1. Title page

Title: Effects of dehydration on cricket specific skill performance in hot and humid conditions

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2. Abstract and Keywords

Abstract:

The aim of the present study was to assess the effects of dehydration on cricket specific motor skill performance among fast-bowlers, fielders, and batsmen playing in a hot and humid environment. 10 fast-bowlers, 12 fielders and 8 batsmen participated in two field trials conducted 7 days apart: a fluid provision trial (FP) and a fluid restriction trial (FR). Each trial consisted of a 2-hour standardized training session and pre-training and post-training skill performance assessments. Bowling speed and accuracy (line and length), throwing speed and accuracy (overarm, sidearm and underarm) and timed running between wickets (1, 2, and 3 runs) was assessed pre to post-training in each trial. Mass loss was 0.6±0.3kg (0.9±0.5%) in FP, and 2.6±0.5kg (3.7±0.8%) in FR trials. Maintaining mass within 1% of initial values did not cause any significant skill performance decline. However, the dehydration on the FR trial induced a significant time and trial effect for bowling speed by 1.0±0.8% reduction (0.3±0.8% reduction in FP trial; $p<0.01$) and 19.8±17.3% reduction in bowling accuracy for line (3.6±14.2% reduction in FP trial; $p<0.01$), but no effect on bowling length. A significant decline was noted in the FR trial for throwing speed for overarm (6.6±4.1%; $p<0.01$; 1.6±3.4% reduction in FP trial) and sidearm (4.1±2.3%; $p<0.01$; 0.6±4.7% increase in FP trial) techniques, and for throwing accuracy for overarm (14.2±16.3%; $p<0.01$; 0.8±24.2% increase in FP trial) and sidearm (22.3±13.3%; $p<0.05$; 3.2±34.9% reduction in FP trial) techniques. Batsmen demonstrated significant performance drop in making three runs (0.8±1.2% increase in time in FP trial and 2.2±1.7% increase in time in FR trial; $p<0.01$). Moderate-severe dehydration of 3.7% body mass loss significantly impairs motor skill performance among cricketers, particularly bowlers and fielders, playing in hot and humid conditions. Fluid ingestion strategies maintaining mass loss within 1% prevented a decline in skill performance.

Key words: Dehydration, performance, cricket skill

3. Text

Introduction

Cricket is a team sport characterized by intermittent short duration high intensity activities interspersed with longer low intensity periods. The physical demands on players are determined by the specific tasks they perform (batting, bowling, fielding and wicket keeping), and intensity and duration of the match being played (Christie, 2012). During the day of a cricket test match, athletes spend about 6 hours on the field typically split into morning, afternoon and evening periods of play, each lasting about 2 hours. Players have opportunities to replace fluid losses during these breaks and at the boundary line according to their convenience. However, it can be practically challenging for most athletes to replace large fluid losses during a period of play in hot and humid conditions. A study conducted among fast bowlers has shown that they lost 4.3% of body mass after two sessions of cricket (4 hours) when playing in a hot environment (Gore et al., 1993). Four test cricket playing nations in the Indian subcontinent (India, Sri Lanka, Pakistan and Bangladesh) experience challenging environmental conditions due to high temperature and humidity.

The hydration status of an athlete can be a vital determining factor in exercise performance. Body mass losses of more than 2% by dehydration can impair an athlete's performance significantly, with decrements being proportional to the degree of fluid loss (Murray, 2007). However, recent studies have revealed performance impairment with body mass losses of as little as 1% (Bardis et al., 2013, Wilk et al., 2014). Exercising in environments at greater than 25°C temperature and 60% relative humidity poses a significant thermal stress for athletes, which results in increased thermoregulatory sweating and considerable fluid loss (Burke, 2010). Consequently, exercise in hot environments decreases both prolonged (Galloway et al., 1997, Parkin et al., 1999) and intermittent exercise capacity (Drust et al., 2005, Morris et al., 2005) among athletes. The degree of physiological strain on cardiovascular and thermoregulatory mechanisms is greater with a higher degree of hypohydration (Montain et al., 1992a, Maxwell et al., 2009, Montain et al., 1992b). In response to these physiological effects, studies have shown thermoregulatory benefits of adequate fluid provision during prolonged exercise in warm environments (Montain et al., 1992b).

Impairment in sports specific skill performance has been noted in team sports where there is more than 2% body mass loss from dehydration (Devlin et al., 2001, McGregor et al., 1999, Edwards et al., 2007, Baker et al., 2007, Dougherty et al., 2006, MacLeod et al., 2012) but these studies have not been conducted under significant heat stress. Data related to effects of dehydration on motor skill performance among cricketers are limited to a single study in fast bowlers which observed a significant decrement in one aspect of motor skill performance, the bowling accuracy (Devlin et al., 2001). To date, there are no data available on other cricket specific skill performances in fielders or batsmen. Most studies which have shown effects on both aerobic (Montain et al., 1992b, Montain et al., 1998, Sawka et al., 1985, Hillman et al., 2011, Ebert et al., 2007), anaerobic (Jones et al., 2008, Hayes et al., 2010), or skill performance (McGregor et al., 1999, Baker et al., 2007, Dougherty et al., 2006) due to dehydration have been conducted in indoor laboratory environments. Hot and humid outdoor conditions typically induce a greater thermoregulatory stress due to the addition of heat gain from solar radiation, particularly when there is little wind. The present study aimed to assess the effects of dehydration on cricket specific motor skill performance among fast-bowlers, fielders and batsmen playing in a hot and humid outdoor field environment. Field studies similar to the present study are important to determine the performance effects of dehydration in real ambient conditions, in comparison to what has been observed from controlled laboratory studies. From this study, we aimed to characterize the potential performance decrements induced by fluid restriction, and provide recommendations on hydration strategies for cricketers playing in hot and humid environments. We hypothesized that fluid restriction, and a greater level of dehydration, would impact upon skill performance measures in bowlers, fielders and batsmen.

