Original Article

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Exercise-Heat Stress, Hyperthermia, Dehydration and Fatigue Effects on Cognitive Performance among Semi-Professional Male Athletes

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Abstract

Background: Evidence regarding heat stress, dehydration, hypohydration and fluid balance effects on semi-professional athletes' cognitive function is still limited. This study aimed to examine the effects of exercise heat-stress, hyperthermia, dehydration and fatigue on cognitive performances in semi-professional athletes. *Methods:* Eighteen healthy male athletes from individual and team sports participated. Participants completed a cognitive and mood test battery prior, immediately after and post 120 min of treadmill exercise. A soccer-specific intermittent treadmill exercise protocol was completed in four experimental trials in temperate (normothermic) and hot (hyperthermic) conditions. Participants were hydrated and dehydrated in both conditions. Trial conditions were; normothermic 16.4 ± 0.02°C and 52 ± 1% RH, while hyperthermic 33.9 ± 0.3°C and 61 ± 1% RH. *Results:* Response times; the Stroop effect and Visual search tasks were quicker (584 to 690 ms, p= 0.001; 1978 to 2213 ms, p= 0.003) in the heat. Cognitive tasks showed that reaction time, visual process, motor speed and mood were similar in normothermic (p=0.001). Accuracy improved in hydrated hyperthermic by 1.2% (p=0.002) in Visual search. Total Mood Disturbance was significant in heat (p<0.001). Hydration status had no major effect in some cognition performance markers except for mood. *Conclusion:* The response times and accuracy improved following the cognitive testing in semi-professional athletes exercising in relatively humid, hot conditions. However, semi-professional athletes' cognitive performances were relatively affected by hypohydration and their hydration status needs to be closely monitored during exercise.

Keywords: cognitive function, hypohydration, intermittent exercise, physiological strain

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INTRODUCTION

Water, a key human body component, is known for its crucial metabolic, electrolyte maintenance, and osmotic pressure normalization functions. In daily living, homeostasis is challenged exposing the human body; hence an understanding of how to effectively maintain fluid balance and the body core temperature is essential. Athletic training in a hot environment exposes athletes to suffering significant physiological stress experiencing hyperthermia, dehydration, and fatigue. These physiological stressors discourage an athlete's general physiologic and cognitive functions and athletic performance during acute and prolonged exercises [1-3]. Exhaustive physical activity and sport-related exercise lead to induced-heat stress, body core temperature increase beyond compensatory levels, and task complexity impair cognitive function [4-7]. To mitigate substantial dehydration elevation, a timeous-adequate fluid intake during endurance exercise in a hot environment attenuates factors that adversely affect the general body's physiological function [2].

With physiological and cognitive strain placed on athletes in adapting to the different environments, specific individual and team sports that have hypohydration risk during exercise may need close hydration monitoring [8,9] and attentional resources for optimal cognitive function [6]. Scientific findings of heat stress and dehydration impact cognitive function, central neuromotor performances are still inconsistent [1,3].

Therefore, the current study is aimed to investigate the effects of exercise-heat stress, hyperthermia, progressive dehydration, and fatigue on cognitive functioning in semi-professional athletes.

METHODS

Participants

Eighteen healthy males athletes (age 25 ± 5 years, weight 69.3 ± 6.6 kg; height 172.5 ± 7.8 cm, BMI 23.2 ± 0.9 kgm^{-2} and body fat 9.2 ± 1.8 %) from individual and team sports purposively selected participated in this study. These were actively participating in individual sports (eg. tennis, >2hr running) and team sports (eg. hockey, rugby). All participants were involved in a minimal exercise of at least 6-8 hours per week at a moderate-to-vigorous intensity, a minimum duration of 1½ hours, with 4-5 training days per week. Those excluded were on medical treatment.

Ethical considerations

Participants were informed about all experimental procedures, discomforts, and associated risks before the informed consent form was completed. Ethical clearance was obtained from the University of Zululand's Ethical Advisory Committee (UZERC171110-030-PGM2021/72).

Design

Participants completed four experimental sessions. These sessions included two temperate conditions (normothermic: hydrated; dehydrated) and two hot environmental conditions (hyperthermic: hydrated; dehydrated). The trial averages for the normothermic conditions were 16.4±0.02°C and 52±1% relative humidity (RH), while the hyperthermic conditions were 33.9±0.3°C and 61±1% RH. The chosen temperatures were 17°C and 35°C, for moderate and hot environments respectively resembling dry season temperatures at 100–400m altitude.

Familiarisation

Participants reported to the sports emporium laboratory four times. They were instructed to drink at least 500ml water before they sleep a night before and upon waking up before three familiarisation sessions. The first session was orientation and completion of informed consent form. The second session was for gathering anthropometric measurements; heights, body mass, percentage body fat, VO_2max, and sweat rate. The third and fourth sessions involved wearing of the heart rate monitor, putting on a weighted vest equivalent to 12% of individual body weight on a 5% inclined treadmill with speed between 4.8 – 6.4 km/hr that one can sustain for the 90-minute duration, at agepredicted maximal of >90% heart rate. Pre and post-exercise measurements to determine sweat rate were done. The Cognitive Performance test battery [10] and the Profile of Mood States [11] were performed in all four sessions. All participants ingested a thermometer pill for gastrointestinal temperature (Tgi) [12], 8-10 hours within the 48 hours before the start of the first trial.

