Loughborough University

This item was submitted to Loughborough's Research Repository by the author.
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

Mixed-methods pre-match cooling improves simulated soccer performance in the heat

PLEASE CITE THE PUBLISHED VERSION

https://doi.org/10.1080/17461391.2018.1498542

PUBLISHER

Taylor & Francis

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

This is an Accepted Manuscript of an article published by Taylor & Francis in European Journal of Sport Science on 24 July 2018, available online: http://www.tandfonline.com/10.1080/17461391.2018.1498542.

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Aldous, Jeffrey William Frederick, Bryna Catherine Rose Chrismas, Ibrahim Akubat, Charlotte Anne Stringer, Grant Abt, and Lee Taylor. 2018. “Mixed-methods Pre-match Cooling Improves Simulated Soccer Performance in the Heat”. figshare. https://hdl.handle.net/2134/11617596.v1.

Manuscript Title: Mixed-Methods Pre-Match Cooling Improves Simulated Soccer Performance in The Heat.

Running Head: Cooling during simulated soccer

Authors: Jeffrey William Frederick Aldous[1], Bryna Catherine Rose Chrismas[2], Ibrahim Akubat[3], Charlotte Anne Stringer[1], Grant Abt[4], And Lee Taylor[5, 6, 1]

Departments and Institutions

[1]Institute of Sport and Physical Activity Research (ISPAR), School of Sport Science and Physical Activity Research, University of Bedfordshire, Bedford, UK; [2]Sport Science Program, College of Arts and Sciences, Qatar University, Doha, Qatar; [3]Newman University, Department of Physical Education and Sports Studies, Birmingham, UK; [4]Department of Sport, Health and Exercise Science, The University of Hull, Hull, UK; [5]ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Athlete Health and Performance Research Centre, Aspire Zone, Doha, Qatar & [6]School of Sport, Exercise and Health Sciences. Loughborough University, Loughborough, UK.

Laboratory: Polhill Campus, University of Bedfordshire, Bedford, Uk, Mk41 9ea

Corresponding Author: Dr Lee Taylor, Aspetar Orthopaedic and Sports Medicine Hospital, Athlete Health and Performance Research Centre, Aspire Zone, Doha, Qatar, P.O. Box 29222, Telephone: +(974) 4413 2403, Email: Lee.taylor@aspetar.com

Word Count: 3,997

Number of Figures: 3

Number of Tables: 1

Number of References: 38

Funding: Acknowledgements: This research was funded by the João Havelange Research Scholarship on behalf of The International Centre of Sports Studies (CIES) and Fédération Internationale de Football Association (FIFA). No commercial or financial incentives were provided that can have caused any potential conflict of interest.

This is an Accepted Manuscript of an article published by Taylor & Francis in European Journal of Sport Science on 24 Jul 2018, available online: http://www.tandfonline.com/10.1080/17461391.2018.1498542.

Abstract: This investigation examined the effects of three pre-match and half-time cooling manoeuvres on physical performance and associated physiological and perceptual responses in eight University soccer players during a non-motorised treadmill based individualised soccer-specific simulation [intermittent soccer performance test (iSPT)] at 30ºC. Four randomised experimental trials were completed; following 30-min (pre-match) and 15-min (half-time) cooling manoeuvres via: (1) ice slurry ingestion (SLURRY); (2) ice-packs placed on the quadriceps and hamstrings (PACKS); (3) mixed-methods (MM; PACKS and SLURRY concurrently); or no-cooling (CON). In iSPT first half, a moderate increase in total (Mean ± Standard Deviation: 108 ± 57m, qualitative inference: most likely, Cohen's *d*: 0.87, 90%CL: ±0.31), high-speed (56 ± 46m, very likely, 0.68 ±0.38) and variable run (15 ± 5m, very likely, 0.81 ±0.47) distance covered was reported in MM compared with CON. Additionally, pre-match reductions in thermal sensation (-1.0 ± 0.5, most likely, -0.91 ±0.36), rectal (-0.6 ± 0.1ºC, very likely, -0.86 ±0.35) and skin temperature (-1.1 ± 0.3ºC, very likely, -0.88 ±0.42) continued throughout iSPT first half. Physical performance during iSPT first half was unaltered in SLURRY and PACKS compared to CON. Rectal temperature was moderately increased in SLURRY at 45-min (0.2 ± 0.1ºC, very likely, 0.67 ±0.36). Condition did not influence any measure in iSPT second half compared to CON. Only MM pre-match cooling augmented physical performance during iSPT first half, likely due to peripheral and central thermoregulatory factors favourably influencing first half iSPT performance. Further practical half-time cooling manoeuvres which enhance second half performance are still required.