Methods

Subjects

Thirty elite cricketers including 8 batsmen, 10 fast-bowlers and 12 fielders (mean age = 22.2±2.1 years) from the Sri Lankan training squad were recruited into the study after obtaining informed written consent. The Ethical Review Committee of the Faculty of Medicine, University of Colombo reviewed the study proposal and approval granted. All athletes received a voucher as an incentive for their participation in the study.

Study design

The study was conducted using a cross-over design with two outdoor field trials: a Fluid Provision trial (FP) and a Fluid Restriction trial (FR). Trials were conducted 7 days apart with diet and activity control for 48 hours preceding each trial and fasted from 10pm on the day before the trial. On the trial day morning, we provided the breakfast with a standardized volume of fluid to ensure that athletes were approximately euhydrated prior to each trial. Breakfast included a meat sandwich (~215g), a piece of butter cake (~30g), a medium size banana (~120g) and a packet of milk (200ml), which comply with the recommended pre event meal for these athletes (Total energy of 828 kilocalories with 62% of carbohydrate, 26% of fat and 12% protein). Body mass, urine specific gravity and urine colour measurements were taken before each trial to evaluate hydration status at pre-trial on both trial days. Each trial was conducted over 4-hours and included a 2-hour training session with pre-training (Pre-test) and post-training (Post-test) skill performance assessments lasting one hour each (Figure 1). The 2-hour training session consisted of cricket specific drills (short distance running and sprints, cricket specific exercises and field drills) conducted in their routine training, which was developed and supervised by the strength and conditioning coach of the team. Training sessions were controlled to maintain the same duration and intensity of activity on both trial days in order to avoid a confounding effect upon post-test performance. The objective was to ingest fluids at a steady rate and at regular intervals during the 2-hour training session to maintain lower body mass loss in the FP trial with higher fluid intake (12-15ml/kg/hour), and to achieve higher body mass loss in the FR trial by restricting fluid intake (4ml/kg/hour). Pre-test and Post-test performance assessments included bowling, fielding and batting performance tests. These performance assessment sessions for both trial days were conducted over the same duration and intensity to maintain consistency.

Measurements and calculations

Mass, mass loss and stature

Pre-trial body mass (W1) and post-trial body mass (W2) was measured using a calibrated digital weighing scale (Seca Clara 803) to the nearest 0.1kg. Mass measurements were obtained with minimal clothing worn (underwear only) after emptying the bladder and wiping off sweat. Height was measured to the nearest 0.1 cm using a stadiometer (Seca 217).

Sweat loss and sweat rate

Each athlete was provided with a separate drink bottle for fluid ingestion and a separate container for urine collection. Total volume of fluid ingested (FV) and total volume of urine produced (UV) during the 4-hour trial period was measured. Total sweat loss over the 4-hour period and sweat rate were then calculated using the formula, *sweat rate (ml/h) = ((W1-W2) + (FV-UV)) / 4*

Sweat electrolytes

A sample of sweat was collected on each trial day using a sweat patch (Tegaderm Pad®) applied on the lumbar para-vertebral region. The skin over that area was first cleaned with 70% alcohol solution and then with deionized water using a sterile technique. Sweat patches were removed after one-hour (end of Pre-test) and analyzed on the same day in an accredited medical laboratory for sweat Sodium (Na^+) and Chloride (Cl^-) content (Chemistry Analyzer, Beckman coulter AU680 with ISE unit, Japan).

Urinary indices

Pre-trial and Post-trial urine samples were obtained to measure urine colour (UC) and urine specific gravity (USG), as measures of hydration status of the athletes. UC was measured using a urine color chart (scale 1-8) and USG using a refractometer (model FG-301, China).

Performance tests

All participants were familiar with the skill performance tests assessments being used in the study as they routinely undertook these tasks during training. Furthermore, a warm-up was given before each skill performance assessment to ensure participants were ready for the assessments.

Bowling performance test

Each fast bowler performed 18 deliveries at match intensity. Their aim was to produce a good length delivery hitting the top of the off-stump with maximum delivery speed. Ball release speed was measured using a Stalker Pro II speed radar gun (± 0.2 km/h, Stalker Pro II, Tualatin, Oregon, USA) located behind the batting stump aiming at the ball release point. Bowling accuracy was determined by 2 parameters: bowling line and length. Bowling line was determined by a measuring grid consisting of rectangular zones, which was positioned behind the batting stump (Portus et al., 2010). According to the scoring system, 100 points were awarded for direct hit on the top of the off stump and lower scores (90, 75, 50, 25 or 0) when the ball hit the grid further away from the target. Video images were recorded using a HD 60fps camera (Sony FS100) kept 10m behind the bowling stump. These video images were analyzed using computer software and ball contact point with the grid was captured to determine the scores. Accuracy scores for bowling length were determined based on the ball landing position on the pitch. Video images were recorded using a HD 60fps camera (Sony FS100) positioned at the side of the pitch. The videos were analyzed and images of ball contact point with the pitch were captured. 3 points were given for good length deliveries, 2 points for short and full length deliveries and 1 point for balls pitching outside these pointers. The testers recording these parameters were blind to the trial conditions of each participant.

