

Research article

## Field-based pre-cooling for on-court tennis conditioning training in the heat

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### Abstract

The present study investigated the effects of pre-cooling for on-court, tennis-specific conditioning training in the heat. Eight highly-trained tennis players performed two on-court conditioning sessions in 35°C, 55% Relative Humidity. Sessions were randomised, involved either a pre-cooling or control session, and consisted of 30-min of court-based, tennis movement drills. Pre-cooling involved 20-min of an ice-vest and cold towels to the head/neck and legs, followed by warm-up in a cold compression garment. On-court movement distance was recorded by 1Hz Global Positioning Satellite (GPS) devices, while core temperature, heart rate and perceptual exertion and thermal stress were also recorded throughout the session. Additionally, mass and lower-body peak power during repeated counter-movement jumps were measured before and after each session. No significant performance differences were evident between conditions, although a moderate-large effect ( $d = 0.7-1.0$ ;  $p > 0.05$ ) was evident for total ( $2989 \pm 256$  v  $2870 \pm 159$ m) and high-intensity ( $805 \pm 340$  v  $629 \pm 265$ m) distance covered following pre-cooling. Further, no significant differences were evident between conditions for rise in core temperature ( $1.9 \pm 0.4$  v  $2.2 \pm 0.4$ °C;  $d > 0.9$ ;  $p > 0.05$ ), although a significantly smaller change in mass ( $0.9 \pm 0.3$  v  $1.3 \pm 0.3$ kg;  $p < 0.05$ ) was present following pre-cooling. Perceived thermal stress and exertion were significantly lower ( $d > 1.0$ ;  $p < 0.05$ ) during the cooling session. Finally, lower-body peak power did not differ between conditions before or after training ( $d < 0.3$ ;  $p > 0.05$ ). Conclusions: Despite trends for lowered physiological load and increased distances covered following cooling, the observed responses were not significantly different or as explicit as previously reported laboratory-based pre-cooling research.

**Key words:** Cooling, heat, training, GPS, racquet sports.

### Introduction

Exercise in the heat can augment the physiological and perceptual load of an exercise bout, often resulting in an earlier reduction in exercise intensity during prolonged exercise (Marino, 2004; Tucker et al., 2006). To counter this noted effect, pre-cooling is reported to be of benefit to improve performance and reduce the thermoregulatory and physiological loads during prolonged duration exercise in the heat (Arngrimsson et al., 2004; Kay et al., 1999; Lee and Haymes, 1995). To date, experimental evidence generally supports the use of pre-cooling to improve prolonged, laboratory-based, continuous (Arngrimsson et al., 2004; Duffield et al., 2010; Kay et al., 1999) and intermittent-sprint (Castle et al., 2006) exercise performance. Based on such findings, the application of pre-cooling to sports performed in warm environments is

popular, although limited evidence exists for the ergogenic benefits in such field-based environments (Marino, 2002; Quod et al., 2006).

In relation to tennis, during certain parts of the competitive year, tennis players may be exposed to warm-hot ambient conditions for both training and competition. To date, there is limited evidence on the effects of hot environmental temperatures on tennis performance, although it is well known that exercise performance is reduced and physiological responses are exacerbated in the heat (Gonzalez-Alonso et al. 1999); which may also be further exacerbated by additional radiant heat sources from court surfaces (Hornery et al., 2007a; Morante and Brotherhood, 2008). Although pre-cooling may provide some assistance for exercise performance in the heat (Quod et al., 2006), there is a lack of field-based evidence and limited evidence for tennis in the heat (Hornery et al., 2007b). Further, pre-cooling in the field is often constrained by the logistics of the interventions, for example, cold water immersion requires the facilities and time which may not be available (Quod et al., 2006). Accordingly, the use of court-side, field-based pre-cooling interventions may be beneficial to improve performance and reduce the thermoregulatory load of court-based conditioning sessions for tennis in the heat.

The physiological load of singles tennis match-play has been reported to include  $\text{VO}_2$  responses between 10 - 40  $\text{ml kg}^{-1} \text{min}^{-1}$  (Smekal et al., 2001), heart rates between 120 - 180 bpm (Davey et al., 2003; Fernandez et al., 2006), lactate values between 1 - 8  $\text{mmol L}^{-1}$  (Smekal et al., 2001; Mendez-Villanueva et al., 2007), core temperatures between 37.9 - 39.0 °C (Bergeron et al., 2006; Morante and Brotherhood, 2008), body mass changes of 1 - 2 kg (Bergeron et al., 2006; Hornery et al., 2007a) and rate of perceived exertion between 9 - 17 (Mendez-Villanueva et al., 2007). While tennis match-play is intermittent in nature, the prolonged duration of training and/or matches may result in excessive increases in the physiological load, above tolerable homeostatic ranges (Hornery et al., 2007a; Mendez-Villanueva et al., 2007). Moreover, often court-based training, for both skill and conditioning are preferred methods of training for players to simulate these physical and physiological demands (Reid et al., 2008; Reid and Schneiker, 2008). Despite the lack of explicit research on the effects of hot environments on tennis performance (Morante and Brotherhood, 2008), exercise in the heat is known to reduce exercise performance, and it is not uncommon for players to encounter hot environments throughout a season.

Accordingly, pre-cooling has been proposed as be-

ing beneficial for prolonged exercise (Castle et al., 2006; Duffield et al., 2010) in both laboratory and field environments (Duffield et al., 2009; Kay et al., 1999). Despite this evidence, previously Hornery et al., (2007b) reported no effect of pre-cooling on stroke velocity or accuracy during simulated tennis match play. However, the volume and quality of physical work performed was not measured as a performance variable, and thus far there is little research to suggest pre-cooling can improve sports-specific skill performance (Duffield et al., 2009; Drust et al., 2000). Previous research (Duffield et al., 2009) has reported that pre-cooling can improve distance covered during generic physical conditioning sessions for team-sport athletes (Lacrosse) in the heat; however, few pre-cooling studies have attempted to investigate these reported benefits in ecologically valid, sports-specific contexts. As such, the aim of this study was to investigate the effects of an applied, field-based, pre-cooling intervention on performance, physiological and perceptual responses to on-court, tennis-specific conditioning training in the heat. It was hypothesised that pre-cooling prior to on-court conditioning could improve physical performance and reduce the thermal load of the session.

