Water Intake and Urine Output During a 194-Kilometre Unsupported Desert March

British troops are required to deploy rapidly to environments that expose them to high levels of heat stress, with limited natural sources of water upon which to survive. Potable water must therefore be supplied by military logistics to reduce the risk of heat illness and degraded physical and mental performance caused by dehydration. Mathematical models can be used to predict water requirements for desert operations, but they often provide estimates that exceed military guidelines (15 litres per man per day) [1] [2]. This study measured the amount of water consumed during a simulated military operation in a hot, desert environment to compare the need with military guidelines [1] [3]. Methods: 5 men (mean (1 SD) aged 41.8 (9.1) years; body mass 81.1 (6.8) kg; body fat (bioimpedance) 17.8 (3.1) %) consented to participate in this Ethics Committee approved study. A 194-km desert march was conducted along the length of Qatar. Mean hourly dry-bulb temperature during the march was 25 (4)°C, and relative humidity averaged 48 (17) %. All water, food (high-energy bars and High5 carbohydrate-electrolyte energy source) and equipment was transported in two, 2-wheeled carts (total load including carts was 320 kg). The rate of oxygen uptake when pulling the carts in temperate conditions in the UK was measured using a portable expired gas analyser (Cosmed K4b^2). This rate was then used during cycle ergometer exercise in controlled conditions (dry-bulb and globe temperatures 40°C; relative humidity 50%; airspeed 1ms^{-1}) to estimate the amount of water needed for the expected 60 hour march. A 50 litre per person water budget was allowed. Following a 6-day heat acclimatisation phase in Qatar, subjects began the march hydrated. Body mass was recorded every 6 hours. The mass of water and food intake, urine and faeces output was recorded throughout the march. Other measurements were: heart rate (HR) (every 15s, from which HRreserve was calculated); gastrointestinal temperature (Tgi) (every 10s); and ankle and wrist activity (every 2s). Total body water (TBW) and body fat (%) were recorded by bioimpedance immediately pre- and post-march. Paired data were compared using a t-test. Results: Four of five subjects completed the march in 78 hours. Physical activity (mean relative intensity 58 (7) % of HRreserve) was recorded during 74 of the 78 hours. A total of 46.0 (10.5) MJ were consumed. Water intake was 34.7 (6.4) litres; 2.9 (0.6) litres of urine were excreted. TBW increased by 0.3 (0.4) litres (range of 0.8 to 1.5%) compared with pre-march values ($p<0.05$). Mean Tgi was 38.1 (0.6)°C; occasionally it rose above 39.3°C. Fat mass declined ($p<0.05$) by 3.4 (1.0) kg, accounting for the loss in total body mass of 3.3 (1.6) kg. Conclusions: Daily consumption of up to 11 litres of water per man was sufficient to maintain hydration when working at up to 58% HRreserve during this prolonged, self-sufficient desert march. These data support the existing military guidelines for the provision of potable water [18].

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Introduction

Since the end of the Cold War British troops have been deployed in a number of quite diverse environments to conduct a wide range of roles. Military operations are no longer limited to those extremely cold conditions experienced during the Falklands conflict (1982). During the last 10 years deployed personnel have been required to maintain high levels of operational effectiveness to combat a relatively new threat in the predominantly hot climates of Kuwait, Iraq, Oman, and Sierra Leone. The rapid changes in environmental conditions experienced during the low-to-high-altitude operations in Afghanistan have posed a further threat to the well-being of British troops since the terrorist activities observed on September 11 2001.

Military operations

Irrespective of the nature and location of the deployment, military operations and training exercises have always been recognised to be very physically demanding (with personnel expending energy at a rate of 11.3 [lowest] to 45.9 [highest] MJ.day^{-1} [5]). The ability to meet the nutritional requirements of troops during military operations can determine the successful outcome of their mission and indeed the success of the entire campaign. Water is a critical requirement without which no military force can operate effectively. There is a need to identify how much water is required by troops in order to allay the onset of performance-degrading dehydration and the risk of heat illness.

Ruby *et al* 2003 [6] have shown that during arduous and extended assignments, euhydration and energy balance are challenged when total energy expenditure increases to more than 3.6 times the basal metabolic rate. Large decreases in total body water (TBW) and energy balance have been demonstrated during studies of military exercises in hot conditions. Mudambo *et al* 1997 [7] reported a 3.0 (SD 0.1) kg loss in body mass, attributed mostly to a loss in TBW during a 12-day exercise in the African bush. Similarly energy balance has often been compromised in extreme exposure to cold stress [8] during tasks which are representative of military operations. However, the greatest losses in body mass for work scenarios that are representative of military operations have been reported [6] when personnel are exposed to a combination of:

- elevated ambient temperature;
- rough terrain;
- sustained high levels of total daily energy expenditure (TDEE).