Throwing performance test

Fielders performed 24 throws in total using three different throwing techniques which included 8 overarm, 8 sidearm and 8 underarm throws. Overarm and sidearm throws were performed from a distance of 20m from a target stump and underarm throws were performed from a 10m distance. They were instructed to make the throws with maximum speed and hit the target stump. Throws were carried out from a fixed marker on the ground while maintaining a relatively stationary position. Throwing speed was measured using a speed radar gun (Stalker Pro II, Tualatin, Oregon, USA) positioned behind the target stump aiming at the ball release point. The accuracy of throws was measured using a specifically designed grid located behind and centered to the single target stump (Freeston et al., 2007). The grid consisted of four marked zones surrounding the target stump with each zone measuring 14cm in width. Ball contact point with the measuring grid was recorded using a HD 60fps video camera (Sony FS100) placed behind the throwing arm. Video images were analyzed, and accuracy score determined based on the ball position in relation to the target stump. Accuracy scores ranged from 0-5, taking 5 points for the throws that directly hit the stump and lower scores (4, 3, 2, 1, 0) when the ball hit the grid further away from the target. The testers recording these parameters were blind to the trial conditions of each participant.

Running performance test

The batter performance test assessed the time taken to run between wickets. Participants prepared as for routine batting, wearing pads, helmet and other protective gear. The performance test consisted of 4 sets of single runs, two runs and three runs with 5-minutes break between each set. Athletes were advised to run as fast as possible between wickets. Two examiners at the batting crease independently measured the time taken to complete runs using a digital timer. Measurements taken to the nearest 0.01 seconds and mean value of the two measures was taken. The testers recording these parameters were blind to the trial conditions of each participant.

Statistical analysis

All data are presented as mean ± standard deviation (SD). Two-factor repeated measures analysis of variance (ANOVA, SPSS 19.0) was used to compare means between the Pre-test (control) and Post-test performance variables in FP and FR. Within-subject factors were also analyzed to demonstrate trial effect (FP vs FR), time effect (pre-trial vs post-trial) and trial-time interaction effects. Follow up analysis was performed using paired sample T-tests only when a significant main effect was observed. Other outcomes assessed (ambient conditions, urine and sweat analyses) were all assessed using a one way ANOVA. Correlation analyses between percent body mass loss and percent change in the skill performance test scores were conducted using Pearson correlation coefficient analysis. In all cases the level of statistical significance was taken at $p<0.05$.

Results

Mean ambient temperature (30.8±2.1°C and 30.1±2.1°C) and humidity (76±9% and 77±8%) was not different for FP and FR trials, respectively. Ambient temperature range throughout the 4-hour period on each trial day was 27.7-32.8 °C and 27.2-32.2 °C on FP and FR, with relative humidity of 66-89 % and 68-87 % on FP and FR, respectively. Wind speed was not recorded but the Colombo meteorology department data indicated a mean wind speed of ~2 mph during the study days.

Data on mean mass loss, volume of fluid ingested, volume of urine passed and calculated sweat loss over the 4-hour period for each athlete group on FP and FR trials are presented in Table 1. Overall, there was a significant difference in body mass loss with athletes losing 0.9±0.5 % body mass during the FP trial vs. 3.7±0.8 % body mass during the FR trial ($p<0.01$). The average sweat rate was 1208±171 ml/hour in the FP trial and 861±148 ml/hour in the FR trial, and were significantly different ($p<0.01$). Batsmen had significantly higher sweat loss, sweat rate ($p<0.05$) and fluid intake ($p<0.01$) compared with fielders in FP trial only. No other significant differences were noted between playing positons on the FP or FR trials. Urine output was significantly lower in the FR trial compared to FP trial ($p<0.01$). In the urinary markers of hydration status (table 2), urine color increased significantly from pre-trial to post-trial in the FR trial only ($p<0.01$). Similarly, urine specific gravity significantly increased in the post-trial sample on the FR trial only ($p<0.01$; Table 2).

Performance tests

Results of the performance tests for fast bowlers, fielders and batsmen are presented in Table 3. In the FP trial there were no significant differences in the performance measures for fast bowlers, fielders or batsmen when comparisons were made between pre-test and post-test.

Fast bowling performance revealed a significant trial and time effects in bowling speed and bowling line measurements (both $p<0.05$). There were no significant trial-time interaction effects but bowling speed ($p=0.056$) and bowling line ($p=0.093$) approached significance. Post-hoc analysis revealed that fast bowling speed declined in the FR trial (124.5±5.5 km/hour in Pre-test vs. 123.2±5.2 km/hour in Post-test; $p<0.01$) only. Bowling accuracy scores revealed a significant deviation in bowling line score by 19.8±17.3% (34.4±4.2 in Pre-tests vs. 27.5±6.4 in Post-test; $p<0.01$) on the FR trial only. We did not observe any significant trial, time or trial-time interaction effects for bowling length data.

