



Original research

Brief in-play cooling breaks reduce thermal strain during football in hot conditions



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ABSTRACT

Objectives: The study examined if three feasible strategies involving additional in-play cooling periods attenuate the core (rectal) temperature rise during simulated football matches.

Design: Four counterbalanced experimental trials in an environmental chamber set to 35 °C ambient temperature, 55% relative humidity, and 30 °C WBGT.

Methods: Twelve healthy well-trained football players completed a regular simulated match (REG), regular simulated match with additional 3-min cooling periods at the 30-min mark of each half inclusive of chilled water consumption (COOL_{water}), regular simulated match with additional 3-min cooling periods at the 30-min mark of each half inclusive of chilled water consumption and the application of an ice towel around the neck (COOL_{towel}), regular simulated match with an extended (+5 min; total of 20-min) half-time break (HT_{extended}).

Results: The difference in rectal temperature change was significantly lower in the COOL_{water} (−0.25 °C), COOL_{towel} (−0.28 °C), and HT_{extended} (−0.21 °C) trials in comparison to the REG (all $p < 0.05$). Exercising heart rate and session rating of perceived exertion was lower in the COOL_{water} (−13 bpm; −1.4 au), COOL_{towel} (−10 bpm; −1.3 au), and HT_{extended} (−8 bpm; −0.9 au) trials in comparison to the REG trial (all $p < 0.05$). The cooling interventions did not significantly change skin temperature or thermal sensation in comparison to the REG (all $p > 0.05$).

Conclusions: All three cooling interventions attenuated core body thermal strain during simulated matches. The laboratory-based study supports the use of brief in-play cooling periods as a means to attenuate the rise in core temperature during matches in hot and humid conditions.

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Practical implications

- The efficacy of currently advocated brief in-play cooling breaks are supported by this laboratory-based study.
- The COOL_{water} and HT_{extended} strategies appear more feasible for all levels of play than COOL_{towel} whilst providing similar cooling benefits.
- The HT_{extended} strategy may be preferred by organisations that do not desire breaks during each half of play and allows further

time for additional and more extensive cooling strategies during half-time.

1. Introduction

Numerous worldwide football competitions (A-League [Australia] and Major League Soccer [United States]) and tournaments (2014 World Cup in Brazil) occur in stressful thermal conditions. Hot and humid environments influence the cardiovascular, cardiorespiratory, metabolic, perceptual, and fatigue response to exercise,¹ and therefore have a modulating effect upon football players physical output during matches.^{2–4} Furthermore, there is an additional thermal burden onto the heat stress already induced by intense exercise, predominantly through

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the impediment of sweat evaporation, subsequently leading to lower skin surface heat dissipation and thus greater internal heat storage.⁵ Significant rises in internal heat storage increase the risk of heat-related health problems,^{6,7} which are preventable and encompass a range of conditions.^{5,8} The potentially fatal nature of heat-related illness⁹ warrants precaution and additional safety measures should mitigate the risk of exertional heat illness during competition in environmentally stressful conditions.

Core body temperature is the primary indicator of human thermal strain. Mean core temperature values above 39 °C have been observed during football matches in hot^{6,10} and temperate^{11,12} conditions. Notably, individual peak values over 40 °C have been reported,^{6,10,13} which is associated with a substantial increase in the risk of heat stroke.¹⁴ A feasible strategy for all levels of participation (amateur to professional) to potentially reduce the rise of core body temperature during matches is brief in-play cooling breaks.¹⁵ Indeed, a review by Grantham et al.⁵ recommended additional 'fluid' breaks if the wet-bulb globe temperature (WBGT) exceeds 30 °C during football competition. In 2014, the Fédération Internationale de Football Association (FIFA) sanctioned additional 3-min cooling periods for the World Cup competition at the 30-min mark of each half during matches that were played in conditions of >32 °C WBGT.¹⁶ Brief cooling periods are also implemented in the A-League (Australia) and Major League Soccer (United States) competitions when environmental conditions exceed 26 °C and 28 °C WBGT, respectively. Additional breaks during play provide an opportunity to restrain the exercise-induced rise in core temperature and facilitate additional fluid intake. Additional cold water ingestion may be an effective strategy to facilitate cooling of an athlete during exercise in hot, humid, and still environments.¹⁷ This relates to the high efficiency of internal heat loss in the face of restrictions that the prevailing conditions place upon heat loss via sweat efficiency.¹⁷ Previous studies have examined the use of simple cooling strategies during simulated^{18–20} and field¹⁰ football matchplay, but were applied only during the pre-match and half time periods.^{10,18,19} No evidence is available that examines the effectiveness of in-play (i.e. during each half of play) cooling periods, yet they are already currently advocated by FIFA. Therefore, the study will inform the extreme heat policy guidelines for football governing bodies by testing the efficacy of in-play cooling breaks within a controlled environment.

