality as a dissertation to be submitted in partial fulfilment for the Bachelor of Exercise and Sports Science.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research, and promotional purposes.

Farah

……………………………………..

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Date: 21 June 2021

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May God shower the above cited personalities with success and honour in their life.

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PRESTASI SENAMAN DAN TINDAK BALAS PENTERMOKAWALATURAN TERHADAP SEMBURAN AIR SEJUK: KAJIAN SKOP

ABSTRAK

Pengenalan: Dalam keadaan tekanan panas, keletihan berlaku lebih awal dan keupayaan bersenam berkurangan. Kebelakangan ini, alat penyejukan terkini untuk penyejukan sebelum dan semasa senaman telah dibangunkan tetapi peranti-peranti tersebut mempunyai masalah logistik untuk digunakan semasa pertandingan. Oleh itu, tinjauan ini bertujuan untuk menganalisis literatur yang relevan berkaitan strategi penyemburan air sejuk dalam mempengaruhi prestasi senaman dan tindak balas pentermokawalaturan dalam persekitaran panas dan lembap.

Kaedah: Pencarian dilakukan dengan menggunakan Item Pelaporan Pilihan untuk Pedoman Sistematik dan Meta-Analisis (PRISMA) dengan menggunakan pangkalan data ProQuest, ScienceDirect, PubMed, SpringerLink.

Hasil: Lapan kajian penerbitan dimasukkan. Hanya tiga kajian yang mengkaji pengaruh semburan air sejuk pada prestasi sukan sementara lima kajian melaporkan semburan air sejuk terhadap tindak balas termoregulasi. Tiga kajian menunjukkan prestasi sukan meningkat dengan semburan air sejuk. Sebilangan besar kajian menunjukkan bahawa penyejukan dengan semburan air sejuk menurunkan suhu dahi, muka dan kulit, dan degupan jantung sambil tidak menunjukkan kesan yang signifikan terhadap suhu badan teras semasa bersenam.

Kesimpulan: Intervensi penyejukan menggunakan penyembur air sejuk menjadi cara yang berkesan untuk meningkatkan prestasi senaman di persekitaran yang panas, Namun, kajian yang menyelidek keberkesanan strategi penyejukan ini adalah terhad. Berdasarkan bukti terkini, kesan semburan air sejuk pada suhu teras tidak menunjukkan perbezaan yang signifikan, sementara faktor kardiovaskular dan suhu kulit menunjukkan hasil yang sebaliknya.

EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO COLD-WATER SPRAY STRATEGY: A SCOPING REVIEW

ABSTRACT

Introduction: In heat thermally stress conditions, fatigue occurs earlier and exercise capacity is reduced. In recent years, newer pre- and per-cooling devices have been developed but those devices seem logistically challenging for use in competition or field settings. Thus, this review aimed to analyse relevant literature of cold-water spray strategy effects on exercise performance and thermoregulatory response in a hot-humid environment.

Methods: The search was conducted by applying the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines using ProQuest, ScienceDirect, PubMed, SpringerLink databases.

Results: Eight publication studies were included. There were only three studies that investigated the effect of cold-water spray on exercise performance while five reported the cold-water spray intervention on thermoregulatory responses. Cold-water spray intervention improved exercise performance in three studies. Most of the studies showed that cooling by cold-water spray lower the forehead, face and skin temperatures, and heart rate while showing no significant effect on core body temperatures during exercise.

Conclusion: Cooling intervention using cold-water spray could be an effective way of improving exercise performance in a hot environment. However, studies investigating the effectiveness of this cooling strategy are limited. Based on the current evidence, the effect of cold-water spray on core temperature shows no significant differences, while cardiovascular and skin temperature factors showed the opposite result.

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Endurance performance in hot conditions is impaired compared with the cooler environment. In heat thermally stress conditions, fatigue occurs earlier and exercise capacity is reduced. In such conditions, attainment of critically high body temperature is the main limiting factor for inhibiting exercise performance (Ross, Abbiss, Laursen et al., 2013). Many major competitive sporting events take place in hot-humid environments such as Le Tour de Langkawi in Malaysia and the coming 2021 Olympic Games in Tokyo and the 2022 World Cup in Qatar. During exercise with heat stress, there is a consensus that performance is decreased, including an increased risk of heat illness, especially in high humidity.

Numerous scientific investigations have been attempted to improve exercise performance in the heat with cooling strategies and became a well-established ergogenic practice for endurance athletes (Stevens, Kittel, Sculley et al., 2017a). Most strategies aimed to reduce thermoregulation strain, including hydration intervention, acclimation, and cooling. It must be acknowledged that cooling has been a popular strategy for those who are competing in a hot and humid environment. However, the use of per-cooling or mid-cooling has received considerably less research attention, despite recent evidence to suggest that the advantage gained from mid-cooling may outweigh that of pre-cooling (Stevens et al., 2017a). The body cooling methods, pre-cooling (prior exercise), per-cooling (during exercise), and post-cooling (after exercise), are to reduce the risk of heat-mediated decrements in performance (Best, Payton, Spears et al., 2018; Butts, Torretta, Smith et al., 2017; Ruddock, Robbins, Tew et al., 2017; Stevens et al., 2017a) and to reduce body core temperature. Investigating per-cooling strategies, such as using cold air exposure, ice vest, and neck cooling, is a continuing concern within field application compared to laboratory testing. There were complaints about excess weight and skin irritation, even sporting regulations limited per-cooling interventions (Tyler, Sunderland & Cheung, 2015).