Throwing speed data showed significant trial, time and trial-time interaction effects for overarm and sidearm throwing techniques ($p<0.05$). In the FR trial only, there was a significant reduction in the throwing speed for the overarm technique by 6.6±4.1% (96.4±5.4 km/hour in Pre-tests vs. 90.0±6.4 km/hour in Post-test; $p<0.01$) and for the sidearm technique by 4.1±2.3% (88.9±6.7 km/hour in Pre-tests vs. 85.3±6.2 km/hour Post-test; $p<0.01$). Throwing accuracy data for the overarm technique showed a significant trial effect and trial-time interaction effect, but no time effect. Sidearm throwing technique accuracy data also showed significant trial-time interaction effect and time effect, but no significant trial effect. Throwing accuracy scores for overarm and sidearm throws revealed a significant performance drop by 14.2±16.3% (2.8±0.5 in Pre-tests vs. 2.3±0.3 Post-test; $p<0.01$), and 22.3±13.3% (2.1±0.3 in Pre-tests vs. 1.6±0.2 Post-test; $p<0.05$, respectively, in the FR trial only. There was no significant trial, time or interaction effects in the underarm throwing speed or accuracy data.

In the running test for batsmen, we observed a significant trial, time and trial-time interaction effects for the three run times ($p<0.05$) but not for the single or two run times. Follow-up analysis revealed a-significant performance drop in making three runs on the FR trial only, due to athletes being significantly slower in the Post-test (10.52±0.21 sec) compared to the Pre-test (10.29±0.19 sec; $p<0.01$).

Percentage differences in positional performance outcome scores in FP and FR trials are presented in Table 3. We observed a greater number of athletes dropped their performance during FR trial by more than twice the mean performance outcome differences recorded in FP trial. The data from the correlation analyses assessing the association between degree of dehydration induced and the change in skill performance outcome scores for each of the playing positions (fielders, batsmen and fast bowlers) are shown in Table 4. There were no significant associations between percent change in body mass and percent change in any of the motor skill performance outcomes in the FP and FR trials. In the FP trial there were two associations that nearly reached significance. These were a positive association of percent change in body mass with fast bowling line performance score and a positive association with overarm throwing speed.

Discussion

The main observation from this study was significant impairment in fast bowling, fielding and running motor skill performance among elite cricketers with fluid restriction that resulted in dehydration by 3.7% body mass. Other studies have shown similar impairment in sports specific skill performance among team sport players in relation to dehydration. These include performance decline in cricket fast bowlers with 2.8% dehydration (Devlin et al., 2001), soccer skills with 2% dehydration (McGregor et al., 1999, Edwards et al., 2007), basketball skills with 2-4% dehydration (Baker et al., 2007, Dougherty et al., 2006), and hockey skills with 2% dehydration (MacLeod et al. 2012).

Throwing and accurately delivering a ball with maximum force in a single effort tests muscle strength and motor control. Based on the available data, some studies have observed detrimental effects of acute dehydration on anaerobic muscular performance with more than 2% body mass loss (Jones et al., 2008, Hayes et al., 2010). Our study has revealed a significant reduction in throwing speed for overarm (6.6±4.1%; $p<0.01$) and sidearm (4.1±2.3%; $p<0.01$) techniques as well as a reduction in throwing accuracy in FR trial only. Bowling speed also revealed a significant impairment in performance with a drop in bowling speed by 1.0±0.8% ($p>0.01$) in the FR trial only. In contrast, Devlin and colleagues (Devlin et al., 2001) found a significant performance drop only in bowling accuracy but not in bowling speed with 2.8% body mass loss. In our study, 9 out of 10 fast bowlers were dehydrated by >3% body mass during FR trial (1 fast bowler with 2-3%, 4 with 3-4% and 5 with 4-5% body mass loss), which suggest significant impact on bowling speed with greater degree of dehydration. Throwing performance measures in cricket have been examined in several other studies, but have mainly focused on training methods (Freeston et al., 2007, Freeston et al., 2008). To date, there are no published data on effects of dehydration on throwing performance among cricketers and these are presented for the first time in this study.

Running between wickets can be considered as an intermittent high intensity activity where players sprint between wickets (21m). Data on effects of dehydration on short distance running and sprinting activities are limited. A review of the literature on hydration and muscular performance suggests that hypohydration has negative effects on muscular strength, power and high intensity endurance activities lasting more than 30 seconds but less than 2 minutes (Judelson et al., 2007). Impairments in shuttle running performance with 2.8% body mass loss among cricketers (Devlin et al., 2001) and drop in Yo-Yo intermittent running test performance by 13-15% with 2% body mass loss among soccer players (Edwards et al., 2007) have been reported but these are much longer task durations assessing aerobic performance rather than sprint speed. In our study, we did not observe a significant performance decline in the running speed between wickets, except for in time to make three runs ($p<0.01$) when batsmen were fluid restricted.

On examining the relationship between the degree of dehydration (% body mass loss) and change in performance outcome, we noted that there no significant associations (Table 4). This indicates that those who had the largest percentage decline in body mass were not those who had the biggest declines in skill performance outcomes. These observations highlight the individual nature of the impact of dehydration on skill performance in athletes. Individual variation in the performance among players also indicates that some athletes were capable of maintaining their performance, while others demonstrate significant decline in their performance, with the same level of dehydration. These observations suggest that it is imprecise to make definite figures for upper limits of body mass losses through dehydration in maintaining cricket performance. Further studies identifying individual variability that exists in cricket skill performance related to different levels of dehydration would help to understand this complex relationship.