Furthermore the authors believed that during active wildfire suppression, TDEE was mostly influenced by the terrain and the duration of each daily shift. The physical demands associated with pulling a line and transporting heavy loads during wildfire suppression was believed to contribute significantly to TDEE and subsequently result in a negative energy balance and loss in TBW. Interestingly the fire-fighters who operated during these wildfire suppression scenarios were seen to ingest a minimum of 6.0 to 8.0 litres of potable water (maximum 9.6 litres) for each of the 5 days that they fought the wildfire.

High daily levels of TDEE are not the sole domain of high-intensity physical activities. Moderate or low intensity work that is sustained over a prolonged period (this can often be achieved in contrast to the high intensity work) is often reported to result in the greatest TDEE [8] [11] and hence present the greater risk when considering the effect on TBW and energy balance [2] [6].

Qatar

Qatar is a peninsula in the Middle East which borders the Persian Gulf and Saudi Arabia (25°15'N 51°34'E). It has 11,437km^2 of land that is mostly flat and barren desert covered with loose sand and gravel, and 563km of coastline. The lowest point in Qatar is found at the point with the Persian Gulf (0m) whilst the highest point is located near to the border with Saudi Arabia at Qurayn Abu al Bawl (103m above sea level). Qatar hosted the central headquarters for the American forces during Operation Telic (2003). The nature of the terrain and the characteristics of the environment are very similar to those encountered by British and American Forces during military operations that have been conducted over the past decade.

Predicting the requirement for water

It is important to know how much water personnel need to drink in order to avoid the risks that are associated with dehydration. However, robust and valid mathematical models that have been established following the input of many years of highly relevant, empirical data (from scientific studies with military personnel) are rarely used by military planners to calculate this requirement. Some reports that have utilised such mathematical models have shown that the British military's previous daily, upper limit of 15 litres of potable water issued to each person [1] can often be exceeded for typical operational scenarios [2]. This study applied the predictions provided by the QinetiQ Human Limits Prediction System [12] to determine the requirement for water during the march along the length of Qatar.

Study objective

The aim of the study was to identify the quantity of water that was required by a small team to successfully complete a prolonged march in a hot desert environment without re-supply. It was also the intention to monitor those variables that may serve to explain the subsequent results. This information will assist military logistics to determine the necessary volume of water with which to provide personnel who conduct such a march in the future.

Methods

The subjects

Five men participated as subjects in this study (table 1), whilst a further two men (the 'safety crew') drove along the route at a distance of approximately 1km from the subjects throughout the march. Two of the subjects were serving members of the British Army (Corps of Royal Engineers), whilst a third subject had former service with the Royal Signals. One of the remaining subjects was a very experienced explorer and also a qualified practitioner of medicine. The final subject was an extremely experienced adventurer, despite being almost completely blind (98% visual impairment).

The march

The 194km march commenced by the military 'border post' which separated Saudi Arabia from Qatar at 10:00hrs (local time) 02 April 2002 (this will be referred to as 'M') and was completed 78 hours later at 16:00hrs (local time) on 05 April 2002 (M+78 hours) at Ar Ruwais (a point where the mainland ends and is met by the Persian Gulf, see figure 1). The five subjects transported everything that they needed to complete the march by hand and without the support of any other source. The provision of 50 litres of water per person, (providing a total of 250 litres of bottled water, contained within 125, 2 litre bottles) was transported within 2 portable handcarts (Charlie's Horse Ltd, USA) (one of the carts is shown in figure 1). Spare parts for the carts, food, protective clothing, a GPS navigation system, scientific monitoring equipment, and two sets of hiking poles (Makalu ultralite titanium air ergo PA AS Poles, LEKI™ Ltd) were contained within these carts. The total mass of the load that was transported by the subjects during the march was 320kg. The carts were constructed from 6061-T6 aluminium and were fully anodised with all stainless steel components, and their wheels were fibreglass-reinforced nylon with 440 stainless steel sealed bearings (with 16" x 2" micro-cellular urethane (non-pneumatic) tyres). The carts were transported separately, with 2 subjects assigned to each, at any given point during the march. One subject wore a harness which was connected to the front of the cart in order to provide a forward propulsive force (pulling), whilst the second pushed the cart from a point at its rear using the handles provided. With only two subjects on each cart, this afforded the fifth subject a period of 'active rest' whilst navigating (using the hand held GPS system). Throughout the march, and at regular intervals each subject performed each role on a rotation basis (ie pulling the cart; pushing the cart; walking alongside the cart whilst navigating). A 45 minute work, 15 minute rest schedule had been planned for the march. It had initially been expected that the march would be completed in 60 hours (ie $4km.hour^{-1}$ with a total period of 10 hours inactive rest).