## Methods

### Subjects

Eight, highly trained, tennis players (6 male and 2 female) from the Indonesian Elite Athlete High Performance Program (Program Atlet Andalan) and Tennis Indonesia (Persatuan Tenis Seluruh Indonesia) volunteered to participate in the present study. Subject characteristics included for males,  $20.1 \pm 2.5$  years, mass  $72.1 \pm 5.6$  kg and height  $1.79 \pm 0.05$  m, while for females, age  $21.5 \pm 0.5$  years, mass  $64.2 \pm 3.5$  kg and height  $1.65 \pm 0.03$  m. Subjects were part of the Tennis Indonesia program and included the top 2 ranked female athletes and top 3 ranked junior and senior male athletes (Females ranked in ATP top 300 and males ranked in ITP top 200). The squad represented the total number of players available for testing at that time of the competitive season. Specifically, the two female athletes were older and were more seasoned competitors than the males; hence, data were grouped for increased statistical analytical power, despite the gender inequity. However, all subjects trained 8 - 10 times per week and competed in  $22 \pm 3$  tournaments during the competitive season, including South East Asian Games, Davis and Federation Cup tournaments, respectively. Testing was conducted in-season on a Rebound Ace hard court surface during respective training sessions outside of competitive tournaments. All subjects were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for use of Human subjects.

### Overview

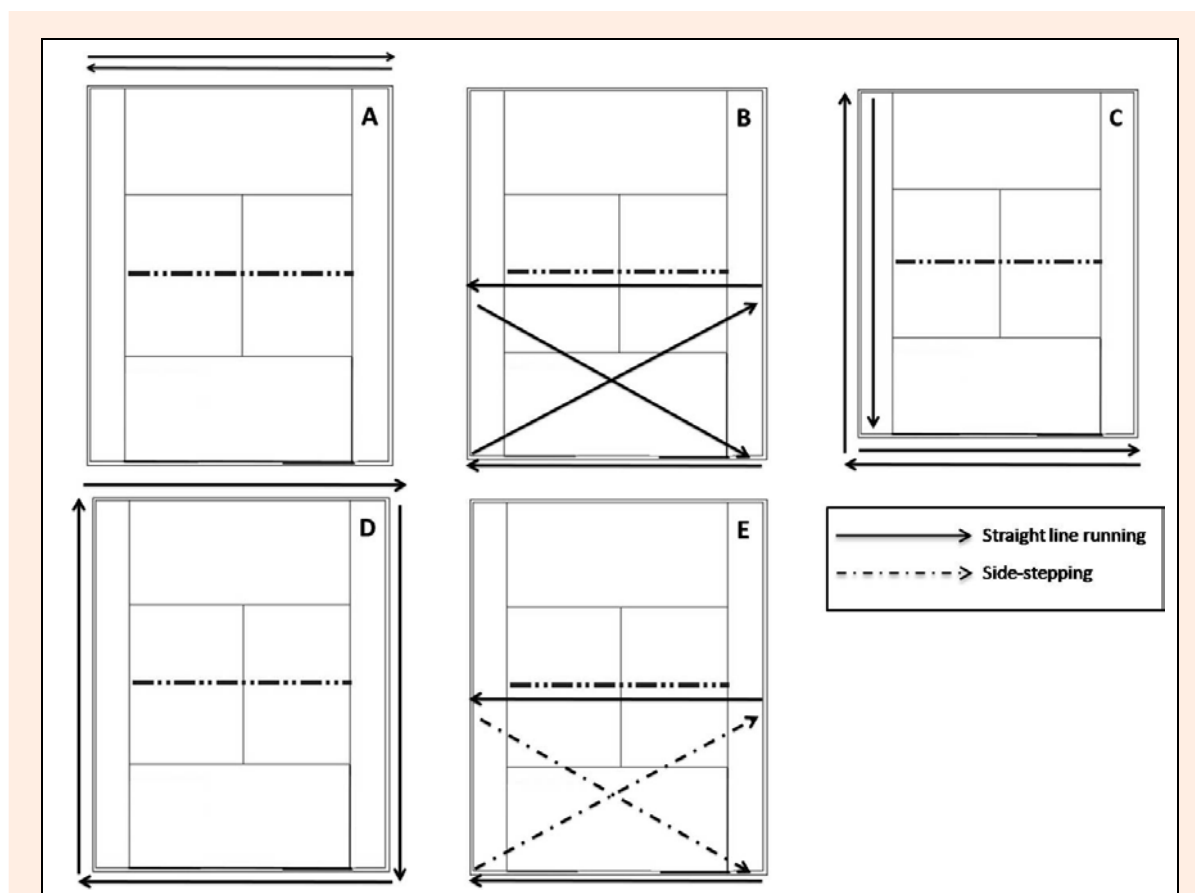
A randomised, cross-over design was used to investigate the effects of pre-cooling on tennis-specific conditioning training in the heat. The respective testing sessions were conducted in hot environmental conditions of  $35.2 \pm 0.4^\circ\text{C}$ ,  $55 \pm 4$  % relative humidity (RH) and  $30.1 \pm 0.3^\circ\text{C}$

Wet Bulb Globe Temperature (WBGT; Questtemp<sup>®</sup>15, Quest, USA). The testing sessions consisted of an initial 20-min pre-cooling or control (no cooling) intervention while seated in a court-side environment, followed by a 10-min warm up and 30-min conditioning session. The 10-min warm up consisted of general and specific movement patterns, while the conditioning session consisted of 5 x 5-min of on-court, tennis-specific conditioning drills, with each drill separated by 2 min of recovery. Prior to each session it was made clear to all subjects that the session was to be treated as a conditioning session requiring maximal effort. Prior to and following each session, capillary blood markers of anaerobic metabolism, body mass and lower-body power were assessed. Further, throughout each session subjects were monitored for core temperature, movement performance (distance and velocity), Rating of Perceived Exertion (RPE) and Rating of Thermal Sensation. All testing sessions were performed at the same time of day and separated by 24 h of recovery. Subjects were required to abstain from strenuous physical activity for 12 h prior to testing and all caffeine and food substances 2 h prior to testing. Additionally, subjects were required to standardize all food consumed and activity performed in the 24 h prior to all testing sessions via recording all information in prescribed diaries and present in a euhydrated state based on measures of Urine Specific Gravity (USG) from a pre-training mid-stream urine sample.