Keywords: Environmental Physiology, Fatigue, Performance, Team Sport

Introduction

Elite soccer competition can occur within high ambient temperatures exceeding 30ºC, as seen during the 2014 Fédération Internationale de Football Association (FIFA) World Cup in Brazil (Nassis, Brito, Dvorak, Chalabi and Racinais, 2015). Soccer match-play performed at 43ºC demonstrated a reduction in physical performance (7–26%) and dramatic increases in peak core (T_c: 39.5 ± 0.1ºC) and muscle (T_{mu}: 40.3 ± 0.1ºC) temperatures (Mohr, Nybo, Grantham and Racinais, 2012). Although variable, high T_c (e.g. >40ºC) as seen in other codes of football (Aughey, Goodman and McKenna, 2014) can be associated with the onset of heat illnesses (Armstrong et al., 2007). Whilst augmented T_{mu} improves single sprint performance through enhanced muscle contractility (Racinais and Oksa, 2010), progressive reductions in intermittent and repeated sprint performance/ability (RSA) are observed when T_c exceeds 39°C (Girard, Brocherie and Bishop, 2015). Indeed, elevated T_c (39.2 ± 0.2ºC) coincided with reduced sprint performance (-5.8%) in the final 15-min of simulated soccer at 30ºC (Aldous et al., 2016); important given a sprint is the most frequently observed movement prior to a goal or assist during soccer match-play (Faude, Koch and Meyer, 2012). Strategies such as cooling manoeuvres [e.g. Ice packs, Ice slurry etc. - (Bongers, Thijssen, Veltmeijer, Hopman and Eijsvogels, 2014)] that can attenuate elevated body temperatures during soccer match-play in the heat are therefore needed relative to performance (Mohr et al., 2012) and player safety (Armstrong et al., 2007) agendas.

Cooling manoeuvres can be applied to the body (external) or ingested (internal), via a singular or combined (mixed-methods) approach pre-match and/or at half-time in soccer (Grantham et al., 2010). Given that T_c exceeding 39ºC can decrease RSA (Girard et al., 2015), it is logical that directly pre-cooling the locomotive muscles will create a heat sink that may eventually benefit

72 subsequent RSA in the heat (Castle et al., 2006). This is provided an appropriate warm-up is
73 observed post-pre-cooling (Castle et al., 2006), given that decreased T_{mu} (Lovell, Barrett, Portas
74 and Weston, 2013) may negatively influence initial (i.e. at the start of each half) RSA related
75 performance (Russell et al., 2015a). Practical cooling via ice packs applied to quadriceps and
76 hamstrings reduced both T_c (0.2 ± 0.2°C) and T_{mu} (1.0 ± 2.5°C) prior to a warm up, coinciding
77 with an augmented power output during prolonged intermittent sprint cycling exercise at 33°C
78 (Castle et al., 2006). Ice slurry ingestion causes a pre-exercise decrease in T_c (~0.5°C), attributed
79 to a reduction in body heat storage (Jay and Morris, 2018), which can elicit a similar ergogenic
80 effect on endurance performance at ~34°C compared with impractical pre-exercise cold-water
81 immersion (Siegel, Mate, Watson, Nosaka and Laursen, 2012). However, despite ice slurry
82 ingestion reducing thermal sensation and T_c prior to intermittent sprint performance at 30°C,
83 performance was not favourably altered (Gerrett, Jackson, Yates and Thomas, 2017). Furthermore,
84 evidence regarding combined external and internal mixed-method cooling manoeuvres relative to
85 RSA in the heat is sparse, despite reductions in body temperatures being potentially augmented
86 compared with their singular use (Bongers et al., 2014).

87 During soccer match-play, combined pre-match and half-time cooling via ice vests, ice towels and
88 ice slurry ingestion revealed a moderate effect ($4m \cdot min^{-1}$, $d = 0.6$) on total running distance,
89 alongside blunted elevations in T_c and thermal sensation (Duffield, Coutts, McCall and Burgess,
90 2013). However, soccer match-play is highly variable (e.g. tactics, environment, etc.) which
91 renders meaningful inferences from interventions upon key physical performance measures (e.g.
92 high-speed running), challenging without a practically unrealistic sample size [e.g. 80 players
93 (Gregson, Drust, Atkinson and Di Salvo, 2010)]. One solution for quantifying the efficacy of a
94 cooling strategy relative to soccer performance is to utilise an appropriate soccer-specific

simulation rather than match-play (Aldous et al., 2016). To date only three such studies have been conducted, however the omission of a warm up post-pre-cooling (Price, Boyd and Goosey-Tolfrey, 2009), any relevant performance measures (Clarke, Maclaren, Reilly and Drust, 2011) and the use of non-practical pre-cooling interventions such as prolonged cold-water showering (Drust, Cable and Reilly, 2000) are impractical to soccer. Additionally, their utilised simulations did not include the recommended individualised and externally cued speed thresholds to enable appropriate quantification of the efficacy of their cooling manoeuvres (Taylor and Rollo, 2014). The intermittent Soccer Performance Test (iSPT) adheres to these recommendations and is a valid, reliable and individualised soccer simulation (Aldous et al., 2014) that has successfully identified changes in simulated soccer performance in hot environments (Aldous et al., 2016). Thus, iSPT would provide an appropriate tool to determine the effects of pre-match and half-time cooling on simulated soccer.

The aim of this study was to investigate the efficacy of pre-match and half-time cooling strategies: (1) external (ice packs placed on the quadriceps and hamstrings; PACKS); (2) internal (ice slurry ingestion; SLURRY); and (3) mixed-methods (PACKS and SLURRY procedures combined; MM) on simulated soccer performance at 30ºC. It was hypothesized that all cooling strategies would augment physical performance throughout iSPT compared to control (no cooling).

Methods

Participants

Eight male, University-level soccer players [mean ± SD; 22 ± 3y; 76 ± 11kg; 187 ± 20cm; $\dot{V}O_{2max}$ = 56 ± 9mL·kg^{-1}·min^{-1}] volunteered for this study which was approved by the University of

Bedfordshire Ethics Committee and conformed to the Declaration of Helsinki. Participants trained ≥2 times and played at least one full 90-min match in the British Universities and Colleges Sport Midlands 2B Division per week. Based on an *a priori* power calculation (using Aldous et al. 2016; G*Power 3); a minimum of 8 participants were required to achieve 99% power, at $P<0.05$ and $d = 0.5$ for a change in high-speed distance covered.

