The Impact of Passive Heating Strategies on Exercise Performance: Systematic Review & Meta-Analysis.

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Research Article

Keywords: clothing, core temperature, muscle temperature, passive heating, performance, temperature

Posted Date: April 29th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1489527/v1

Abstract

Prior to exercise, a warm-up routine has been suggested to be an imperative factor in task readiness with the anticipation that it will enhance performance. Key benefits of a warm-up are the increase of muscle and core temperature, which can be achieved in a variety of ways. An effective way to achieve improvements in core and muscle temperature is by performing an active warm up. However, lengthy transition periods between an active warm-up and exercise performance, is known to decline core and muscle temperature, thereby reducing performance capability. As such, methods are needed to assist athletes during transition periods, to maintain the benefits of a warm-up with the aim of optimising performance. Accordingly, the purpose of this review is to systematically analyse the evidence base that has investigated the use of passive heating to aide sporting performance when a transition period is experienced. A systematic review and meta-analysis were undertaken following relevant studies being identified using PudMed, Web of Science, and EBSCO. Studies investigating the effects of passive heating strategies during the transition period between an active warm-up and exercise performance were included. The quality of included studies was assessed by 2 independent reviewers using a modified version of the Physiotherapy Evidence Database scale. Seven studies, all high quality (mean = 7.6), reported sufficient data (quality score > 5) on the effects of passive heating strategies on exercise performance. Passive heating strategies used between an active warm-up and exercise, appear to work favourably in all studies which examined peak power output (ES = 0.54 [95% CI 0.17 to 0.91]), however, only a favourable trend was evident for time to completion of exercise performance (ES = 1.07 [95% CI -0.64 to 0.09]). However, such conclusions are only based upon a limited number of well-conducted, randomised, controlled trials. Therefore, more studies are needed to further determine the role passive warming, during the transition period, has on exercise performance. Furthermore, additional research is necessary to determine the optimum procedure for passive warm-up strategies, including environmental conditions, length of time to the wear a heated garment, garment temperature, and the placement of the heating elements embodied into the garment.

1.0 Introduction

Prior to exercise, a warm-up routine has been suggested to be an imperative factor in task readiness with the anticipation that it will enhance performance (Park et al, 2018). One of the key benefits of a warm-up is the increase of muscle and core temperature and this can be achieved in a variety of ways (Silva et al, 2018). The most effective way to achieve improvements in core and muscle temperature is by performing an active warm up, which involves a series of dynamic movements (Bishop, 2012). The subsequent increase in muscle temperature results in various physiological advantages, including an increased speed of contraction and relaxation of muscle fibres, increased anaerobic metabolic capacity and an improved nerve conduction within the peripheral, and central, nervous systems (Mohr et al, 2004). Therefore, maximising the effectiveness of the active warm-up phase prior to sports performance is an integral part of preparation. Generally, after the active warm-up period, performers can often wait between 10 and 30 minutes before the start of competition (transition period). Zochowski et al. (2007) found that a reduction in length of transition period, yields performance benefits whereas a lowering of core and muscle temperature occurs when transition periods are prolonged (West et al, 2013). However, it can be challenging to alter competition schedules by a substantial margin. As such, methods are needed to assist athletes through transition periods, to maintain elevated core and muscle temperatures gained from warm-up with the aim to optimising performance.

Initially, hot showers or baths were used to combat the decline in muscle and core temperature in swimming (Carlile, 1956; Muido, 1946; Asmussen & Bøje, 1945), however, logistical and practical issues make these methods difficult to use in the majority of sporting scenarios. Therefore, recent investigations have developed methods to maintain an elevated muscle and core temperature during the transition phase between the warm-up and subsequent exercise performance. Faulkner et al. (2012) was the first to implement a passive heating device following an active warm-up. Specifically, these authors investigated the use of heated tracksuit pants in the marshalling period before a sprint cycling race, and the intervention significantly reduced the decline muscle temperature whilst time trial performance improved. Additionally, similar passive heating garments and blizzard survival jackets have been used to manipulate body temperature during the transition phase and have improved bobsled (Cook et al, 2013), rugby (Russell et al, 2015), swimming (McGowen et al, 2017; Wilkins & Havenith, 2018), and rowing (Cowper et al, 2020) performance.