In recent years, newer pre and per-cooling devices have been developed, such as portable plunge baths and cooling garments that were demonstrated well or effective in the laboratory. But those devices seem logistically challenging for use in competitions or field settings. In addition, there is also a lack of research on the cold-water spray to improve sports performance and as a way to minimise the risk of heat-related illness. Finding from this review will benefit Malaysian athletes to reduce heat-related illness during training or competition in the condition of the Malaysian climate, which may negatively affect their performance. Hence, this review sets out to provide an overview the cold-water spray cooling strategy on running performance in a hot and humid environment. Thus, the purpose of this review was to identify the interventions or applications of cold-water spray during pre- and per-cooling in actual sporting events.

1.2 Problem Statement & Study Rationale

The most important purpose of applying cold-water spray strategy is to reduce thermoregulatory and physiological strain for people exercising in heat thermal stress conditions and to minimise health risks such as hyperthermia. To our knowledge to date, there is a lack of information regarding the recommended cooling or acclimatisation guideline specifically for tropical dwelling population residing in the hot-humid Malaysian weather. Several manufacturers have designed ice-cooling garments/vests which had proven advantages but not necessarily affordable or practical for certain sports. Thus, this review is proposed to examine whether cold-water spray, as the cheaper alternative cooling strategy, elicits similar benefits as the more advanced and expensive commercial cooling devices. The effects of cold-water as a cooling strategy on exercise performance in Malaysian are unknown, and this review will provide first information regarding cold-water spray cooling strategy while exercising in the hot-humid Malaysian climate.

1.3 Research Questions

1. Does cold-water spray strategy improve exercise performance in a hot-humid environment?
2. Does cold-water spray reduce core, skin temperatures and heart rate during exercise in a hot-humid environment?

1.4 Objectives

1.4.1 General Objective

1. To determine the effects of cold-water spray before and during exercise performance and thermoregulatory response in a hot-humid environment.

1.4.2 Specific Objectives

1. To compare exercise performance between cold-water spray trial and control trial in a hot-humid environment.
2. To compare core body temperature response between cold-water spray trial and control during exercise in a hot-humid environment.
3. To compare mean skin temperature between cold-water spray trial and control trial during exercise in a hot-humid environment.
4. To compare heart rate response between cold-water spray trial and control during exercise in a hot-humid environment.

1.5 Significance of Review

The present review is proposed for adding new scientific information on the cold-water spray cooling strategy while exercising in a hot and humid environment. Information from this review can assist individuals who are training and competing in the Malaysian climate to make better decisions in opting for an effective cooling strategy. This review also provides new insights into cold-water spray recommendation guidelines for an active person or athlete to continue exercising in a hot-humid environment to ensure safety and optimal performance.

CHAPTER 2: LITERATURE REVIEW

Exercising in hot, humid conditions disproportionately increases the rate of heat storage, body temperature, and heat illness susceptibility, subsequently decreasing muscle activation and force production. An increase in core temperature to a critical level of 40ºC may subsequently cause hyperthermia which inhibits central nervous system activation thereby reducing force production (Randall, Ross & Maxwell, 2015).

According to Bergeron (2014), in his clinical commentary on heat stress and thermal strain challenges in running, he included an overview of key environmental and other contributing factors that affect thermal strain, sweat loss, well-being, exertional heat illness, and injury risk, and performance during running training and competition. Environmental stress, specifically heat stress, increases the demand placed on the cardiovascular system. Exercise also induces stress on the cardiovascular system, and the combination of heat stress with exercise can lead to a physiological challenge where demands for blood flow begin to challenge the maximal output of the heart, and eventually leading to fatigue, exhaustion, and/or a decline in performance (Denby, Caruso, Schlicht et al., 2020). Athletes training and competing in hot, humid environments are particularly susceptible to exertional heat illnesses such as heat cramps, heat exhaustion, and heat stroke (Cleary, Toy & Lopez, 2014).

Decreasing core temperature below 40ºC as quickly as possible reduces the likelihood of organ damage and concomitantly increases the rate of survival (Butts, McDermott, Buening et al., 2016). With fluid loss occasionally as high as 6-1-% of body weight, dehydration appears to be one of the most common risk factors for heat illness in individuals exercising in the heat (Coris, Ramirez & Van Durme, 2004). Identifying athletes at risk, limiting environmental exposure, and monitoring closely for signs and symptoms are all important components of preventing heat illness. However, monitoring hydration status and early cooling intervention may be the most important factors in preventing severe heat illness (Coris, Ramirez & Van Durme, 2004). At any competition with expected hot/humid conditions, it has been reported that less than one-fifth of the athletes' heat acclimatised, half had a pre-cooling strategy and almost all a hydration plan (Périard, Racinais, Timpka et al., 2017).

2.1 Thermoregulatory Challenges during Exercise in a Hot and Humid Environment

Exercise sustained at a sufficient intensity and duration may elevate core body temperature to the upper limit of its thermoregulatory zone. Core body temperature has been shown to raise an additional 0.15–0.2°C for every 1% of body weight lost to dehydration during exercise (Coris, Ramirez & Van Durme, 2004). Excess heat production during exercise is a major determinant of behaviour and, therefore, performance. This is because as muscle's metabolic rate is increased during the early stages of exercise, a progressive increase in the muscle-to-core temperature gradient occurs such that the heat content of the active musculature exceeds that of the core region (Flouris & Schlader, 2015). Exercise in the heat can pose a severe challenge to human cardiovascular control, and thus the provision of oxygen to exercising muscles and vital organs. This is due to increased thermoregulatory demand for skin blood flow, as well as dehydration and hyperthermia. Cardiovascular strain, typified by reductions in cardiac output, skin and locomotor muscle blood flow, and systemic and muscle oxygen delivery, accompanies marked dehydration and hyperthermia during prolonged and intense exercise, is characteristic of many summers' Olympic events (González-Alonso, Crandall & Johnson, 2008).