General Experimental Controls

In the 24 h prior to experimental trials, participants standardised their food and water consumption (food diary), and consumed 2-3 L of water, in-line with their normal drinking habits. Alcohol, cigarettes, caffeine and strenuous exercise were abstained from for >48 h prior to testing. Participants refrained from ergogenic aids supplementation throughout the study and had not been exposed to >30ºC for three months prior to this study. All familiarisation (FAM), peak speed assessments (PSA) and iSPTs were completed on the same calibrated non-motorised treadmill (NMT: Force 3.0, Woodway, Cranlea, Birmingham). Participants were secured onto the NMT using a tether belt and harness attached around the waist. The harness was attached to the NMT at an angle of 8º from horizontal (Aldous et al., 2014, 2016). Hydration status was assessed via urine osmolality (Atago-Vitech-Scientific, Pocket-PAL-OSMO, HaB-Direct, Southam) with euhydration accepted at <600 $mOsm \cdot L^{-1}$ (Hillman et al., 2013).

Experimental Design

Three FAM and two PSA sessions (visits 1-3) were sufficient to minimise learning effects and produce valid and reliable [Intraclass Correlation = 0.80-0.98] physical performance and associated physiological and perceptual responses data (Aldous et al., 2014). In a randomized and

counterbalanced repeated measures design, iSPT was completed on four occasions; (1) SLURRY; (2) PACKS; (3) MM: PACKS and SLURRY concurrently; or CON. All experimental trials were completed within a controlled laboratory environmental chamber (Flower-House, Farm-House, Two-Wests and Elliot, Chesterfield) at an air temperature of 30.7 ± 0.3ºC and relative humidity of 50.9 ± 4.2% and administered using a portable heater (Bio-Green, Arkansas-3000, Hampshire). All trials comprised of the following time periods: 30-min pre-match (cooling or no cooling), 10-min warm up at 30ºC on the NMT at a speed of 8 $km \cdot hr^{-1}$, including two brief 4 s sprints, a 10-min rest period, 45-min iSPT first half, 15-min half-time (cooling or no cooling) and 45-min iSPT second half.

The intermittent Soccer Performance Test (iSPT): The iSPT consists of two 45-min halves comprised of three identical 15-min intermittent exercise blocks (Aldous et al., 2014, 2016). Throughout each exercise block, for all target speeds (apart from the variable run) participants interacted with a computer program (Innervation, Pacer Performance System Software, Lismore, Australia) by matching a red line on the screen (target speed) with their current (actual) speed (green line). Participants were instructed to match their current speed with the target speed as closely as possible throughout iSPT, apart from the variable run. Audio cues specific to each movement category (e.g. run) were also presented by three audible tones, followed by an audible command (e.g., “beep”, “beep”, “beep”, “run”). Finally, four self-selected high-speed ‘variable runs’ were completed at 13-14-min of each 15-min block. During the variable run, participants were instructed to cover as much distance as possible without sprinting. A sprint was defined as the peak sprint speed (PSS) achieved in the PSA, with no incidences of sprinting observed during the variable run. The variable run was executed at 82 ± 5% (range: 68-89%) of the defined PSS across all experimental trials. The variable run has been shown reliable to quantify the distance

160 covered by a participant above the second ventilatory threshold, at a self-selected running speed
161 without an external cue (Aldous et al., 2014).

162 *Cooling Manoeuvres:* All cooling manoeuvres were completed with participants seated in a
163 temperate environment (18.0 ± 0.9ºC; 50.3 ± 4.7% rH). Room temperature water (21.0 ± 0.6ºC)
164 was consumed during CON and PACKS, divided into three portions to be ingested every 10-min
165 (pre-match) and 5-min (half-time). The volume of room temperature water drunk was relative to
166 the individualised melted liquid volume in SLURRY. In MM, SLURRY and PACKS
167 methodologies were performed simultaneously.

168 *SLURRY:* Participants ingested 7.5 g·kg^{-1} body mass of ice slurry (−1°C) pre-match (volume: 500-
169 800mL) and 3.75 g·kg^{-1} at half-time (volume: 250-400 mL). On each occasion, the ice slurry was
170 divided into three equal portions ingested every 10-min (pre-match) and 5-min (half-time)
171 ensuring even ingestion throughout the cooling phase. The drink consisted of two-thirds shaved
172 ice, using a snow cone maker (Snow Cone Maker, JM Posner, Amazon Ltd, Alton) and one-third
173 sugar free diluted drinking cordial (Tesco, UK).

174 *PACKS:* Ice packs (Aeroplast, hot/cold pack, Hertfordshire Suppliers, Hertfordshire) were
175 removed from a freezer (freezer temperature: -20ºC) with a surface temperature of -14.0 ± 4.6ºC
176 and wrapped in a cotton cloth (Compression Cuff Holder, Lewis-Plast, Lewis Medical Supplies,
177 Stockport) to avoid damage to the skin. Ice packs were placed on the anterior, lateral and posterior
178 aspects of the quadriceps and hamstring muscle groups. Ice packs were replaced every 15-min
179 (pre-match), as pilot data indicated that the packs were nearly melted by this time.

Physical performance measures: Total distance covered (TD) comprised all movement categories [categories as a percentage of PSS were: walk (20%), jog (35%), run (50%), fast run (65%), variable run (unset) and sprint (100%)] and was calculated across both halves. Data for high-speed distance (HSD) covered was derived from fast run, variable run (VRD) and sprint (SD) distances covered, while low-speed distance (LSD) covered, included walk, jog and run distances covered (Aldous et al., 2014). For each half, LSD, HSD, VRD and SD covered were computed with performance changes calculated in distance covered (m) between halves (Aldous et al., 2014).

