**Title:** Head, face and neck cooling for performance: A systematic review and meta-analysis

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**Abstract**

**Purpose:** Cooling the head, face and neck can have strong perceptual effects that contribute to improved performance. This systematic review aimed to determine the effect of cooling strategies targeting the head, face and neck on physical and cognitive performance, determine any associated physiological and perceptual responses, synthesize adverse events, and provide practical applications.

**Methods:** We conducted a systematic review and multi-level meta-analysis, adhering to the PRISMA guidelines. Studies that investigated the effect of cooling strategies targeting the head, face, or neck on a physical or cognitive task using a controlled trial design were included.

**Results:** Sixty-three studies were identified, involving 618 participants (86.6% male). Cooling strategies included water-perfused devices (18.7%); phase change neck collars (17.3%); fanning/cold air (14.7%); phase change headwear (13.3%); ice/gel packs (13.3%); cold towels (5.3%); menthol application (4.0%); water spraying/dousing (4.0%); or a combination of strategies (9.3%). The effect of cooling on both self-paced and fixed-intensity exercise tasks was inconclusive; the 95%CI of the pooled effect was compatible with no effect and medium beneficial effects, but not harmful effects. We were unable to pool cognitive data. Cooling reduced the skin temperature at the target site and improved thermal sensation and thermal comfort. Effects on heart rate, and core and mean skin temperatures were negligible. Adverse events were rare, and no intervention subgroup was superior.

**Conclusion:** We recommend that athletes experiment with a range of head, face and neck cooling strategies, including using different doses and timings, to determine the optimal strategy for their individual and sport context.

**Keywords:** Exercise; Endurance; Cognition; Physiology; Perception; Thermal sensation; Thermal comfort

**1.0 Introduction**

Global mean temperatures for the past 8 years were the highest on record, with heat waves more frequent and severe.1 These rising temperatures create increasing challenges for sport, especially for elite athletes, with major sporting events often held in hot climates and seasons such as recent and upcoming summer Olympic Games and FIFA World Cups.2,3 A hotter environment is also negatively impacting recreational athletes and exercisers.4 Regardless of the environmental conditions, muscle contractions produce heat,5 which can increase the body heat content.6 If heat loss pathways are impeded (e.g. by high ambient temperature, high humidity, protective clothing or equipment worn), thermal and cardiovascular strain will ensue (i.e. increased core temperature and heart rate), often impairing exercise performance and/or causing premature onset of fatigue.7-9 Indeed, endurance sports competition in the heat has seen elite athletes present core temperatures ≥40 °C.10,11 In a recent review on athletes competing in sports competitions, 11.9% of 1,450 athletes experienced a core temperature ≥40 °C, and 2.8% of those experienced symptoms of exertional heat illness.12

Cooling strategies (e.g., cold-water immersion,13 cooling vests,14 cold drinks15 etc.) can mitigate some16 of the detrimental effects of heat on performance and are widely adopted, with 52-80% of athletes using cooling strategies across four major sporting championships.17 A recent meta-analysis demonstrated cooling led to improvements in fixed-intensity exercise tests (g=0.62, 95% CI 0.44-0.81) and self-paced exercise tests (g=0.30, 95% CI 0.18-0.42),16 which are both exercise tests that are relevant to sport. Fixed-intensity exercise tests are also useful to provide precise measurement of physiological responses, while self-paced exercise tests are useful to simulate the demands of time trials that often occur in sport competition, thereby providing an ecologically valid assessment of performance. Heat acclimation/acclimatisation training affords the greatest protection to performance and health during exercise in the heat18 and can attenuate the magnitude of improvements from cooling.19 Nevertheless, cooling strategies are strongly recommended for athletes competing in the heat,18 and can be implemented prior to (i.e. pre-cooling) or during exercise (i.e. per-cooling), with decisions on implementation often driven by resource availability, timing and competition rules. While both pre- and per-cooling strategies can be beneficial, studies that directly compared them demonstrated that per-cooling was either equal to,20 or more effective than pre-cooling on performance.21,22

