High intensity intermittent running and field hockey skill performance in the heat

Caroline Sunderland

Division of Sports Science, Nottingham Trent University, Clifton Lane, Nottingham, NG11 8NS, UK

Mary E Nevill

Institute of Youth Sport, School of Sport and Exercise Sciences, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK.

Address for correspondence:

Dr Caroline Sunderland

Division of Sports Science, Nottingham Trent University, Clifton Lane, Nottingham, NG11 8NS, UK.

Tel: +44(0)115 8486379

Fax: +44(0)115 9486636

E-mail: caroline.sunderland@ntu.ac.uk

Acknowledgements

The authors wish to acknowledge the invaluable assistance of Miss Helen Milne, Mr Karl Cooke, Dr John Morris, Dr Mark Bruce and Dr Keith Stokes in the data collection.

Running title: Intermittent running and field hockey skill in the heat

Keywords: Intermittent running, skill, heat, women, hockey

Abstract

Nine, well-trained, unacclimatised female hockey players performed the Loughborough Intermittent Shuttle Test (LIST) interspersed with three field hockey skill tests in hot (30^{o}C, 38% relative humidity) and moderate (19^{o}C, 51% relative humidity) environmental conditions. Field hockey skill performance declined in both the hot and moderate conditions following 30 and 60 min of the LIST compared with pre-LIST values (P<0.01). This decrement in performance was compounded in the hot environment with a 6% poorer performance in the heat recorded for the second skill test at 30 min (P<0.05, hot 101.7 ± 3.6 vs moderate 95.7 ± 2.9 s; mean $\pm s_{\bar{x}}$). However, no difference was found in the decision-making element of the skill test. Fifteen metre sprint times were slower in the hot condition (P<0.01). In the hot environment, rectal temperatures (P<0.01), perceived exertion (P<0.05) perceived thirst (P<0.01) blood glucose concentrations (P<0.05) and serum aldosterone concentrations (P<0.01) were higher. Estimated mean $\pm s_{\bar{x}}$ sweat rate of 1.27 ± 0.10 $l.h^{-1}$ was greater in the hot trial than the 1.05 ± 0.12 $l.h^{-1}$ in the moderate trial (P<0.05). Body mass was well maintained in both trials. No difference in serum cortisol, blood lactate, plasma volume and plasma ammonia concentrations were found. These results demonstrate that field hockey skill performance is decreased following intermittent, high intensity shuttle running and that this decrease is greater in hot environmental conditions. The exact mechanism for this decrement in performance remains to be elucidated, but is unlikely to be due to low glycogen concentration or dehydration.

Introduction

Team sports, which are characterised by intermittent high intensity exercise bouts, also require a contribution of motor skill performance and cognitive functioning (Burke, 1997). In terms of the assessment of the physiological demands of team sports, soccer has been most extensively investigated (Shi and Gisolfi, 1998). Few researchers have investigated the demands of field hockey and the few studies completed (Wein, 1981; Fox, 1984; Lothian and Farrally, 1992; Lothian and Farrally, 1994) are becoming dated due to the new surfaces and rule changes that have altered considerably the characteristics of the game in recent years.

While the maintenance of physiological function is clearly important in team sports such as field hockey, soccer and rugby, during such activities, the completion of the required skills is at least as important in determining success in the particular sport. However, very few researchers have investigated how fatiguing exercise may influence motor skill performance and cognitive functioning (Dawson et al., 1985; Rico-Sanz et al., 1996; Vergauwen et al., 1998; McGregor et al. 1999). In this context, fatigue does not refer to the termination of a particular form of exercise, but rather that in the course of an activity, such as soccer or field hockey, distance run and exercise intensity will be reduced, but not terminated during a match. Research into the performance of field hockey during National League matches has shown that during the second half of a normal match there is a decrease in the level of high intensity activity performed (Lothian and Farrally, 1994). However, Lothian and Farrally (1994) made no reference made to the extent to which field hockey specific activities were affected by the duration of a match.

Few researchers have assessed changes in some measure of ‘skill’ performance are scarce and researchers have concentrated on the effects of exercise in moderate environmental conditions on skill performance, particularly soccer skills. This lack of research is partially due to the difficulties of undertaking field-testing. McGregor et al. (1999) found that, following prolonged intermittent high intensity running in moderate conditions, skill performance is decreased when subjects refrained from fluid replacement. Skill performance was maintained when water was ingested ad libitum. However, following 2 h of tennis training, fluid ingestion did not prevent a decline (9%) in skill performance, during defensive rallies (Vergauwen et al., 1998). Suggested mechanisms underlying such performance decrements following either match play or prolonged intermittent high intensity running include low glycogen concentrations, hypoglycaemia or dehydration (Shephard and Leatt, 1987; Jacobs, 1988; Leatt and Jacobs, 1988; Rico-Sanz et al., 1996; McGregor et al., 1999).

Many important World Championship events, Olympic and Commonwealth Games are held in hot environmental conditions, in which the challenge to the homeostatic mechanisms in the body is probably substantially greater than that presented in moderate conditions. Further, dehydration and glycogen utilisation have been shown to be greater in the heat (Febbraio et al., 1994) and therefore a greater impairment of skill performance may be observed. Nevertheless, research into the effects of exercising in hot environmental conditions compared with moderate conditions on skill performance in general is limited (Dawson et al., 1985) and hockey skill performance in particular has not been investigated. Dawson et al. (1985) compared the performance of tennis players following 1 h of match play in moderate conditions ($23^{o}C$) or intervalised treadmill running in the heat ($35^{o}C$). Following exercise in the hot environment, skill performance was poorer by 19, 26 and 14% respectively for serving, groundstrokes and volleys than after the match in a moderate temperature. Similarly, soccer skill performance of elite players following a match in the heat (27^{o}C) was decreased by 6% (Rico-Sanz et al., 1996). Cognitive performance, when the athlete is exposed to heat stress appears to be dependent upon the task performed, the level of dehydration and deep body temperature (Gopinathan et al., 1988; Brisswalter et al., 2002). Significant decreases in arithmetic ability (8%) and short-term memory (11%) were reported when subjects were dehydrated by 2% or more (Gopinathan et al., 1988). The majority of field hockey matches are played on an artificial playing surface. When exposed to solar radiation, the surface is heated and reradiates thermal energy to the hockey players on the pitch. The temperature on the pitch can be raised by 1-5^{o}C in the presence of solar radiation (Buskirk et al., 1977). Thus the sun on the pitch surface compounds the performance of field hockey in hot environments and the thermal strain on the players.