Physiological Measurements: Prior to FAM, height (cm) was measured using a Holtain Stationmaster (Stadiometer, Harpenden, HAR 98.602, Holtain). To quantify fluid loss, participant nude dried body mass change was measured pre- and post-iSPT using digital scales (Tanita, BWB0800, Allied Weighing). Heart rate [HR – Coefficient of variation (CV): 1.8%] was recorded beat-by-beat using a telemetric HR monitor (Polar, FS1, Polar Electro, Oy) using a 1-min mean approach within analyses. A single-use rectal thermistor (Henleys, 400H, Henleys Medical, Welwyn Garden City) was used to measure rectal temperature (T_{re} - CV: 0.4%) from a depth of 10 cm past the anal sphincter and read by a connected data logger (Measurement, 4600, Henley-medical, Welwyn Garden City). Skin thermistors (Grant, EUS-U-VS5-0, Wessex-Power, Dorset) were attached to the right side of the body at the centre of the pectoralis major, biceps brachi, rectus femoris, and gastrocnemius to measure skin temperature (T_{sk} - CV: 2.0%) as per the Ramanathan (1964) equation; with this data recorded by a data logger (Eltek/Squirrel, Squirrel Series/model 451, Wessex Power, Dorset). All T_{re} and T_{sk}, perceived exertion [CV: 3.3% - RPE: Borg 6-20 scale - (Borg, 1998)] and thermal sensation [CV: 4.5% - TS: 0-8 scale - (Young, Sawka, Epstein, Decristofano and Pandolf, 1987)] measures were collected at 15-min intervals across the experimental data collection period.

Statistical Analysis

All data in tables, text and figures are presented as mean ± SD with 90% confidence limits/intervals (90% CL/CI) and were analysed using the contemporary magnitude based inferences qualitative approach (Hopkins, Marshall, Batterham and Hanin, 2009). Using a customised spreadsheet (Hopkins, 2003), all data were first log transformed to reduce bias arising from non-uniformity of error and then back-transformed. Comparisons between pre-match cooling strategies throughout iSPT were standardised using Cohen's *d* effect sizes with qualitative interpretations [0.00-0.19, trivial; 0.20-0.59, small; 0.60-1.19, moderate; >1.20, large (Hopkins et al., 2009)]. The differences with uncertainty of the estimates are shown as 90% CL. If the 90% CI overlapped positive and negative trivial ES values, the effect was deemed unclear. As per best practice for team-sport specific measures, the smallest worthwhile change for all physical performance measures was estimated by using 0.2 × between-subject SD (Hopkins et al., 2009). The smallest worthwhile change for all physiological and perceptual responses was taken from a previous meta-analysis (Choo, Nosaka, Peiffer, Ihsan and Abbiss, 2018). Qualitative chances of measurements affecting performance were assessed qualitatively as follows: <1%, most unlikely; 1-5%, very unlikely; 5-25%, unlikely; 25−75%, possible; 75−95%, likely; 95−99%; very likely; >99%, almost certain (Hopkins et al., 2009).

Results **Table 1, Figure 1, 2 and 3 near here**

Physical performance: In CON, a moderate decrease for all physical performance measures was evident in iSPT second half compared with the first half, which was not influenced by condition. In PACKS and SLURRY, physical performance was unaltered compared with CON throughout both halves of iSPT. There was a moderate increase in TD (most likely, 0.87 ±0.31), HSD (very

likely, 0.68 ±0.38) and VRD (very likely, 0.81 ±0.47) covered in the first half of MM, compared with CON. There was an unclear improvement to physical performance in PACKS and SLURRY compared with CON, however, no changes were evident to TD, HSD and VRD covered in the second half between all conditions (Figure 1, 2 and 3). No changes in LSD and SD covered were evident throughout iSPT.

Body Temperatures, Physiological and Perceptual Measures: A large increase in T_{re}, T_{sk}, RPE and TS were seen throughout iSPT first half at 30-min and 45-min compared with 0-min. In iSPT second half, at 90-min and 105-min a large increase in T_{re}, T_{sk}, RPE and TS were evident compared with 60-min (start of the second half) in CON. However, RPE, HR and body mass changes were unaltered between all conditions throughout iSPT. In PACKS, a moderate reduction in T_{sk} (very likely, -0.88 ±0.47) and TS (very likely, -0.63 ±0.27) post cooling was evident compared with CON. In PACKS, throughout iSPT T_{re}, T_{sk} and TS were all unchanged compared with CON. Pre-match cooling revealed a moderate reduction in T_{re} (very likely, -0.66 ±0.24) and TS (very likely, -0.63 ±0.26) in SLURRY compared with CON. No differences in TS and T_{sk} arose, however, a moderate elevation in T_{re} was evident at 45 min (very likely, 0.67 ±0.36) in SLURRY compared with CON. In MM, there was a moderate reduction in both rectal temperature, (very likely, -0.86 ±0.35), skin temperature (very likely, -0.88 ±0.42) and TS (very likely, -0.91 ±0.36) pre-match which continued throughout the first half of iSPT compared with CON. No differences in T_{re}, T_{sk} and TS were observed between all conditions in the second half (Table 1, Figure 2 and 3).

Discussion

The major findings of the present study are that 30-min of MM pre-match cooling revealed a moderate increase in physical performance and a moderate reduction in T_{re}, T_{sk} and TS in iSPT

247 first half. The 30-min of pre-match cooling in PACKS and SLURRY reduced TS, T_{re} and T_{sk}
248 without changes in physical performance during iSPT first half, whilst T_{re} moderately increased in
249 SLURRY at 45-min compared to CON. Finally, half-time cooling strategies revealed no effect
250 upon physical performance in iSPT second half.