Since the regular cancellation of matches in hot and humid conditions is not feasible, cooling strategies need to be devised that are pragmatic for not only professionals, but community-based amateur competitions that are vital for public health.¹⁵ The aim of the study was to examine if three feasible interventions (trials) involving additional cooling periods attenuate the core (rectal) temperature rise during simulated football matches in comparison to a regular match (REG trial). The three strategies were inclusive of: 1) two additional 3-min cooling periods with chilled water ingestion (as advocated by FIFA; COOL_{water} trial), 2) two additional 3-min cooling periods with chilled water ingestion and an ice towel placed around the neck (COOL_{towel} trial), 3) an additional 5-min cooling break at the end of half time (HT_{extended} trial). We hypothesised that all three strategies would result in an attenuation of the core temperature rise in comparison to REG.

2. Methods

Twelve healthy well-trained football players were recruited, provided written informed consent to participate, and completed the study. The mean age, height, body mass, and maximal oxygen consumption was 24 ± 7 y, 179 ± 5 cm, 75 ± 6 kg, and 58 ± 3 mL/kg/min, respectively. Additionally, five other participants withdrew from the research due to illness and injuries

sustained during football participation external to the study. The study had institutional ethics approval.

Participants completed one preliminary and four experimental sessions, separated by at least 48-h. Maximal oxygen consumption was assessed on a motorized treadmill²¹ using a metabolic cart (Quark CPET, Cosmed, Italy) during the preliminary trial. All experimental trials were completed in an environmental chamber set to 35 °C ambient temperature, 55% relative humidity, and 30 °C WBGT (according to indoor formula for WBGT²²). Participants refrained from strenuous exercise and alcohol 24-h prior to experimental trials. Caffeine was prohibited 8-h prior to trials and participants consumed a cold 600 mL sports drink (Gatorade, Australia) two hours prior to attending the laboratory. Participants completed the REG trial first and then were assigned using blocked randomization into the COOL_{water}, COOL_{towel}, and HT_{extended} trials using a counter-balanced approach across possible trial order combinations.

The simulation protocol for the REG trial is outlined in Fig. 1 (total duration: 106-min). The REG trial was completed first to quantify *ad libitum* consumption of chilled water (10 °C) during the half-time break so that fluid intake could be subsequently matched during the half-time periods of the intervention trials. Participants remained seated in the chamber outside of the direct flow of the fan during the half-time period.

The COOL_{water} and COOL_{towel} trials included the same protocol as the REG but with the addition of 3-min cooling periods at the 30-min mark of each half (total duration: 112-min). The 3-min cooling periods during the COOL_{water} trial involved the administering of an additional 3.2 mL/kg of body mass of chilled water (10 °C) to participants whilst they remained standing outside of the direct flow of the fan. The total volume of water and time requirement for consumption is similar to previous studies examining endurance performance in the heat.²³ The COOL_{towel} trial involved participants consuming chilled water (10 °C; 3.2 mL/kg) and draping an ice towel around the neck and shoulders for 2.5-min during each 3-min cooling period. The ice towel (100% cotton) was soaked with cold water, wrung, and filled evenly with 2.5 kg of ice, consistent with similar studies in tennis players.^{24,25}

The HT_{extended} trial included the same simulation protocol as the REG trial but with an extended half time period (20-min instead of 15-min; total duration: 111-min). No extra fluid was provided during the half time break in addition to the matched quantity for all other half time periods.