A limited number of studies have examined fluid intakes and sweat losses among cricketers, with none examining the impact of dehydration on skill performance of players from different playing positions. A survey carried out among Australian cricketers during a 2.5-hour training session in hot (29°C) and humid (50%) conditions revealed that players lost 1202 ml of sweat on average per hour with large individual variation (AIS, 2011). Similarly, fluid losses among female cricketers across a tournament (6 innings) showed that mean sweat losses ranged from 0.30±0.31 L/h to 1.44±1.25 L/h (percentage body mass loss range from 0.97 – 3%) with no statistically significant difference between batsmen, bowlers and fielders (Soo et al., 2007). The outcome of these studies, supported by the sweat rate results from our present work (861±148 ml/hour in FR trial vs. 1208±171 ml/hour in FP trial) reveals that cricketers have large individual variation in their sweat losses. However, our data also highlights an often not reported role that fluid ingestion plays upon the capacity to lose fluid through sweating. The significantly higher sweat rate in the FP trial reflects a greater capacity to produce sweat to aid in evaporative cooling (Nielsen, 1974, Moroff et al., 1965). The mean sweat sodium concentration of athletes in this study (51±18 mmol/L in FP trial and 48±12 mmol/L in FR trial) were similar to those found in elite soccer players (Maughan et al., 2004, Maughan et al., 2005, Maughan et al., 2007, Godek et al., 2010), but higher than the values reported among Australian cricketers, 33.2 mmol/L. (AIS, 2011). Cricketers engage in long periods of play and some may therefore be at risk of large sweat volume and sweat electrolyte losses, which could be a significant concern. Therefore, consideration of fluid replacement volume and sodium content of drinks is likely to be important when recommending individual hydration strategies to cricketers in hot / humid environments.

Practical Application

Considerable individual variation in sweat losses and their impact upon motor skill performance is observed among cricketers across all playing positions. Generalized fluid replacement guidelines are therefore of limited use for cricketers and individualization of fluid intake strategies should be emphasized. Evidence from this study shows significant impairment in performance with 3-4% body mass loss by dehydration, which emphasizes the importance of hydration strategies for cricketers to help preserving performance in the later stages of matches. Fluid ingestion strategies to maintain mass loss within 1% should likely be adopted to prevent declines in motor skill performance of cricketers.

Conclusion

A fluid deficit of 3.7% body mass loss induced by fluid restriction in a 4-hour cricket session resulted in significant impairments in motor skill performance among elite cricketers playing in hot and humid conditions. Performance declines were observed in bowling speed and accuracy among fast bowlers, in sidearm and overarm throwing speed and accuracy among fielders, and in completing three runs among batsmen. Performance level was not altered when players ingested sufficient fluid to maintain a mean body mass loss of <1%.

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Ethical Approval - The study was approved by the Ethical Review Committee, Faculty of Medicine of University of Colombo, Sri Lanka.

Conflict of Interest - The authors declare that they have no conflict of interests.

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6. Tables

Table 1: Mean body mass, mass loss, sweat loss and sweat rate, sweat electrolyte content (sodium and chloride), fluid intake and urine output on the fluid provision (FP) and fluid restriction (FR) trials. Values are expressed as Mean ± SD.

		Fast Bowlers (n=10)	Fielders (n=12)	Batsmen (n=8)	Total (n=30)
FP	**Pre mass (kg)**	73.0±10.4	68.1±11.4	69.0±4.5	70.0±9.6
	Post mass (kg)	72.3±10.5	67.6±11.5	68.5±4.5	69.4±9.7
	Body mass loss (g)	640±353	575±339	525±249	583±315
	Body mass loss (%)	0.91±0.52	0.89±0.64	0.76±0.36	0.86±0.52
	Sweat loss (ml)	4923±703	4450±530	5297±591[a]	4833±683
	Sweat rate (ml/hour)	1231±176	1112±132	1324±148 [a]	1208±171
	Sweat sodium (mM)	45±20	59±17	45±14	51±18
	Sweat chloride (mM)	38±19	52±15	34±12	42±17
	Fluid intake (ml)	4674±373	4251±424	4997±404[b]	4591±497
	Fluid rate (ml/hour)	1168±93	1063±106	1249±101[b]	1148±124
	Urine (ml)	391±176	376±228	225±97	341±192
FR	**Pre mass (kg)**	72.9±10.4	68.2±11.4	68.8±4.6	69.9±9.6
	Post mass (kg)	70.1±10.3	65.9±11.2	66.1±4.8	67.3±9.5†
	Body mass loss (g)	2760±506	2283±478	2725±602	2560±554*
	Body mass loss (%)	3.82±0.72	3.37±0.66	3.99±0.97	3.69±0.79*
	Sweat loss (ml)	3671±569	3107±502	3666±558	3444±591†
	Sweat rate (ml/hour)	918±142	777±126	916±139	861±148†
	Sweat sodium (mM)	43±13	49±13	54±8	48±12
	Sweat chloride (mM)	32±15	35±12	36±9	34±12††
	Fluid intake (ml)	1061±162	972±226	1045±162	1021±189†
	Fluid rate (ml/hour)	265±41	243±56	261±40	255±47†
	Urine (ml)	150±79	148±73	105±41	137±69†

† Significantly lower than the corresponding measure in FP trial for all athletes († = p<0.01; †† = <0.05)

* Significantly higher than the corresponding measure in FP trial for all athletes ($p<0.01$)

[a] Significantly higher than the sweat loss and sweat rate of fielders in the FP trial only ($p<0.05$)

[b] Significantly higher than the fluid intake and fluid intake rate in the FP trial only ($p<0.01$)

Table 2: Urine color and urine specific gravity parameters on the fluid provision (FP) and fluid restriction (FR) trials for fast bowlers, batsmen and fielders. Values are expressed as Mean ± SD.