251 Pre-iSPT cooling

252 Pre-match cooling in MM was the most effective strategy, with favourable reductions in T_{re}, T_{sk}
253 and TS pre-match and across iSPT first half compared with CON. This coincided with a clear
254 moderate increase in TD, HSD and VRD covered during iSPT first half in MM compared to CON.
255 Utilising soccer match-play designs to examine the efficacy of a cooling intervention can be
256 problematic due to a plethora of match-factors [e.g. score line, tactics, etc. (Gregson et al., 2010)]
257 and the adaptive pacing strategies employed (Aldous et al., 2016). The iSPT minimises the
258 presence of both match factors and pacing strategies, due to the same exercise being performed in
259 each half, facilitated by the individualised and externally cued speed thresholds employed (Aldous
260 et al., 2014). These contribute to a reduction in variation for key physical performance measures
261 [HSD – CV: 1.5% (Aldous et al., 2014)] compared with match-play data [HSD – CV: 17.1%
262 (Gregson et al., 2010)]. Therefore, the efficacy of pre-match cooling was established within the
263 present study, without both adaptive pacing strategies (Aldous et al., 2016) and a plethora of
264 confounding match factors occurring (Gregson et al., 2010).

265 The elevation in VRD covered during iSPT first half in MM compared to CON suggests
266 participants chose a faster self-selected running speed in MM. This may be due to a strong sensory
267 effect, as the present data revealed a moderate decrease in TS during the first half in MM compared
268 to CON. Indeed, reductions in T_{sk} and TS can on occasions be beneficial to an athlete, without

changes in T_{re}, HR or RPE (Stevens, Mauger, Hassmen and Taylor, 2018). Menthol mouth rinse cooling, in the absence of T_{re} changes, has been shown to improve endurance performance (Stevens et al., 2016b) via the activation of thermoreceptors in the mouth, which was reported to favourably influence the interpretation of tissue temperature by higher centres (Stevens, Taylor and Dascombe, 2016a). However, ice slurry ingestion has recently be shown to directly reduce brain temperature (Onitsuka et al., 2018). Therefore, it is likely that the ice slurry ingestion activated the thermoreceptors located in the mouth [i.e. perceptual effect (Stevens et al., 2018)] and perhaps directly reduced brain temperature (Onitsuka et al., 2018), while the ice packs reduced T_{sk} (and perhaps T_{mu}) of the quadriceps dampening TS and eliciting an ergogenic effect on VRD and HSD covered in MM during the first half of iSPT. However, pre-cooling with ice on the locomotive muscles should be used cautiously as an uncontrolled reduction in T_{mu} can decrease subsequent exercise performance by diminishing muscle contractility (Gray, De Vito, Nimmo, Farina and Ferguson, 2006). Thus, to help offset the drop in T_{mu} and prevent exercise performance decline early in the first half, ice pack pre-cooling should be followed by an appropriate warm-up after cooling, prior to match-play (Russell et al., 2015a).

In PACKS, a moderate reduction in T_{sk} and TS pre-iSPT was seen alongside a trivial change in T_{re} (-0.1^{o}C) throughout iSPT first half. This coincided with no improvement to physical performance in PACKS compared with CON, likely from the volume (Minett, Duffield, Marino and Portus, 2011) and/or duration (Minett, Duffield, Marino and Portus, 2012) of the ice packs pre-cooling being inadequate to reduce T_{re} by the sufficient magnitude (~0.2^{o}C) to improve heat storage capacity and oxygen delivery to the working muscles (Girard et al., 2015). Pre-exercise ice slurry ingestion reduced T_{re} in SLURRY, but an undesirable, moderate increase in T_{re} still occurred during iSPT first half compared with CON. The elevation in T_{re} is likely from pre-exercise ice

292 slurry ingestion delaying both sweating and vasodilatory responses (Jay and Morris, 2018), thus
293 increasing heat storage during the first half. Similarly, pre-exercise ice slurry ingestion prior to
294 prolonged RSA (Gerrett et al., 2017) revealed no improvement in physical performance despite
295 pre-exercise reductions in T_c. In MM, PACKS and SLURRY were used simultaneously, resulting
296 in peripheral (T_{sk}) and central (T_{re}) thermoregulatory factors being reduced pre-exercise and
297 throughout the first half compared with CON. Therefore, heat transfer and central drive were likely
298 increased in MM, facilitating a reduction in various tissue temperatures (Castle et al., 2006;
299 Onitsuka et al., 2018) and their favourable interpretation by higher centres (Stevens et al., 2018).

300 Half-time iSPT cooling

301 Half-time cooling strategies had no effect on physical performance, physiological and perceptual
302 measures at half-time nor throughout iSPT second half. The data contradicts Minett et al. (2011)
303 who used 5-min of whole body mixed method external cooling (ice packs, towels and vest)
304 between halves, which significantly improved TD covered by 5% during the second half of a self-
305 paced intermittent sprint exercise protocol at 33^{o}C. The 5-min duration of half time cooling is
306 highly practical (Minett et al., 2011), unlike the 15-min duration used within the present
307 experimental design, since, soccer practitioners only have 2-6-min available to implement
308 interventions at half-time (Russell, West, Harper, Cook and Kilduff, 2015b). Therefore, future
309 half-time cooling strategies should be more aggressive compared with a pre-match cooling strategy
310 (Minett et al., 2011) and abide by the limited time practitioners have with players during the half-
311 time interval (Russell et al., 2015b) while incorporating an appropriate re-warm-up (Lovell et al.,
312 2013). An appropriate re-warm-up (Lovell et al., 2013) is important to offset reduced T_{mu}

313 medicated performance decrements (Russell et al., 2015b), a potential risk of aggressive 5-min
314 half-time cooling.