Cooling strategies that target the head, face and neck during exercise (e.g., cooling caps,23 facial water spraying,20 cooling collars,24 etc.) can be beneficial for exercise performance in the heat.25 The combination of water spraying and fanning the head and face significantly improved cycling time to exhaustion at 75% maximal oxygen consumption (V̇O2max) by 51%.26 While the fanning aspect of this strategy is not practical to implement in competition, it demonstrated how powerful such cooling strategies can be. Cooling the face has a greater benefit on thermal comfort than cooling the torso and limbs during exercise in the heat27 and manipulating this feeling via non-thermal cooling and heating of the face, increased and decreased work output in an exercise test, respectively.28 As such, cooling the face has strong perceptual effects that could enhance self-pacing strategies in combination with thermoregulatory responses. These findings, along with the practicality and accessibility of most head, face and neck cooling interventions in field settings, may explain why cold-water dousing, often performed over the head, face and neck, is the most commonly utilized cooling strategy by athletes in sports competition.17 A narrative review has recently been published on head, face and neck cooling that provided useful recommendations for athletes,29 however, it would also be beneficial to extend this work to a systematic review with meta-analysis to combine all available data, enabling quantitative comparisons between different intervention types. There is also a growing body of work on the effect of cooling the head, face and neck on cognitive performance,30-34 however, cognitive performance has not been included as an outcome in previous reviews on the topic.

Therefore, the aims of this systematic review were to; i) determine the effect of cooling strategies targeting the head, face and neck on physical and cognitive performance; ii) determine any associated physiological and perceptual responses; iii) synthesize any reported adverse events following the use of these strategies; and iv) provide practical applications for the use of these strategies to improve performance.

**2.0 Method**

2.1 Protocol

This systematic review was prospectively registered on 25th December 2023, with the International Prospective Register of Systematic Reviews (PROSPERO ID number: 466825) and reporting was guided by the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines.35,36

2.2 Eligibility Criteria

Studies eligible for inclusion were randomized control trials or randomized cross-over trials on humans, which investigated the effect of a cooling strategy targeting the head, face, or neck on a physical or cognitive task. Included cooling strategies were those designed to provide external physical or perceptual cooling to the head, face, or neck. Cooling strategies that were ingested or swilled in the mouth and those that targeted the head, face, or neck in combination with other body regions were excluded. Primary outcome variables were measures of physical and cognitive performance (e.g. self-paced work/distance/time trials, fixed-intensity time/distance trials, as well as decision-making, memory and reaction time tasks. Secondary outcome variables were physiological (core temperature, skin temperatures, heart rate) and perceptual responses (rate of perceived exertion, thermal sensation and thermal comfort). Studies were excluded if they focussed on participants experiencing an acute medical condition or associated treatment. There were no limits placed on environmental conditions or date of publication. Studies must have contained empirical data and been published in a peer-reviewed journal in English.

2.3 Information Sources and Search Strategy

An electronic database search was conducted in Academic Search Premier, Medline, SPORTDiscus, AMED, Web of Science (Core Collection) and Scopus. The search strategy was developed based on the PICO model and the search string was piloted to ensure that it was comprehensive. The complete search string and variations for different databases are presented in Supplementary File 1. The final search was conducted on 11th October 2023. Retrieved titles and abstracts were imported into Endnote reference management software (Clarivate, United Kingdom) and duplicates were removed before the results were imported into Covidence screening software (Covidence, Australia).

2.4 Screening Process

Two authors independently screened all titles, abstracts and full-text articles to determine if studies met the eligibility criteria (CS and CT). Any disagreements regarding eligibility of the studies were resolved following arbitration with a third author when required (LT). A manual search was also conducted for any articles not retrieved by the database search, which involved screening the reference lists of included studies, until no further studies were discovered.