		FP		**FR**	
		Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
Urine Color (1-8)	Fast Bowlers (n=10)	2.80±0.79	3.30±0.95	2.70±0.82	4.00±1.15*
	Fielders (n=12)	2.67±0.78	2.83±0.72	2.75±0.75	4.08±1.24†
	Batsmen (n=8)	2.63±0.74	3.25±0.89	2.75±0.89	3.63±0.92†
	Total (n=30)	2.70±0.75	3.10±0.85	2.73±0.78	3.93±1.11*
Urine Specific Gravity	Fast Bowlers (n=10)	1.019±0.002	1.022±0.003†	1.021±0.003	1.026±0.002*
	Fielders (n=12)	1.020±0.003	1.023±0.003†	1.021±0.002	1.026±0.002*
	Batsmen (n=8)	1.022±0.003	1.024±0.001†	1.021±0.003	1.027±0.001*
	Total (n=30)	1.020±0.003	1.023±0.003*	1.021±0.003	1.026±0.002*

* Significantly higher than Pre-test of the corresponding trial only ($p<0.01$)

† Significantly higher than Pre-test of the corresponding trial only ($p<0.05$)

Table 3: Percentage differences in performance outcome scores in FP and FR trials. Values are expressed as Mean ± SD.

		FP	FR	N[a]
Fast bowling	Speed (km/hour)	-0.3±0.8	-1.0±0.8*	8/10
	Line	-3.6±14.2	-19.8±17.3*	9/10
	Length	2.33±7.84	0.94±5.22	4/10
Overarm Throwing	Speed (km/hour)	-1.6±3.4	-6.6±4.1*	10/12
	Accuracy	0.8±24.2	-14.2±16.3*	10/12
Sidearm Throwing	Speed (km/hour)	0.6±4.7	-4.1±2.3*	11/12
	Accuracy	-3.2±34.9	-22.3±13.3†	11/12
Underarm Throwing	Speed (km/hour)	0.6±4.7	-1.1±3.6	6/12
	Accuracy	5.79±19.16	2.41±15.61	3/12
Running between wickets	Single Run (sec)	-1.15±1.77	1.028±1.94	3/8
	Two Runs (sec)	-0.98±1.15	0.45±0.79	1/8
	Three Runs (sec)	0.8±1.2	2.2±1.7*	5/8

[a] number of athletes whose performance dropped during FR trial by more than twice the mean performance difference in the FP trial.

*Significant change in the percentage difference in performance outcome score compared to FP trial ($p<0.01$)

† Significant change in the percentage difference in performance outcome score compared to FP trial ($p<0.05$)

Table 4: Associations between percentage change in body mass and percentage change in skill performance outcomes scores for fast bowlers (speed, line and length scores), fielders (throwing speed and accuracy scores) and batters (run time) on the fluid provision (FP) and fluid restriction (FR) trials. Values are Pearson correlation coefficient and p-value.

		FP		FR	
		Pearson correlation	**p-value**	**Pearson correlation**	**p-value**
Fast bowling	Speed	-0.06	0.87	0.11	0.77
	Line Score	0.64	0.05	-0.07	0.86
	Length Score	0.55	0.10	0.40	0.27
Overarm Throwing	Speed	0.58	0.05	-0.23	0.47
	Accuracy	0.50	0.10	0.46	0.13
Sidearm Throwing	Speed	0.24	0.46	0.13	0.68
	Accuracy	-0.10	0.75	-0.07	0.82
Underarm Throwing	Speed	-0.42	0.18	-0.47	0.12
	Accuracy	0.44	0.15	0.12	0.71
Running between wickets	Single Run	0.45	0.27	0.33	0.42
	Two Runs	0.18	0.67	-0.15	0.73
	Three Runs	-0.44	0.28	0.20	0.63

Note: the percent change in body mass in the FP trial ranged from 0.1% to 2.5%, and in the FR trial from 2.4% to 5.5%

7. Figure legends

Figure 1: Diagrammatic representation of the study design, illustrating the hydration protocol, measurement time points, procedures and tests carried out during the 4-hour trial period.

Figure 2: Comparison between Pre-test and Post-test mean performance scores among fast bowlers in FP and FR trials. Values are Mean ± SD. N=10. *Significant difference from Pre-test of the FR trial ($p<0.01$).

Figure 3: Comparison between Pre-test and Post-test mean performance scores among fielders in FP and FR trials. Values are Mean ± SD. N=12. †Significant difference from Pre-test of the FR trial ($p<0.05$). *Significant difference from Pre-test of the FR trial ($p<0.01$).

Figure 4: Comparison between Pre-test and Post-test mean performance scores among batsmen in FP and FR trials. Values are Mean ± SD. N=8. *Significant difference from Pre-test of the FR trial ($p<0.01$).