315 Practical Applications

316 The data from this study reveals that 30-min of mixed method pre-match cooling can augment
317 simulated soccer performance in 30ºC, albeit only within iSPT first half. Dramatic elevations
318 (>39ºC within ~20-45-min) in T_c are seen during simulated (Coull et al., 2015; Aldous et al., 2016)
319 and match-play (Mohr et al., 2012) soccer performed in the heat (30-43ºC). As discussed, elevated
320 T_c (>39ºC) is considered a primary factor to progressive reductions to RSA (Girard et al., 2015).
321 The T_{re} values seen in CON (>39ºC) exceeded this threshold within a similar high ambient
322 temperature likely to occur at the upcoming 2022 FIFA World Cup (Qatar). There are currently no
323 governing body restrictions upon the use of pre-match and/or half-time cooling prior to soccer
324 performance. Therefore, these findings may be of interest to practitioners from soccer teams that
325 are competing in a hot environment, when acclimation or acclimatisation is not possible and/or for
326 players that have a history of exertional heat illness given their increased susceptibility (Nichols,
327 2014). Furthermore, both ice slurry ingestion and ice packs are simple to use, easily portable and
328 inexpensive, so could be considered by players and practitioners prior to training sessions and
329 match-play in the heat. However, as detailed in the present study, both methods should only be
330 used simultaneously, as their singular use is ineffective. The application of ice to active muscle
331 groups (e.g. quadriceps and hamstrings) pre-exercise should also be followed by an appropriate
332 warm-up post-pre-cooling, prior to match-play (Russell et al., 2015a). This is important as
333 perturbations in T_{mu} may potentially decrease RSA at the start of the first half during match-play
334 from diminished muscle contractility (Gray et al., 2006). An increase in high-speed running during

the first half was seen in MM and consequently, a coach could take advantage of this elevated exercise intensity by orchestrating a team to play at a higher intensity during the first half (e.g. play a higher pressing match). However, playing style is likely influenced by a myriad of factors [e.g. environmental, tactics etc. (Gregson et al., 2010)] and caution should be taken to ensure soccer players do not select a pace that is too fast within the first half, exacerbating heat-induced decrements in the second half.

Conclusions

In conclusion, only 30-min of mixed-methods pre-match cooling (ice slurry ingestion and ice packs) improved simulated soccer performance at 30^{o}C. However, the elevation in physical performance was only present within iSPT first half and likely due to a decrease in tissue temperatures and TS. No half-time cooling strategy when combined with pre-match cooling improved simulated soccer performance in the heat. Therefore, future research should attempt to apply the pre-match cooling findings from this study in a match-play setting, whereas, laboratory-based research should identify aggressive half-time cooling strategies (compatible with the 2-6-min practitioners have access to players at half-time) to augment second half performance.

Declarations/Acknowledgements

There was no conflict of interest for any author in this study. Each author contributed to experimental design, data collection and data analysis, manuscript drafting and agreed to the submitted version of the manuscript.

355 References

356 Aldous, J.W.F., Akubat, I., Chrismas, B.C.R., Watkins, S.L., Mauger, A.R., Midgley, A.W., Abt,
357 G., and Taylor, L. (2014). The reliability and validity of a soccer-specific non-motorised
358 treadmill simulation (Intermittent Soccer Performance Test). *Journal of Strength &*
359 *Conditioning Research, 28*(7), 1971-1980. doi:10.1519/JSC.0000000000000310
360 Aldous, J.W.F., Chrismas, B.C.R., Akubat, I., Dascombe, B., Abt, G., and Taylor, L. (2016). Hot
361 and hypoxic environments inhibit simulated soccer performance and exacerbate
362 performance decrements when combined. *Frontiers in Physiology, 6*.
363 doi:10.3389/fphys.2015.00421
364 Armstrong, L.E., Casa, D.J., Millard-Stafford, M., Moran, D.S., Pyne, S.W., and Roberts, W.O.
365 (2007). Exertional Heat Illness during Training and Competition. *Medicine & Science in*
366 *Sports & Exercise, 39*(3), 556-572. doi:10.1249/MSS.0b013e31802fa199
367 Aughey, R.J., Goodman, C.A., and Mckenna, M.J. (2014). Greater chance of high core
368 temperatures with modified pacing strategy during team sport in the heat. *Journal of*
369 *Science and Medicine in Sport, 17*(1), 113-118. doi:doi.org/10.1016/j.jsams.2013.02.013
370 Bongers, C.C., Thijssen, D.H., Veltmeijer, M.T., Hopman, M.T., and Eijsvogels, T.M. (2014).
371 Precooling and percooling (cooling during exercise) both improve performance in the heat:
372 a meta-analytical review. *British Journal of Sports Medicine, 49*(6), 377-384.
373 doi:doi:10.1136/bjsports-2013-092928
374 Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL, US: Human Kinetics.
375 Castle, P.C., Macdonald, A.L., Philp, A., Webborn, A., Watt, P.W., and Maxwell, N.S. (2006).
376 Precooling leg muscle improves intermittent sprint exercise performance in hot, humid
377 conditions. *Journal of Applied Physiology, 100*(4), 1377-1384.
378 doi:10.1152/japplphysiol.00822.2005
379 Choo, H.C., Nosaka, K., Peiffer, J.J., Ihsan, M., and Abbiss, C.R. (2018). Ergogenic effects of
380 precooling with cold water immersion and ice ingestion: A meta-analysis. *European*
381 *journal of sport science, 18*(2), 170-181.
382 Clarke, N.D., Maclaren, D.P.M., Reilly, T., and Drust, B. (2011). Carbohydrate ingestion and pre-
383 cooling improves exercise capacity following soccer-specific intermittent exercise
384 performed in the heat. *European Journal of Applied Physiology, 111*(7), 1447-1455.
385 doi:10.1007/s00421-010-1771-5
386 Coull, N.A., Watkins, S.L., Aldous, J.W., Warren, L.K., Chrismas, B.C., Dascombe, B., Mauger,
387 A.R., Abt, G., and Taylor, L. (2015). Effect of tyrosine ingestion on cognitive and physical
388 performance utilising an intermittent soccer performance test (iSPT) in a warm
389 environment. *European Journal of Applied Physiology, 115*(2), 373-386.
390 Drust, B., Cable, N.T., and Reilly, T. (2000). Investigation of the effects of the pre-cooling on the
391 physiological responses to soccer-specific intermittent exercise. *European Journal of*
392 *Applied Physiology, 81*(1-2), 11-17. doi:10.1007/PL00013782
393 Duffield, R., Coutts, A., Mccall, A., and Burgess, D. (2013). Pre-cooling for football training and
394 competition in hot and humid conditions. *European Journal of Sport Science, 13*(1), 58-
395 67. doi:10.1080/17461391.2011.589474
396 Faude, O., Koch, T., and Meyer, T. (2012). Straight sprinting is the most frequent action in goal
397 situations in professional football. *J Sports Sci 30*(7), 625-631.
398 doi:10.1080/02640414.2012.665940