2.5 Quality Assessment

Version 2 of the Cochrane risk-of-bias (RoB2) tools for cross-over trials and randomized trials were used to assess the risk of bias in the included studies. These tools involved a series of questions being answered independently by two reviewers (CS, and either CB, CT, LL, or SC). The individual domains within the RoB2 tools address potential sources of bias relating to randomization procedures, period and carryover effects, deviations from intended interventions, missing outcome data, measurement techniques, and selective reporting of results. Each domain proposed a judgement risk as either ‘low’, ‘some concerns’ or ‘high’ based on a standardized assessment framework.

2.6 Data Extraction

Data extraction was performed with a custom data extraction tool by one author (CB, LL, or SC) and checked by a second author (CS). Extracted data included: authors, participant characteristics (sample size, population, VO2max, sex, and age), study design and setting, protocol, environmental conditions, intervention, outcome measures, results and adverse events. For physiological and perceptual results, absolute values post protocol were extracted, however, where a test to exhaustion was employed, values at the last available equivalent timepoint were extracted. When data needed to be extracted from figures, WebPlotDigitizer was used.37 When articles had missing or ambiguous data, authors were contacted to acquire data.

2.7 Meta-analysis

We planned to conduct separate meta-analyses to determine the effect of cooling on the primary outcomes of physical and cognitive performance, and secondary outcomes of core temperature, mean skin temperature, target site skin temperature, heart rate, whole-body RPE, whole-body thermal sensation and whole-body thermal comfort.

Effect size estimates were combined using a three-level model, with effect sizes nested within studies. We chose this modelling approach as several studies contributed multiple effect sizes to the same analysis, and therefore, these effect sizes could not be treated as independent.38 Estimates were inverse variance weighted. We used the standardized mean difference (SMD; Hedges’ *g*) between the cooling intervention and control condition for self-paced exercise tests, fixed-intensity exercise tests, RPE, and thermal sensation and comfort, as these outcomes were not on the same scale across all studies. Standardized mean differences were interpreted with thresholds defined as *small* 0.2, *medium* 0.5, and *large* 0.8.39 Where relevant, we reversed completion time and thermal comfort data (multiply by –1), to ensure that all positive SMDs in these models reflected improvements or benefits. The mean difference in core temperature, mean skin temperature, target site skin temperature and heart rate between the intervention and control condition was used, as these variables were reported on the same scale.

The three-level model was fitted using restricted maximum likelihood estimation.40 Confidence intervals were calculated based on a *t*-distribution with *k* – *m* degrees of freedom, where *k* is the total number of estimates and *m* is the total number of model coefficients, including the intercept. Using our modelling approach, heterogeneity variance (*τ*2) is separated into two components: within-studies and between-studies. We report the *τ*2 for each level, in addition to the distribution of variance across the levels, using the multilevel version of *I*2. We used moderator (subgroup) analysis to determine whether the intervention effect was different between cooling modalities for each outcome variable of interest.

Studies that returned a high risk-of-bias were excluded from the meta-analyses. Leave-one-(effect)-out analysis was used to determine whether the pooled effect and heterogeneity were reliant on the inclusion of one influential study. Small-study effects were evaluated using funnel plots and Egger’s regression test, which examines whether there is a relationship between the estimated intervention effects and their precision.41 All analyses were conducted in R42 using the RStudio environment (version 2024.04.2) and the packages *metafor*,43 *dmetar*,44 *metaviz*,45 and *tidyverse*.46 The R code and data are available here: [https://doi.org/10.5281/zenodo.14253041](https://url.au.m.mimecastprotect.com/s/_MQoCJyBN8UZopALcVfBIyq9xj?domain=doi.org).