The pre-programmed treadmill (Pulsar 3p, h/p/cosmos Sports & Medical gmbh, Germany) protocol followed similar principles to previous motorized treadmill simulations²⁶ but was adjusted in consideration of the environmental conditions and pilot testing (Fig. 1). Participants wore football shorts, shin guards, socks, running shoes, and a standardized jersey (100% polyester, Nike, Thailand) during match simulations. A Kestrel 4600 heat stress tracker monitored environmental conditions and was placed next to the treadmill, in line with both the position of the participant and airflow generated by an electric fan. Ambient temperature (n = 12), relative humidity (n = 12), and WBGT (n = 8 due to technical issues) were recorded at the start and end of each half of play. Urine specific gravity (USG) (Atago[®] refractometer, Japan) was measured at the beginning of all experimental trials to estimate hydration status. Change in body mass (±0.2 g; Mettler, Germany) over the duration of the simulation was used to calculate whole body sweat loss (g/h), corrected for weight gain through fluid ingestion. Rectal temperature (T_{rec}) was continuously monitored following the self-insertion of a temperature probe (Covidien[™] Mon-a-Therm[™] 400TM, USA) 15-cm past the anal sphincter. Exercising HR was continuously monitored (Polar RS400, Finland). Regional skin temperature was continuously measured wirelessly by sensors (iButton[®] DS1922L, Maxim Integrated, USA) placed on the chest, arm, mid-thigh, and calf to determine mean skin temperature.²⁷ Thermal sensation was

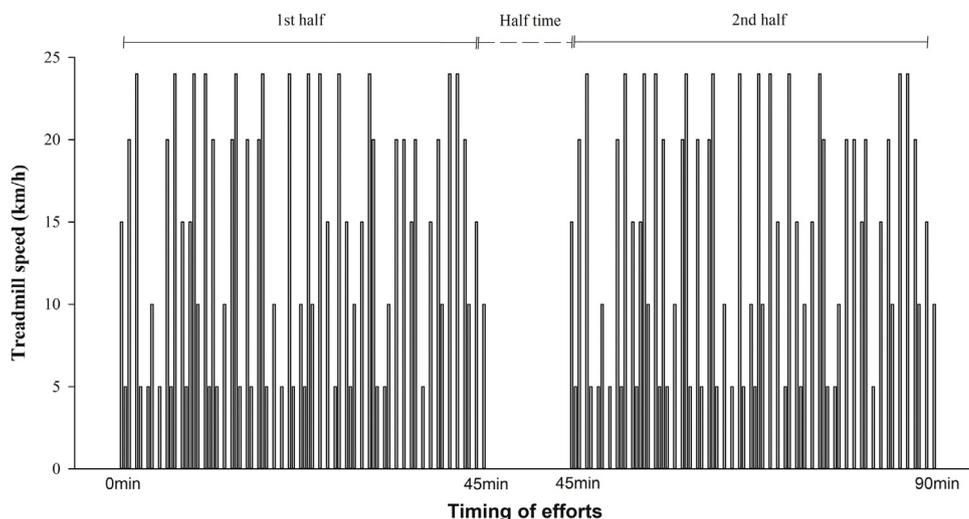


Fig. 1. A schematic of the treadmill protocol for the REG trial. All trials followed an identical exercise protocol, with the addition of either in-play cooling breaks (+3 min each) at the 30-min mark of each half (COOL_{water} and COOL_{towel}) or an extended half time break (+5-min; HT_{extended}).

The total distance of the treadmill protocol was 10.8 km and the duration of each half for the REG trial was 45-min and 15 s, separated by a 15-min half-time break. The prescribed bout duration and percentage of total distance that participants remained at each designated speed was: 0 km/h (17 s; 31.7%), 5 km/h (40 s; 27.6%), 10 km/h (30 s; 27.6%), 15 km/h (22 s; 24.8%), 20 km/h (4 s; 8.0%), and 24 km/h (3 s; 7.8%). Treadmill acceleration (level 3 ['moderate']; 0.34 m/s²) and deceleration (level 7 ['very fast']; -0.68 m/s²) times were additional to the duration of the listed times. No warm-up was completed prior to the start of the simulation. The REG protocol elicited a mean exercising percentage of maximum heart rate (HR) of 73.7 ± 8.2% during the first half and 83.2 ± 6.1% during the second half of play.