### Procedures

*On-court conditioning session:* The exercise protocol used in the present study involved the use of common on-court conditioning drills that were based on prior familiarity to the players, but also on those reported in previous research (Reid et al., 2008). Prior to the on-court session, subjects performed a standardised 10-min warm up consisting of continuous jogging, dynamic movement patterns and ballistic sprint drills, as supervised by the Strength and Conditioning coach. Subjects then performed a series of 5 x 5-min on-court movement drills familiar to the players and similar to those reported by Reid et al., (2008). Movement patterns for each respective drill are presented in Figure 1; which included (A) Suicide, (B) Star, (C) Big 'L', (D) Box and (E) Star with side-stepping drills. For each respective 5 min on-court drill, 5 efforts of 30 s of work were performed with a work to rest ratio of 1:1 (30 s work, 30 s recovery). A recovery of 2 min was permitted between each drill and subjects were instructed to cover as much distance as they could during each respective 30 s effort. Based on data calculated from previous research (Reid et al., 2008), the Intra-class correlation (ICC) and co-efficient of variation (CV) between repeated drill efforts for on-court movements were  $r = 0.95$  and  $CV = 5.0\%$ . Verbal encouragement was given to all subjects during each session. Subjects were spaced on each end of respective tennis courts to avoid any potential external pacing stimuli from other participants, with no more than four players tested at any one time.

*Cooling interventions:* In a randomised, cross-over fashion, subjects performed either a pre-cooling or control condition while seated in a court-side, shaded environ-



**Figure 1.** Schematic representation of the movement patterns of on-court conditioning drills; including (A) Suicide, (B) Star, (C) Big 'L', (D) Box and (E) Star with side-stepping drills.

ment ( $30.2 \pm 0.4^{\circ}\text{C}$ ,  $55 \pm 4\%$  RH). Pre-cooling consisted of a 20-min mixed-method cooling procedure of an ice-vest to the torso (Arctic Heat, Brisbane, Australia) and a cold towel to the head, neck and arms that had previously been soaked in  $5^{\circ}\text{C}$  cold water. To prolong the cooling stimulus until as close to the start of the training session, following removal of the ice-vest, subjects donned an upper-body compression garment (short sleeved t-shirt) (Bioslyx, Slazenger, Australia) that had also been soaked in  $5^{\circ}\text{C}$  cold water to wear during the ensuing warm-up (and was removed following warm up). Alternatively, during the control condition subjects remained in a passive seated (court-side) setting for 20min and received no cooling prior to or during the warm-up. Previous research suggests a dose-dependent volume effect of pre-cooling (Duffield and Marino, 2007); however, the ability to cool players prior to training with whole body immersion is limited due to demands of players and coaches and availability of facilities. Accordingly, we attempted to combine multiple methods to increase the cooling intervention in a way that would provide minimal intrusion.

### Measures

**Exercise performance:** During each testing session subjects wore the same portable Global Positioning Satellite (GPS) device, which was worn between the scapulae of the shoulders in a custom made harness (SPI elite, GPSports Systems, Australia). The GPS devices recorded distance and velocity every second (1 Hz) during all test-

ing sessions. Following each session, GPS data was downloaded and analysed using specialised software (Team AMS, GPSports Systems, Australia). The technical CV for this device for measuring distance has previously been reported to be 5%, while velocity measures were 5–20%, with improved accuracy for slower velocity bands (Coutts and Duffield, 2010), although due to short movement patterns in tennis, high speed zone frequencies were few. GPS data were time-aligned to include each of the five respective on-court drills. Data for distance travelled during each drill and the total session were then categorised into three pre-defined zones based on previous research (Coutts and Duffield, 2010), including; 1) low-intensity activity (speeds  $<7.0\text{ km}\cdot\text{h}^{-1}$ ), 2) moderate-intensity activity (speeds  $7.0 - 14.4\text{ km}\cdot\text{h}^{-1}$ ) and 3) high-intensity running (speeds  $>14.5\text{ km}\cdot\text{h}^{-1}$ ). Additionally, relative distance ( $\text{m}\cdot\text{min}^{-1}$ ) was also calculated for each drill and the whole session.

**Core temperature, heart rate and hydration status:** Eight hours prior to each session, subjects swallowed an ingestible telemetric capsule (VitalSense, Mini Mitter, NJ, USA) to ensure that it had passed into the gastro-intestinal tract and would be insensitive to temperature changes resulting from fluid intake during testing. Core temperature was recorded on a hand held monitor (VitalSense, Mini Mitter, NJ, USA) that received measures transmitted from the ingestible capsules. On arrival and following each session, subjects voided their bladder to collect a urine sample for analysis of Urine

Specific Gravity (USG) as a measure of hydration status (Pocket Refractometer, Atago, Japan). Further, nude mass was measured on a set of calibrated electronic weigh scales (HW-100KAI, GEC, Avery Ltd, Miranda, Australia) prior to and following each session to determine the change in mass as a representative measure of sweat loss. During each session the volume of fluid consumed was calculated based on change in mass of drink container and used to calculate final mass change. Heart rate was measured via a chest transmitter and receiver (RS100, Polar Electro Oy, Kempele, Finland). Core temperature and heart rate were recorded prior to and following the cooling intervention, following the warm-up and after each 5min drill of the on-court conditioning session. Finally, on-court environmental conditions, as measured via WBGT, were measured during all data collection sessions (Questtemp<sup>o</sup>15, Quest, USA).