Exercising in the heat decreases skin blood flow, of which places unusual demands on the human body's thermoregulatory centre in the hypothalamus. Without hydration, heat production during exercise is 15–20 times greater than at rest and is sufficient to raise 1°C core body temperature every 5 minutes if there are no thermoregulatory adjustments. In hot, dry conditions, evaporation may account for as much as 98% of dissipated heat. In addition to the influence of dehydration on core body temperature rise, athletic performance suffers considerably with even 2–3% dehydration (Coris, Ramirez & Van Durme, 2004).

Prolonged and heavy exercise in the heat is likely to induce hypohydration due to increased sweating and insufficient fluid intake. In turn, the hypohydration impairs autonomic thermoregulation such as skin vasodilation and sweating, which results in hyperthermia (Tokizawa, Matsuda-Nakamura, Tanaka et al., 2016). In human, hypohydration also decreases the thermal sensation of heat. However, exercise training helps maintain autonomic thermoregulatory responses to heat despite the presence of plasma hyperosmolality and even decrease the plasma osmolality threshold for the autonomic responses (Tokizawa et al., 2016). The performance was slower in hot solo cycling time trial than cool solo cycling time trial. However, performance in hot competition mode is faster than self-paced cool condition. The thermal strain was greater in competition mode. So, competition in hot condition increases the risk of heat illness. During self-paced exercise in a hot environment, performance may be impaired with modest hyperthermia and the work rate is often reduced (Corbett, White, Barwood et al., 2018).

Thermoregulation can be affected negatively by a number of factors, including an environment that is hot and humid and dehydration which may result in serious heat illness. A large amount of energy is released as heat during exercise. It is necessary to promote the loss of excess heat through mechanisms such as cutaneous vasodilation and sweating to prevent a continuous rise in the body's core temperature. In terms of rehydration, athletes should consume fluids at a rate that closely matches their sweat and urine losses. Through heat acclimatisation, which typically takes 7-14 days, athletes can minimise the risks associated with exercising in the heat (Wendt, van Loon & Lichtenbelt, 2007).

2.2 Cooling Strategies for Exercise in the Hot and Humid Environment

The cooling methods prior (pre-cooling), and during (per- or mid-cooling) exercise may attenuate the rise of core body temperature and improve exercise performance (Bongers, Hopman & Eijsvogels, 2017). There were many methods of pre-cooling that were investigated in a hot environment, including water immersion application of ice packs onto the skin, the wearing of ice-cooling garments, cold-air exposure, and a combination of these approaches (Tyler et al., 2015). Although these pre-cooling strategies showed performance benefits, these strategies were less practical for on-field settings. For example, cold-air exposure requires a refrigerated chamber and poses a logistical problem to be transported and placed at competition sites (McNeely, 2015).

Mid-cooling method is a method of cooling during exercise that can be achieved through the ingestion of cold fluids or ice slurry (with or without a menthol additive), as well as cooling the neck and face region via a cooling collar or water spray. These mid-cooling strategies are particularly beneficial for endurance performance in the heat (Stevens, Taylor & Dascombe, 2017b). The effects of mid-cooling may differ from pre-cooling since such strategies act to cool the body when the athletes are already under heat stress, with an immediate impact on performance. The combination of pre-cooling and mid-cooling has also been effective, but few comparisons exist between the timing and type of such interventions (Stevens et al., 2017a).

From present review of one article by Steven, Bennett, Sculley et al. (2017c), the combination of these mid-cooling interventions and their further combination with the pre-cooling interventions improved performance by 3.5%. Importantly, the mid-cooling interventions had several effects that may have caused the performance improvements, including attenuations in forehead temperature, blood prolactin concentration, and thermal sensation, and increased expired air volume (Stevens et al., 2017c). Mid-cooling significantly increased expired air volume and respiratory exchange ratio compared with control, whereas pre-cooling decreased rectal temperature, mean skin temperature, heart rate, and sweat rate significantly. Significant decreases in forehead temperature, thermal sensation, and postexercise blood prolactin concentration were observed in all conditions compared with control. Mid-cooling improved performance, whereas precooling had little or no effect. Mid-cooling may have enhanced performance by reducing the inhibitory psychophysiological and endocrine response to heat. (Stevens et al., 2017c). In addition, mid-cooling with cold water/ice slurry ingestion was found to be the most effective strategy for improving exercise performance, followed by ice- or cooling vest, facial wind or water spray, cooling packs, and menthol cooling. These findings demonstrated that pre-cooling, as well as mid-cooling, are effective in improving exercise performance in both moderate and hot ambient conditions (Bongers et al., 2017).

Based on previous studies selected in our review, most of the results showed that both pre-and mid-cooling strategies improve exercise performance in the hot and humid conditions.