measured every 5-min using a 200-mm modified ASHRAE visual analogue scale ranging from "very cold" (0 mm), through "neutral" (100 mm), to "very hot" (200 mm). An electric fan was placed four metres away from the exercising participant and operated to elicit a wind speed of approximately 1 m/s. Post-exercise session rating of perceived exertion (sRPE) was measured 15-min after the cessation of exercise.²⁸

Data are expressed as means and 95% confidence intervals. One-way repeated measures ANOVA tests with a factor of 'session' (4 levels: REG, COOL_{water}, COOL_{towel}, and HT_{extended}) were used to analyse resting USG and sRPE. The change in exercising thermal (T_{rec} [end value] and skin temperature [mean of final 5-min]) and perceptual strain (thermal sensation [end value]) indicators were analysed at the end of each 15-min interval between the 30–90-min mark of each simulation. The first 30-min of each trial was identical and classified as a control period. Therefore, the 30-min mark was treated as a 'baseline' (i.e. '0' [no change]). Cardiovascular strain (HR) was analysed over the same time period (30–90-min), but using absolute values rather than change values and using the mean value of each 15-min interval. All variables displayed in figures are shown in absolute values across the entirety of the match to improve contextualization. Two-way repeated measures ANOVA with a factor of 'time' (5 levels: 45-min, end of half-time, 60-min, 75-min, and 90-min) and 'session' (4 levels: REG, COOL_{water}, COOL_{towel}, and HT_{extended}) were used to examine the dependent variables of T_{rec}, skin temperature, HR, and thermal sensation. In the event of a significant main effect, post-hoc analyses were performed using paired-samples t-tests. The probability of making a type I error in all tests was maintained at 5%. All analyses and figures were performed and created in SPSS version 24 (Chicago, USA), Sigmaplot 13 (San Jose, USA), and GraphPad Prism 7.0 (La Jolla, USA).

3. Results

Resting USG was similar among the REG (1.011 [1.007–1.015]), COOL_{water} (1.013 [1.007–1.019]), COOL_{towel} (1.014 [1.008–1.019]), and HT_{extended} (1.009 [1.004–1.013]) trials (p=0.308). The mean trial environmental conditions were 35.7 (35.6–35.8)°C ambi-

ent temperature, 52.5 (52–53.1)% relative humidity, and 30.1 (30.1–30.2)°C WBGT.

The mean difference in T_{rec} change between rest and the 30-min mark for each trial was similar (p=0.377; Fig. 2). There was a main effect of session between the 30 and 90-min match period (per 15-min interval), with the difference in exercising T_{rec} change significantly lower in the COOL_{water} (-0.25 [-0.40 to -0.10]°C; p=0.004), COOL_{towel} (-0.28 [-0.39 to -0.17]°C; p<0.001), and HT_{extended} (-0.21 [-0.28 to -0.14]°C; p<0.001) in comparison to REG. The difference in exercising T_{rec} change was similar between all cooling intervention trials (all p>0.05). There was a significant session by time interaction (p=0.002), with Fig. 2 demonstrating that a smaller change in T_{rec} (i.e. remained cooler) was evident during all 15-min intervals between the 30–90-min period for the COOL_{water} and COOL_{towel} trials (all p<0.05). The smaller change in T_{rec} was evident from half-time onwards during the HT_{extended} session (all p<0.05). Supplementary material 1 demonstrates the individual total change in T_{rec} during the 30–90-min period of each cooling intervention in comparison to REG.