**Capillary blood samples:** To determine changes in blood markers of metabolite and electrolyte concentrations, capillary blood samples were collected at rest prior to the intervention and immediately following the on-court conditioning session. A 100  $\mu$ l sample of capillary blood was obtained from a fingertip with a sterilized lancet and collected in sterile, single use collection cartridge (i-stat CG8+, Abbott, NJ, USA) to measure pH, Bicarbonate ( $\text{HCO}_3^-$ ), hematocrit (Hct), Haemoglobin (Hb), and electrolyte concentrations of sodium ( $\text{Na}^+$ ) and potassium ( $\text{K}^+$ ) (i-stat portable clinical analyser, Abbott, NJ, USA).

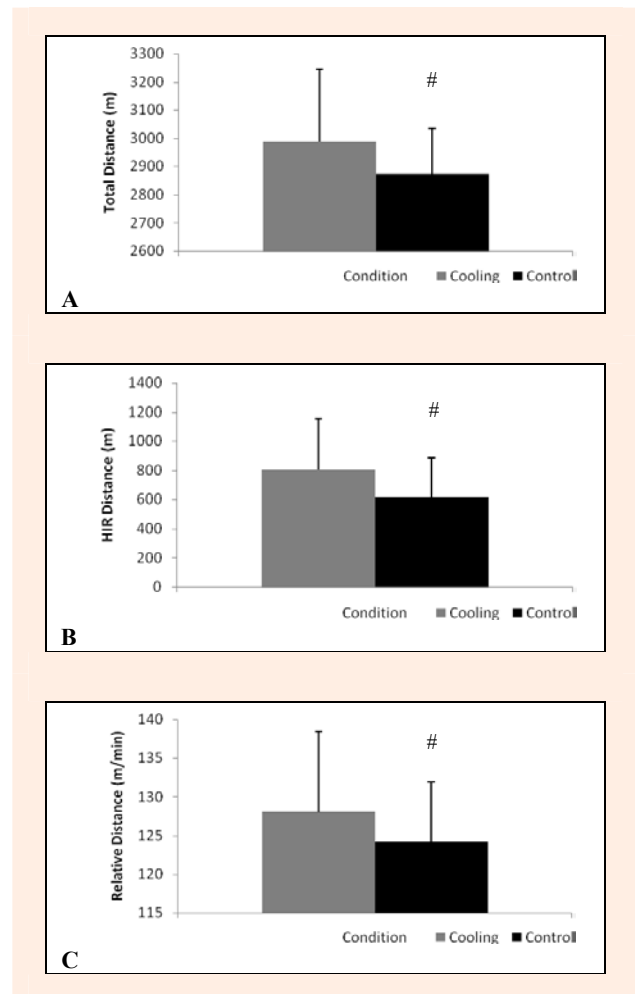
**Peak lower-body power:** To determine peak lower-body power, repeated unweighted counter movement jumps (CMJ) were performed using a linear position transducer (G1706374B; Fitness Technology, Adelaide, Australia) and Ballistic Measurement System software (Fitness Technologies, Adelaide, Australia) to determine maximal displacement. CMJ were performed pre-exercise in a rested state and post-exercise. In order to standardise jump patterns, subjects used a dowel rod placed across the shoulders to eliminate arm swing. Subjects commenced from a standardised starting position (knee flexion of approximately 90°) performing six maximal, explosive CMJ's. The linear position transducer was calibrated prior to data collection by the use of a known displacement distance.

**Perceptual measures:** Rate of Perceived Exertion (RPE) and a rating from the Thermal Sensation Scale (TSS) were obtained based on 10-point (Borg CR-10 scale) and 8-point (TSS) Likert scales, respectively. Both scales were translated into Bahasa Indonesia, and answers were confirmed in the native language. Measures for both RPE and TSS were recorded following the warm-up and following each respective 5min on-court conditioning drill.

### Statistical analyses

Data are reported as mean  $\pm$  standard deviation (sd). A two-way (condition  $\times$  time) repeated measures ANOVA was used to determine differences between the two conditions (cooling v control). Post-hoc paired t-test analyses were performed to determine the location of significant differences with Bonferroni corrections. Significance was set at  $p < 0.05$ . Finally, effect size data (ES) were calcu-

lated (Cohen's d) to determine the magnitude of effect of the cooling intervention on performance and physiology with an ES of  $<0.2$  classified as 'trivial',  $0.2 - 0.4$  as 'small',  $0.4 - 0.7$  as 'moderate' and  $>0.8$  as 'large' effects.

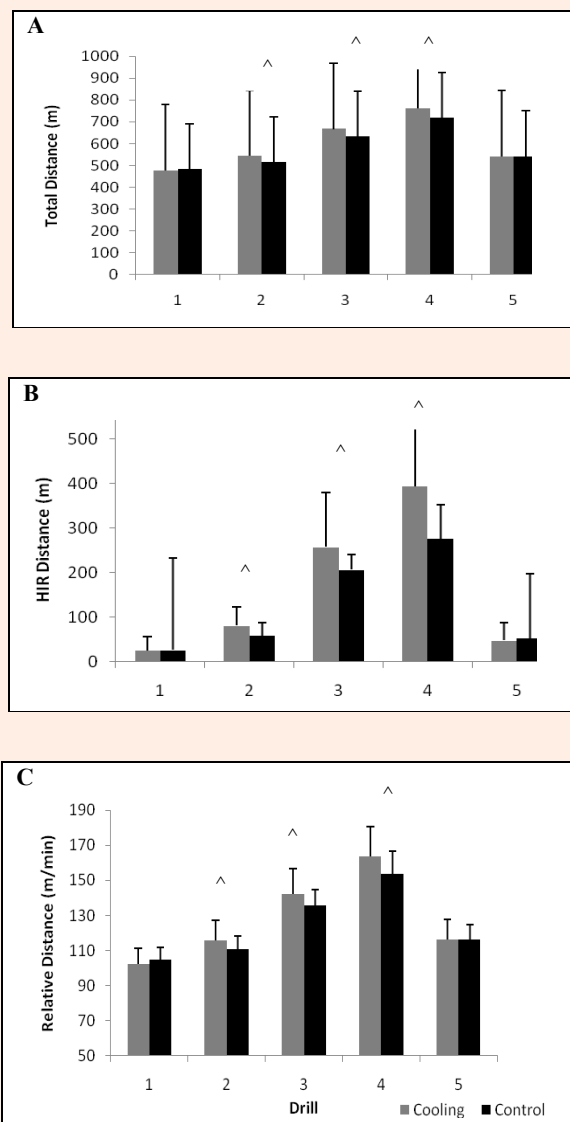


**Figure 2.** Mean  $\pm$  SD **A)** Total (m), **B)** High-intensity running (HIR) (m) and **C)** relative ( $\text{m}\cdot\text{min}^{-1}$ ) distance covered during the tennis-specific on-court conditioning session with and without pre-cooling. # represents a moderate-large effect size compared to cooling condition ( $d > 0.75$ )