Thus, passive heating, seems to be a logical practical intervention to maintain warm-up induced elevations in core and muscle temperature throughout the long transition periods observed in sports competitions. The use of a heat maintenance device during the transition period following a warm-up, and prior to competition, has the capacity to yield performance enhancing benefits akin to those of an active warm up. Therefore, the purpose of this review is to systematically analyse the evidence base that has investigated the use of passive heating in the transition period to aide sporting performance.

2.0 Methods

2.1 Search Strategy

A systematic review was conducted according to Preferred Reporting Items for Systematic reviews and Meta Analyses guidelines (PRISMA; Moher, 2015). Relevant publications published prior to March 2021 in three databases (PudMed, Web of Science & EBSCO) were identified. The search was performed using the Boolean search criteria, which limited the search results with operators including AND/OR to only those documents containing relevant key terms in the scope of this review (see Table 1).

Table 1
Search Strategy and inclusion/exclusion criteria based on PICO (Population, Intervention, Comparison and Outcome)

Databases	Search Terms	PICO	Inclusion Criteria	Exclusion Criteria
PubMed, EBSCO, Web of Science.	((sport* OR exercise* OR perform*) AND (“post-warm-up” OR “warm-up” OR “half-time” OR “rewarming” OR “re-warming” OR “passive warming” OR “interval” OR “quarter”) AND (“passive heat*” OR “heat* jacket” OR “heat* pants” OR “blizzard survival jacket*” OR “heat* garment”))	Population	Trained Athletes	Non-Trained Athletes
		Intervention	An Active Warm-Up combined with a Passive Heating Intervention	No Passive Heating Intervention applied following an active warm up.
		Comparison	Passive Heating strategies and control	No Comparison between a Passive Heating Intervention and control
			Core and/or muscle temperature variations during passive heating intervention	No core and/or muscle temperature variations during passive heating intervention
		Outcome	Performance Measures (Time to competition, Distance covered)	Performance measures not recorded.

2.2 Eligibility Search

Research articles were included or excluded using criteria defined with the Population, Intervention, Comparison and Outcome criteria (PICO; Methley 2014), and the literature searches were limited to studies involving trained athletes, defined as an athlete who regularly competes in key regional or national tournaments in their specific sport. Grey literature such as thesis dissertations, and conference abstracts were excluded. Additionally, all included studies had to be written in the English language and had to be published in a peer-reviewed journal. The search strategy and eligibility criteria are shown in Table 1.

2.3 Study Selection

The initial search identified 114 articles with potential relevance. After removing duplicates and studies that were not specific to passive warm-up strategies, a manual screening according to the abstract was performed, and those that were not relevant were excluded. Two authors (G.C., M.B.) independently assessed articles against the inclusion criteria. From these studies, 21 original full text research articles were assessed for eligibility, and those that did not meet the inclusion criteria were excluded. For the quantitative analysis, seven articles were included (Fig. 1).

Once the articles were removed based on the exclusion criteria, the final papers underwent an assessment of quality, using a modified version of the Physiotherapy Evidence Database (PEDro) scale. Due to the specificity of the topic, the scale was altered and questions 3–6 were replaced with more pertinent related questions. The PEDro scale is an 11-item scale designed to measure the methodological quality of experimental studies, with the reliability of the database being previously established (Maher et al., 2003). Each satisfied criterion (with the exception of item 1, which pertains to external validity) is graded one point to the overall score (possible range of 0–10 points). Eight items on the scale assess the internal validity with the remaining two analysing the sufficiency of the statistical information. In agreement with previous reviews, studies with a score of 5 out of 10 or higher were included in the review to improve the credibility of the analysis (Russell and Kingsley, 2014; Kromer et al. 2009).

2.4 Data Extraction

From the included articles, data on sample size and participant sex, passive heating strategy and the duration of the passive heating strategy, physiological temperature changes during the intervention, exercise protocol and the performance outcomes was extracted. In addition to the ambient temperature and humidity. Outcome data was presented using a Microsoft Excel 2016 spreadsheet (Microsoft, Redmond, WA, USA) (Table 2).

2.5 Meta-Analysis

To analyse the impact of passive heating strategies on exercise performance, the mean and standard deviation of performance outcomes and physiological effects was inputted in a Microsoft Excel 2016 spreadsheet (Microsoft, Redmond, WA, USA). Cohen’s d was used to calculate effect sizes, this was categorised as follows: < 0.2 = poor effect size, 0.2–0.5 = small effect size, 0.5–0.8 = medium effect size and > 0.8 = large effect size (Cohen, 1992). Following this, the standard error of the effect size was calculated.