399 Gerrett, N., Jackson, S., Yates, J., and Thomas, G. (2017). Ice slurry ingestion does not enhance
400 self-paced intermittent exercise in the heat. *Scand J Med Sci Sports, 27*(11), 1202-1212.
401 doi:10.1111/sms.12744
402 Girard, O., Brocherie, F., and Bishop, D.J. (2015). Sprint performance under heat stress: A review.
403 *Scand J Med Sci Sports, 25 Suppl 1*, 79-89. doi:10.1111/sms.12437
404 Grantham, J., Cheung, S.S., Connes, P., Febbraio, M.A., Gaoua, N., González-Alonso, J., Hue, O.,
405 Johnson, J.M., Maughan, R.J., Meeusen, R., Nybo, L., Racinais, S., Shirreffs, S.M., and
406 Dvorak, J. (2010). Current knowledge on playing football in hot environments.
407 *Scandinavian Journal of Medicine and Science in Sports, 20*(3), 161-167.
408 doi:10.1111/j.1600-0838.2010.01216.x
409 Gray, S.R., De Vito, G., Nimmo, M.A., Farina, D., and Ferguson, R.A. (2006). Skeletal muscle
410 ATP turnover and muscle fiber conduction velocity are elevated at higher muscle
411 temperatures during maximal power output development in humans. *American Journal of*
412 *Physiology - Regulatory, Integrative and Comparative Physiology, 290*(2), R376-R382.
413 Gregson, W., Drust, B., Atkinson, G., and Di Salvo, V. (2010). Match-to-match variability of high
414 speed activities in premier league soccer. *International Journal of Sports Medicine, 31*(4),
415 237-242.
416 Hillman, A.R., Turner, M.C., Peart, D.J., Bray, J.W., Taylor, L., Mcnaughton, L.R., and Siegler,
417 J.C. (2013). A Comparison of Hyperhydration Versus Ad Libitum Fluid Intake Strategies
418 on Measures of Oxidative Stress, Thermoregulation, and Performance. *Sports Medicine,*
419 *21*(4), 305-317. doi:10.1080/15438627.2013.825796
420 Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. (2009). Progressive statistics for studies
421 in sports medicine and exercise science. *Medicine and Science in Sports and Exercise,*
422 *41*(1), 3.
423 Hopkins, W.G. (2003). A spreadsheet for analysis of straightforward controlled trials.
424 *Sportscience, 7*.
425 Jay, O., and Morris, N.B. (2018). Does Cold Water or Ice Slurry Ingestion During Exercise Elicit
426 a Net Body Cooling Effect in the Heat? *Sports Medicine*, 1-13.
427 Lovell, R., Barrett, S., Portas, M., and Weston, M. (2013). Re-examination of the post half-time
428 reduction in soccer work-rate. *Journal of Science and Medicine in Sport, 16*(3), 250-254.
429 Minett, G., Duffield, R., Marino, F., and Portus, M. (2012). Duration-dependant response of
430 mixed-method pre-cooling for intermittent-sprint exercise in the heat. *European Journal*
431 *of Applied Physiology, 112*(10), 3655-3666. doi:10.1007/s00421-012-2348-2
432 Minett, G.M., Duffield, R., Marino, F.E., and Portus, M. (2011). Volume-dependent response of
433 precooling for intermittent-sprint exercise in the heat. *Medicine and Science in Sports and*
434 *Exercise, 43*(9), 1760-1769.
435 Mohr, M., Nybo, L., Grantham, J., and Racinais, S. (2012). Physiological responses and physical
436 performance during football in the heat. *PLoS One, 7*(6), e39202.
437 doi:10.1371/journal.pone.0039202
438 Nassis, G.P., Brito, J., Dvorak, J., Chalabi, H., and Racinais, S. (2015). The association of
439 environmental heat stress with performance: analysis of the 2014 FIFA World Cup Brazil.
440 *British Journal of Sports Medicine, 49*(9), 609-613. doi:10.1136/bjsports-2014-094449
441 Nichols, A.W. (2014). Heat-related illness in sports and exercise. *Current Reviews in*
442 *Musculoskeletal Medicine, 7*(4), 355-365. doi:10.1007/s12178-014-9240-0