**3.0 Results**

3.1 Study Characteristics

A Prisma flow diagram of the screening results is illustrated in Figure 147 and the characteristics of the 63 included studies are presented in Table 1. Search returns that were excluded after full-text screening are listed in Supplementary File 2. Included studies comprised a total of 618 participants, including 535 males (86.6%), 83 females (13.4%), and 13 had a spinal cord injury (2.1%). Almost all studies employed a cross-over design (n=62, 98.4%), but one study employed an independent groups design (n=1, 1.6%). A total of 75 cooling strategies were investigated. The frequency of the cooling strategies investigated, and their target sites is illustrated in Figure 2. The frequency of the studies conducted in different temperatures were as follows; 20-25 °C (23.3%), 26-30 °C (23.3%), 31-35 °C (35.0%), ≥36 °C (18.3%).

\*\*Insert Figure 1 here\*\*

\*\*Insert Figure 2 here\*\*

\*\*Insert Table 1 here\*\*

3.2 Quality Assessment

A summary of the ROB2 results is presented in Figure 3, and the full results are available in Supplementary File 3. Overall, 61/63 studies returned ‘some concerns’, which was predominantly a result of none of the studies pre-specifying an analysis plan. The other 2/62 studies returned a ‘high’ risk of bias, which was due to either missing outcome data or a deviation from the intended intervention.

\*\*Insert Figure 3 here\*\*

3.3 Meta-analyses

The meta-analysis results are summarized in Table 2 and funnel plots for the meta-analyses are illustrated in Figure 4. Forest plots for self-paced exercise tests and fixed-intensity exercise tests are presented in Figures 5 and 6. Forest plots for physiological and perceptual responses are presented in Supplementary File 4 and a sensitivity analysis is presented in Supplementary File 5. For cognitive performance outcomes, no meta-analyses could be performed due to limited data, and variability in the tests implemented and data reported.

\*\*Insert Table 2 here\*\*

\*\*Insert Figure 4 here\*\*

\*\*Insert Figure 5 here\*\*

\*\*Insert Figure 6 here\*\*

*3.3.1 Physical Performance*

The effect of cooling on self-paced exercise tests was *inconclusive* (Figure 5), with the 95% CI of the pooled effect (SMD, –0.12 to 0.61) compatible with both no effect and positive effects. The 95% CI was not compatible with harmful effects. There was no evidence of within-study (*τ*2 = 0.000; *I*2 = 0.00%) or between-study (*τ*2 = 0.000; *I*2 = 0.00%) heterogeneity. The test of moderators indicated the intervention effect was not statistically different between cooling modalities (*F*3,4 = 0.17, *p* = .91). There was no evidence of small-study bias based on the funnel plot (Figure 4a) and Egger’s regression test (Table 2). No single study had a large influence on the pooled effect or heterogeneity (Supplementary File 5).

The effect of cooling on fixed-intensity exercise tests was *inconclusive* (Figure 6), with the 95% CI of the pooled effect (SMD, 0.09 to 0.61) compatible with both no effect and positive effects. The 95% CI was not compatible with harmful effects. There was no evidence of within-study (*τ*2 = 0.000; *I*2 = 0.00%) or between-study (*τ*2 = 0.000; *I*2 = 0.00%) heterogeneity. The intervention effect was not statistically different between cooling modalities (*F*6,4 = 0.25, *p* = .94). There was no evidence of small-study bias based on the funnel plot (Figure 4b) and Egger’s regression test (Table 2). No single study had a large influence on the pooled effect or heterogeneity (Supplementary File 5).

*3.3.2 Physiological Responses*

There was no effect of cooling on heart rate, and effects on core temperature and mean skin temperature were *inconclusive* (Table 2, Supplementary File 4). There was no evidence that cooling had a harmful effect on heart rate, core temperature or mean skin temperature. As expected, cooling had a large effect on reducing the skin temperature at the target site (Table 2, Supplementary File 4).