Meta-analyses and forest plots were produced using commercially available software (JASP Team, Amsterdam, Netherlands). The Cochrane’s Q test was performed to test the null hypothesis of heterogeneity to identify whether studies had similar effect size. Statistical heterogeneity was defined as I^2 small (< 30%) and large (> 50%) respectively (Higgins & Thompson, 2002). If specific data wasn’t presented in the study, the corresponding author was contacted and given 30 days to respond. If no response was received, the data was excluded from the meta-analyses.

3.0 Results

3.1 Study Identification and selection

Initially, a total of 114 studies were retrieved from the literature search. From these 114 articles, duplicates were removed (n = 51). The titles and abstracts of each entry (63 articles) were then screened for their relevance, which resulted in the rejection of 42 articles from the analysis. Following this trimming, the full texts of the remaining 21 articles were reviewed. Of the 21 articles, 15 were excluded due to their irrelevance to the topic area. After one article was retrieved and accepted through other source, seven articles were accepted for the systematic review completing the full screening process. A summary of the process involved in retrieving suitable studies can be viewed in the flowchart presented based on the process developed for the quality of reporting of meta-analyses (Moher et al., 1999; see Fig. 1).

3.2 Methodological Quality

After application of the pre-defined exclusion criteria, the remaining full text articles were assessed for methodological quality via a Modified Physiotherapy Evidence Database (PEDro) scale. All seven of the remaining articles achieved a PEDro score of 5 or above and thus were included in the review commentary. The mean range of quality scores was 7.6 ± 1.1 (range, 6–9 out of 10) (Table S1).

3.3 Study Characteristics

A chronological analysis of the articles that comprised this review showed a recent interest in this area of research, with all the included studies published in the last seven years (2013–2020). In the seven eligible articles, outcomes were presented for 85 participants (individual study sample sizes ranging from six to 20 participants), which were well-trained athletes of whom 78 were male and seven were female. Exercise modalities included cycling, rowing, bobsleigh, repeated sprints, plyometric and bodyweight exercises. Considerable methodological variation also existed with regards to the active warm-up and strategies of passive heating. Most prominent variations were in the passive heating duration and choice of garment (see Table 2).

3.5 Performance Responses to Passive Heating

In the seven studies involving performance responses following the passive heating intervention, all seven studies individually found a significant improvement ($P < 0.05$) in one or more performance parameter. Based on the included, four out of the seven eligible studies assessed peak power output (PPO) which was measured in the form of cycling (Faulkner et al, 2013a; Falkner 2013b), and countermovement jumps (Killduff et al, 2013; West et al, 2015). The overall effect size suggests a significant improvement in PPO following a passive heating strategy (ES 0.54 [95% CI 0.17 to 0.91], $P = 0.005$, $I^2 = 0\%$). Additionally, four out of seven studies measured performance in a form of time trial, which included rowing (Cowper et al, 2020), repeated sprints (Kilduff et al, 2013; West et al, 2015) and swimming (Wilkins & Havenith, 2018). Interestingly, the improved PPO did not translate into an overall effect for time trial performance (ES = − 0.27 [95% CI − 0.64 to 0.09], $P = 0.141$, $I^2 = 0\%$) (Fig. 2).

3.6 Temperature Responses to Passive Heating

Following the passive heating period between the active warm-up and performance, five out of the seven included studies displayed specific core temperature readings. Two out of the five studies implemented aural tympanic thermometry (Cowper et al, 2020; Wilkins & Havenith, 2018), two implemented rectal thermometry (Faulkner et al, 2013a; Falkner et al, 2013b), whilst Kilduff et al, (2013) implemented ingestible sensors to measure core temperature. Overall, no significant effect was found in core temperature following the application of a heated garment (ES = 0.56 [95% CI -0.09 to 1.21, P = 0.09, I^2 = 68%) (Fig. 2). Two out of the seven studies implemented muscle temperature measurements from depths of 1, 2 and 3 cm in the vastus lateralis. Faulkner and colleagues found muscle temperature to be approximately 1°C higher at a depth of 1 cm ($P < 0.001$) and 0.4°C higher at 3 cm ($P < 0.01$) following the use of heated trousers against standardised tracksuit bottoms (Faulker et al, 2013a). Furthermore, in a supplementary study, Faulkner and colleagues observed that following the passive rest period, muscle temperature declined in all conditions, however, remained higher during the use of heated trousers at all muscle depths compared to standardised tracksuit pants and insulated pants ($P < 0.001$) (Faulkner et al, 2013b).