2.3 Cold-Water Spray Strategy

The cold-water strategy is likely ergogenic for endurance running performance in the heat. Among the most reported cold-water strategies were cold-water ingestion and cold-water immersion (Bongers et al., 2017). Mid-cooling by facial water spray has no reported effect on core temperature but strong sensory adjustments seen in the lower perception of thermal sensation and exertion (Stevens et al., 2017a). It has been suggested that cooling the face has a two-to-five folds more powerful suppression on thermal discomfort and the onset of sweating than cooling an equivalent area of any skin segment due to a greater density of thermal afferents in this area (Stevens et al., 2017a). A previous study by Stevens et al. (2017b) observed a 5-km running performance improvement with mid-cooling by intermittent facial water spray compared to no cooling intervention. This performance improvement also accords with the earlier assumption, which showed that facial water spray intervention significantly reduced rectal temperature and improved self-selected work output at the end of exercise (Stevens et al., 2017b). It is interesting to note that repeated application of menthol-spray to the torso improved time-to-exhaustion performance of trained cyclists in hot conditions (Barwood, Kupusarevic & Goodall, 2019).

In a 3-km time trial study, Steven et al., (2017c) mentioned that the combination of mid-cooling interventions of menthol mouth rinse and facial water spray resulted in a 3.5% significant performance improvement, and the 3-km performance time in the heat was significantly faster in both pre-cooling (water immersion) and mid-cooling (water spray) compared to no cooling (control). The present study has demonstrated that head cooling by water spray to the face leads to a considerable improvement in whole body sub-maximal exercise performance in a warm environment. Continuous facial fanning with additional facial water spraying at 30 s intervals during cycling exercise at 75% maximal oxygen uptake (VO_2max) increased time to exhaustion by 51% in a related study (Ansley, Marvin, Sharma et al., 2008). The previous study by Griggs, Havenith, Price et al., (2015) observed that cold water spraying during running in addition to precooling with an ice vest lowers thermal strain to a greater degree than pre-cooling only.

The cold-water spray may be a simple, practical and useful strategy for athletes to improve exercise performance in a hot and humid condition. This findings from this review are purposeful for individuals exercising in the hot and humid Malaysia climate where the cold-water spray is a practical strategy to be applied in actual sporting events.

CHAPTER 3: METHODOLOGY

3.1 Data Sources

Previous related studies were obtained electronically using the following databases: ProQuest, ScienceDirect, PubMed, SpringerLink. Peer-reviewed articles were published in the English language from January 2004 until December 2020. For additional information, no attempts were made to contact the authors. All the searches were made to be compared with other databases.

3.2 Study Selection

The search was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines *(Figure 1)*. The following keywords were used during the search: #cold water and (#exercise performance or #hot humid). Articles were screened for studies that used cold water spray as intervention, and exercise performance, core and skin temperature, as well as heart rate responses as outcome measures. This review included controlled trials and laboratory studies on humans. The intervention comprised of (i) cold water spray with placebo-controlled, and (ii) cold-water spray in combination with an exercise programme. Exercise performance was described as: (1) exercise to exhaustion, (2) time trial performance.

The inclusion criteria were: (1) any articles testing cold-water spray intervention on running and cycling protocols; (2) any articles included core, skin temperature, and heart rate responses outcome measure; (3) any articles testing on men and/or women, well-trained athletes, or physically active human participants; and (4) any articles testing in a laboratory-based and climate controlled-environment.

Articles that were excluded (1) non-peer-reviewed articles; (2) any articles testing on non-human participants; and (3) any articles published in languages other than English.

3.3 Data Extraction

The articles were reviewed based on the titles and abstracts using the criteria specified to determine whether full-texts were required for further analysis. Each full-text manuscript was selected systematically according to the study: (1) objective/s, (2) characteristics of the study (study design, participants, gender, age, and sample size), (3) contents of intervention (intervention types, length of intervention) (4) targeted outcome/s, and (5) main findings. Due to the nature of this scoping review, the outcomes extracted from those studies were not combined, reanalysed or changed.