8. Figures

Figure 1

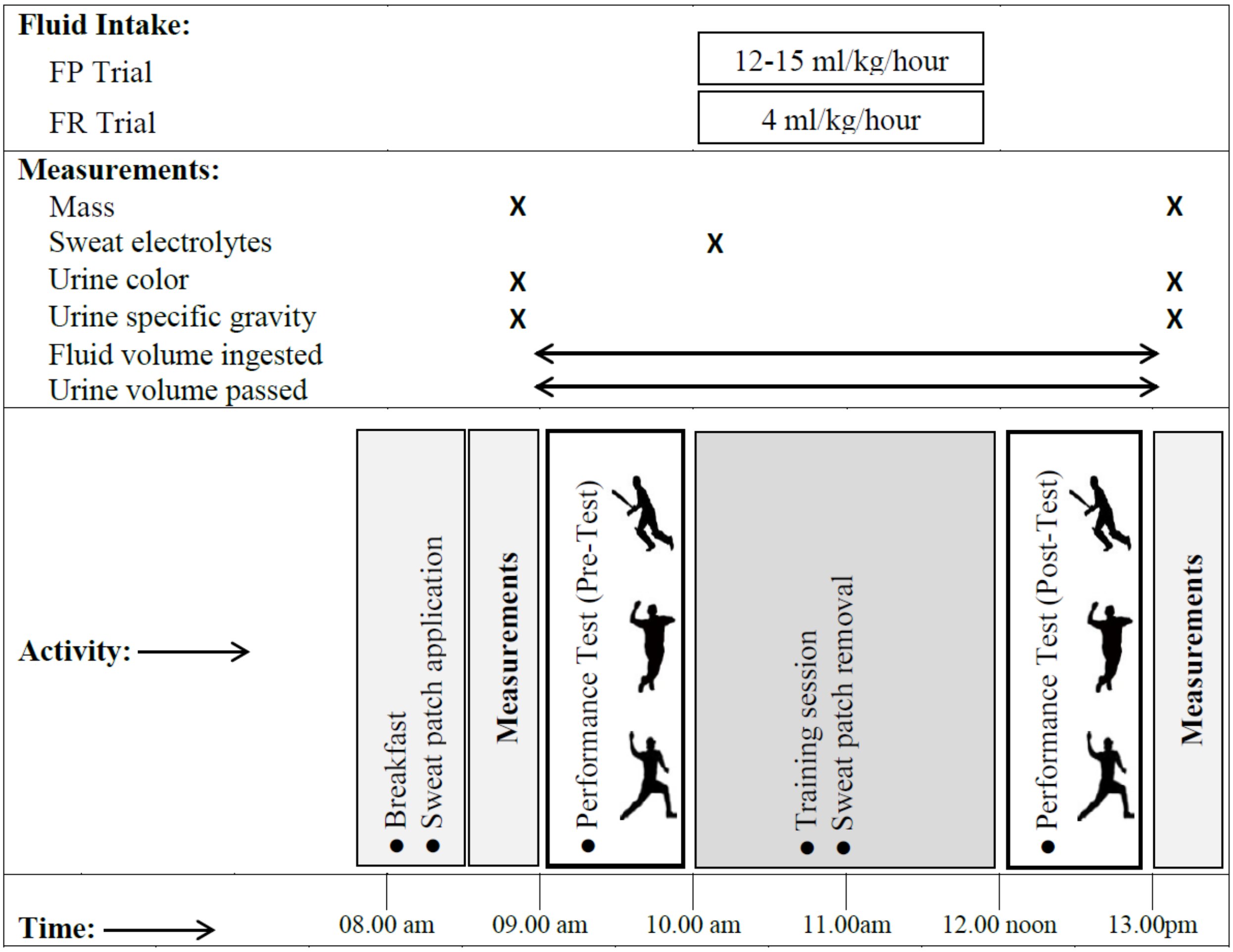


Figure 2.

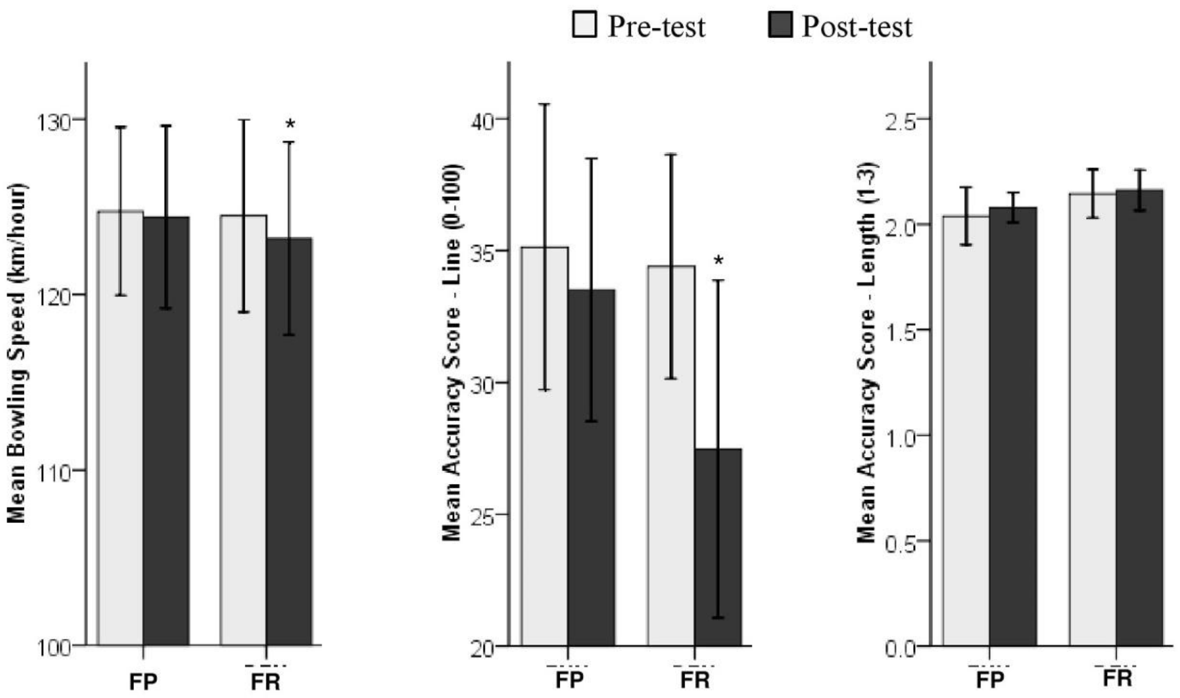

Pre-test
Post-test
Mean Bowling Speed (km/hour)
130
120
110
100
FP
FR
*
Mean Accuracy Score - Line (0-100)
40
35
30
25
20
FP
FR
*
Mean Accuracy Score - Length (1-3)
2.5
2.0
1.5
1.0
0.5
0.0
FP
FR