Fig. 3A demonstrates the mean absolute HR during all trials. There was a main effect of session, with the COOL_{water} (-13 [-13 to -8]bpm; p<0.001), COOL_{towel} (-10 [-17 to -3]bpm; p=0.010), and HT_{extended} (-8 [-13 to -2]bpm; p=0.011) trials associated with a lower mean exercising HR in comparison to REG. Exercising HR was also lower during the COOL_{water} (-5 [-10 to -1]bpm; p=0.016) trial in comparison to HT_{extended} (Fig. 3A). Fig. 3B illustrates the mean skin temperature during all trials. The difference in mean skin temperature change during the 30–90-min period was similar between all sessions (main effects p=0.357). There was a main effect of session, but the difference in the change of thermal sensation during the 30–90-min period in comparison to the REG trial was similar during the COOL_{water} (-9 [-20 to 3]mm [cooler]; p=0.128), COOL_{towel} (-2 [-11 to 6]mm [cooler]; p=0.582), and HT_{extended} (+3.2 [-6 to 13]mm [warmer]; p=0.466) trials. However, the difference in the change of thermal sensation was lower (i.e. remained cooler) during the COOL_{water} (-12 [-21 to -3]mm; p=0.011) and COOL_{towel} (-5 [-11 to 0]mm; p=0.042) trials in comparison to HT_{extended}.

Whole body sweat rate during the simulated matches was similar between the REG (1200 [1085–1315]g/h), COOL_{water} (1208

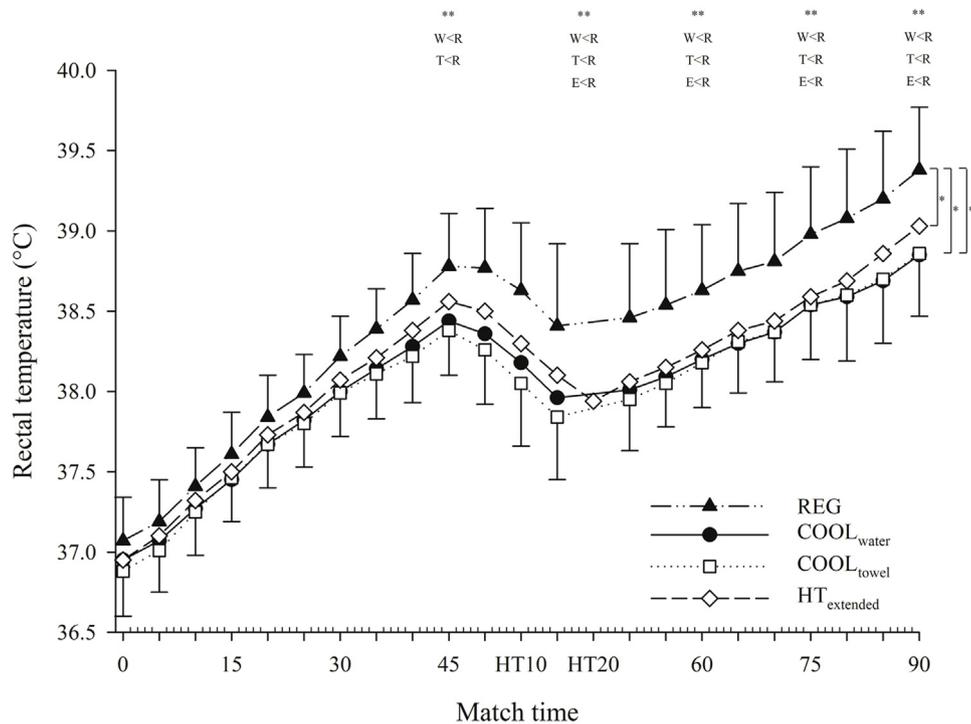


Fig. 2. Mean absolute rectal temperature throughout the four experimental trials. Data are presented as means and standard deviations (for the low and high trials). *Significant ($p < 0.05$) session difference in comparison to REG for the mean rectal temperature change during the 30–90-min time period. **Significant ($p < 0.05$) difference in comparison to REG trial for specific 15-min time intervals; R regular game; W COOL_{water} trial; T COOL_{towel} trial; E HT_{extended} trial.