Heterogeneity was present in all physiological variable models (Table 2). Except for core temperature, heterogeneity was greatest at the between-study level. The test of moderators indicated there was no statistical difference in the intervention effect on heart rate, core temperature or skin temperate at the target site between subgroups (Table 2). There was evidence that the intervention effect on mean skin temperature differed between subgroups (*F*8,16 = 3.43, *p* = .017), however, this was due to the influence of Gordon, et al.48 where one of the mean skin temperature sites was also the target site of the cooling strategy used. When Gordon, et al.48 was removed from the model, there was no evidence that the intervention effect differed between subgroups (*F*8,15 = 0.60, *p* = .76). There was evidence of funnel plot asymmetry for heart rate (Figure 4c), and possibly skin temperature at the target site (Figure 4f), which was supported by Egger’s regression test results (Table 2). While there were influential individual effects on the pooled effect and/or between-study heterogeneity for heart rate,30,49,50 core temperature,51 mean skin temperature,48 and skin temperature at the target site,52 removing these effect size estimates did not change the substantive conclusions of these analyses (Supplementary File 5).

*3.3.3 Perceptual Responses*

Cooling had a beneficial effect on thermal sensation and thermal comfort (i.e. decreased whole body warm sensations and discomfort; Table 2, Supplementary File 4). The effect of cooling on RPE was *inconclusive*, however, there was no harmful effect (Supplementary File 4). Heterogeneity was present in all models at the between-study level, by at least a small amount (Table 2). Moderator analysis showed that the intervention effect on perceptual variables was not statistically different between cooling modalities (Table 2).

There was no evidence of small-study bias for thermal sensation (Figure 4h; Table 2) or thermal comfort (Figure 4i; Table 2). Egger’s regression test (*β*0 = 2.60, 95% CI = –5.26, 0.07) indicated there may have been asymmetry in the RPE funnel plot (Figure 4g), however, this was due to the influence of Walters, et al.49 There were no concerns of asymmetry when Walters, et al.49 was removed from the analysis (*β*0 = 0.31, 95% CI = –2.12, 2.74).

3.4 Adverse Events

Out of the 63 studies, in which 75 interventions were assessed, there were 3 reports of adverse events associated with the cooling interventions. Two participants were excluded from one study as they could not tolerate the intervention, which involved application of a frozen gel pack (0-3 °C) to the forehead and eyes.53 One participant experienced heat induced orthostatic intolerance immediately after application of a water-perfused (13 °C) head-neck cooling device, however, this also occurred during the control condition.54 In a separate study, one participant’s trial was terminated due to muscle cramps, however, it was not reported if this occurred during the intervention or control condition.55 There was no report of any cooling strategy making a participant feel cooler and then pushing beyond their thermal limits, causing exertional heat illness.

**4.0 Discussion**

4.1 Physical Performance

The effect of cooling the head, face and neck on self-paced and fixed-intensity exercise tests was inconclusive, as effects ranged from no effect to medium beneficial effects. There was not enough data to meta-analyse other components of physical performance, where individual studies demonstrated contrasting effects on measures of speed, strength and skill. For example, cold towels applied to the neck,55 or a combination of the head and neck,56 had no effect on subsequent sprint times, yet, a phase change neck collar worn during a simulated football match protocol improved mean power output across 5 x 6 second sprints.57 Further, application of an ice pack to the neck or face had no effect on the number of bicep curl repetitions in a strength test to failure,58 however, facial fanning increased the number of hand-grip repetitions to failure.59 Sport specific skill was only assessed in one study, where an ice pack applied to the neck resulted in improved table tennis shot accuracy across four simulated table tennis matches.31 There were no harmful or detrimental effects on physical performance in any study and no intervention subgroup was superior, leaving endurance athletes to experiment/pilot a range cooling strategies, exploring their compatibility with their sport’s regulations alongside personal preferences.