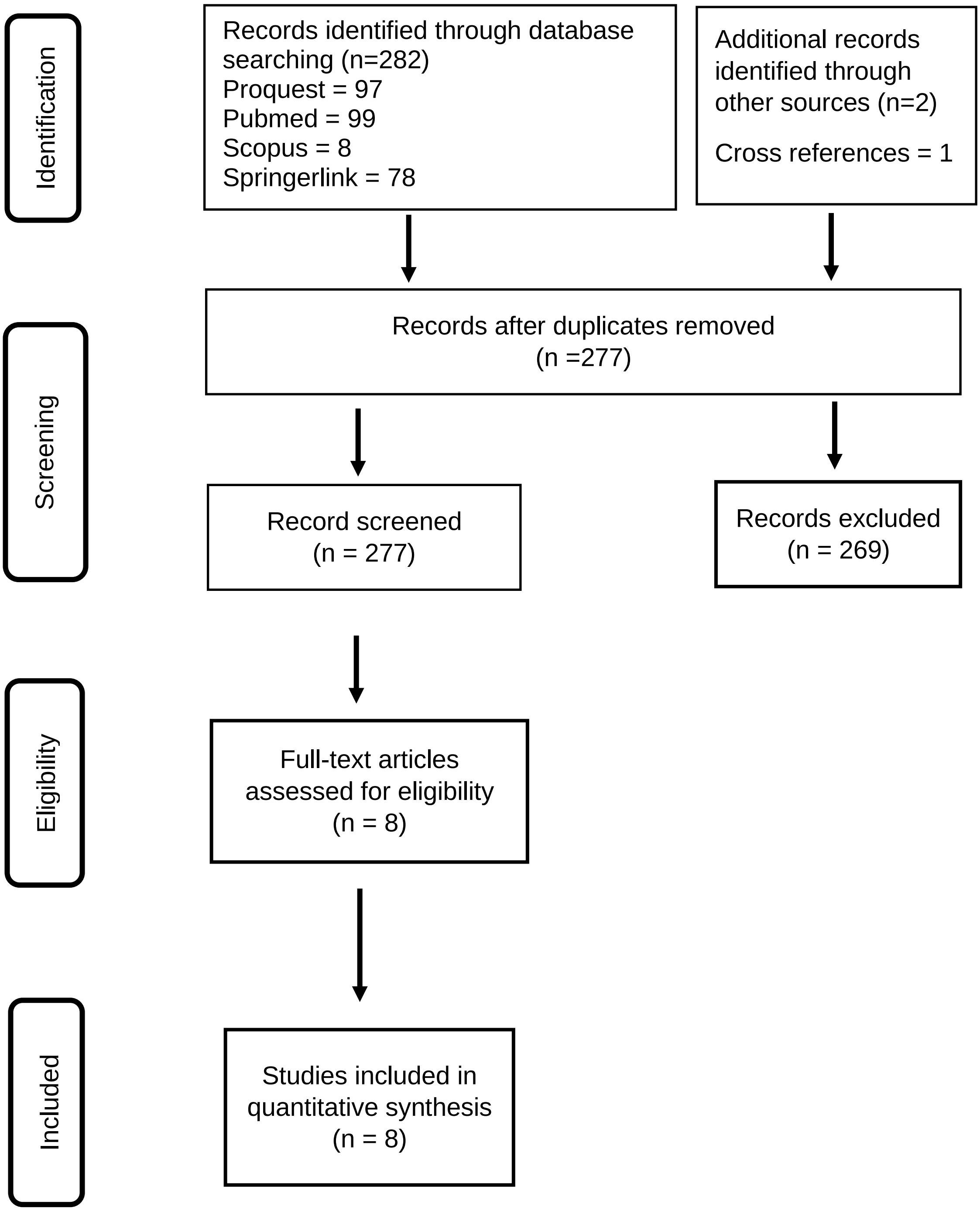

Figure 1: PRISMA flow for study selection

CHAPTER 4: RESULTS

4.1 Article Retrieved

The initial search from the database identified 282 potential articles. After screening for inclusion and exclusion criteria, 8 published articles were included in the review. After detailed analysis only 8 full-text articles were included in this scoping review. Pertinent data extracted from each article are presented in *Table 1*.

4.2 Article characteristics

All 8 articles were published between year 2004 and 2017. Specifically, articles were published in 2004 (n=1), 2007 (n=1), 2008 (n=1), 2009 (n=1), 2012 (n=1), 2015 (n=1), and 2017 (n=2). There was a total sample of 77 participants across all articles consisting of various population (*Figure 2*). Among the studies, four (50%) articles reported on the investigation of cold-water spray only as an intervention, while another four (50%) articles studies used cold water spray and fan.

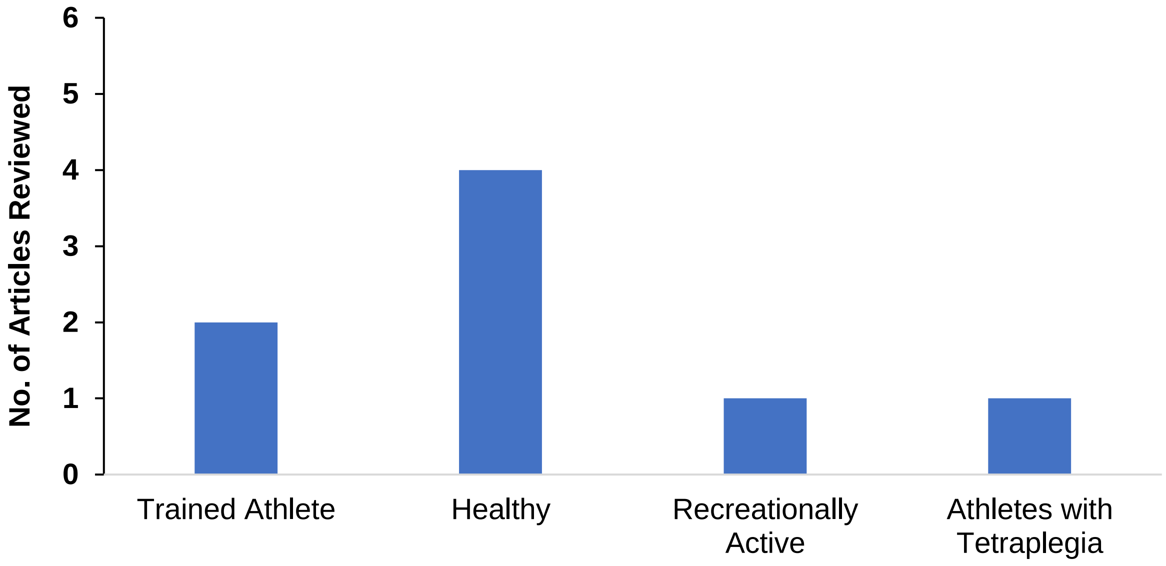

Figure 2: Distribution of Study Participants

4.3 Exercise and Intervention Protocols

Figures 3 and *4* consist of different timing and methods of exercise protocol, respectively. All the studies used different method of exercise for assessment. Four (50%) articles consist studies that utilised cycling protocol, three (37.5%) articles had studies that used running protocol and one (12.5%) article used adapted intermittent exercise protocol. Most of the articles (n=5, 62.5%) consisted of investigation that determined the effect of cold-water spray on heart rate, core and skin temperature. Some of the studies measured time trial (TT) (n=3, 37.5%) and one study measured time-to-exhaustion (n=1, 12.5%) performance.