In light of the previous research, the current study tested the hypothesis that performance of a field hockey skill test would be decreased following intermittent running, and that the performance decrease would be greater in hot conditions.

Methods

Participants

Nine, well-trained, unacclimatised female university hockey players gave their written informed consent for this study which had the approval of the University Ethical Advisory Committee. Six of the nine had normal menstrual cycles, and three had been taking oral contraceptives for over one year. The mean ± $s_{\bar{x}}$ age of the participants was 21.7 ± 0.4 years, body mass was 68.5 ± 3.6 kg and height was 167.3 ± 2.2 cm. The estimated $\dot{V}O_2$ max (from the multistage shuttle run test) for the group was 50.3 ± 1.1 ml·kg^{-1}·min^{-1}.

Experimental design

Subjects performed the Loughborough Intermittent Shuttle Test (LIST; Nicholas et al., 1995, 2000) and field hockey skill tests (Sunderland et al., 2003) in hot (30 ± 0.5^{o}C DB; 37.9 ± 4.6% RH) and moderate (19.1 ± 1.3^{o}C DB; 50.8 ± 4.2% RH) environmental conditions. During the LIST subjects exercised over a 20m distance and repeated a walk, sprint, run (~85% $\dot{V}O_2$ max) and jog (~50% $\dot{V}O_2$ max) pattern of exercise for 15 min which incorporated 11 sprints, followed by a 3 min rest period. This pattern of activities constituted 1 set of the LIST. Subjects performed 4 sets of the LIST in total.

The field hockey skill test, which has previously been reported to be reliable and valid (Sunderland et al. 2003), was performed prior to the LIST and after the 2nd and 4th sets of exercise. The skill test was started from a line 16 yards (14.56 m) from a goal and was undertaken on an artificial surface (Desso), which is in common use for field hockey. The field hockey skill test required the subjects to dribble round cones in a specified order, before breaking an infra-red beam (RS Components Ltd.), which randomly turned on a light at either the left or right hand side of the goal. The subjects then passed the hockey ball off a rebound board (Exportise Ltd) before shooting at a target on the opposite side of the goal to the light. This was repeated 6 times to complete the field hockey skill test, with the total time being recorded. Any errors (for example missing the target on the goal, touching cones or the ball touching the players feet) would result in a 2 s penalty being added to the total time. A further time was recorded automatically (BBC microcomputer), which will be referred to as the ‘decision time’. This was the time taken between breaking the infra-red beam and hitting the backboard with the shot, which was determined by a microphone attached to the backboard. The ‘decision time’ incorporates the time to make a pass against the backboard, receive the ball, shoot at goal and the ball reach the backboard.

Each trial consisted of three skill tests and four sets of the LIST; one skill test was completed prior to the commencement of the LIST and then repeated after two sets and again after four sets of the LIST. The subjects rested for a total of 10 min after the first two sets to mimic half-time in a match situation. If subjects were unable to complete all four sets of the LIST (volitional exhaustion or rectal temperature >40^{o}C), the final skill test was undertaken immediately after the subject had stopped running. The order of trials was randomly assigned and 28 days elapsed between the moderate and hot trials. The trials were conducted one month apart to take account of menstrual cycle phase, which was verified by measurement of serum progesterone concentration. Prior to the main trials maximal oxygen uptake ($\dot{V}O_2\,max$) was estimated using a progressive multistage fitness test (Ramsbottom et al., 1988) and participants were also familiarised with the LIST at 30^{o}C for 2 sets or 33 min and fully familiarised with the field hockey skill test.

Main trials

Subjects reported to the laboratory at least 12 hours after their last meal. In the 2 days prior to their first main trial each subject recorded food consumed on dietary sheets provided for them. They were then asked to repeat the same diet prior to the second trial. All experiments were arranged so that each individual ran at the same time of day for both the moderate and hot trials to control for circadian influences (Reilly and

Brooks, 1986). Having reported to the laboratory, a 45 mm cannula was then inserted into a forearm vein of the subject under local anaesthetic (Lignocaine hydrochloride 1%). The cannula was kept patent with saline solution (Sodium choloride 0.9%). Subjects' nude body mass was recorded and a rectal probe (Edale Instruments Ltd.) was inserted to a depth of 10 cm beyond the anal sphincter.

Fifteen minutes after cannulation, during which time subjects remained standing to ensure that changes in posture would not effect the estimated changes in plasma volume, a resting blood sample was collected. A resting rectal temperature was recorded immediately after entering the hot or moderate environment. A standardised warm-up of 15 min was then performed which consisted of jogging, stretching and faster pace running. During the warm-up and throughout the exercise period subjects were allowed to drink water ad libitum.

During each trial investigators ensured that subjects performed the exercise correctly by placing at least one foot on or over the lines marking the 20 m distance. The same procedures were used during the field hockey skill test. Subjects were able to gauge their required running speeds by following an amplified audio signal generated from a microcomputer (BBC). During the sprints and field hockey skill test, subjects were verbally encouraged to perform maximally. Sprint times over 15 m were measured using 2 infra-red photo electric cells connected to the microcomputer.