Experimental procedures

Each of the four test sessions begun with several physiologic measurements; baseline mass, urine specific gravity (Usg), urine color (Ucol), core body temperature, heart rate (HR). Circadian influences were minimized by conducting trials during the same daytime from 07:00–1100 am. To give adequate recovery between trials at least four days were given. Participants refrained consumption of caffeine, alcoholic beverages, and intense exercise for at least 48 hours before trials. Each participant was advised to drink at least 2L of water per day, at least 500ml before sleep to ensure that one arrives at the lab well hydrated. To maintain hydration during hydrated trial sessions, each participant rehydrated with water ad libitum. During dehydrated trial sessions, no fluid was given. In a case where the participant was in hypohydration before the trial, he was given 500ml fluid 30minutes before a trial session. The treadmill exercise lasted 60 minutes with speed in the range between 4.8 - 6.4 km/hr at a 5% incline. Participant's previously selected speed was used in all sessions. Each participant wore a weighted vest equivalent to 12% of body weight during trials. The Tgi and HR were continuously monitored, and recorded every 15minutes. This exercise protocol was for raising core body temperatures to a hyperthermic level and necessitates fatigue. A cognitive test battery was performed soon after treadmill intermittent exercise.

Soccer Specific Intermittent Treadmill Protocol

A Soccer Specific Intermittent Treadmill Protocol (SSITP) was used [13]. Familiarisation and trial sessions were performed using a motorized and programmable treadmill (Circle Fitness, M8 Led Treadmill, Taiwan). Ninety-minutes of active movement was categorized in eight modes replicating a soccer match playtime, with 6x15min blocks separated by a 15-minute passive activity designed to imitate half-time. Jogging time and sprint pace for individualized protocol was equivalent to 75% (11± 2 km^{-1}) and 95% (14 ± 2km^{-1}) VO_2 max, a reflective of soccer and other team sport speeds [13, 14]. Distance covered in each 15-minute activity profile was 1.62km, resulting in 9.72km traveled during the 90-minute activity duration [15]. A 5% treadmill gradient was set as a reflection of the outdoor running energy cost at speeds used in the protocol.

Cognitive Testing (CT)

The CT battery consisted of the Stroop Effect Task (ST) and Visual Sensitivity Test (VST). This was for evaluating working memory, inhibitory control, and constant continual attention in sport. Participants were expected to complete the test in 15 minutes. Laptops with Millisecond-Resolution Timing single software package were used. To reduce noise distractions, participants wore ear protection during tests. These tests were performed as follows:

Stroop Effect Task

Stroop's [16] 2-minute test demonstrates the ability of sensitivity to interference versus suppuration of an automated response. Stroop baseline task (SBT) and Stroop color task (SCT) were the two test levels included under the Stroop Effect Task (ST). The SBT baseline task has 15 stimuli which reading of color names (congruent) and the SCT color-interference task has 40 stimuli, front color naming not reading of color name printed (incongruent). Within task test levels, each stimulus colored word is placed at the screen center with a randomly presented target and distractor counterbalanced either on the left or right side. Participants were instructed to press the left or right key arrow to a specific point of the target word in the minimal possible time. The reaction times, accuracy to color-meaning congruent and incongruent blends, and score percentages were recorded for statistical analysis. To minimize manipulation of fast and slow reaction time outliners in test levels, when analyzing, a baseline of 2000ms, slower than 1300ms times, and faster than 100ms times were filtered and removed.

Visual Sensitivity Task (VST)

The VST was for the assessment of visuomotor response times. It consisted of two levels: the baseline and the complex levels. In these two levels, participants were asked to detect a triangle on the laptop screen. An instruction followed immediately was to press a key in their shortest time possible to the target. Only touch screen version laptops were used in this study. These displayed only valid stimulus responses and disregarded outliner responses. When one response was made new targets followed and appeared at a rate of at least 500ms random delays. Correct stimulus-response rate percentages were recorded for statistical analysis.

Visuomotor response time's distribution comprised of; 20 targets for baseline levels formed from solid green lines drawn on a black background and in the complex level, 40 targets of random moving dots were distractors on the entire screen. The baseline level assessed simple visuomotor speed while the complex level initiated a complex visual component. Participants were instructed to draw a new visible dotted line on target triangles and as dotted points density gradually increases linearly with time a keypress is registered. After every 250ms, a new set of distractor dots were re-drawn on the screen. These stir up the visual distracting effect of a glittery background. To reduce uncalled for manipulation of response times and outliners, filtration was done for a baseline for less than 300ms and greater than 850ms and complex level for greater than 6000ms.