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Left: One of the carts that was used to transport the water and food during the march. **Right**: The route that was taken by the subjects in Qatar.

A safety crew (composed of 2 men in 2 separate, air conditioned, 4 wheel-drive vehicles) accompanied the subjects at an agreed 1km distance, and were under instruction not to provide any unsolicited assistance to any subject during the march. The role of the safety crew was to provide visual and documented record and confirmation (using dictaphones, video cameras and a diary) of progress made throughout the march, to provide urgent medical support in the event of a casualty, and to provide the necessary liaison with the interested authorities in Qatar (ie the military, event sponsors and the media).

Pre-deployment preparation

Energy cost of transporting the carts

The energy cost of pushing handcarts has been investigated by a number of researchers in the past [13]. However: (a) the type of cart that was used by the subjects during this march; (b) the diverse nature of the desert terrain in Qatar; and (c) the various methods by which the cart could be transported, demanded a direct assessment of the energy cost to be conducted.

Following a 6-day reconnaissance trip to Qatar (conducted during September 2001) the military training areas at Long Valley and Hawley, UK were identified as appropriate locations to assess the energy cost of transporting the carts (using similar loads, distributed as intended during the march, and over the type of terrain that was evident in Qatar). Unpublished tests to assess the energy cost of pulling and pushing the carts (whilst the carts were loaded to their 'march' weight) were conducted by each subject using a portable breath-by-breath analyser (Cosmed $K4b^2$ system, Cosmed®, Italy).

Table 1

Subject	Age (years)	Height (metres)	Body mass (kg)	Body fat (%)	Total body water (litres) (estimated[1])
1	35.0	1.67	74.0	12.8	45.8
2	48.0	1.67	75.0	18.7	45.5
3	32.0	1.85	90.5	17.0	51.4
4	54.0	1.80	82.0	20.0	45.7
5	40.0	1.75	84.0	20.5	42.9
Mean	**41.8**	**1.75**	**81.1**	**17.8**	**46.3**
1 standard deviation	*9.1*	*0.08*	*6.8*	*3.1*	*3.1*

Descriptive data for the subjects (obtained prior to the march).

Heat familiarisation (UK)

Four of the subjects completed an initial 2 hour phase in the environmental chamber (25 March 2002: 'M'-190 hours) at QinetiQ two days before they were deployed to Qatar in order to familiarise themselves with the heat (conditions in the chamber were intended to reflect those that had been reported for Qatar at that time, which was 40°C dry bulb temperature; 50% relative humidity, air speed $1m.s^{-1}$). Subjects conducted 150W (external work) cycloergometry exercise over a 2 hour heat exposure within the chamber. Changes in body mass over this period were used to estimate sweat loss (table 2).

[1] Total Body Water (TBW) was estimated using measurements of bioimpendance.

Table 2

Subject	Sweat rate ($l.hour^{-1}$)
1	1.46
2	0.81
3	1.05
4	n/a
5	1.03
Mean	**1.09**
(1 standard deviation)	*(0.27)*

Pre-deployment sweat rates for subjects (unacclimatised to the heat) at M-142 hours conducting 150W cycloergometry for 2 hours under conditions of 40°C dry bulb temperature and 50% relative humidity.

Heat acclimatisation (Qatar)

Subjects arrived in Qatar 6 days (142 hours) prior to the start of the march. A daily 2 hour training session with full equipment was conducted under the heat of the mid-day sun (the carts and clothing were used as intended during the march, and at operational tempo) up until the day of the march itself. Subjects monitored their heart rate (using Polar® Vantage NV heart rate monitors at a 5-second sample rate) during these submaximal training sessions in the heat.

No other measures of adaptation to the heat were made during this period. It was assumed that the subjects would acquire a sufficient degree of acclimatisation to the heat as a result of the daily training sessions. Time was a limiting factor and it was not possible (for practical reasons) to extend the period that was allowed for heat acclimatisation.