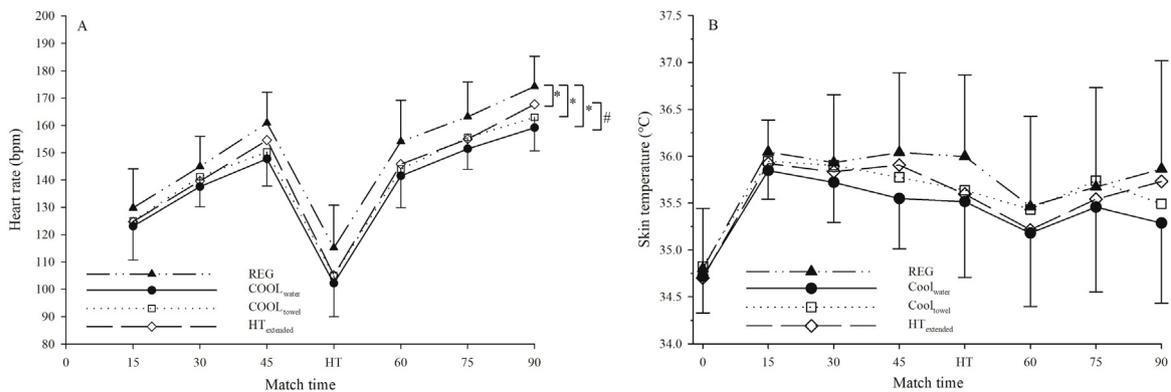


Fig. 3. The mean heart rate (A) and mean skin temperature (B) response to the four experimental trials. Data are presented as means and standard deviations (for the low and high trials). *Significant ($p < 0.05$) session difference in comparison to REG for the mean heart rate during the 30–90-min time period. #Significant ($p < 0.05$) session difference in comparison to HT_{extended} for the mean heart rate during the 30–90-min time period.

[1110–1305]g/h), COOL_{towel} (1185 [1088–1282]g/h), and HT_{extended} (1173 [1059–1287]g/h) ($p = 0.622$) trials. The mean sRPE for the four trials was; REG (6.4 [5.2–7.7]), COOL_{water} (5.0 [3.8–6.3]), COOL_{towel} (5.1 [4.0–6.2]), and HT_{extended} (5.5 [4.4–6.6]). There was a main effect of session, with sRPE significantly lower in the COOL_{water} (-1.4 [-2.3 to -0.5]; $p = 0.006$), COOL_{towel} (-1.3 [-2.3 to -0.3]; $p = 0.013$), and HT_{extended} (-0.9 [-1.8 to -0.1]; $p = 0.038$) trials in comparison to REG. Session RPE was also lower during the COOL_{towel} (-0.4 [-0.7 to 0.0]; $p = 0.043$) trial in comparison to HT_{extended}.

4. Discussion

In support of our hypothesis, the COOL_{water}, COOL_{towel}, and HT_{extended} trials attenuated thermal (T_{rec}) strain in comparison to a REG trial. Neither intervention resulted in a significantly greater

cooling effect upon core body temperature than the others. The brief cooling interventions also reduced markers of exercise intensity (HR and sRPE) but did not significantly influence mean skin temperature or thermal sensation.

This is the first study to examine the effect of advocated brief in-play cooling periods during a simulated football match. The cooling interventions are considered feasible in a low-cost community setting, especially the COOL_{water} and HT_{extended} strategies. In a field setting, it may be necessary for players to seek shade during breaks to minimise potential heat gain from additional overall solar radiation exposure time (due to the prolonged total match time). A true control trial in comparison to the COOL_{water} and COOL_{towel} trials was not included. A true control trial would require players to complete a match with either no additional fluid ingestion during the 3-min breaks, or alternatively, players consume identical fluid intake at the same intervals during the 3-min break and

REG trials. However, these options are not practical or possible in a field setting, since most players will consume fluid during dedicated break periods (i.e. “drinks breaks”), and secondly, it is impossible to provide additional fluid to a team throughout a match without dedicated rest periods.

The T_{rec} response was attenuated following the first cooling period (30-min mark) of the first half for the COOL_{water} (mean of -0.25°C) and COOL_{towel} (mean of -0.28°C) trials. The implementation of cooling periods following 30-min of match-play is recommended by FIFA due to the finding that peak player core temperature in hot field matches occurs at the 30-min time point.⁶ The T_{rec} response was attenuated at the end of half-time and throughout the remainder of the match for the HT_{extended} trial (mean of -0.21°C). A potential advantage of the HT_{extended} trial is the additional time that the strategy affords for other extensive cooling practices (that might be logistically difficult during the 3-min breaks) during the major rest period that can reduce the change in core temperature during the second half of play.¹⁸ However, not all half-time cooling strategies substantially influence core temperature during the second half of football,¹⁹ therefore, potentially highlighting the importance of the 3-min cooling period during the second half of play for attenuating thermal strain in the latter stages of matches. Notably, the attenuation of absolute exercising core body temperature during the cooling intervention trials is similar to the magnitude commonly conferred through adaptations from a heat acclimation regime.²⁹ Intuitively, an aggregate effect between in-play cooling strategies and acclimation also likely exists.