Heart rate was continuously monitored throughout each trial using short-range telemetry (5 s sampling, Vantage NV, Polar Electro Fitness Technology). Rating of perceived exertion, using the Borg scale (1962) and perceived thirst using a 10 point scale from ‘not thirsty’ to ‘very very thirsty’, and thermal comfort (adapted from Young et al. 1987 using a 21 point scale) were recorded prior to the 11th sprint in each exercise set. A 10 ml blood sample was collected from each subject between the sets of exercise and before and after each skill test. Rectal temperatures were measured using a probe and logger (Edale Instruments Ltd.) before the 4th and 8th sprint of each set and prior to, and post each skill test. When rectal temperatures were measured, subjects were stationary for the equivalent time of 40 m of the 60m walk prior to the sprint.

Blood sampling and analysis

Three ml of blood was dispensed into an EDTA tube and aliquots were used for determination of haematocrit and haemoglobin concentration (by microcentifugation and the cyanmethaemoglobin method respectively). Changes in plasma volume (%) were estimated using the method of Dill and Costill (1974). One ml of blood was immediately analysed for blood glucose and lactate concentrations using a fully automated machine (Yellow Springs Instruments Ltd. Stat 2300 Plus). One ml of blood was dispensed immediately into a calcium-heparin tube, centrifuged for 3 min at 12,000 $rev.min^{-1}$ and the plasma frozen at -70^{o}C. Ammonia concentration was determined within 24 h using a commercially available kit (Sigma Diagnostics). The remaining blood was centrifuged for 15 min at 6000 $rev.min^{-1}$ at ~3^{o}C. The resulting plasma was then stored at -20^{o}C.

The remaining blood was allowed to clot for 1 h in a plain tube (Serum Z/5 ml, Sarstedt). This was centrifuged at 3^{o}C for 15 min at a speed of 6000 $rev.min^{-1}$ (Burkard Koolspin), and the reulting serum stored at –70^{o}C for the determination of progesterone, aldosterone and cortisol concentrations by using commercially available radio immunoassay kits (Diagnostic Products Corporation). The progesterone assay has a sensitivity of 0.06 $nmol.l^{-1}$, an intra-assay coefficient of variation (CV) of 2.7-8.8% and an inter-assay CV of 3.9-9.7%. The aldosterone assay has a sensitivity of 44.4 $pmol.l^{-1}$, an intra-assay CV of 2.7-8.3% and an inter-assay CV of 3.9-10.4%. The cortisol assay has a sensitivity of 11.5 $nmol.l^{-1}$, an intra-assay CV of 3.0-5.1% and an inter-assay CV of 4.0-6.4%.

Statistical analyses

A two-way (condition and time) analysis of variance with repeated measures was used to establish if any significant differences existed between subject response in terms of physiological and metabolic parameters to the performance of the LIST and the field hockey skill test in the two different environmental conditions. Where necessary, significant differences in the way subjects responded to the LIST and the skill test in the 2 conditions were located using Post-hoc Tukey tests. A students t-test was also used to assess differences in body mass, sweat rate, plasma volume change and fluid ingestion. Data are presented as means ± standard error of the mean ($s_{\bar{x}}$) and are based on a subject sample of 9 unless otherwise stated. Statistical significance is at the $P<0.05$ level.

Results

When subjects performed the field hockey skill test following a warm up, but prior to any intermittent running, the time taken to complete the test was not different when performances in hot and moderate conditions were compared. Field hockey skill performance declined following 30 and 60min of the LIST compared with pre-LIST in both the hot and moderate condition (main effect time $P<0.01$, $F_{2, 16} = 7.5$). This decrement in performance was compounded in the hot environment with a 6% poorer performance in the heat recorded for the 2nd skill test (main effect trial $P<0.05$, $F_{1, 8} = 8.0$; Figure 1). However, no difference was found in the 'decision making' element of the skill test (Table 1).

Three subjects were unable to complete the full distance in the hot environmental condition, whereas only 1 subject failed to complete the moderate trial. However, there was no significant difference in the total distance completed which was 7442 ± 414 m and 7881 ± 196 m in the hot and moderate trials. Table 3 shows that subjects sprinted faster in the moderate trial than the hot trial (main effect trial $P<0.01$, $F_{1, 9} = 11.3$). The average time taken to complete the 15 m sprints increased during the first 3 sets of exercise in the hot and moderate trials (main effect time $P<0.01$, $F_{3, 27} = 14.0$; Table 2).

Figure 2 shows that rectal temperature was higher in the hot trial in comparison with the moderate trial (main effect trial $P<0.01$, $F_{1, 8} = 12.6$) and increased throughout the exercise period in both trials (main effect time $P<0.01$, $F_{15, 120} = 89.6$).

Body mass, as a percentage of resting body mass was well maintained in both environmental conditions (hot -0.57 ± 0.23 vs moderate -0.39 ± 0.25%). However, estimated sweat rate was 20% higher in the heat (hot 1.27 ± 0.10 vs moderate 1.05 ± 0.12 $l.h^{-1}$ $P<0.05$) and concurrently water consumption during the hot trial was also greater (hot 14.6 ± 1.7 vs moderate 12.3 ± 1.6 $ml·kg^{-1}·h^{-1}$ $P<0.05$).

Average heart rates were higher throughout exercise when the environmental conditions were hot (main effect trial $P<0.05$, $F_{1, 8} = 8.0$; Figure 3). Perceived exertion and perceived thirst were higher during the hot trial than the moderate trial (main effect trial $P<0.05$, RPE $F_{1,8} = 5.7$, thirst $F_{1,8} = 21.3$; Table 3). Similarly, there was a tendency for a greater feeling of thermal stress during the hot trial (main effect trial $P=0.05$, $F_{1,8} = 5.3$; Table 4).

Blood glucose concentrations were similar at rest and following the first skill test, however with the onset of intermittent running glucose concentrations increased to a higher concentration in the heat (interaction trial x time $P<0.01$, $F_{7,56} = 3.7$; Figure 4). Blood lactate concentrations were not different between trials but were elevated above resting values throughout exercise and were further elevated following the performance of the field hockey skill test (main effect time $P<0.01$, $F_{7,56} = 45.8$; Figure 5).