443 Onitsuka, S., Nakamura, D., Onishi, T., Arimitsu, T., Takahashi, H., and Hasegawa, H. (2018). Ice
444 slurry ingestion reduces human brain temperature measured using non-invasive magnetic
445 resonance spectroscopy. *Sci Rep, 8*(1), 2757. doi:10.1038/s41598-018-21086-6
446 Price, M.J., Boyd, C., and Goosey-Tolfrey, V.L. (2009). The physiological effects of pre-event
447 and midevent cooling during intermittent running in the heat in elite female soccer players.
448 *Applied Physiology, Nutrition, and Metabolism, 34*(5), 942-949.
449 Racinais, S., and Oksa, J. (2010). Temperature and neuromuscular function. *Scandinavian journal*
450 *of medicine & science in sports, 20*(s3), 1-18.
451 Ramanathan, N.L. (1964). A new weighting system for mean surface temperature of the human
452 body. *Journal of Applied Physiology, 19*(3), 531-533.
453 Russell, M., West, D.J., Briggs, M.A., Bracken, R.M., Cook, C.J., Giroud, T., Gill, N., and Kilduff,
454 L.P. (2015a). A passive heat maintenance strategy implemented during a simulated half-
455 time improves lower body power output and repeated sprint ability in professional Rugby
456 Union players. *PLoS One, 10*(3), e0119374. doi:10.1371/journal.pone.0119374
457 Russell, M., West, D.J., Harper, L.D., Cook, C.J., and Kilduff, L.P. (2015b). Half-time strategies
458 to enhance second-half performance in team-sports players: a review and
459 recommendations. *Sports Medicine 45*(3), 353-364. doi:10.1007/s40279-014-0297-0
460 Siegel, R., Mate, J., Watson, G., Nosaka, K., and Laursen, P.B. (2012). Pre-cooling with ice slurry
461 ingestion leads to similar run times to exhaustion in the heat as cold water immersion.
462 *Journal of Sports Sciences, 30*(2), 155-165. doi:10.1080/02640414.2011.625968
463 Stevens, C.J., Mauger, A.R., Hassmen, P., and Taylor, L. (2018). Endurance Performance is
464 Influenced by Perceptions of Pain and Temperature: Theory, Applications and Safety
465 Considerations. *Sports Med, 48*(3), 525-537. doi:10.1007/s40279-017-0852-6
466 Stevens, C.J., Taylor, L., and Dascombe, B.J. (2016a). Cooling During Exercise: An Overlooked
467 Strategy for Enhancing Endurance Performance in the Heat. *Sports Medicine*, 1-13.
468 doi:10.1007/s40279-016-0625-7
469 Stevens, C.J., Thoseby, B., Sculley, D.V., Taylor, L., Callister, R., and Dascombe, B. (2016b).
470 Running performance and thermal sensation in the heat are improved with menthol mouth
471 rinse but not ice slurry ingestion. *Scandinavian Journal of Medicine & Science in Sports,*
472 *26*(10), 1209-1216.
473 Taylor, L., and Rollo, I. 2014. Impact Of Altitude And Heat On Football Performance. *Gatorade*
474 *Sport Science Institute (GSSI) - Sports Science Exchange (SSE)* [Online], 27. Available:
475 http://www.gssiweb.org/Article/sse-131-impact-of-altitude-and-heat-on-football-
476 performance.
477 Young, A.J., Sawka, M.N., Epstein, Y., Decristofano, B., and Pandolf, K.B. (1987). Cooling
478 different body surfaces during upper and lower body exercise. *Journal of Applied*
479 *Physiology, 63*(3), 1218-1223.

480

481 **Figure 1:** The standardized differences in the change (90% confidence intervals) in TD (A), HSD
482 (B) and VRD (C) covered during the first and second half of iSPT for CON, PACKS, SLURRY
483 and MM. [a]Most likely moderate ES between CON and MM ($d > 0.6$); [b]Very likely moderate ES
484 between CON and MM.

485 **Figure 2:** The mean and SD for TD (A), HSD (B) VRD (C) covered during the first and second
486 half of iSPT for CON, PACKS, SLURRY and MM. The change in T_{re} (D), T_{sk} (E) and TS (F)
487 during the pre-match cooling, warm up (WU), first half (0-45 min), half-time cooling (45-60 min)
488 and second half (60-105 min) of iSPT for CON, PACKS, SLURRY and MM conditions. [a]Most
489 likely moderate ES between CON and MM ($d > 0.6$); [b]Very likely moderate ES between CON and
490 MM. [c]Very likely moderate ES between CON and SLURRY ($d > 0.6$). [d]Very likely moderate ES
491 between CON and PACKS ($d > 0.6$). [e]Very likely moderate ES between the first and second half.
492 [f]Very likely large ES increase compared with 0 min in all conditions. [g]Very likely large ES increase
493 compared with 60 min in all conditions.

494 **Figure 3:** Individual responses for TD (A), HSD (B), VRD (C) covered during the first and second
495 half of iSPT. for CON, PACKS, SLURRY and MM. Individual responses for T_{re} (A), T_{sk} (B) and
496 TS (C) during iSPT for CON, PACKS, SLURRY and MM conditions.