### Results

**Exercise performance and peak power:** No significant differences were present between conditions for total distance or high-intensity running for either the whole conditioning session or for each respective drill ( $p = 0.15 - 0.90$ ; Figure 2). Moderate - large effects were present to indicate a trend for a  $5 \pm 4\%$  larger total distance covered during the session ( $d = 0.76$ ), and in particular, during the Star ( $d = 0.86$ ), Big 'L' ( $d = 0.84$ ) and Box ( $d = 0.76$ ) drills following pre-cooling. Moreover, moderate - large effect sizes indicated a trend for a  $17 \pm 20\%$  greater distance of high-intensity running following pre-cooling for the total session ( $d = 0.85$ ), and again, specifically for the Star ( $d = 0.87$ ), Big 'L' ( $d = 0.71$ ) and Box ( $d = 1.15$ ) drills (Figure 2 and 3). Finally, relative distance was not significantly different between conditions ( $p = 0.19 - 0.95$ ); although moderate - large effect sizes indicate a trend

increased relative distance following pre-cooling for the whole session ( $d = 0.69$ ). Finally, lower-body peak power before ( $2713 \pm 447$  v  $2654 \pm 457$  W) and following ( $2833 \pm 464$  v  $2625 \pm 455$  W for cooling and control, respectively) were not significantly different and trivial effects present between conditions ( $p = 0.40$ ;  $d < 0.3$ ).



**Figure 3.** Mean  $\pm$  SD **A**) Total (m), **B**) High-intensity running (HIR) (m) and **C**) relative ( $m \cdot \text{min}^{-1}$ ) distance covered during each drill of the on-court conditioning session with and without pre-cooling. ^ represents a large effect size compared to cooling condition ( $d > 0.80$ )

**Physiology:** Post-intervention core temperature was not significantly reduced by the cooling intervention ( $p = 0.44$ ). Further, the exercise-induced change in core temperature was also not significantly different between conditions ( $p = 0.10$ ). Large effect sizes were present for the rise in core temperature during the training session ( $1.9 \pm 0.4$  v  $2.2 \pm 0.4$  °C for cooling and control, respectively;  $d = 1.2$ ; Figure 4). Although final core temperatures were not significantly different ( $p = 0.25$ ), large effect sizes ( $d = 1.1$ ) suggested a lower final core temperature in the pre-cooling condition ( $39.3 \pm 0.3$  v  $39.5 \pm$

$0.3$  °C for cooling and control respectively). Heart rate did not differ significantly ( $p = 0.40$ - $0.95$ ) between conditions and only small effect sizes ( $d < 0.4$ ) were present between conditions throughout the conditioning session (Figure 4).

The change in mass was significantly reduced in cooling compared to control conditions ( $0.9 \pm 0.3$  v  $1.3 \pm 0.3$  kg;  $p = 0.03$ ;  $d = 1.9$ ), which represents a percentage body mass lost of  $1.3 \pm 0.5$  v  $1.9 \pm 0.5$  % ( $p = 0.04$ ,  $d = 1.7$ ) for cooling and control, respectively. Additionally pre and post-session USG were not different between conditions (pre:  $1.021 \pm 0.004$  v  $1.022 \pm 0.004$  and post:  $1.025 \pm 0.005$  v  $1.026 \pm 0.004$  for cooling and control, respectively;  $p = 0.40$ - $0.80$ ,  $d < 0.4$ ). Finally, measures of capillary blood variables are presented in Table 1. No significant differences ( $p = 0.65$ - $0.89$ ) and small to moderate effect sizes ( $d = 0.2$  –  $0.6$ ) were evident for all capillary blood variables at both pre and post-session measures.

**Table 1.** Mean ( $\pm$ SD) capillary blood pH, Bicarbonate ( $\text{HCO}_3^-$ ), haematocrit (Hct), haemoglobin (Hb), Sodium ( $\text{Na}^+$ ) and Potassium ( $\text{K}^+$ ) in response to on-court conditioning drills in the heat with and without pre-cooling.