4.0 Discussion

The present review aimed to quantitatively analyse, the literature to establish the effect of passive warm-up maintenance strategies on performance in well-trained athletes. This study has identified that completing a passive warming strategy with the use of heated garments between an active warm-up and competition can improve subsequent performance in the form of increased PPO (ES = 0.54 [95% CI 0.17 to 0.91]. From the studies included, improvements have been demonstrated in aerobic and anaerobic type sports such as rowing (Cowper et al., 2020), cycling (Faulkner et al., 2013a; Falkner 2013b) and swimming (Wilkins & Havenith, 2018). Improvements have also been shown in the activities of vertical jumping (Kilduff et al., 2013; West et al., 2015) and repeated sprint performance (Kilduff et al., 2013; West et al., 2015, Cook et al., 2013). However, despite a consensus on the effect of heated garments, the degree of improvement varied widely, from less than 1 to over an 11% improvement, however, the studies included have exhibited sufficient quality as evidenced through extensive critique. The use of multiple variations of active and passive warm-up protocols, the wide variation in results may be attributable to the specifics of the warm-up practices employed, post warm-up strategies and the exercise itself. This emphasises the need for continued research to determine which methods of warm-up are best for a given sport or activity.

4.1.1 Passive Warm-Up Strategies and Exercise Performance

Asmussen & Boje (1945) and Bergh & Ekblom (1979) reported that the velocity dependent effect of muscle temperature on maximum external power to be ~ 4% higher in force and power per 1°C rise in quadriceps muscle temperature. Furthermore, per 1°C increase in muscle temperature, observed a 2–5% (Racinais & Oksa, 2010), and a 2–10% (Sargent, 1984) increase in peak power during exercise performance.

A passive warm-up, unlike a continuous active warm-up, during a transition period between the active-up and exercise performance allows a rise in muscle and/or core temperature without the reduction of energetic substrates (Faulkner et al, 2013a; Faulkner et al, 2013b). Initial studies emphasising passive warming strategies were solely laboratory based, with the method of increasing body temperature being accomplished by methods, such as hot baths/showers. Although impactful, these passive warm-up strategies are not often practical in a sporting scenario. Therefore, alternate methodologies and passive warm up strategies have been sought after, given that: (1) a lengthy period is expected (transition phase), between the end of the warm-up and the beginning of an event; (2) muscle temperature starts to fall immediately following exercise termination; and (3) substantial declines in body temperature occurs as early as ~ 15–25 minutes post-exercise (Mohr et al, 2004; West et al, 2013).

4.1.2 External Heating Garments and Blizzard Survival Jackets and Performance

All of the included studies in this review used either blizzard survival jackets or external heating garments, the majority of heated garments used across various sporting activities have heat filaments in the fabric. Faulkner et al. (2013a) reported an improvement in muscle temperature (1°C rise in muscle temperature at a depth of 1 cm and a 0.4°C rise at a 3 cm depth) and ~ 9% improvement in relative and PPO during a sprint cycling task when using an active warm up and heated tracksuit pants in the 30-minute transition period in comparison to standard tracksuit pants. Additionally, further research by Faulkner and colleagues reported that muscle temperature remained increased when wearing heated tracksuit pants solely during the transition period (36.9 ± 0.3°C) and when worn throughout the active warm-up and transition phase (37.0 ± 0.2°C) in contrast to only an active warm up (36.6 ± 0.3°C; Faulkner et al., 2013b). Although, an additional performance benefit was not found when wearing the heated tracksuit pants during an active warm-up and during the transition phase (Faulkner et al, 2013b). Supporting this, Cook et al. (2013) reported that wearing a blizzard survival jacket produces a rise in tympanic temperature and improved a 20 m sled sprint performance. Additionally, Kilduff et al. (2013) reported an improved repeated sprint performance in elite rugby players when an active warm-up was followed by wearing a blizzard survival jacket throughout a 15-minute transition period. The decrease in core temperature during the transition phase was minimised when the blizzard survival jackets were worn (− 0.19 ± 0.08°C) compared to the standardised tracksuit top (− 0.55 ± 0.10°C). Therefore, participants began the tests with an elevated core temperature, suggesting that an increased core temperature prior to exercise can improve exercise performance (Kilduff et al, 2013).