Mood Testing: Profile of Mood States

A standardized POMS questionnaire was used to assess participants' mood to how they felt the experimental trial session went. This questionnaire consisted of seven subscales; forty adjectives on a five-point scale that measured tension, fatigue, depression, vigor, anger, confusion and esteem-related affect. Total mood disturbance (TMD) comprises of (depression+ tension + anger + confusion + fatigue) - (esteemed-related + vigor) [17]. Scores were evaluated by choosing one scale for each adjective that conforms to the individual participant's situation from the five-point scales. A 6-point rating was used to analyze all the participants' responses.

Temperature Assessment

Gastrointestinal temperature (Tgi): Participants were instructed to remove the magnetic strip from the pill and ingest the telemetric temperature pill (Core Temp® Ingestible Body Temperature Sensor, HQ Inc, USA) with water 6 hours before the experimental trial to circumvent possible interaction with fluid ingestion [12]. Serial and calibration numbers were retained to the research team for record-keeping before trial sessions commencement. The participants were made aware that the pill will leave their body through the natural feces way in the toilet. Tgi was recorded at a 15-minute interval.

Heart rate: HR monitors before familiarisation and experimental trials. HR was monitored at 5 seconds intervals continuously using the Polar M430 GPS running watch (Polar Team System, Polar Electro Oy, Finland). In every 15-minute exercise interval, the mean HR was calculated.

Hydration Status Assessment

Participant's hydration status was confirmed by urine color (Ucol), urine specific gravity (Usg) and urine osmolality (UOsmo). Ucol was measured using a validated urine eight-color scale and Usg was measured using a clinical digital hand-held refractometer (Euromex RD.5712, Holland) with automatic temperature compensation. Previous studies reveal that Usg <1.020 and urine osmolality, UOsmo <850 mOsmol kg^{-1} and urine color, Ucol <4 indicate dehydration [18-20]. Samples were collected before and after the trial sessions from participants.

Perceptual responses of Rate of Perceived Exertion, Thirst sensation and Fatigue severity

The Borg-15 point scale, ranging from very light (6) to extreme unbearable (20), was used to assess participants' Ratings of Perceived Exertion (RPE). Visual Analog Scale was used to measure participants' subjective satiety and thirst sensation, VAS-T [21]. Thirst sensation was evaluated at baseline, post-trial and recovery. The VAS-T has labels from the left, "Not at All," to the right, "Extremely." The participants were instructed to use a pencil to mark with an X on their corresponding levels of sensation.

A self-report, validated VAS with 18 subjective items was used to evaluate Fatigue severity (VAS-F). Extreme labels on the VAS-F are from the left, lowest extreme (No Fatigue) to the right, highest extreme (Severe Fatigue) respectively [22, 23].

Statistical Analysis

Data collected during trials was initially recorded on a Microsoft Excel 2010 and later transferred and analyzed using SPSS v 23.0. Descriptive data were reported as mean ± standard deviation (M±SD) of these:

- 1-way (condition): score changes (post-pre, recovery-post, recovery-pre)
- 2-way (condition x time): baseline body mass, estimated total body weight loss (sweat loss), environmental condition
- 3-way (condition x fluid x time): Gastrointestinal temperature and heart rate, RPE, Ucol, Usg, UOsm, fatigue
- 4-way (condition x fluid x time x test level): Cognitive function test data from Stroop Effect Task, Visual Sensitivity Task, POMS.

Repeated measures ANOVA were used to evaluate differences between and within the environmental conditions. Considering the complexity of cognitive function, data analyses, insignificant findings were not presented. The significance level was set at 5%. For all analysis with a priori level of significance of 0.05, Tukey HSD tests were conducted for post hoc testing where necessary. A mixed model of repeated measures ANOVA was used to investigate the effect of induced-heat stress, hyperthermia and dehydration on changes in cognitive function and mood status while covarying fluid intake, BMI, age, oxygen saturation and blood pressure.

RESULTS

Participant characteristics

A significant difference was observed after exploring the age, weight, height, BMI and body fat mass ($p < 0.001$).

Environmental conditions

These sessions included two in temperate conditions (normothermic: hydrated; dehydrated) and two in hot environmental conditions (hyperthermic: hydrated; dehydrated). The trials in temperate (normothermic) conditions (HyN= 16.3 ± 0.02°C; DehyN=16.5 ± 0.01°C) were lower compared to and two in hot (hyperthermic) environmental conditions (HyHot = 33.4 ± 0.03°C; DehyHot= 34.3 ± 0.04°C) with $p < 0.001$. There was no statistical difference ($p = 0.314$) between hydrated normothermic and hyperthermic trials. Among the four conditions where $p = 0.010$; hyperthermic condition trials (HyN= 61 ± 1%; DehyN=61 ± 1°C) had greater relative humidity (RH) compared to normothermic condition trials (HyN= 52 ± 1%; DehyN= 52 ± 2%). The trial averages for normothermic conditions were 16.4 ± 0.02°C and 52 ± 1% RH, while the hyperthermic conditions were 33.9 ± 0.3°C and 61 ± 1% RH.