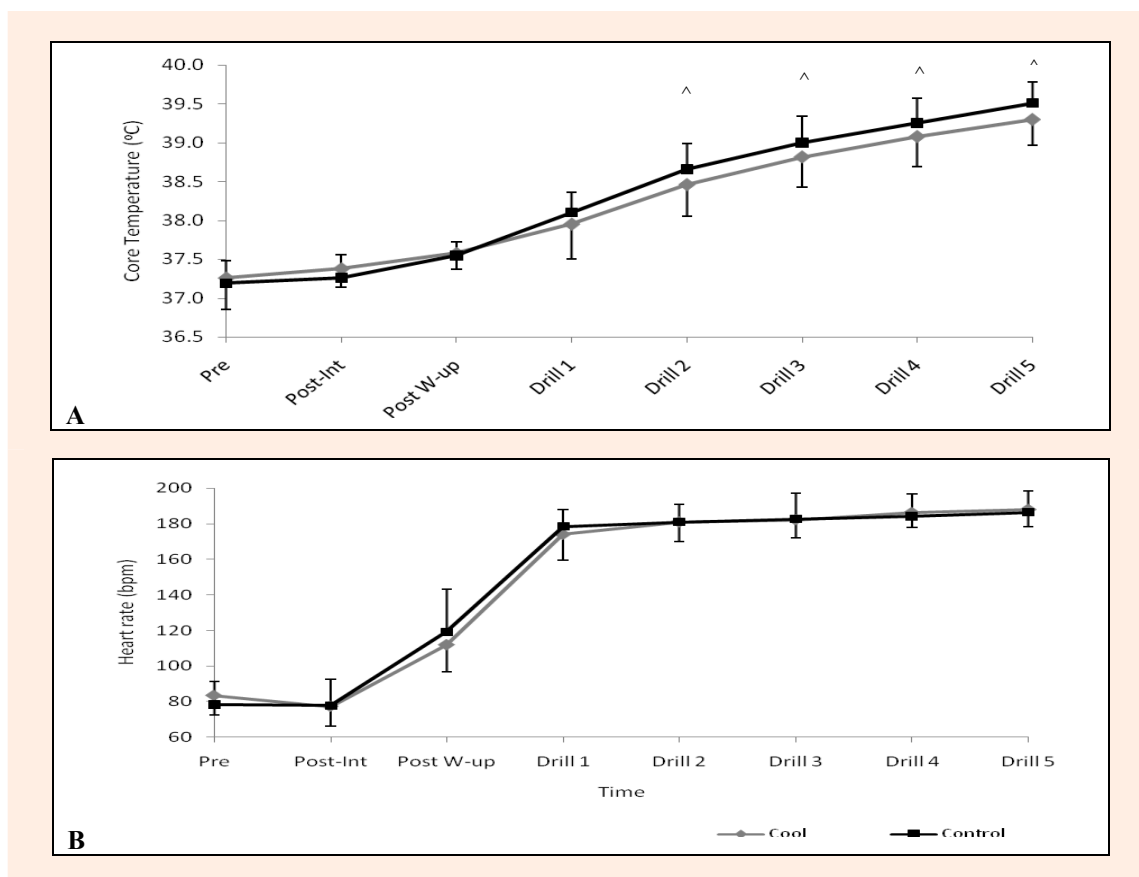
Measure	Condition	Pre	Post
pH (au)	Cooling	7.43 (.04)	7.32 (.04)
	Control	7.42 (.04)	7.31 (.04)
$\text{HCO}_3^-$ ( $\text{mmol} \cdot \text{L}^{-1}$ )	Cooling	23.7 (2.5)	12.7 (1.9)
	Control	24.1 (2.3)	13.1 (2.3)
Hct (%)	Cooling	.49 (.03)	.48 (.06)
	Control	.48 (.04)	.50 (.04)
Hb ( $\text{g} \cdot \text{mL}^{-1}$ )	Cooling	16.5 (.9)	16.3 (1.9)
	Control	16.3 (1.2)	17.1 (1.2)
$\text{Na}^+$ ( $\text{mmol} \cdot \text{L}^{-1}$ )	Cooling	143 (2)	148 (2)
	Control	143 (2)	147 (2)
$\text{K}^+$ ( $\text{mmol} \cdot \text{L}^{-1}$ )	Cooling	3.8 (.4)	4.0 (.5)
	Control	4.0 (.5)	4.6 (.6)

No significant difference between conditions for any measure ( $p > 0.05$ )

**Perceptual:** RPE during the conditioning session was not significantly reduced by the cooling intervention ( $p = 0.10$ - $0.15$ ); although large effect sizes were present to indicate a  $10 \pm 8\%$  trend for a lower RPE following cooling ( $d = 1.0$ - $1.7$ ; Figure 5). TSS was significantly reduced up to  $50 \pm 30\%$  by the pre-cooling intervention and remained lower during the ensuing conditioning session ( $p = 0.01$ - $0.04$ ;  $d = 1.0$ - $8.0$ ). As would be expected, the cooling intervention significantly reduced the post-intervention rating of thermal stress ( $2.8 \pm 0.7$  v  $6.1 \pm 0.4$  au for cooling and control, respectively).

## Discussion

In the present study, pre-cooling did not significantly improve on-court physical performance, or lower the thermoregulatory load of the session. Despite trends for altered performance, physiological and perceptual responses following pre-cooling, no significant differences were present between conditions; suggesting pre-cooling did not benefit on-court training. The noted trends do resemble results from previous studies performed in laboratory conditions, although were only minor in comparison. That said, the noted difference in distance covered was similar to noted variance between sessions in GPS