Cooling the head, face and neck had no effect on heart rate, and the effect on core and mean skin temperature was inconclusive, but effects were so small that they can be considered physiologically negligible (see Table 2). Our analysis combined data from studies that used fixed-intensity and self-paced exercise tasks. While we viewed this as a potential source heterogeneity, it is possible that the physiological effects of cooling are smaller in self-paced tasks, particularly if work rate increased with cooling. Using subgroup analysis, we investigated whether exercise task type had a moderating effect on these physiological responses. We found no evidence that exercise task had a moderating effect on heart rate [*F*(df1 = 1, df2 = 38) = 0.70, *P* = 0.41], core temperature [*F*(df1 = 1, df2 = 36) = 0.002, *P* = 0.97], or mean skin temperature [*F*(df1 = 1, df2 = 22) = 0.05, *P* = 0.83]. As such, there is no evidence that cooling the head, face and neck provides any meaningful changes to core temperature or physiological mechanisms that control body temperature.

Cooling the head, face and neck had a large effect on reducing skin temperature at the target site and improved thermal sensation and thermal comfort. Therefore, the mechanisms underlying the effects of cooling the head, face and neck on performance are likely psychophysiological. Specifically, cooling-induced reductions in thermal sensation and discomfort could in turn alleviate mental and/or physical fatigue and improve endurance performance.60 The psychobiology of physical and mental fatigue remains complex, particularly when applied to endurance exercise.61 Nevertheless, evidence from clinical groups experiencing heightened fatigue indicate that central interoceptive networks involved in the perception of fatigue are located within the insular cortex,62 which is a well-known area for the integration of thermosensory afferents contributing to thermal sensation and comfort.63 When considered in the context of cooling the head, face and neck, this framework may therefore indicate that lowering thermal discomfort may impact the psychobiology of mental and physical fatigue, which may ultimately lead to performance improvements independently of meaningful changes in whole-body thermal state. An illustration of the psychophysiological mechanism of cooling the head, face and neck that leads to improved physical performance is presented in Figure 7.

\*\*Insert Figure 7 here\*\*

It is beyond the scope of the present review to directly compare how the psychobiology of cooling-induced dampening of perceived strain may be differentially impacted by localised (e.g. head, face and neck) vs. whole-body interventions (e.g. self-dousing in combination with forced convection). Nevertheless, it is worth noting that the varied distribution of thermal sensitivity across the body (e.g. whereby the head is more sensitive to warm discomfort and to its alleviation) indicates that, when appropriately targeted, local thermal manipulations can provide perceptual benefits that could potentially match the effects of whole-body thermal manipulations.28,64,65 Localised interventions that leverage perceptual mechanisms offer significant energy efficiency when compared to whole-body interventions66 that may facilitate implementation and accessibility in the field.

It has been suggested that cooling the head, face, and neck region may pose a risk to athlete health because these regions are more thermally sensitive and stimulation can lead to greater comfort gains than cooling other regions of the body,27,67,68 which may allow athletes to experience dangerously high core temperatures, potentially leading to exertional heat illness.25 While we found some evidence of higher core body temperature following cooling, there were no data to support the suggestion that cooling caused dangerously high core body temperature or heat illness. For example, in one laboratory investigation, neck cooling increased the mean rectal temperature at which runners voluntarily terminated exercise (39.61 °C vs. 39.18 °C) by dampening perceived strain,69 but there were no adverse outcomes in this study and the body core temperatures at volitional termination are below those typically observed following real competition.10,12 Additionally, although facial cooling at rest suppresses the local sweat response more than cooling the forearm, thigh, leg, or foot27 (which may increase physiological strain while dampening perceptual strain), there are no data to implicate head, face, and neck cooling in the development of severe hypohydration, and head and neck cooling does not appear to increase whole body sweat rate during exercise in the heat.70 As reported in this paper, head, face, and neck cooling is generally well-tolerated (only 3 reports of adverse effects) and, despite effectively dampening perceived strain, there are no data that suggest that cooling this region poses a risk to athlete health. Despite this, it would be prudent to ensure that the athletes and their staff are made aware of the potential risks and discomfort of localized cooling and that physiological monitoring is undertaken to minimize any risks because perceived strain may not be a true reflection of the strain experienced.