Heart Rate and Gastrointestinal Temperature

Participants' mean heart rate during the pre-test, post-test, and after is shown in Figure 1(a) below. There was a significant increase in heart rate from pre-test to post-test ($p<0.001$) with many effects in hot conditions ($p= 0.001$) and where participants were restricted to fluid ($p=0.010$). ANOVA revealed that after recovery HR for hot conditions was greater than the baseline for pre-test ($p=0.005$). Figure 1(b) shows gastrointestinal temperature. Tgi increased from baseline to post-test in hot conditions ($p=0.020$) compared to temperate conditions followed by a post-recovery decline in all four trials ($p<0.001$).

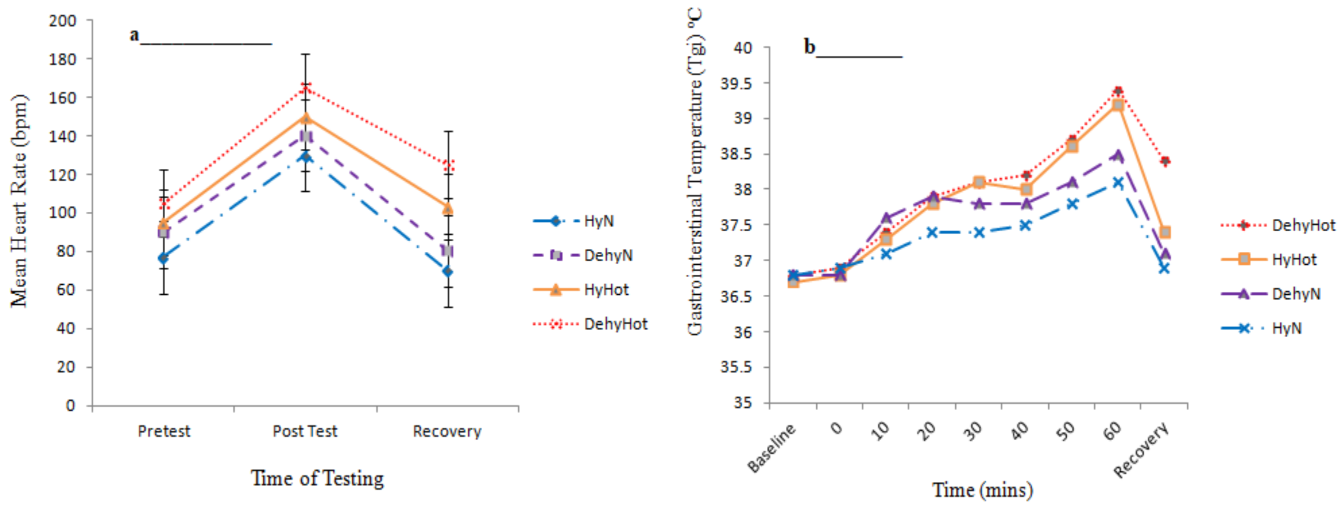

Figure 1. The heart rate (HR) and gastrointestinal temperature (Tgi) data (mean ± SD) observed during SSITP under; HyN: hydrated normothermic; DehyN: dehydrated normothermic; HyHot: hydrated hyperthermic; DehyHot: dehydrated hyperthermic. For (a), HR: main effect condition (p=0.001), time (p=0.001), hydration status (p=0.010) and p=0.005 for condition x time. For post trial and recovery, p<0.05 between HyN and HyHot, while p<0.05 between HyN and DehyHot during post trial. For (b), Tgi: main effect condition (p=0.021), time (p<0.001) and p <0.001 for condition x time. P<0.05 between: HyN and DehyH (20-30mins), HyN and HyHot (baseline and recovery), HyN and DehyHot (60min).