Plasma ammonia concentrations were similar at rest, but increased so that at the end of the first set of LIST, the concentration was significantly higher in the moderate environment (interaction trial x time $P<0.01$, $F_{7,56} = 2.6$; hot 46.9 ± 7.8 vs moderate 68.7 ± 7.4 $\mu mol \cdot l^{-1}$). Throughout the remaining exercise period the plasma ammonia concentration was similar for both trials, attaining a plateau at approximately 50 $\mu mol \cdot l^{-1}$.

Plasma volume changes were not different between the hot and moderate trials. The change in plasma volume was -10.3 ± 3.1 and $-7.1 \pm 1.9\%$ at the end of the hot and moderate trials respectively. Plasma volume decreased significantly following each of the skill tests from pre skill test values (main effect time $P<0.01$).

Serum progesterone concentrations were not different between trials confirming similar menstrual status in both trials (hot 10.58 ± 4.70 vs moderate 11.00 ± 4.94 $nmol.l^{-1}$). Serum cortisol concentrations and increases in concentration from rest were similar in both environmental conditions and remained above rest (rest; hot 766 ± 126 vs moderate 640 ± 67 $nmol.l^{-1}$) throughout exercise (main effect time P<0.01, $F_{7, 56}$ = 8.6; end; hot 1206 ± 141 vs moderate 1034 ± 129 $nmol.l^{-1}$). Serum aldosterone concentrations were similar at rest and increased during the exercise period (main effect time P<0.01, $F_{7, 56}$ = 38.7). The rate of rise was faster in the hot condition such that there was a higher aldosterone concentration at the end of exercise in the hot trial (interaction trial x time P<0.01, $F_{7, 56}$ = 3.4; hot 2223 ± 348 vs moderate 1746 ± 217 $pmol \cdot l^{-1}$).

Discussion

The main findings of the present study were that hockey skill test performance was decreased following prolonged intermittent high intensity running and that the decrement in performance was greater in the hot environment. However, ‘decision making’ times were not different following prolonged intermittent high intensity running and were not different between environmental conditions. Deep body temperature, heart rate, rating of perceived exertion, perceived thirst and blood glucose and serum aldosterone concentrations were significantly higher in the hot trial compared to the response seen in the moderate trial. Repeated 15 m sprint performance was slower when the environmental conditions were hot. Blood lactate, and serum cortisol concentrations did not differ between the hot and moderate trials.

The LIST interspersed with the field hockey skill test reflected the demands of a field hockey match. The skill test has previously been shown to be a valid measure of field hockey skill (Sunderland et al., 2003). The performance of the hockey skill test resulted in a rapid rise in blood lactate concentration to ~9-10 $mmol.l^{-1}$ which was higher than that found immediately after a match (5.6 $mmol.l^{-1}$) or training (7.7 $mmol.l^{-1}$) in Indian senior players, but the concentration during the LIST (5.1 $mmol.l^{-1}$) was representative of that during a hockey match (Ghosh et al., 1991). Furthermore the heart rate ranges (moderate 158-198 $beats.min^{-1}$) during the trials were representative of those seen in field hockey matches (161-189 $beats.min^{-1}$; Lothian and Farrally, 1992) suggesting that the LIST was fairly representative of the physiological demands of field hockey. The higher blood lactate concentration following the skill test may be due to the long period dribbling the ball (~8 s). Lothian and Farally (1992) found the majority of hockey related activity (time spent directly involved with the ball) to take place within 2 s and Wein (1981) indicated that 61% of the time on the ball lasted from 0.5 to 2.0 s with only 5% lasting longer than 7 s. Nevertheless, during competitive soccer matches blood lactate concentrations above 12 $mmol.l^{-1}$ have been recorded. Thus, the blood lactate concentrations in the current study do not seem unduly high in comparison with values during match play.

In the present study subjects were dehydrated by 0.57 and 0.39% of pre-exercise body mass in the hot and moderate trials, respectively. Previous studies have suggested that decrements in skill performance and cognitive functioning following exercise in hot or moderate conditions are due to dehydration (Gopinathan et al., 1988; McGregor et al., 1999). McGregor et al. (1999) performed a soccer skill test prior to and following 90 min of prolonged intermittent high intensity running or 6 sets of LIST and showed that when subjects were dehydrated by 2.4% of body mass, there was a decrement in skill performance of 5%. In contrast, following a soccer match in a hot environment ($27^{o}C$), performance on a skill test has been shown to decline similarly in players who were hyperhydrated (4.6 $l.day^{-1}$) and voluntary hydrated (2.7 $l.day^{-1}$) for 1 week prior to the match, even though their total body water content was higher and their thermoregulation was improved in comparison to the voluntary hydrated players (Rico-Sanz et al., 1996). It could be suggested that in the study of Rico-Sanz (1996) the subjects in both hydration states may have been sufficiently dehydrated to reduce skill performance as body mass decreases of >2.5% were recorded and it has been suggested that decreases of only 2% can effect exercise performance and capacity (Armstrong et al., 1985; Sawka, 1992).

In the current study, it seems unlikely that the subjects were dehydrated. This observation was due to the ingestion of 1.00 ± 0.12 and 0.84 ± 0.11 $l \cdot h^{-1}$ of water during exercise in the hot and moderate trials respectively. Furthermore, it has been suggested that in team sports for the prevention of dehydration water intake should be one half of the individual's sweat rate (Gisolfi and Duchman, 1992). For both the hot and moderate trials fluid intakes of 75% of sweat rates were recorded. Furthermore serum aldosterone concentrations were only different between the two environmental conditions at the end of exercise, suggesting that dehydration levels did not differ (Montain et al., 1997). In previous studies in this laboratory, performance of the LIST has been investigated in hot (~30^{o}C, 26% RH) and moderate (~15^{o}C, 54% RH) conditions with and without fluid replacement (Morris et al., 1998b). In comparison to the moderate fluid trial, performance in terms of distance run were 2, 23 and 35% lower in the moderate, no fluid, hot fluid and hot no fluid trials respectively. Osmolality and sodium concentrations were higher and rectal temperatures and heart rates higher in the 'no water' trials, clearly demonstrating that in the water trials, the water was being absorbed from the stomach, helping to attenuate the thermoregulatory strain of exercising in the heat. Thus it is likely that dehydration did not affect hockey skill performance in the current investigation.