4.2 Cognitive Performance

Passive heat stress is a major occupational hazard due to compromised cognitive performance.71 The effect of cooling the head, face and neck on cognitive performance could not be determined meta-analytically, due to limited and inconsistent data. Studies implemented mostly generic computerized tests that examined executive function, selective and sustained attention, and reaction time. Most studies that measured cognitive performance reported either no effect on all measures tested,30,31,33,72,73 or no effect on the majority of measures tested.74,75 There was, however, some evidence for improved working memory following cooling.32,34,74,75 The measurement of generic executive functions and their relevance to sport performance has been criticized.76 Its hypothesized that athletes likely require a certain level of executive function ability to compete at a high level, but any further improvement is not likely to affect performance.77 The most specific cognitive test implemented across the studies tended to focus on occupational performance, with a tracking task that simulated flying an aircraft experiencing vertical wind buffeting, but head and neck cooling did not affect tracking performance.72 No sport-specific cognitive tasks were assessed, perhaps due to the complexity in ensuring sport and situation specificity regarding validity, therefore, this may be an area for future research. However, when a football specific video-based decision-making task was developed and assessed for this purpose, it lacked discriminant validity,78 suggesting practical video-based decision-making assessments might not be effective tests of cognitive performance in athletes. Therefore, researchers should ensure sport-specific cognitive tests are valid and reliable before implementing them to investigate the effects of cooling.

4.3 Methodological Considerations and Limitations

The median sample size of studies in the review was 9 participants (central 90% interval = 5 to 17). Studies generally lacked sufficient statistical power to detect smaller effects. For example, 90% of studies had between 10.2% and 16.3% to detect a 0.25 standardized mean difference between the intervention and control condition, assuming a crossover design and a Type I error rate of 5%. Underpowered studies can have a range of issues including an increased Type II error rate, an overestimation of the effect size when statistically significant effects are detected, and a greater proportion of statistically significant effects will be Type I errors.79 We found only eight studies (12.7%) included a sample size calculation,33,48,52,57,80-83 and of these, only five studies reported enough information for the calculation to be replicated.33,48,80-82 Given that head, face and neck cooling strategies are likely to have at best, only small effects on performance outcomes, future studies need to ensure adequate power by carefully considering sample size planning, including justifying a smallest effect size of interest.84 For simple designs (e.g., paired *t*-tests) we recommend conducting sample size calculations using the statistical software Jamovi, following the tutorial by Bartlett and Charles.85 For more complex factorial designs, we recommend the R package *Superpower*.86

Some meta-analyses in the review contain subgroups with only one effect size estimate, for example, the water-perfused device subgroup in the meta-analysis of self-paced exercise tests (Figure 5). The summary estimate (i.e., pooled effect and 95% CI) for subgroups with only one effect size should be interpreted as an individual study effect, rather than a *true* “subgroup” effect, as the summary is based on a single data point. Further, results from moderator analyses (i.e., tests of subgroup differences) should be interpreted with caution when subgroups contain only one or a few effect sizes. In such instances, it is possible that the *true* intervention effect varies between subgroups, but the meta-analysis is not sufficiently powered to detect these differences.

No studies adopted transparent research practices, evidenced by a lack of pre-registration,87 lack of reporting guideline citation,88 and absence of public data sharing.89 The pre-registration of a study’s aim(s), methods and analytical plan is an important mechanism for improving the trustworthiness of research. We recommend the article by Caldwell et al.87 for guidance on pre-registration. Reporting guidelines can further improve the transparency and reproducibility of research studies.88 Guidelines for most health research designs, including randomized, crossover designs,90 the most common design used by studies in the review, are listed on the Enhancing the QUAlity and Transparency Of health Research (EQUATOR) network (<https://www.equator-network.org/>). For guidance on data sharing, we recommend the article by Tierney and Ram.91