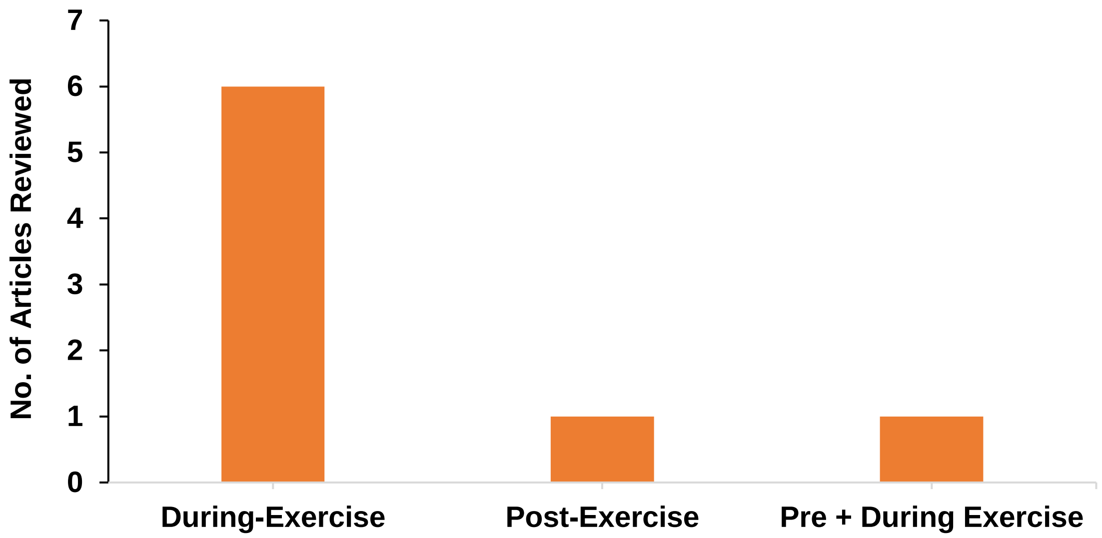

Figure 3: Distribution of Cold-water spray Intervention Timing

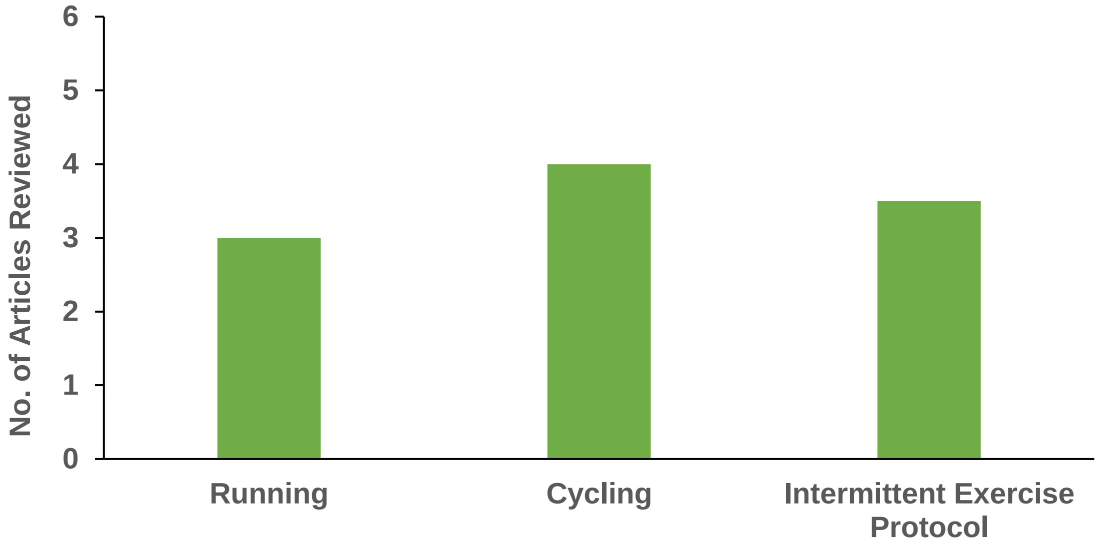

Figure 4: Distribution of Test-Protocols

4.4 Synthesis of Result

4.4.1 Cold-water spray Intervention on Exercise Performance

Self-paced 5 km running performance was improved by a similar magnitude (~3%) with intermittent facial water spray compared to control. Significantly, faster running times per kilometre were observed first 2 km in SPRAY (*P* < 0.02). The facial water spray improved performance at the start of the time trial (0-2 km) compared to control (Stevens et al., 2017a). In 3 km performance time was significantly faster in mid-cooling by combined facial water spray and menthol mouth rinse (MID) (Stevens et al., 2017c). Continuous facial fanning with additional facial water spraying at 30 s intervals during cycling exercise at 75% maximal oxygen uptake (VO_2max) increased time to exhaustion by 51% in a related study (Ansley et al., 2008). However, Griggs et al., 2015, showed that cold-water spray had no effect on exercise performance while studies by Armada-da-Silva, Woods & Jones 2004; Leicht, Sinclair, Patterson et al., 2009; Miyazawa, Horiuchi, Ichikawa et al., 2012 & Mündel, Bunn, Hooper et al., 2007 did not measure the effect of cold-water spray on exercise performance.