During intermittent sports such as hockey, glycogenolysis is the major metabolic pathway by which energy is transferred to exercising muscles, thus performance is partially dependant upon glycogen stores. Not surprisingly therefore, depletion of muscle glycogen has also been suggested to decrease skill test performance (Rico-Sanz et al., 1996; McGregor et al., 1999) with low muscle glycogen concentrations being recorded after soccer matches (Jacobs et al., 1982; Leatt & Jacobs, 1988). In previous studies in this laboratory muscle glycogen concentrations that have still been high (180 - 190 mmol·kg dry mass^{-1}) following 100 min of the LIST in a hot environment (Morris et al. 1999) and after 90 min (6 sets) in moderate conditions (Nicholas et al., 1999). As the total exercise time in the present study was approximately 70 min, it is unlikely that the subjects were glycogen depleted. This suggestion is supported by the significant decline in skill after only the first 2 sets of the LIST (30 min). Furthermore, blood lactate concentrations have been suggested to be representative measures of whether or not the rate of energy transferred from glycogen breakdown has decreased as a result of low glycogen concentrations (Jacobs, 1988). In the present study blood lactate concentrations did not differ between trials during the LIST or following the performance of the field hockey skill test. However, it should be recognised that blood lactate concentrations only represent a balance between the appearance and disappearance of blood lactate rather than the actual concentration. The similar concentrations recorded after the field hockey skill test suggest that there was no difference in rate of glycogenolysis rate during the skill tests or between the two environmental conditions. Therefore, while glycogen concentrations were not measured, it seems unlikely that glycogen depletion occurred in the current study and thus does not seem to be the reason for the decline in skill performance observed.

The similar increase in blood lactate concentrations during the three hockey skill tests and across both environmental conditions suggests that the further decline in skill in the heat and within trials was not due to the build up of acid metabolites. Impaired skill performance may be due to an accumulation of acid metabolites (Carron, 1972), though the results in the present study cannot be attributed to this.

Hypoglycaemia has been associated with a decrease in soccer skill performance as the central nervous system is dependent upon glucose for its metabolism (Shephard and Leatt, 1987). Carbohydrate supplementation has been shown to reduce the deterioration in stroke performance in tennis following a 2 h training session. Although the exact mechanism for this attenuation was unclear, blood glucose concentrations may have been better maintained (Vergauwen et al., 1998). In the present study, blood glucose concentrations were higher in the hot environment compared to the moderate and were maintained above rest throughout. Thus, it seems clear that hypoglycaemia is not the source of the poorer skill performance in the current study in either the hot or the moderate trial.

‘Decision making’ times in the three skill tests did not differ during the time course of each trial and were not affected by the two environmental conditions. Very few researchers have examined the effect of exercise on cognition or psychomotor ability and of these, the relevance of the findings in these studies with respect to the present study which investigated skill performance during 60 min of prolonged intermittent high intensity running is questionable. Nevertheless, Hammerton (1971) suggested that exercise did not affect cognition, but he only used 400 s of submaximal exercise. Sjoberg (1980) investigated training status and found no difference in psychomotor ability or cognition between the two groups at various exercise intensities. Also, it has been suggested by Reilly and Smith (1986) that an inverted-U relationship exists between exercise intensity and cognitive task ability. Whilst cycling at intensities ranging from 25-85% $\dot{V}O_2$ max, individuals completed an arithmetic adding task in the study by Reilly and Smith (1986). Cognitive function was attenuated at the lowest and highest intensities and was estimated to be optimised at 44% $\dot{V}O_2$ max. In the present study, the exercise intensity during the skill test did not change. The observation of no difference in 'decision making' time is therefore consistent with the findings of Hammerton (1971), Sjoberg (1980) and Reilly and Smith (1986).

Hockey skill performance was poorer in the heat than in moderate environmental conditions. Sport-specific skill performance has previously been shown to be significantly impaired due to heat stress in a study on tennis players (Dawson et al., 1985). Dawson et al. (1985) completed a comparison of tennis skill following a 1 h match in moderate conditions (23^{o}C 64% RH) and following 1 h intervalised treadmill running (which was supposed to mimic the tennis game in moderate conditions) in hot conditions (35^{o}C 65% RH). Skill performance was measured in terms of service, groundstroke and volley power and accuracy. Heat stress resulted in a 19, 26 and 14% decrement in service, groundstroke and volley performance. This decrement in performance was attributed partially to the greater cardiovascular and thermoregulatory strain experienced by the subjects. The decrements in performance were similar to those in the present study, but the tennis study has numerous limitations. Though the treadmill running was designed to represent the work – rest patterns of the match (by heart rate matching), it did not include turning, moving backwards or sidewards or postural changes that are seen in the match. Thus the total work and muscle fibre type recruitment will have differed markedly between the match and the intervalised treadmill running. Furthermore, players were allowed to ‘knock up’ after the treadmill run in the heat, during which time rectal temperatures would have been decreasing. Thus, the thermal strain prior to the skill tests was unknown and could not be compared.