Additional chilled water ingestion was provided during the COOL_{water} and COOL_{towel} trials (during the 3-min in-play breaks) whereas participants consumed the same quantity of fluid during the REG and HT_{extended} trials. The lack of substantial difference in core body temperature cooling between all three cooling intervention trials may suggest that the additional chilled fluid intake during the COOL_{water} and COOL_{towel} trials had a trivial thermoregulatory effect. Cold fluid consumption during exercise may potentially lower evaporative drive due to the cooling effect from the internal heat transfer, with a subsequent potential to limit a net body cooling effect.¹⁷ Overall, the observed attenuation of T_{rec} may relate more to the additional cessation in exercise and restraining of the exercise-induced rise in core temperature rather than the modest additional hydration per se, which on average mitigated trial percent total body mass losses by $0.5 \pm 0.2\%$ (2.2% vs 1.7%).

Cardiovascular (HR) and perceived physiological strain (sRPE) were substantially lower during all intervention trials in comparison to the REG trial. However, there was a lack of difference between all four experimental trials in the mean skin temperature change, and moreover, a lack of substantial change in thermal sensation in comparison to the REG trial. Additional rest periods during field matches may encourage players to upregulate their playing intensity (in comparison to the time period prior to the break) upon returning to play and the subsequent higher metabolic heat generation may offset any positive cooling benefits from the breaks.³⁰ However, it is uncertain if changes to activity pacing profiles will actually occur in an uncontrolled field setting based upon the inconsistent response of likely influencing contributing factors (cardiovascular strain, perceived physiological strain, and thermal sensation).

The primary limitation of the study is the controlled design of the treadmill protocol and subsequent applicability to field-based matches. The treadmill simulation isolated the effect of the cooling periods upon thermal strain, however, it does not represent the uncontrolled nature of field-based matches where player physical output is often paced. Further research should examine the translation of these laboratory-based results to uncontrolled field-based scenarios to examine the interaction between performance and thermal strain following brief in-play cooling strategies. Second, no

exercise warm-up period was undertaken prior to each trial, with the resultant additional effect upon body temperature potentially influencing the response to subsequent cooling strategies.

5. Conclusion

The current laboratory-based controlled study supports the use of brief in-play cooling periods, as currently advocated by FIFA and other football organisations, as a means to attenuate the rise in core body temperature during matches in hot and humid conditions. The implementation of the cooling interventions are considered feasible in a low-cost community setting, especially the COOL_{water} and HT_{extended} strategies.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.jsams.2019.04.009>.