4.4. Future Research Directions

There are several areas for future research. Females were underrepresented (13.4% of 618 participants) and only two studies made comparisons between male and female cohorts with no clear sex-specific effects, as such, it is unclear whether our findings are also supported in female populations, and the effect, if any, of ovarian hormones on responses to the interventions. The influence of cooling in Para athlete populations is largely unknown, as athletes with disability (spinal cord injury) accounted for only 2.1% of all participants. There is a need for a greater understanding about the responses and potential risks in Para athletes, to develop best practice guidelines. Repeat sprint and team sport performance, and sport-specific cognitive performance received little attention, as most studies focussed on endurance tasks. Commercially available cooling hats and headbands are currently very popular with endurance athletes, however, the cooling hats and headbands that have been assessed were generally custom-made by the researchers.23,81,92 As such, there is a need to investigate commercially available products, which may be more effective than custom-made inventions that lack input from design experts.

1. **Practical Applications**

Cooling the head, face and neck is recommended for athletes, as these strategies can improve physical performance, however, athletes should also be aware that their use might not benefit performance. Since no individual strategy type was superior, athletes are recommended to experiment with a range of strategies, including different methods, doses and timings, to determine the optimal strategy for their individual context or sport scenario. Since the mechanism of action is psychophysiological, athletes should focus on strategies that maximize the perceptual effects. Common strategies that have been demonstrated to be beneficial include phase change neck collars,24,52,69 spraying/dousing the face with water20,93 and the use of phase change cooling caps.23,30,81 Such strategies are well-suited to use during exercise where possible, however, there is also evidence for the benefit of 7-20 minutes of pre-cooling with phase change,81 or water-perfused head cooling devices.49 For athletes who can apply cooling during breaks in play, application of an ice pack,31 or iced towels around the neck,55 can be beneficial. The use of iced towels as a cooling strategy is highly practical in field settings as it only requires a cooler of ice water and 2-3 towels, which are immersed and wrung out prior to application to prevent the person becoming too wet. Spraying/dousing with water for the purpose of perceptual cooling is recommended in all environments. However, to maximise physical cooling, spraying/dousing with water would likely be more beneficial in hot and dry environments, as there is more capacity for evaporation of the fluid, and alternatively, a phase change collar or headband would likely be more beneficial in humid environments, as these do not rely upon evaporation. Application of a frozen gel pack (0-3 °C) to the forehead and eyes was not well-tolerated and therefore is not recommended. Athletes should also consider maximising the cooling response by combining head, face and neck cooling with cooling the rest of the body, and/or the ingestion of cold or iced beverages when possible, and when such a strategy proves effective in simulated competition scenarios. Athletes should also ensure that any cooling strategy they plan to use is compatible with sport-specific rules and regulations. Ultimately, the provision of cooling resources during sporting competition (and physical activity) will drive adoption at the elite level, where there are complex logistical factors to consider. An infographic summarizing the major findings and practical applications are illustrated in Figure 8.

\*\*Insert Figure 8 here\*\*

**6.0 Conclusions**

The effect of cooling the head, face and neck on self-paced and fixed-intensity exercise tests was inconclusive, with both no and medium beneficial effects possible. We found no evidence of harmful performance effects. Cooling the head, face and neck reduced the skin temperature at the target site and improved thermal sensation and thermal comfort. There was no effect on heart rate, and effects on core temperature and mean skin temperature were so small they can be considered physiologically negligible. Adverse events associated with the interventions were rare, and there was no report of any cooling strategy making a participant feel cooler and then pushing beyond their thermal limits, causing exertional heat illness. No intervention subgroup was superior, and hence, athletes are recommended to experiment with a range of rule-compatible and available head, face and neck cooling strategies, including different doses and timings, to determine the optimal strategy for their individual and sport context.

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Figure 7: An illustration of the psychophysiological mechanism of cooling the head, face and neck that leads to improved physical performance

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**Data Availability Statement**

All data and code is available from [https://doi.org/10.5281/zenodo.14253041](https://url.au.m.mimecastprotect.com/s/_MQoCJyBN8UZopALcVfBIyq9xj?domain=doi.org)

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