Measurements

Body mass (BM)

Seca heavy duty analogue floor scales (Seca Ltd, UK) were used to measure body mass. Subjects were weighed immediately before the start of the march, at the end of the march and at 6 hourly intervals throughout the march. The scales were transported by the safety crew.

Body composition

Single frequency bioimpedance (z) analysis (200kHz) was performed with tetrapolar distal limb surface electrodes on each subject using a Bodystat1500 system (Bodystat®, Douglas, Isle of Man) to estimate total body water and relative body fat (% of total body mass). Total body water was calculated as follows (equation 1):

Equation 1

TBW (litres) = [(0.24517 x height^2)/impedance (200kHz)] + (0.18782 x weight) + 8.197

These tests were conducted consecutively, before exercise, at least 2 hours after food, and after the bladder had been emptied. Subject's height, weight, date of birth were obtained prior to this test. Measurements were taken pre- and post-march (M-14 hours; and M+83 hours respectively).

Water intake

In order to record water intake in a practical and accurate way, subjects were required to drink water only from the 2 litre bottles that were transported in the carts. Bottles were marked by each subject for their own consumption. Subjects recorded the exact time when each of their allocated water bottles became empty. Those subjects who chose to use a portable 'bag' system from which they could drink water by means of a connecting tube (Camelbak® system, Petaluma, USA) ensured that they emptied the bag completely before re-filling it with another bottle of water. The time at which the bag was emptied following the use of a complete bottle of water, was recorded in the subject's diary.

Food consumed

All items of food that were consumed had been identified prior to the start of the march (each subject packed the food that they wanted to eat during the march in bags that were marked with their name and placed in the carts). Wherever possible at least one of the wrappers from the various food items had been obtained to enable the subsequent estimate of energy intake (Microdiet computer dietary analysis system, Salford University, UK). Subjects recorded the time and the food item that was consumed in their diary. When only part of a standard portion of the respective food item was consumed at a given time, the subject provided a subjective estimate of the quantity eaten.

Urine output

Each cart was equipped with a 1000ml measuring cylinder (with 1ml graduations). Subjects ensured that all urine passed during the march was measured using one of the tubes available and recorded in the diary together with the time of the void. The measuring tubes were suspended, inverted from a point close to the axle of each cart with the intention of ensuring that any subsequent residue was lost as the cart was transported. The time of defecation was recorded in the subject's diary.

Physical activity (PA)

Two Actiwatch® -AW4 systems (Cambridge Neurotechnology Ltd., UK) were placed on each subject: (1) on the lateral aspect of the subject's right wrist; and (2) lateral aspect of the right ankle. These accelerometry-based systems were set to record movement throughout the march, at 2s epochs. Data were expressed in counts.min-1 and they described the number of movements recorded in the vertical (z) axis evident at the wrist and ankle. This enabled the degree of upper and lower body physical activity to be estimated. Periods of sustained inactivity were assumed to describe bouts of 'sleep'.

Subjects recorded in their diary the type of action that they conducted (ie rest, pull, push, or navigate) and the time at which they commenced each action. The safety crew provided time-matched, video confirmation of these records.

Distance travelled

The exact route that was taken by the subjects during the march was recorded using a Magellan® hand held global positioning system (GPS), model number 315. This was downloaded to a computer and the distance was calculated for the exact trail that was taken. Military personnel from the Qatar special forces provided an independent verification of the distance that was covered, based upon their recorded observations of the subjects' movements during the march.

Heart rate (HR)

Each subject wore a Polar® Vantage NV heart rate monitor that was set to sample data at 15-second intervals throughout the march. During pre-deployment tests at the QinetiQ laboratories in the UK, baseline data were obtained for resting heart rate. Maximum heart rate for each subject was accepted as the highest reported heart rate resulting from: (a) the pre-deployment training phases conducted at Long Valley and the military training area, Hawley, UK; or (b) 220 – subject age in years. It was possible to assess the relative cardiovascular strain of the march by using the heart rate reserve (HRreserve) method described by Karvonen (this is discussed in detail in [5] and [14]).

Gastrointestinal temperature (Tgi)

All subjects ingested a CorTemp© CT2000 temperature sensitive pill (referred to as a 'radio pill') approximately 2 hours prior to the start of the march and following an initial 'test' to check that the pill was functioning correctly. Transmissions from the radio pill were detected and interpreted using a CT2000 data logger system (HQ Inc., Palmetto, USA), reporting temperature (assumed to reflect deep body temperature) data every 10 seconds, as the radio pill passed along the gastrointestinal tract. These data were downloaded to a computer (using an RS232 to COM1 link) for subsequent analysis at the end of the march. Subjects ingested additional radio pills following each defecation throughout the march.