The responses in the current study of a higher rectal temperature and a decline in sprint performance in the hot compared to the moderate trial are consistent with previous research relating to prolonged intermittent high intensity running in the heat (Morris et al., 1998a; Morris et al., 1998b; Morris et al., 1999). The rectal temperature at the end of the LIST was 39.0 ± 0.1 ^{o}C in the moderate trial and 39.6 ± 0.1 ^{o}C in the hot trial. The greater thermal strain on the subjects may partially explain the poorer skill performance in the heat. A critically high deep body temperature has been suggested to induce reductions in the motivation or ‘drive’ to exercise (Nielsen et al., 1993). Motivation, however, is difficult to define and therefore to test for. The subjects in the current study perceived the exercise to be harder in the heat and tended to feel less comfortable, which may have impacted on their motivation. Field hockey relies heavily on motivation, as individuals self-determine the pace adopted and distances covered in a match. Furthermore a high deep body temperature has been suggested to be the key factor inducing the earlier onset of exhaustion in hot environmental conditions (Nielsen et al., 1993). The high body temperature may have a physiological impact on brain serotonergic activity (Marvin et al., 1998), muscle function or metabolism (Gonzalez-

Alonso et al., 1999), cardiovascular strain and/ or some other mechanism that remains to be elucidated. It seems likely that a higher rectal temperature and thus greater thermoregulatory strain in the heat is associated with the poorer skill performance and 15m sprint performance. The high rectal temperature (>39°C) during the moderate trial may also partially explain the decline in skill performance following the LIST.

The results of the present study show that field hockey skill performance is decreased following 30 and 60 min of intermittent, high intensity shuttle running and that this decrease is greater in hot environmental conditions. A greater thermoregulatory strain, reflected by a higher deep body temperature and heart rate, may partially explain the poorer performance in the heat and following the LIST. However, the exact mechanism for this decrement in performance remains to be elucidated but is unlikely to be due to low glycogen concentration or dehydration as skill declined after only 30 min.

References

Armstrong, L. E., Costill, D. L. and Fink, W. J. (1985). Influence of diuretic-induced dehydration on competitive running performance. *Medicine and Science in Sports and Exercise*, **17**, 456-61.

Borg, G. (1962). *Physical Performance and Perceived Exertion.* Lund, Gleerup.

Brisswalter, J., Collardeau, M. and Réne A. (2002) Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine,* **32**, 555-566.

Burke, L. M. (1997). Fluid balance during team sports. *Journal of Sports Sciences,* **15**, 287-95.

Buskirk, E. R. (1977). Temperature regulation with exercise. *Exercise and Sport Sciences Reviews,* **5**, 45-88.

Carron, A. V. (1972). Motor performance and learning under physical fatigue. *Medicine and Science in Sports and Exercise,* **4,** 101-106.

Dawson, B., Elliot, B., Pyke, F. and Rogers, R. (1985). Physiological and performance responses to playing tennis in a cool environment and similar intervalised treadmill running in a hot climate. *Journal of Human Movement Studies,* **11**, 21-34.

Dill, D. B. and Costill, D. L. (1974). Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *Journal of Applied Physiology,* **37**, 247-8.

Febbraio, M. A., Snow, R. J., Stathis, C.G., Hargreaves, M. and Carey, M.F. (1994). Effect of heat stress on muscle energy metabolism during exercise. *Journal of Applied Physiology*, **76**, 2827-2831.

Fox, E. L. (1984). *Sports Physiology*. Philadelphia, Saunders College Pub.

Ghosh, A. K., Goswami, A., Mazumdar, P. and Mathur, D. N. (1991). Heart rate and blood lactate response in field hockey players. *Indian Journal of Medical Research Section B - Biomedical Research Other than Infectious Diseases,* **94,** 351-356.

Gisolfi, C. V. and Duchman, S. M. (1992). Guidelines for optimal replacement beverages for different athletic events. *Medicine and Science in Sports and Exercise*, **24,** 679-87.

Gonzalez-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T. and Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *Journal of Applied Physiology*, **86,** 1032-1039.

Gopinathan, P. M., Pichan, G. and Sharma, V. M. (1988). Role of dehydration in heat stress-induced variations in mental performance. *Archives of Environmental Health,* **43**, 15-17.

Hammerton, M. (1971). Violent exercise and a cognitive task. *Ergonomics* **14**: 265-267.

Hargreaves, M., Angus, D., Howlett, K., Conus, N. M. and Febbraio, M. (1996). Effect of heat stress on glucose kinetics during exercise. *Journal of Applied Physiology,* **81,** 1594-1691.

Jacobs, I. (1988). Nutrition for the elite footballer. In *Science and Football*. (edited by T. Reilly, L. A., K. Davids and W. J. Murphy), pp. 23-32. London: E. and F.N. Spon.

Jacobs, I., Westlin, N., Karlsson, J., Rasmusson, M. and Houghoton, B. (1982). Muscle glycogen and diet in elite soccer players. *European Journal of Applied Physiology***, 48**, 297-302.

Leatt, P. B. and Jacobs, I. (1988). Effect of a liquid glucose supplement on muscle glycogen resynthesis after a soccer match. In *Science and Football.* (edited by T. Reilly, L. A. K. Davids and W. J. Murphy), pp. 42-47. London: E. and F.N. Spon.

Lothian, F. and Farrally, M. (1992). Estimating the energy cost of women's hockey using heart rate and video analysis. *Journal of Human Movement Studies,* **23**, 215-231.

Lothian, F. and Farrally, M. (1994). A time-motion analysis of women's hockey. *Journal of Human Movement Studies,* **26**, 255-265.

Marvin, G., Nobbs, L., Sharma, A. and Jones, D. A. (1998). Hypothalmic thermoreceptors and central fatigue. *Proceedings of the Third Annual Congress of the European College of Sport Science*, Manchester.

McGregor, S. J., Nicholas, C. W., Lakomy, H. K. A. and Williams, C. (1999). The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. *Journal of Sports Sciences,* **17**, 895-903.

Montain, S. J., Laird, J. E., Latzka, W. A. and Sawka, M. N. (1997) Aldosterone and vasopressin responses in the heat: hydration level and exercise intensity effects. *Medicine and Science in Sports and Exercise,* **29**, 661-668.

Morris, J. G., Nevill, M. E., Boobis, L. H., Williams, C. and Macdonald, I. A. (1999). Muscle metabolism and temperature during prolonged, intermittent, high intensity running at ~33 and ~17^{o}C. *Journal of Physiology* **515P**, 69P-70P.