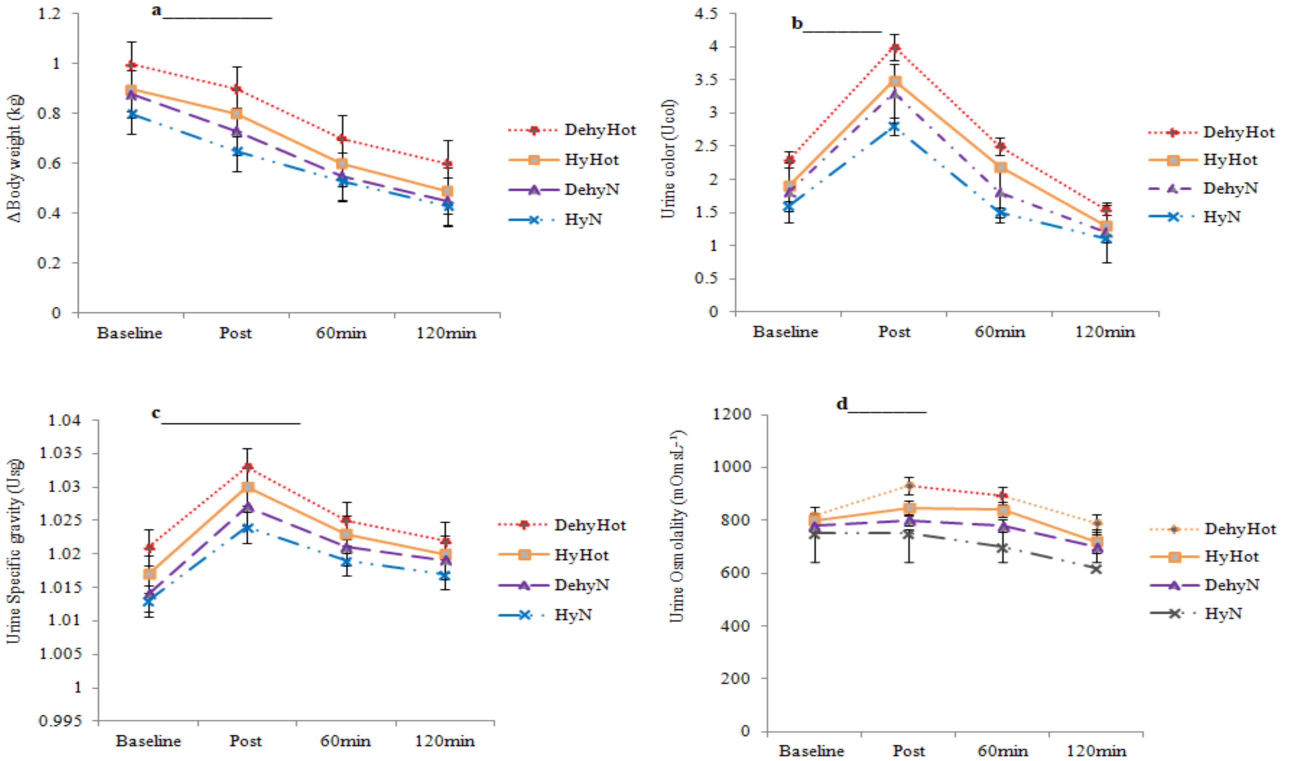

Figure 2. The hydration status measurements (mean ±SD). a). Change in body weight (ΔBW), b). Urine color (Ucol), c). Urine specific gravity (Usg), and d). Urine osmolality (Uosm) observed during SSIP under; HyN: hydrated normothermic; DehyN: dehydrated normothermic; HyHot: hydrated hyperthermic; DehyHot: dehydrated hyperthermic. ΔBW: Main effect condition (p=0.001), time (p<0.001), condition x time (p<0.003). Ucol: Main effect fluid (p<0.001), fluid (p=0.0026), time (p<0.001), condition x time (p<0.001), and condition x fluid x time (p=0.015). Usg: Main effect condition (p=0.001), fluid (p=0.002), time (p<0.002) and condition x time (p<0.001). Uosm: Main effect condition (p<0.001), time (p<0.001) and condition x time (p<0.001). P<0.005) between: HyHot and HyN (baseline and 120min), HyHot and DehyN (immediate post trial), DehyHot and HyN (120min), HyHot and DehyHot (60min and 120min).

Table 1. Profile of Mood State.

POMS Variables	Condition	Pretest (score 1-5)	Post Test (score 1-5)	Recovery (score 1-5)
		Mean±SD	Mean±SD	Mean±SD
Tension	HyN	2.20 ± 0.13	1.94 ± 0.12	2.40 ± 0.17
	Dehy	2.22 ± 0.11	1.98 ± 0.09	2.45 ± 0.14
	HyHot	2.27 ± 0.09	1.99 ± 0.09*	2.53 ± 0.13
	DehyHot	2.35 ± 0.12	2.40 ± 0.11	2.76 ± 0.18
Depression	HyN	1.96 ± 0.13	1.60 ± 0.11	1.79 ± 0.15
	Dehy	2.02 ± 0.14	1.65 ± 0.12	1. 82 ± 0.17
	HyHot	2.06 ± 0.11	1.68 ± 0.14	1.78 ± 0.12
	DehyHot	2.11 ± 0.14	1.93 ± 0.15	1.98 ± 0.16
Confusion	HyN	2.06 ± 0.14	1.66 ± 0.12	1.67 ± 0.13
	Dehy	2.09 ± 0.15	1.74 ± 0.19	1.78 ± 0.15
	HyHot	2.64 ± 0.19	2.68 ± 0.20	2.88 ± 0.19
	DehyHot	3.01 ± 0.12	3.12 ± 0.21*	3.24 ± 0.20
Anger	HyN	1.65 ± 0.11	1.32 ± 0.09	1.55 ± 0.15
	Dehy	1.66 ± 0.10	1.32 ± 0.07	1.56 ± 0.13
	HyHot	1.78 ± 0.12	1.40 ± 0.10	1.66 ± 0.14
	DehyHot	1.89 ± 0.13	1.45 ± 0.10	1.57 ± 0.15
Vigor	HyN	3.09 ± 0.13*	3.36 ± 0.14*	2.59 ± 0.16
	Dehy	3.11 ± 0.12	3.42 ± 0.16*	2.76 ± 0.17
	HyHot	3.10 ± 0.10	3.40 ± 0.14	2.58 ± 0.15
	DehyHot	3.06 ± 0.12	3.35 ± 0.16*	3.05 ± 0.14
Fatigue	HyN	2.93 ± 0.17*	2.50 ± 0.14*	3.66 ± 0.21
	Dehy	2.96 ± 0. 16	2.64 ± 0.15	3.71 ± 0.19
	HyHot	3.67 ± 0.12*	3.76 ± 0.19*	3.82 ± 0.20
	DehyHot	3.98 ± 0.14	4.25 ± 0.16	4.28 ± 0.23
TMD	HyN	7.49 ± 0.58	5.76 ± 0.43*	8.48 ± 0.59
	Dehy	7.56 ± 0.54	6.56 ± 0.48	8.89 ± 0.57
	HyHot	7.78 ± 0.62*	7.64 ± 0.45	9.01 ± 0.38
	DehyHot	8.24 ± 0.56	7.82 ± 0.46	9.34 ± 0.61