4.4.2 Cold-water spray Intervention on Thermoregulatory and Heart Rate Responses

Four studies reported changes in core and skin temperature (Ansley et al.,2008, Armada-da-Silva et al., 2004, Griggs et al., 2015 & Miyazawa et al., 2012). Armada-da-Silva et al, (2004) investigated that core and skin temperature were significantly higher in the SAU (sauna) and SAU_{FAN} (Face cooling with mist of cold water, adapted electrical fan that directed the airflow to the face) trials compared respectively to control (CON and CON_{FAN}) trials, throughout the entire duration of the exercise. In the SAU trial, rectal temperature (T_{re}) remained stable during exercise, at an average value of 38.89 ± 0.02^{o}C at the start and slightly increasing to 38.98 ± 0.05^{o}C at the end of the exercise. In the control trial, rectal temperature showed a modest but significant increase during exercise. In the SAU_{FAN} trial, rectal temperature values were similar to those observed during SAU and varied non-significantly between 38.93 ± 0.05^{o}C and 38.85 ± 0.14^{o}C from the start to the end of exercise, showing that face fanning did not affect rectal temperature during the course of the 14-min exercise. In the CON_{FAN} trial, rectal temperature increased significantly during the exercise. Mean skin temperature was higher in both SAU and SAU_{FAN} trials compared with CON and CON_{FAN}, respectively. During the exercise, mean skin temperature remained fairly constant in the SAU and SAU_{FAN} trials, while it progressively increased in the CON and CON_{FAN} trials. The effect of face cooling on face temperature can be seen, after an initial drop at the start of cooling, remained fairly constant at values just below 32^{o}C and 30^{o}C in SAU_{FAN} and CON_{FAN} trials, respectively (Armada-da-Silva et al., 2004).

Another study reported that exercise with head cooling (cold-water spray with fan) was more comfortable than under control conditions. Exercised at 75% VO_2max to volitional fatigue on a cycle ergometer at an ambient temperature of 29±1.0°C, with a relative humidity of approximately 50%. Tympanic temperature and sinus skin temperature were reduced by head cooling and remained low throughout the exercise. (Ansley et al., 2008). Miyazawa et al., (2012) investigated that overall skin temperature significantly increase during exercise and face cooling did not change mean skin temperature at rest or during exercise. However, face temperature was decreased during rest and exercise which indicate that body part other than face was not affected by face cooling. (Rest -6.2 ± 0.3°C, Exercise -6.9 ± 0.3°C).

Studies found in this review stated that pre-cooling with an ice vest and water sprays between quarters during intermittent sprint protocol on a wheelchair (ISP) reduce skin temperature. The reduction in skin temperature over the pre-cooling period was significantly greater in pre-cooling with an ice vest (P) and pre-cooling with an ice vest with water sprays between quarters (PW) compared to no cooling (NC). By the end of the second quarter to completion of ISP, the reduction in skin temperature was lower in PW compared to P and no cooling (Griggs et al., 2015).

Two studies investigated cold-water spray on heart rate in exercise. Walk-run exercise on a motorised treadmill, heart rate was significantly reduced over time in FAN treatments (industrial fan cooling with intermittent water spray). Heart rate was lower in FAN during 40 min exercise compared to intravenous cold saline infusion (IV) and ice packs (ICE) (Leicht et al., 2009). Another study, noted that cycling increased heart rate significantly from 5 min to the end of each trial with a relative bradycardia, a condition of slowed heart rate, during face cooling trial, the rate being approximately 5 beats.min^{-1} lower than during the CON trial (Mündel et al., 2007).

Table 1: Data extracted from each article included for review (N=8)

Articles	Study Participants	Study Design	Test Protocol	Cold-water spray dosage	Intervention	Key Exercise Performance Finding	Key Thermoregulatory Responses Finding
Steven et al., (2017a)	9 trained heat-acclimatised male runners	Randomised, crossover and counter-balanced	5 km running time trials on a non-motorised treadmill in the heat (33°C).	3 water sprays (22^{o}C) / kilometre	The trials included pre-cooling by cold-water immersion (CWI), mid-exercise cooling by intermittent facial water spray (SPRAY), and a control of no cooling (CON).	Performance time was significantly faster with CWI and SPRAY compared to CON	Both cooling strategies significantly reduced forehead temperatures and thermal sensation, and increased muscle activation. Only pre-cooling significantly lowered rectal temperature both pre-exercise and throughout exercise, and reduced sweat rate.
Steven et al., (2017c)	11 trained heat-acclimatised male runners	Randomised crossover	Pre-loaded running time trials on a nonmotorized treadmill in the heat (33^{o}C)	7 water sprays (22^{o}C)/ 0.5 km of every 1 km	Pre-cooling by combined cold-water immersion and ice slurry ingestion (PRE), mid-cooling by combined facial water spray and menthol mouth rinse (MID), a combination of all methods (ALL), and control (CON).	Performance time was significantly faster in MID and ALL but not PRE when compared with CON	Pre-cooling significantly reduced rectal temperature mean skin temperature, and heart rate responses Mid-cooling significantly decreases in forehead temperature was observed in all conditions compared with control.