Morris, J. G., Nevill, M. E., Lakomy, H. K. A., Nicholas, C. and Williams, C. (1998a). Effect of a hot environment on performance of prolonged, intermittent, high-intensity shuttle running. *Journal of Sports Sciences* **16,** 677-686.

Morris, J. G., Nevill, M. E., Riddell, C. and Williams, C. (1998b). Effects of water or no water on performance and physiological responses to prolonged, intermittent, high-intensity running at ~30 and ~15 ^{o}C. *Journal of Physiology* **506P**, 104P-105P.

Nicholas, C. W., Nuttall, F. E. and Williams, C. (2000). The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. *Journal of Sports Sciences* **18,** 97-104.

Nicholas, C. W., Tsintzas, K., Boobis, L. and Williams, C. (1999). Carbohydrate-electrolyte ingestion during intermittent high-intensity running. *Medicine and Science in Sports and Exercise,* **31,** 1280-1286.

Nicholas, C. W., Williams, C., Lakomy, H. K., Phillips, G. and Nowitz, A. (1995). Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. *Journal of Sports Sciences***, 13**, 283-90.

Nielsen, B., Hales, J. R. S., Strange, S., Christensen, N. J., Warberg, J. and Saltin, B. (1993). Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *Journal of Physiology*, **460**, 467-485.

Ramsbottom, R., Brewer, J. and Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *British Journal of Sports Medicine,* **22**, 141-144.

Reilly, T. and Brooks G. A. (1986) Exercise and the circadian variation in body temperature measures. *International Journal of Sports Medicine,* **7**, 358-62.

Reilly, T. and Smith, D. (1986). Effect of work intensity on performance in a psychomotor task during exercise. *Ergonomics,* **29**, 601-606.

Rico-Sanz, W. R., Frontera, W. R., Rivera, M. A., Rivera-Brown, A., Mole, P. A. and Meredith, C. N. (1996). Effects of hyperhydration on total body water, temperature regulation and performance of elite young soccer players in a warm climate. *International Journal of Sports Medicine***, 17**, 85-91.

Sawka, M. N. (1992). Physiological consequences of hypohydration: exercise performance and thermoregulation. *Medicine and Science in Sports and Exercise*, **24**, 657-70.

Shephard, R. J. and Leatt, P. (1987). Carbohydrate and fluid needs of the soccer player. *Sports Medicine,* **4**, 164-76.

Shi, X. and Gisolfi, C. V. (1998). Fluid and carbohydrate replacement during intermittent exercise. *Sports Medicine,* **25**, 157-72.

Sjoberg, H. (1980). Physical fitness and mental performance during and after work. *Ergonomics*, **23**, 977-85.

Sunderland, C., Cooke, K., Milne, H., Pout, M. and Nevill, M. (2003) Reliability and validity of a field hockey skill test. *Journal of Sports Sciences*, **21**, 289-290.

Vergauwen, L., Brouns, F. and Hespel, P. (1998). Carbohydrate supplementation improves stroke performance in tennis. *Medicine and Science in Sports and Exercise*, **30**, 1289-95.

Wade, C. E. and Freund, B. J. (1990). Hormonal control of blood volume during and following exercise. In *Perspectives in Exercise Science and Sports Medicine* (edited by C. V. Gisolfi and D. R. Lamb). **3,** pp. 207-245. Carmel: Cooper Publishing Group.

Wein, H. (1981). *The Advanced Science of Hockey*. London: Pelham.

Yaspelkis, B. B., 3rd, Scroop, G. C., Wilmore, K. M. and Ivy, J. L. (1993). Carbohydrate metabolism during exercise in hot and thermoneutral environments. *International Journal of Sports Medicine,* **14**, 13-19.

Young, A. J., Sawka, M.N., Epstein, Y., Decristofano, B., and Pandolf, K.B. (1987) Cooling different body surfaces during upper and lower body exercise. *Journal of Applied Physiology,* **63**, 1218-1223.

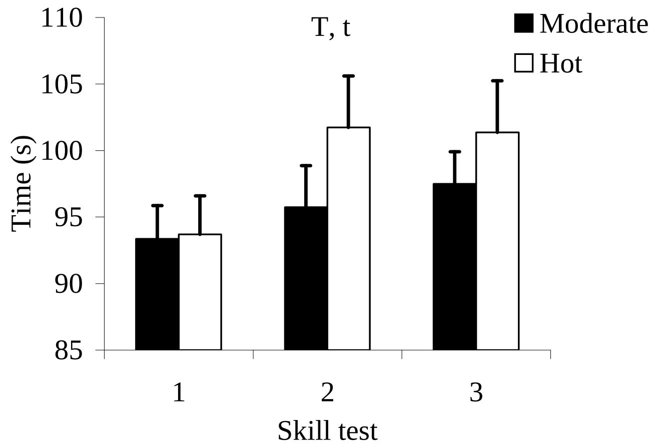

Figure 1 Skill test performance during the hot and moderate trials; T = main effect trial $P<0.05$, $F_{1, 8} = 8.0$; t = main effect time $P<0.01$, $F_{2, 16} = 7.5$.

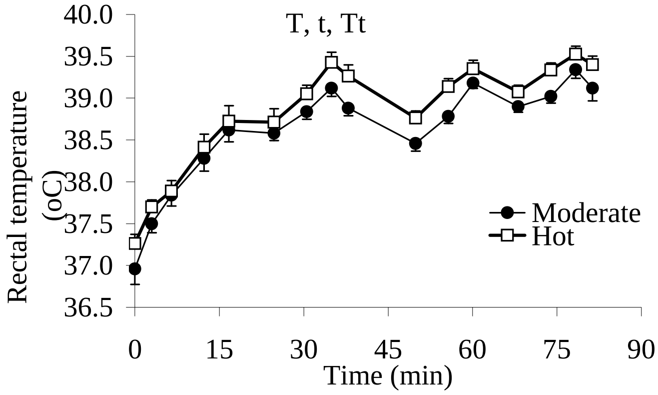

Figure 2 Rectal temperature during the hot and moderate trials; T = main effect trial P<0.01, $F_{1, 8}$ = 12.6; t = main effect time P<0.01, $F_{15, 120}$ = 89.6; Tt = interaction trial x time P<0.01, $F_{15, 120}$ = 3.4.