References

1. Sawka MN, Leon LR, Montain SJ et al. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Compr Physiol* 2011; 1(4):1883–1928.
2. Nassis GP, Brito J, Dvorak J et al. The association of environmental heat stress with performance: analysis of the 2014 FIFA World Cup Brazil. *Br J Sports Med* 2015; 49:609–613.
3. Link D, Weber H. Effect of ambient temperature on pacing in soccer depends on skill level. *J Strength Cond Res* 2015; 31(7):1766–1770.
4. Chmura P, Konefał M, Andrzejewski M et al. Physical activity profile of 2014 FIFA World Cup players, with regard to different ranges of air temperature and relative humidity. *Int J Biometeorol* 2017; 61(4):677–684.
5. Grantham J, Cheung SS, Connes P et al. Current knowledge on playing football in hot environments. *Scand J Med Sci Sports* 2010; 20(S3):161–167.
6. Özgünen KT, Kurdak SS, Maughan RJ et al. Effect of hot environmental conditions on physical activity patterns and temperature response of football players. *Scand J Med Sci Sports* 2010; 20(S3):140–147.
7. Elias SR. 10-year trend in USA Cup soccer injuries: 1988–1997. *Med Sci Sports Exerc* 2001; 33(3):359–367.
8. Yard EE, Gilchrist J, Haileyesus T et al. Heat illness among high school athletes – United States, 2005–2009. *J Safety Res* 2010; 41(6):471–474.
9. Boden BP, Breit I, Beachler J et al. Fatalities in high school and college football players. *Am J Sports Med* 2013; 41(5):1108–1116.
10. Duffield R, Coutts A, McCall A et al. Pre-cooling for football training and competition in hot and humid conditions. *Eur J Sport Sci* 2013; 13(1):58–67.
11. Mohr M, Krstrup P, Nybo L et al. Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time. *Scand J Med Sci Sports* 2004; 14(3):156–162.
12. Edwards A, Clark N. Thermoregulatory observations in soccer match play: professional and recreational level applications using an intestinal pill system to measure core temperature. *Br J Sports Med* 2006; 40(2):133–138.
13. Ekblom B. Applied physiology of soccer. *Sports Med* 1986; 3(1):50–60.
14. Bouchama A, Knochel J. Heat stroke. *N Engl J Med* 2002; 346(25):1978–1988.
15. Chalmers S. In-play cooling strategies for sport in hot and humid conditions. *Temperature* 2017; 4(4):353–355.
16. Fédération Internationale de Football Association, Available from: *A cool first and a historic triumph*, 2014. Cited 6 February 2018 <http://www.fifa.com/worldcup/news/y=2014/m=6/news=a-cool-first-and-a-historic-triumph-2390305.html>.
17. Jay O, Morris NB. Does cold water or ice slurry ingestion during exercise elicit a net body cooling effect in the heat? *Sport Med* 2018; 48(S1):17–29.
18. Price MJ, Boyd C, Goosey-Tolfrey VL. The physiological effects of pre-event and mid-event cooling during intermittent running in the heat in elite female soccer players. *Appl Physiol Nutr Metab* 2009; 34(5):942–949.
19. Aldous JWF, Christmas BCR, Akubat I et al. Mixed-methods pre-match cooling improves simulated soccer performance in the heat. *Eur J Sport Sci* 2019; 19(2):156–165.
20. Holm RL, Pribyslavskva V, Scudamore EM et al. Performance and perceptual responses of collegiate female soccer players to a practical external and internal cooling protocol. *Int J Exerc Sci* 2015; 8(4):331–340.

21. Canadian Society for Exercise Physiology, Ottawa, ON *Certified Fitness Appraiser Resource Manual*, 1986.
22. Budd GM. Wet-bulb globe temperature (WBGT) – its history and its limitations. *J Sci Med Sport* 2008; 11(1):20–32.
23. Lee JKW, Shirreffs SM, Maughan RJ. Cold drink ingestion improves exercise endurance capacity in the heat. *Med Sci Sports Exerc* 2008; 40(9):1637–1644.
24. Lynch GP, Périard JD, Pluim BM et al. Optimal cooling strategies for players in Australian Tennis Open conditions. *J Sci Med Sport* 2018; 21(3):232–237.
25. Schraner D, Scherer L, Lynch GP et al. In-play cooling interventions for simulated match-play tennis in hot/humid conditions. *Med Sci Sport Exerc* 2017; 49(5):991–998.
26. Clarke ND, Maclaren DPM, Reilly T et al. Carbohydrate ingestion and pre-cooling improves exercise capacity following soccer-specific intermittent exercise performed in the heat. *Eur J Appl Physiol* 2011; 111(7):1447–1455.
27. Ramanathan NL. A new weighting system for mean surface temperature of the human body. *J Appl Physiol* 1964; 19(3):531–533.
28. Foster C, Florhaug JA, Franklin J et al. A new approach to monitoring exercise training. *J Strength Cond Res* 2001; 15(1):109–115.
29. Tyler CJ, Reeve T, Hodges GJ et al. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sport Med* 2016; 46(11):1699–1724.
30. Chalmers S, Jay O. Australian community sport extreme heat policies: limitations and opportunities for improvement. *J Sci Med Sport* 2018; 21:544–548.