*Condition x Reaction time, p=0.774; Post-hoc: DehyN & DehyHot (Pretest) > DehyN & DehyHot (Post Test) p= 0.001

Cognitive Functioning Aspects

Tables 1 and 2 below present cognitive function assessment data; mood (POMS) and Stroop effect and visual sensitivity tasks. Across the assessments, no main effect difference of condition ($p< 0.05$) or fluid ($p< 0.05$) on response times on mood ($p=0.022$), Stroop effect task ($p= 0.021$) and visual search ($p = 0.034$). POMS: There was a significant effect difference on hot condition ($p< 0.001$) and fluid ($p< 0.001$) on observed mood state. In all conditions with main effect fluid ($p= 0.001$), a decrease in participants' ratings of depression, anger, vigor while tension, confusion, and fatigue increased (Table 1).

Stroop Effect Task: On average response times (Table 2) were faster in hot condition posttest (Normothermic: pre-test 588 ms, post test 690 ms ($p= 0.368$; diff= 0.15); Hyperthermic: pre-test 602 ms, post test 584 ms ($p= 0.019$; diff= 0.26) condition x reaction time, $p=0.581$; Post-hoc: DehyN & DehyHot (Pretest) > DehyN & DehyHot (Post Test), $p= 0.012$). Color interference did not exist with main effect either condition ($p= 0.043$), fluid ($p= 0.026$) or time on accuracy ($p= 0.031$). Visual Search Task: Similar response times (Table 2) existed on baseline (normothermic 554ms, hyperthermic: 520 ms ($p= 0.748$; diff= 0.35) compared to quicker complex level response times (normothermic 2213 ms, hyperthermic: 1978 ms ($p= 0.003$; diff= 0.38); condition x reaction time, $p=0.003$; Post-hoc: DehyN & DehyHot (Pretest) < DehyN & DehyHot (Post Test), $p= 0.001$).