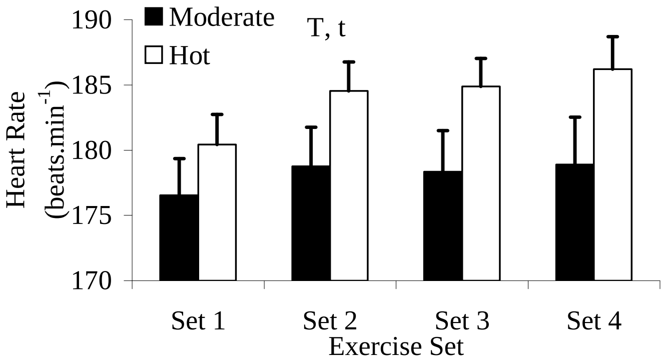

Figure 3 Mean heart rate during the hot and moderate trials; T = main effect trial $P<0.05$, $F_{1,8} = 8.0$; t = main effect time $P<0.01$, $F_{3,24} = 5.1$.

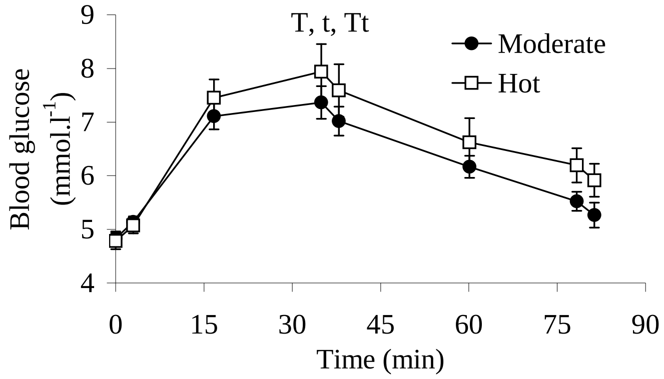

Figure 4 Blood glucose concentrations during the hot and moderate trials; T = main effect trial P<0.05, $F_{1,\,8}$ = 8.1; t = main effect time P<0.01, $F_{7,\,56}$ = 22.7; Tt = interaction trial x time P<0.01, $F_{7,\,56}$ = 3.7. mmol·l^{-1}

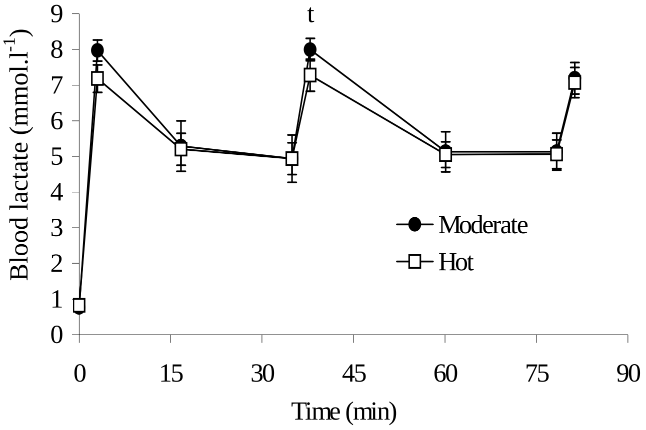

Figure 5 Blood lactate concentrations during the hot and moderate trials; t = main effect time $P<0.01$, $F_{7, 56} = 45.8$.

Table 1 ‘Decision making’ time for the skill test during the hot and moderate trials.

Time (s)	**Skill test**		
	1	**2**	**2**
Moderate	4.37 ± 0.09	4.59 ± 0.20	4.47 ± 0.10
Hot	4.39 ± 0.11	4.67 ± 0.22	4.68 ± 0.21

Table 2 Fifteen metre sprint times during the LIST in the hot and moderate environmental conditions; T = main effect trial $P<0.01$, $F_{2, 16} = 7.5$; t = main effect time $P<0.01$, $F_{3, 27} = 14.0$; Tt = interaction trial x time $P<0.05$, $F_{3, 27} = 8.3$.

Time (s)	**Set 1**	**Set 2**	**Set 3**	**Set 4**
Moderate	2.78 ± 0.04	2.82 ± 0.05	2.87 ± 0.05	2.85 ± 0.04
Hot	2.81 ± 0.03	2.95 ± 0.06	3.08 ± 0.07	3.09 ± 0.08
			T, t, Tt	

Table 3 Perceived ratings of exertion, thirst and thermal comfort during the hot and moderate trials; T = main effect trial $P<0.05$, $F_{1, 8} = 5.7$; T* = main effect trial $P<0.01$, $F_{1, 8} = 21.3$; t = main effect time $P<0.01$, RPE $F_{3, 24} = 40.8$, thirst $F_{3, 24} = 9.7$; Tt = interaction trial x time $P<0.01$, $F_{3, 24} = 5.9$.

	Set 1	**Set 2**	**Set 3**	**Set 4**
Rating of perceived exertion				
Moderate	13 ± 1	14 ± 1	15 ± 1	16 ± 1
Hot	13 ± 1	16 ± 1	17 ± 1	18 ±1
			T, t, Tt	
Perceived thirst				
Moderate	4 ± 0	5 ± 0	5 ± 0	6 ± 0
Hot	6 ± 0	7 ± 0	7 ± 1	8 ±1
			T*, t	
Perceived thermal comfort				
Moderate	3 ± 1	3 ± 1	3 ± 1	1 ± 2
Hot	4 ± 1	4 ± 1	4 ± 1	2 ± 2