Miyazawa et al., (2012)	9 healthy men	Experimental study	Subjects performed 4 min (60 W, 60 revolutions/min) and maintain the frequency of pedalling. Workload was increased 10–30 W every minute until the target heart rate 120 bpm was achieved. workload was held constant (129 ± 12W) for 5 min.	Cold water (~4ºC)	Face Cooling by fanning and spraying the face with a mist of cold water(~4ºC) at rest and during steady-state exercise	Exercise performance were not measured	Skin temperature was significantly increased during exercise, but face cooling did not change skin temperature at rest or during exercise. In contrast, only face temperature (T_{face}) was decreased by face cooling.
Armada-da-Silva et al., (2004)	10 healthy males	Randomised and balanced design	14-min cycling at average power ~63% of maximum power output (W_{max}) an ambient temperature of 35ºC	Unknown	Cycling at temperature control (CON) trial on one occasion, and after sitting in a sauna to raise rectal temperature. Six of the subjects repeated the two trials (CON_{FAN} and SAU_{FAN}) with the face cooled (combining face fanning and spraying the face with a mist of cooled water) during exercise.	Exercise performance were not measured	Face cooling decreased face temperature while no effect on rectal temperature during the course of the 14-min exercise. During the exercise, mean skin temperature remained fairly constant in the Sauna (SAU) and combining face fanning and spraying the face with a mist of cooled water trials (SAU_{FAN})

Ansley et al., (2008)	9 healthy, recreationally active male	Randomised order	Exercise at 75% VO_2max to volitional fatigue on a cycle ergometer at ambient temperature of 29±1.0°C, with a relative humidity of 50%.	Fine mist water sprayed 5 $ml.min^{-1}$	Head cooling by fine mist of water. at 30 second intervals (5-10 $ml.min^{-1}$).	Head cooling resulted in a 51% improvement in exercise time to fatigue.	Head cooling with water sprayed having no effect on rectal temperature. Tympanic temperature and sinus skin temperature were reduced by head cooling and remained low throughout the exercise.
Griggs et al., (2015)	8 wheelchair rugby players with tetraplegia	Experimental study	60 min intermittent sprint protocol (ISP) on a wheelchair ergometer in 20.2°C and 33.0% rh	~ 17°C sprayed twice (~50 mL per 20 s spray)	Pre-cooling with an ice vest or pre-cooling with an ice vest and water sprays between quarters.	Cooling had no effect on performance measures	The reduction in skin temperature over the pre-cooling period was significantly greater in pre-cooling with an ice vest and ice vest and water sprays between quarters compared to no cooling. By the end of the second quarter to completion of the intermittent sprint protocol (ISP), the reduction in skin temperature was lower in ice vest and water sprays between quarters (PW) compared to pre-cooling with an ice vest (P) and no cooling. Cooling had no effect on heart rate during the ISP.

Mündel et al., (2007)	10 healthy, non-heat acclimated males	Randomized, cross-over design	Cycling at 65% of VO_2peak for 40 min in ambient temperature of 33^oC and 27% relative humidity	Cold water (~4^oC)	Exercise with face cooling sprayed by a mist of cold-water (FC) and without face cooling as a control (CON).	Exercise performance were not measured	With face cooling (FC), forehead temperature was maintained ~6^oC lower than control, while other skin sites were similar or slightly warmer in the face cooling condition. Rectal temperature increased by ~1.5C with the same time course in both conditions.
Leicht et al., (2009)	11 healthy males	Randomised order	Three sessions in a climate control chamber separated by at least 72 h. Each session comprised a repeated intermittent exercise protocol consisting of walk–run (2 min.6 kmh^{-1} & 4 min.10 kmh^{-1}) on a motorized treadmill until core temperature was elevated to near 40^oC, followed by 40 min of recovery with a cooling treatment.	Unknown	During recovery, intravenous cold saline infusion (IV) or ice packs (ICE) or fan cooling with intermittent water spray (FAN) for 40 min	Exercise performance were not measured	Heart rate and core temperature were similar between treatments and were significantly reduced over the 40 min recovery period. During recovery, heart rate was significantly reduced from initial levels but were significantly greater for intravenous cold saline infusion (IV) compared with ice packs (ICE) and fan cooling with intermittent water spray (FAN).

CHAPTER 5: DISCUSSION

The primary findings of this scoping review show that cold-water spray is beneficial to exercise performance in hot-humid environment. Secondly, effects of cold-water spray in combination with repeated exercise training sessions can reduce core and skin temperatures and heart rate, during exercise in a hot-humid environment.

5.1 Cold-Water Spray Cooling Strategy on Exercise Performance

Two studies investigated the effect of cold-water spray on exercise performance; 5-km running time trial and 20 minutes at 70% VO_2max with 3-km maximal self-paced running time trial (Steven et al., 2017a & c). Both studies showed cold-water spray improved exercise performance. In the 5-km time trial study, cold-water spray (SPRAY) was compared with cold-water immersion (CWI) and no intervention (CON). The findings showed that both SPRAY and CWI improved performance. When compared to the control condition, self-paced 5-km running performance improved by a similar magnitude (3%) with both pre-cooling by CWI and mid-cooling by intermittent facial water spray. Compared to the control, facial water spray improved performance at the start of the time trial (0-2 km). These early improvements in the facial water spray condition could be attributed to the runners' confidence in accumulating more heat stress in the early stages of the run, whereas the other conditions encouraged a cautious slower start. Both strategies are likely ergogenic for endurance running performance in the heat (Steven et al., 2017a). In the 3-km time trial study, Steven et al., (2017c) mentioned that the combination of mid-cooling interventions (menthol mouth rinse and facial water spray) resulted in a 3.5% significant performance improvement, and a 3-km performance time in the heat was significantly faster in both pre- and mid-cooling (13.7 minutes) compared to pre-cooling only (13.9 minutes) and control (14.2 minutes). Continuous facial fanning with additional facial water spraying at 30-secs intervals during cycling exercise at 75%