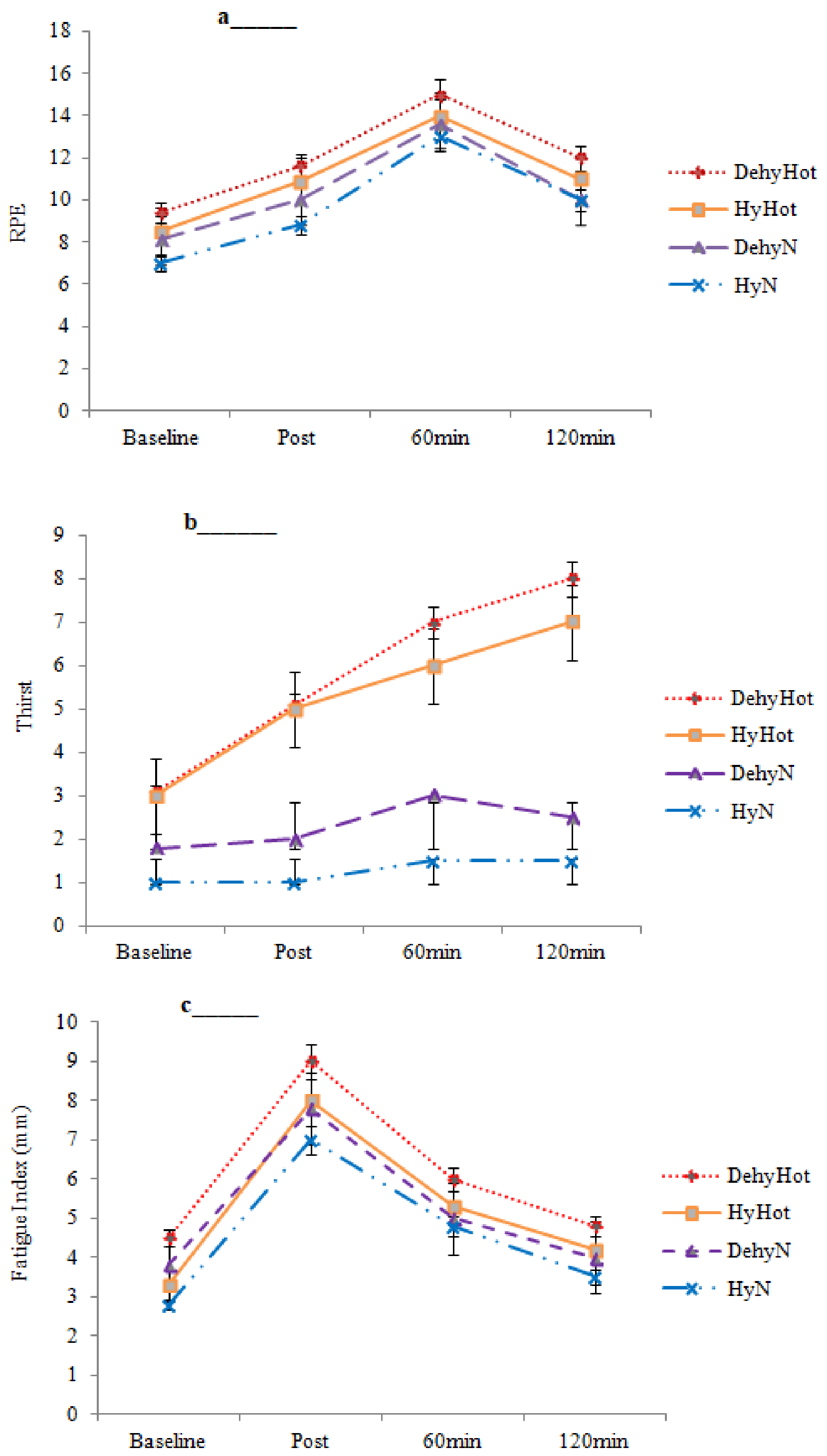

Figure 3. The perceptual responses (mean ±SD) of: a). Rate of Perceived Exertion (RPE), b). Thirst, c). Fatigue, observed during SSIP under; HyN: hydrated normothermic; DehyN: dehydrated normothermic; HyHot: hydrated hyperthermic; DehyHot: dehydrated hyperthermic. RPE: Main effect condition ($p=0.001$), fluid ($p=0.032$), time ($p<0.001$), condition x time ($p<0.001$) and fluid x time ($p= 0.001$). Thirst sensitivity: Main effect fluid ($p<0.001$), time ($p<0.001$), fluid x time ($p<0.001$), (condition x fluid x time ($p=0.013$). Fatigue: Main effect condition ($p<0.001$), time ($p<0.001$) and condition x time ($p<0.001$). $P<0.005$) between: HyHot and HyN (immediate post trial) and HyHot and DehyN (post trial), DehyHot and HyN (120min), HyHot and DehyHot (baseline and 60min).

Table 2. Stroop Effect and Visual Search Task

Test	Level	Response Time (Milliseconds)								Accuracy (Percentage)							
		Normothermic				Hyperthermic				Normothermic				Hyperthermic			
		Hydrated (HyN)		Dehydrated (DehyN)		Hydrated (HyHot)		Dehydrated (DehyHot)		Hydrated (HyN)		Dehydrated (DehyN)		Hydrated (HyHot)		Dehydrated (DehyHot)	
		Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test
Stroop Effect Task	Baseline M ± SD	590 ± 60	571 ± 64	561 ± 58	557 ± 80	586 ± 83	573 ± 92	570 ± 74	553 ± 80	98.2 ±2.4	98.5 ± 2.2	95.8 ± 3.4	98.2 ± 3.5	95.1 ± 3.3	98.2 ± 2.2	98.2 ± 3.5	95.1 ± 3.1
	range	480 -688	472 -676	491 -674	483 -741	472 -746	470 -687	500 -782	463 -692	95 -100	95 -100	92 -100	90 -100	92 -100	95 -100	90 -100	92 -100
	Colour M ± SD	713 ± 94	681 ± 96	716 ± 101	702 ± 91	713 ±150	688 ± 128	743 ± 141	678 ± 96	96.4 ± 4.5	94.6 ± 4.8	96.7 ± 2.9	95.8 ± 2.4	96.9 ± 2.1	96.4 ± 2.2	94.8 ± 3.9	95.9 ± 4.4
	range	578 -890	561 -879	543 -831	617 -869	548 -1040	543 -848	574 -1022	567 -852	88 -100	88 -100	90 -100	92 -98	94 -100	94 -100	90 -100	88 -100
Visual Sensitivity Task	Baseline M ± SD	500 ± 10	510 ± 68	502 ± 26	492 ± 11	492 ± 20	478 ± 26	500 ± 17	495 ± 31	96.7 ± 1.8	100.0 ± 0.0	96.7 ± 1.8	96.7 ± 1.8	97.8 ± 2.9	96.7 ± 1.8	96.7 ± 1.8	99.7 ± 2.1
	range	465 -530	493 -544	488 -554	476 -504	468 -510	460 -522	482 -551	460 -578	94.2 -100	100 -100	94.2 -100	94.2 -100	92.2 -100	94.2 -100	94.2 -100	95.2 -100
	Complex M ± SD	2000 ± 421	2105 ± 321	2163 ± 540	2108 ± 316	1930 ± 278	1839 ± 283	2054 ± 487	1904 ± 298	98.1 ± 2.0	98.0 ± 1.6	97.9 ± 2.4	98.7 ± 0.9	99.6 ± 1.3	99.3 ± 2.0	98.2 ± 3.8	95.3 ± 6.5
	range	1316 -2700	1650 -2740	1273 -2767	1292 -2410	1491 -2334	1223 -2048	1227 -2816	1362 -2250	94.6 -100	95.8 -100	92.1 -100	97 -100	96.2 -100	94.3 -100	89.3 -100	90.9 -100