Figure 3

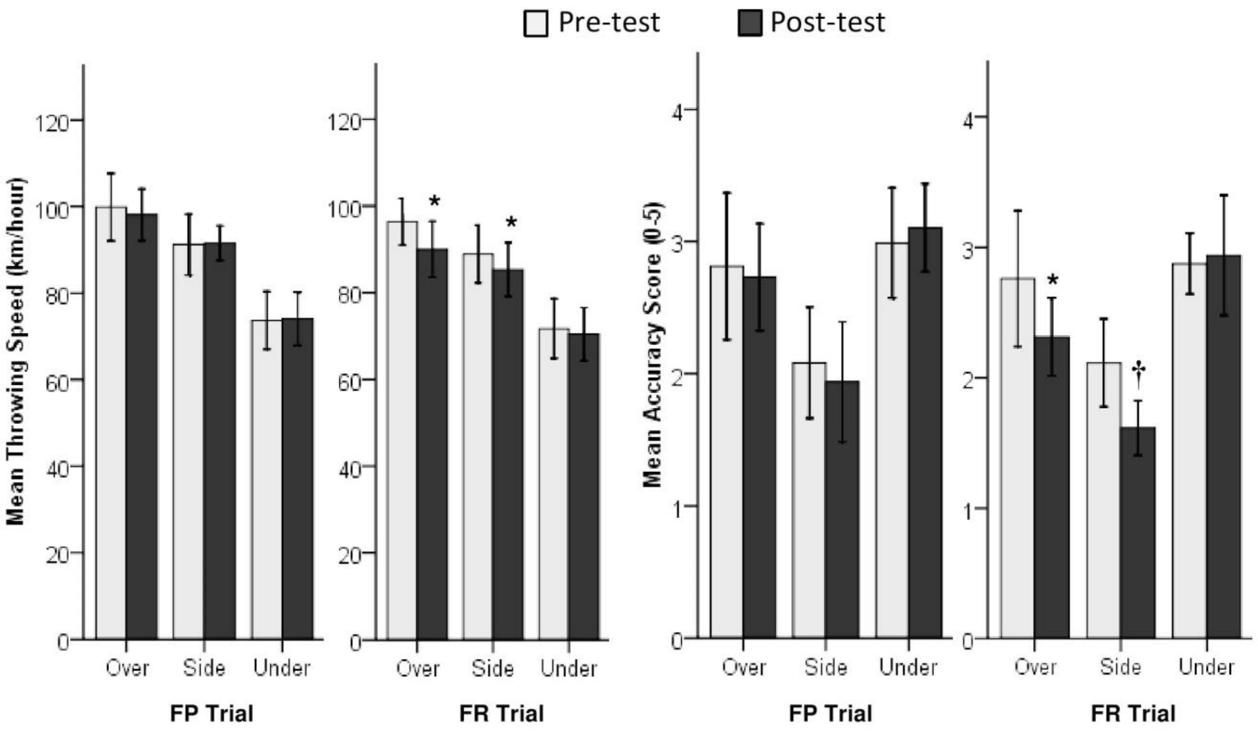
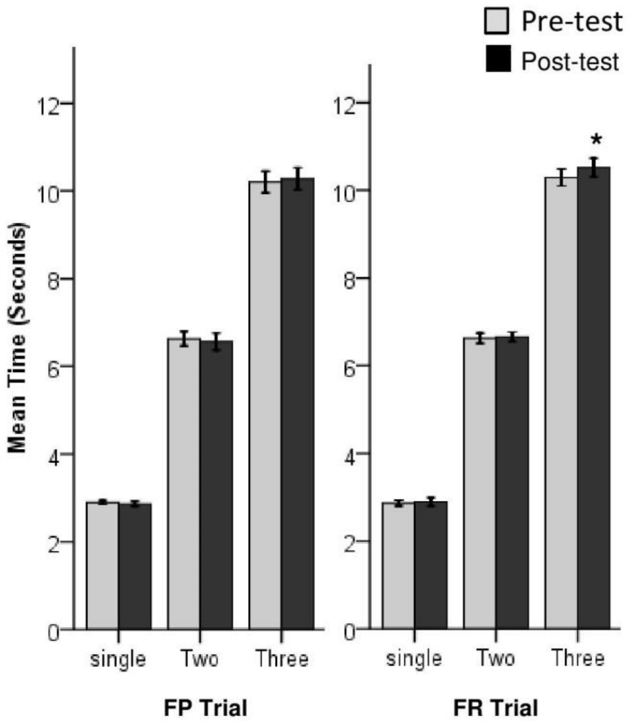

Pre-test
Post-test
Mean Throwing Speed (km/hour)
Mean Accuracy Score (0-5)
Over
Side
Under
FP Trial
FR Trial
*
†

Figure 4.


Pre-test
Post-test
Mean Time (Seconds)
0
2
4
6
8
10
12
single
Two
Three
FP Trial
0
2
4
6
8
10
12
single
Two
Three
FR Trial
*