The use of passive warm up strategies hasn’t been a common method of practice however, the application of it maintaining body temperature during a transition period is gaining recognition. Passive heat maintenance through the wearing of blizzard survival jackets and athletic heating garments appears to be an optimal technique in offsetting the reduction in core and/or muscle temperature and therefore improving exercise performance. However, athletic heating garments can have their limitations. Wired heated garments, do not provide uniform heat across the heating elements. Furthermore, for optimal heat transfer and increase in muscle temperature, the heating elements should be in direct contact with skin, which involves the garment being tight to the skin (Wang et al, 2010). Additionally, Faulkner et al, (2013a) reported a significant decrease in muscle temperature during the inactivity period when the heated garments were worn, however, the decline in muscle temperature was significantly less compared to the application of standard tracksuit bottoms. Furthermore, Raccuglia and colleagues demonstrated by using water-perfused heated trousers, heated to a higher temperature, 43°C, successfully maintained and even increased muscle temperature in the passive recovery period following warm-up (Raccuglia et al., 2016). However, water perfused trousers are not very practical for use in a competition setting as they need to be connected to a heating system, consisting of a temperature-controlled water bath and powered water pump. Alternatively, numerous studies have reported a significant improvement in exercise performance following the application of battery powered athletic heating garments which use integrated flexible heating elements (Cowper et al, 2020; Falkner et al, 2013a; Falkner et al 2013b; Wilkins & Havenith 2017). This allows consumers to use the garments portably, however without multiple batteries, for a limited time period.

All the reviewed literature found a significant improvement in exercise performance ($P < 0.05$); particularly time trial performances, which have shown to display a wide variety in percentage increase. When examining these in more detail, the type of exercises might influence the overall percentage improvement. For example, Cowper et al (2020) exhibited a performance increase of 1.1%, this slight increase in performance, might be because of the competition duration being long (> 5 minutes) in comparison to the other studies which are all predominantly anaerobic and short lasting in nature. Limited studies have determined the physiological outcomes of warming-up passively for long duration performances. This might be because a well-known limiting physiological factor for long-duration performances is excessive bodily heat (Kozlowski et al, 1985; Romer et al, 2001). Consequently, a rise in core temperature before exercise might be detrimental to long duration performance due to impaired thermoregulatory mechanisms (Fortney et al. 1984) and/or a decrease in heat storage capacity (Nadel, 1987). Thus, ambient temperature is a significant aspect to be considered. However, when a heated jacket is utilised following an active warm-up in cool environments, body temperature would be comparatively lower against if the same protocol was applied in standard ambient temperatures (18–20°C) (Mariano et al, 2002). During colder environments, a delayed duration that the body takes to reach critical core temperature would occur and performance might improve. Alternatively, in standard ambient conditions, the use of a heated jacket may elevate core temperature to critical levels and possibly decrease the capacity for exercise performance (Cowper et al, 2020). Therefore, further research is needed to determine the effect on performance following the use of passive heating garments in below ambient temperatures.

4.2 Limitations

Several methodological problems in the studies reviewed could have impacted upon the outcomes reported. Some of the studies did not measure temperature change post active warm-up, therefore it might be difficult to distinguish whether the change in bodily temperature was due to the active warm-up or the passive heating garment. Furthermore, chosen studies in this systematic review and meta-analysis displayed small sample sizes, this led to many of the confidence intervals crossing the “zero point”. While the conclusions from this review are based on mean data, it is important to state that even though none of the included studies displayed an absolute improvement in performance for passive heating when examining both the means and confidence intervals, no studies showed a mean or absolute decrease in performance. This demonstrates additional backing that passive heating during the period between active warm-up and performance being beneficial for exercise performance. There are certain weaknesses in this review, relatively small number of participants in some of the studies which increases the potential effects of chance. Furthermore, the limited number of studies included in the systematic review and meta-analysis and the studies that were included, some authors were unable to provide raw data to fully complete analyses.