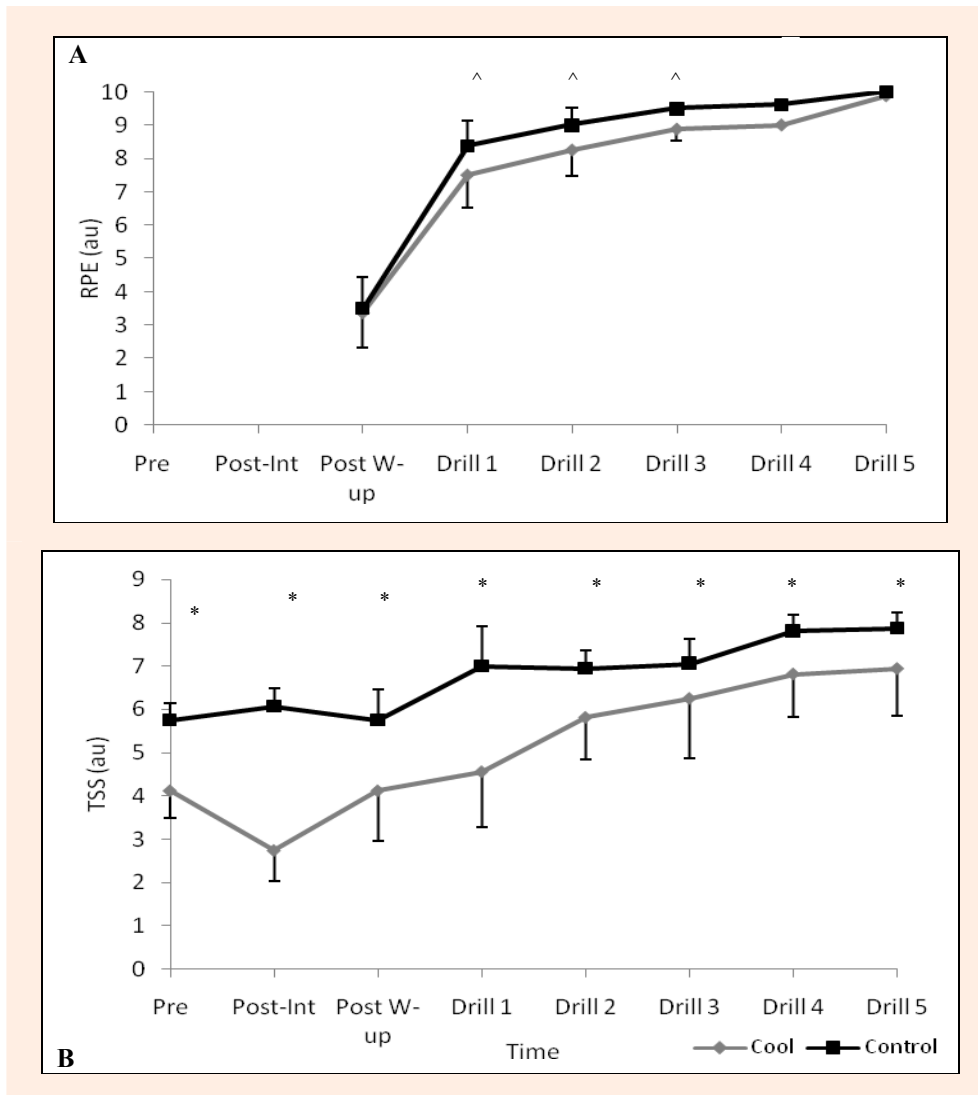
**Figure 4.** Mean  $\pm$  SD **A)** Core temperature ( $^{\circ}$ C) and **B)** heart rate (bpm) during the tennis-specific on-court conditioning session with and without pre-cooling. ^ represents a large effect size compared to cooling condition ( $d > 1.0$ )

measures, and changes in physiology were only minor in comparison to the expected tolerable homeostatic range. Despite no significant effect of pre-cooling on performance of on-court training sessions, some perceptual benefits may be present to reduce thermal strain in hot conditions.

Pre-cooling has been reported to have mixed findings for intermittent-sprint performance (Castle et al., 2006; Duffield and Marino, 2007; Hornery et al., 2007b), although recent evidence indicates free-paced intermittent-sprint bouts can be improved in both laboratory (Castle et al., 2006; Duffield and Marino, 2007) and field (Duffield et al., 2009) environments. To date, few studies have attempted to translate these reported effects to sports specific, field-based environments (Drust et al., 2000; Duffield et al., 2009; Hornery et al., 2007b). Previously, Hornery et al., (2007b) have reported the effects of lower-body pre-cooling in an ice-bath prior to a standardised tennis-specific match play protocol in thermoneutral conditions. While pre-cooling provided advantages of increased blood glucose and reduced perceived thermal stress, no improvements in stroke accuracy or velocity, serve kinematics or change in core temperature were evident during simulated tennis match play (Hornery et al., 2007b). Given the standardised exercise protocol used in this previous study, physical or movement performance was not measured. In contrast, the current study focused on a more conditioning, rather than skill oriented protocol, although again the results were similarly equivocal as to the performance benefits of pre-cooling for tennis train-

ing. In hot conditions, earlier reductions in exercise intensity are commonly reported (Marino, 2004), although there is a paucity of data relating specifically to tennis. Regardless, the maintenance of physical performance during training maybe of presumed benefit for athletes, although such findings were not explicit in the present study. Given the lack of performance benefits in the present study, to date only laboratory evidence indicates performance improvements for pre-cooling, suggesting some issues with translating laboratory pre-cooling findings to field-based practices (Quod et al., 2006).

The present field-based findings on the effect of pre-cooling on tennis training remain equivocal, although some trends for small increases in distance covered during on-court training drills are highlighted. These findings are more muted to previously reported responses for improved intermittent-sprint exercise in a laboratory following cooling (Castle et al. 2006; Duffield and Marino, 2007). The mechanisms responsible for improved free-paced performance in the heat are hypothesised to involve selection of higher exercise intensities either in response to (Gonzalez-Alonso et al., 1999), in anticipation of (Marino, 2004), or a combination of (Duffield et al., 2010) alterations in physiological and perceptual loads (Nybo and Nielsen, 2001). Accordingly, often successful performance improvements following pre-cooling are in the presence of a reduced thermoregulatory and physiological load (Lee and Haymes 1995; Quod et al. 2006). Given most physiological responses were not significantly affected by pre-cooling it is not unexpected that minimal



**Figure 5.** Mean  $\pm$  SD **A)** Rate of Perceived Exertion (RPE) and **B)** Thermal Sensation Scale (TSS) during the tennis-specific on-court conditioning session with and without pre-cooling. ^ represents a large effect size compared to cooling condition ( $d > 1.0$ ). \* represents a significant difference compared to cooling condition ( $p < 0.05$ ).

performance benefits were noted. However, the observed effect size data indicates small trends for reductions in physiological and perceptual load for moderate increases in training distance, even though peak lower-body power did not differ. In the context of the perceptual exposure to pre-cooling in an already hot court-side environment, these trends for a small reduction in physiological load during the session may provide some impetus for ergonomic benefits during training. However, the translation of cooling to field-based practice may result in the diminishment of the strength of these findings due to logistical and environmental influences. Despite no significant differences between conditions, there may still be some practical benefit of pre-cooling for tennis players performing on-court training in the heat.