Stroop Effect Task (Condition x Reaction time, p=0.581; Post-hoc: DehyN & DehyHot (Pre-test) > DehyN & DehyHot (Post Test) p= 0.012); Visual Sensitivity Task (Condition x Reaction time, p=0.003; Post-hoc: DehyN & DehyHot (Pre-test) < DehyN & DehyHot (Post Test) p= 0.001)

DISCUSSION

The current study aimed at investigating the effect of exercise-heat stress, hyperthermia, progressive dehydration and fatigue on cognitive functioning in semi-professional athletes following soccer-specific interval training. The findings showed that dehydration has little impact on cognitive performance despite the existence of total mood disturbance in hot, humid environments (33.4℃, 64% RH). Similarly, reaction times did not change following fluid restriction during 90min exercise in warm (31℃), humid environment, 63% RH [6].

Findings from this study indicate that exercise-induced heat stress is a compound to impairment of visuomotor performance and unpleasant sensation regardless of fluid ingested during trials matching with water loss. These corroborate findings by Wittbrodt and Millard-Stafford [3], meta-analysis, dehydration impaired visuomotor impairment within the first 5-minute finger-tapping task. This suggests that dehydration accompanied by hyperthermia negatively affects the brain and cognitive-motor domain functions. Therefore, we concluded that different dehydration and cognitive assessment methods, hypohydration degree, the volume of fluid ingestion, athletic dehydration experience, training level, and other additional variables influence alteration of cognitive performance in hot conditions [8, 24-26].

The findings suggest that equal higher thirst and thermal sensations, skin, and core temperature (Fig 1 and 3) were significant cognitive performance variables. These were shown in hyperthermic trial conditions where sensations, skin, and Tgi were higher, a cognitive function improvement was observed compared to temperate conditions (Table 2). Similarly, Lee et al. [27] found that exercising in heat improved accuracy during complex tests following cooling the neck to cause a decline in thermal sensation regardless of >39.5℃ body core temperature.

Results of this study showed that the post-trial percentage of body mass loss was 2.4% (DehyN) and 2.9% (DehyHot); respectively. These were similar to what Edwards et al. [28] observed that mild-dehydration, up to 2.5%, during exercise in hot conditions does not affect cognitive function [29, 30]. In support of this, studies done for other intermittent sports pointed that >2% dehydration is a clear indication of hypothesized threshold to adversely cause cognitive performance [6, 31]. The study findings' practical significance may be reflected during some individual and intermittent sport skills performance competitive play in the heat.

When dehydrated and hyperthermic, fatigue development during endurance exercise in hot conditions, coupled with increased core body temperature and closer to maximal heart rate implicating the central nervous system [24, 26, 29, 32]. This study hypothesized that central fatigue influenced physical and cognitive performance, which were higher in hot conditions than temperate conditions (Table 1). Therefore, it is credible that TMD and altered fatigue influenced a decrease in physical and cognitive performance.

Limitations

The same movement speed used in SSITP does not reveal the fatigue level witnessed during matches. Responses to effects on cognitive performance were group mean representations without considering an individual's physiological tolerance and differences.

Practical implications

This study suggests that: a) athletes should be advised and encouraged to keep <2% dehydration during training and competition to avoid detrimental effects on athletic and cognitive performances, b) athletic level has a great influence on cognitive function among athlete's reaction to physiological strain.

CONCLUSION

Maintaining normal hydration has a low physiological strain on athletic performance. Performing prolonged exercise in temperate conditions improved cognitive function and mood despite hydration levels. The intermittent exercise improved general response times on cognitive performances. Response times for complex visuomotor improved in a heated environment. Cognitive performance for semi-professional athletes is relatively affected by ~2% dehydration following SSITP in hot conditions.

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