The findings of this systematic review and meta-analysis offer a partial but best available evaluation of the influence of passive heating techniques prior to sport and exercise performance. This review aimed to eliminate possible sources of bias by employing a systematic review method, however this does not ensure the absence of bias. Furthermore, a modified version of the PEDro scale was applied to distinguish between the quality of different studies. The modified PEDro scale has not likely to have biased our decisions since points are only granted to studies when the criteria are clearly fulfilled. Furthermore, after a precise reading of an included research articles, if it was not evident that the criterion was reported, a point is not presented for that specific criterion.

6.0 Future Considerations

Further research is necessary to determine the optimum procedure for passive warm-up strategies, including the length of time to the wear the garments, garment temperature and the placement of the heating elements embodied into the garment. Furthermore, research on whether passive heating strategies could be applied to scenarios where it is difficult to maintain core temperature from metabolic heat production alone, such as repeated-sprint sports which are separated by low to moderate activity. Specifically, conditions where below ambient temperature been to be utilised, particularly environments where the decline in core and muscle temperature is excessive throughout a lengthy transition.

Cowper et al. (2020) is currently the only study to have examined the effects of longer-term exercise performance using passive heating devices. This may be because earlier studies using hot showers/baths found a detrimental effect in endurance performance at ambient temperatures. The detrimental effects caused by passive heat during the transition period in long duration performances have been reported to be because of a lower heat-storage capacity and an earlier attainment in critical core temperature. However, in below ambient temperatures, the increased depletion of body temperature compared to at ambient temperatures may increase the time the body reaches critical core temperature during endurance performance. This outcome may lead to passive heating being beneficial in preventing bodily temperature dropping too low and overall having a positive impact on endurance performance (Marino, 2002). Therefore, future research is needed to evaluate the effects of external heating garments on long duration sports performance at below ambient temperatures, which may simulate conditions associated with sports played in cooler environments.

5.0 Conclusion

This current systematic review and meta-analysis looked to evaluate the effects of external heating garments post warm-up on the mechanisms associated with thermoregulation and performance. Passive heating devices have shown to reduce the decline in muscle temperature, and therefore have been found to enhance PPO during exercise. Additionally, a favourable yet not significant reduction in the decline of core temperature was observed. Large heterogeneity, low participant numbers and a range of methodologies shows a necessary scope of additional research to observe the effects of core and muscle temperature.

Declarations

7.1 Ethics approval and consent to participate

This review has full ethical approval by Northumbria University, Newcastle Upon Tyne, UK (Reference number: 45401).

7.2 Consent for publication

Not applicable

7.3 Availability of data and materials

All data generated or analysed during this study are included in this published article [and its supplementary information files].

7.4 Competing interests

I declare that the authors have no competing interests as defined by BMC, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

7.5 Funding

This work was not funded by any external organisations.

7.6 Authors’ contributions

All authors contributed to the design of the review. G.C wrote the main manuscript following the advice and revisions from M.B, S.G, K.H and L.B. Additionally, G.C manually screened articles for the systematic review and G.C and M.B. independently assessed the full text articles for inclusion. All authors have approved the submitted version.

References

1. Asmussen, E., & Bøje, O. (1945). Body temperature and capacity for work. Acta Physiologica Scandinavica, 10(1), 1–22.
2. Bergh, U., & Ekblom, B. (1979). Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. Acta physiologica scandinavica, *107*(1), 33–37.
3. Bishop, D. (2003). Warm up I. Sports medicine, 33(6), 439–454.
4. Carlile, F. (1956). Effect of preliminary passive warming on swimming performance. Research Quarterly. American Association for Health, Physical Education and Recreation, 27(2), 143–151.
5. Cohen, J. (1992). A power primer. Psychological bulletin, 112(1), 155.
6. Cook, C., Holdcroft, D., Drawer, S., & Kilduff, L. P. (2013). Designing a warm-up protocol for elite bob-skeleton athletes. International journal of sports physiology and performance, 8(2), 213–215.
7. Cowper, G., Barwood, M., & Goodall, S. (2020). Improved 2000-m rowing performance in a cool environment with an external heating garment. International journal of sports physiology and performance, *16*(1), 103–109.
8. de Morton, N. A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. Australian Journal of Physiotherapy, *55*(2), 129–133.
9. Faulkner, S. H., Ferguson, R. A., Gerrett, N., Hupperets, M., Hodder, S. G., & Havenith, G. (2013a). Reducing muscle temperature drop after warm-up improves sprint cycling performance. Med Sci Sports Exerc, 45(2), 359–365.
10. Faulkner, S. H., Ferguson, R. A., Hodder, S. G., & Havenith, G. (2013b). External muscle heating during warm-up does not provide added performance benefit above external heating in the recovery period alone. European journal of applied physiology, 113(11), 2713–2721.
11. Gray, S. R., De Vito, G., Nimmo, M. A., Farina, D., & Ferguson, R. A. (2006). Skeletal muscle ATP turnover and muscle fibre conduction velocity are elevated at higher muscle temperatures during maximal power output development in humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*.
12. Higgins, J. P., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. Statistics in medicine, 21(11), 1539–1558.
13. Kilduff, L. P., West, D. J., Williams, N., & Cook, C. J. (2013). The influence of passive heat maintenance on lower body power output and repeated sprint performance in professional rugby league players. Journal of Science and Medicine in Sport, *16*(5), 482–486.