Despite the ecologically valid environment, technological limitations of GPS data collection are acknowledged as a potential confounding factor (Coutts and Duffield, 2010). Recent studies highlight the limitations of GPS technology for the measurement of movement patterns, particularly in tennis (Coutts and Duffield, 2010; Duffield et al., 2010b). Although it should be noted that

GPS measures are reported to have the lowest Technical Error of Measurement (TEM) for straight line activities at slow to moderate movement velocities (TEM: 3 – 5%) (Coutts and Duffield, 2010). However, GPS accuracy and reliability have been reported to be reduced at higher velocities or with movement patterns involving change of direction (TEM: 15 - 25%) (Coutts and Duffield, 2010; Duffield et al., 2010b). Further, during simulated on-court movement patterns, GPS technology has been reported to have similar limitations as reported above, especially during repetitive, lateral (side-to-side) movement patterns (Duffield et al., 2010b). As such, the limitations of the technology used should be recognised when interpreting the current findings. That said, the performance measure replicates the demands of players during conditioning sessions and the speeds reached in the present study were low compared to those reported in previous GPS validity papers, with much of the movement linear in nature. Further, those drills in which the movement patterns involved longer, straight line running, with less change of direction (drills 2, 3 and 4) demonstrated greater differences between conditions. However, given the reported limitations

in GPS accuracy during court-based movements, a definitive conclusion regarding the ergogenic benefits of cooling prior to tennis training is difficult.

Studies highlighting performance improvements following cooling are often in the presence of some significant reduction in physiological load (Duffield et al. 2010; Lee and Haymes 1995; Quod et al., 2006). In the present study, the court-side cooling intervention provided only limited blunting of the change in core temperature, although significantly reduced the change in body mass, with both physiological responses within tolerable homeostatic ranges (Marino, 2004, Nybo and Nielsen 2002). Previous studies often report lowered core temperatures and reduced sweat loss following the use of pre-cooling (Lee and Haymes, 1995; Olschewski and Brück, 1988). These reductions in core temperatures alongside smaller sweat losses previously have been highlighted as suggestive of the maintenance of blood volume and improvement in heat loss efficiency via non evaporative mechanisms (Arngrimsson et al., 2004; Lee and Haymes, 1995; Marino, 2004). In the present study, the 30-min session in 35°C temperatures resulted in quite substantial mass changes (>1kg), indicating a high sweat rate for the short training duration. In the current study, limited access to players was available during training, however, court-based conditioning represents only part of a normal court-based session, and continued training in such conditions is likely to induce substantial sweat loss and even further reductions in thermoregulatory efficiency. Pre-cooling interventions have been reported to provide some protective benefit via improved thermoregulatory function, reducing the demands on evaporative sweat loss mechanisms, assist maintenance of blood volume and slow the rise in core temperature, which may assist improve ensuing performance (Castle et al., 2006; Duffield et al., 2009; Olschewski and Brück, 1988). In the current study, the cooling intervention may not have been sufficient enough to have made marked physiological changes within this environment, regardless of the practically manageable court-side cooling strategy. Accordingly, more effective interventions, such as internal cooling via ice-slushies, may be required to induce greater physiological effects, without excessive disturbance to players prior to training.

Further to the limited effect of pre-cooling on core temperature, heart rates or capillary blood based measures of metabolism or electrolyte concentrations were not different between conditions. These results are similar to previously reported literature, in that during high-intensity, free-paced exercise, pre-cooling does not reduce heart rate (Duffield et al. 2010; Kay et al., 1999). Rather, pre-cooling has been reported to result in similar heart rates for increased exercise intensities (Arngrimsson et al., 2004; Duffield et al. 2010). Few studies report changes in blood-based metabolic or electrolyte changes following pre-cooling (Drust et al., 2000; Duffield and Marino, 2007; Olschewski and Brück, 1988). Accordingly, it does not seem apparent that pre-cooling results in altered metabolic substrate appearance, which is not directly responsible for the earlier onset of fatigue in hot conditions (Marino, 2004; Tucker et al., 2006). Moreover, despite trends for greater distance covered following cooling, heart rate did not differ between conditions,

possibly related to the significantly lower sweat loss observed following cooling. This reduction in sweat loss has been reported in other pre-cooling studies (Marino, 2002; Duffield et al., 2009) and may represent a useful by-product of pre-cooling in the heat in regard to slowing the development of hypohydration.

Finally, pre-cooling resulted in a reduced perceptual load of the on-court conditioning session, via both reduced RPE and TSS during the session. Previous research has reported pre-cooling reduces thermal sensation (Castle et al., 2006; Duffield and Marino, 2007; Quod et al., 2006), and may reduce RPE for a given exercise intensity, or increase a given exercise intensity for the same RPE (Duffield et al., 2009; Kay et al., 1999). Despite the lack of a placebo condition, the combination of reduced thermoregulatory and perceptual responses to a free-paced conditioning session may highlight some usefulness of pre-cooling in hot environments. In particular, pre-cooling may supply some benefit for either athletes who require greater protection from the environmental conditions, or acclimatised players who are attempting to invoke a higher quality of training session (Quod et al., 2006). Whether the reduction in both perceived thermal and exertion loads provides assistance to perform at a higher intensity during the session was not clear. However, when faced with high ambient court-side temperatures, pre-cooling can reduce the perceived load, although the resulting selection and maintenance of higher exercise intensities is less clear.

## Conclusion

In conclusion, pre-cooling prior to court-based conditioning session in the heat did not significantly improve performance, physiological or perceptual responses to on-court training in the heat. The lack of difference may be due to limitations in providing effective pre-cooling in court-side environments, as observed by the lack of significant differences in reduction of core temperature or other physiological responses. However, noted trends suggest practical, court-side pre-cooling interventions may only provide small thermoregulatory and perceptual benefits to training sessions in the heat. The combined use of a mixture of smaller, more practical cooling methods before training may benefit the perception and effort of ensuing conditioning sessions where the development of sports-specific skill are not necessarily the priority.

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### Key points

- Pre-cooling did not significantly enhance training performance or reduce physiological load for tennis training in the heat, although trends indicate some benefits for both.
- Pre-cooling can reduce perceptual strain of on-court tennis training in the heat to improve perceptual load of training sessions.
- Court-side pre-cooling may not be of sufficient volume to invoke large physiological changes.

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