14. Kozlowski, S., Brzezinska, Z., Kruk, B., Kaciuba-Uscilko, H., Greenleaf, J. E., & Nazar, K. (1985). Exercise hyperthermia as a factor limiting physical performance: temperature effect on muscle metabolism. Journal of Applied Physiology, 59(3), 766–773.
15. Kromer, T. O., Tautenhahn, U. G., de Bie, R. A., Staal, J. B., & Bastiaenen, C. H. (2009). Effects of physiotherapy in patients with shoulder impingement syndrome: a systematic review of the literature. Journal of Rehabilitation Medicine, 41(11), 870–880.
16. Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. Physical therapy, *83*(8), 713–721.
17. Marino, F. E. (2002). Methods, advantages, and limitations of body cooling for exercise performance. British journal of sports medicine, *36*(2), 89–94.
18. McGowan, C. J., Thompson, K. G., Pyne, D. B., Raglin, J. S., & Rattray, B. (2016). Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. Journal of Science and medicine in sport, 19(4), 354–358.
19. Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., … Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic reviews, *4*(1), 1–9.
20. Mohr, M., Krustrup, P., Nybo, L., Nielsen, J. J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches–beneficial effect of re-warm-up at half-time. Scandinavian journal of medicine & science in sports, *14*(3), 156–162.
21. Muido, L. (1946). The influence of body temperature on performances in swimming. Acta physiologica scandinavica, 12, 102–109.
22. Methley, A. M., Campbell, S., Chew-Graham, C., McNally, R., & Cheraghi-Sohi, S. (2014). PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. BMC health services research, *14*(1), 1–10.
23. Nadel, E. R. (1987). Prolonged exercise and high and low ambient temperatures. Can Journal of Sport Science, 12(31), 140S-2S.
24. Park, H. K., Jung, M. K., Park, E., Lee, C. Y., Jee, Y. S., Eun, D., … Yoo, J. (2018). The effect of warm-ups with stretching on the isokinetic moments of collegiate men. Journal of exercise rehabilitation, *14*(1), 78.
25. Racinais, S., & Oksa, J. (2010). Temperature and neuromuscular function. Scandinavian journal of medicine & science in sports, 20, 1–18.
26. Romer, L. M., Barrington, J. P., & Jeukendrup, A. E. (2001). Effects of oral creatine supplementation on high intensity, intermittent exercise performance in competitive squash players. International journal of sports medicine, 22(08), 546–552.
27. Russell, M., & Kingsley, M. (2014). The efficacy of acute nutritional interventions on soccer skill performance. Sports medicine, 44(7), 957–970.
28. Russell, M., West, D. J., Briggs, M. A., Bracken, R. M., Cook, C. J., Giroud, T., … Kilduff, L. P. (2015). A passive heat maintenance strategy implemented during a simulated half-time improves lower body

power output and repeated sprint ability in professional rugby union players. PloS one, 10(3), e0119374.

29. Sargeant, A. J. (1987). Effect of muscle temperature on leg extension force and short-term power output in humans. European journal of applied physiology and occupational physiology, *56*(6), 693–698.
30. Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M., & Marinho, D. A. (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. Sports Medicine, 48(10), 2285–2299.
31. Wang, F., Gao, C., Kuklane, K., & Holmér, I. (2010). A review of technology of personal heating garments. International journal of occupational safety and ergonomics, 16(3), 387–404.
32. West, D. J., Dietzig, B. M., Bracken, R. M., Cunningham, D. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2013). Influence of post-warm-up recovery time on swim performance in international swimmers. Journal of science and medicine in sport, 16(2), 172–176.
33. Wilkins, E. L., & Havenith, G. (2017). External heating garments used post-warm-up improve upper body power and elite sprint swimming performance. Proceedings of the Institution of Mechanical Engineers, Part P: *Journal of Sports Engineering and Technology*, 231(2), 91–101.
34. Zochowski, T., Johnson, E., & Sleivert, G. G. (2007). Effects of varying post-warm-up recovery time on 200-m time-trial swim performance. International Journal of Sports Physiology and Performance, 2(2), 201–211.

Tables

Table 2 is available in the Supplemental Files section.

Figures

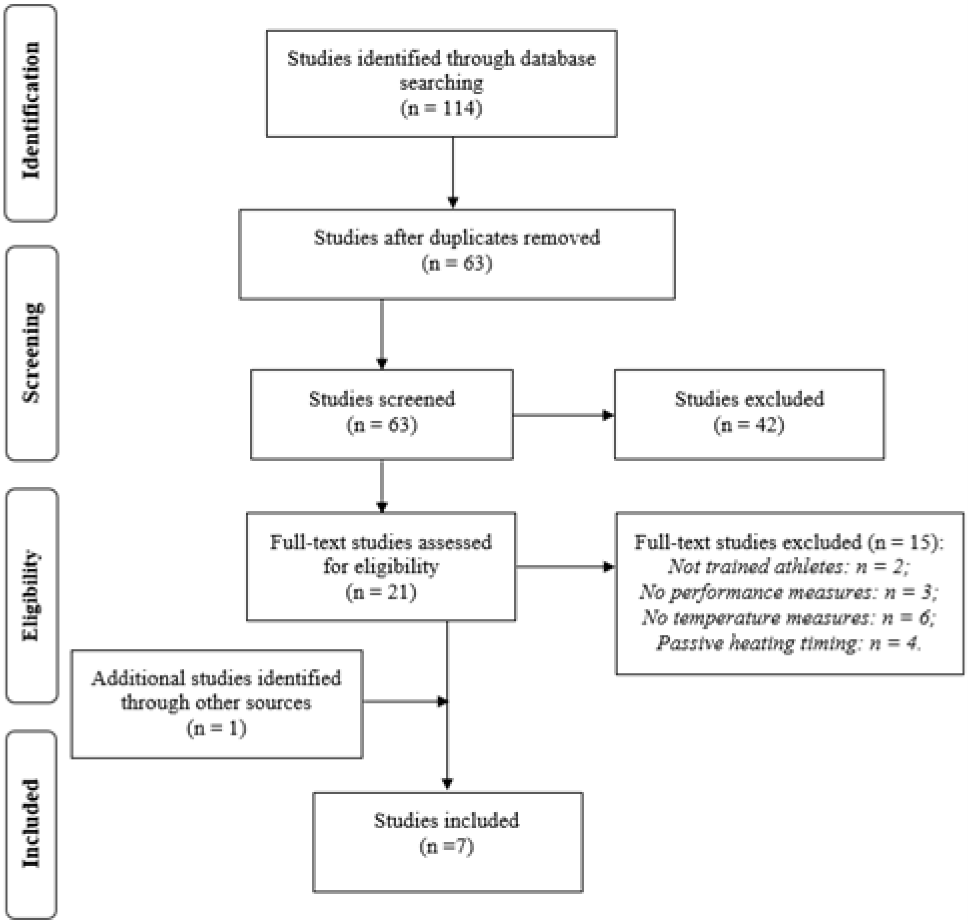

Figure 1

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) study flow diagram.

Figure 2

Forest Plot of multilevel meta-analysis comparing (A) peak power output (B) time to completion activities (C) core temperature, post passive heating jacket invention following an active warm-up. The study specific intervals represent individual effect size estimates and sampling error. The black squares represent the pooled estimate generated with inference along with 95% confidence interval.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table2.xlsx
- TableS1.xlsx