Environmental heat stress (WBGT)

The Wet Bulb Globe Temperature[2] (°C WBGT) was measured at 1 hour intervals throughout the march and logged using an Edale Instruments Ltd (Cambridge, UK) model PTH-1 data recorder. Data were also obtained from the Meteorological Office (MET Office, Defence and Aviation Climatology Branch, Johnson House, UK) for a location near Doha, Qatar (25 degrees 15 minutes north, 51 degrees 33 minutes east and at 11.0m elevation above sea level).

Statistical methods

All data have been reported as mean (1 standard deviation). The students' paired t-test was performed (SPSS version 8.0, SPSS Inc., Chicago, USA) to compare pre- and post- march data. Statistical significance was accepted at the alpha = 0.05 level.

Results

Four of the 5 subjects completed the march in 78 hours. The fifth subject suffered an injury during the march which required medical treatment, and was therefore unable to take any further part in the study. Physical activity was recorded during 74 of the 78 hours, during which the subjects tended to self-select a sustainable work-rate (mean relative intensity 57.8 (9) % of HRreserve). The remainder of this time (4 hours) was spent lying inactive, beside the carts on the desert terrain trying to sleep.

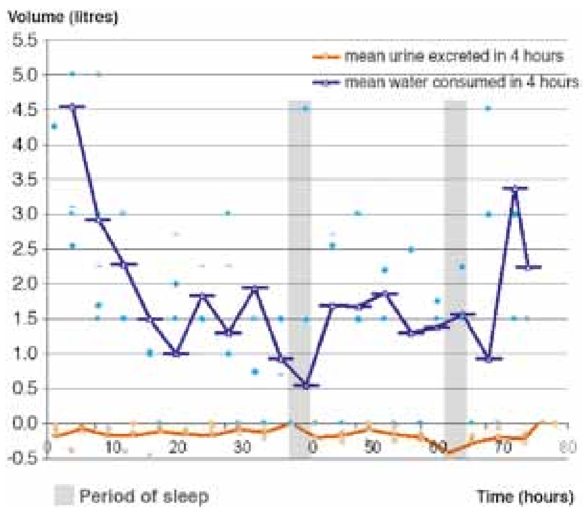
Table 3

	Day 1 **M to M+24** 10:00 (02 Apr) to 10:00 (03 Apr)	Day 2 **M+24 to M+48** 10:00 (03 Apr) to 10:00 (04 Apr)	Day 3 **M+48 to M+72** 10:00 (04 Apr) to 10:00 (05 Apr)	Day 4 **M+72 to M+78** 10:00 to 16:00 (05 Apr)	**Data to describe the entire march** **mean** (1 SD) [max, min]
	mean (1 SD) [max, min]				
Water intake (litres)	**14.2** (1.1) [15.6, 13.0]	**8.1** (2.5) [10.2, 4.5]	**10.4** (3.2) [13.2, 6.0]	**2.3** (0.9) [3.0, 1.5]	**34.7** (6.4) [40.8, 27.5]
Urine output (litres)	**0.8** (0.3) [1.1, 0.5]	**0.7** (0.2) [1.0, 0.6]	**1.3** (0.1) [1.4, 1.2]	**0.2** (0.06) [0.3, 0.1]	**2.9** (0.6) [3.6, 2.5]
Change in body mass (kg)	**–2.0** (1.7) [–4.5, –0.5]	**–1.1** (0.4) [–1.5, –0.5]	**0.2** (0.3) [0.5, 0.0]	**–0.4** (0.4) [–1.0, 0.0]	**–0.8** (1.7) [–4.5, –0.5]
Tgi (°C)	**37.9** (0.5) [39.1, 37.1]	**38.3** (0.4) [38.7, 37.8]	n/a	**38.6** (1.0) [40.1, 37.9]	**38.1** (0.6) [40.1, 37.1]
HRreserve (%)	**63.2** (6.9) [80.0, 51.0]	**54.4** (8.4) [67.7, 35.5]	**55.0** (9.6) [63.6, 24.7]	**48.6** (8.0) [58.5, 36.1]	**57.8** (9.3) [80.0, 24.7]
Energy intake (MJ)	**15.8** (4.3) [19.5, 10.8]	**9.7** (1.8) [11.8, 8.2]	**14.4** (5.8) [21.9, 9.2]	**0.3** (0.6) [1.3, 0.0]	**46.0** (10.5) [55.2, 30.8]
Distance travelled (km)	**36.0**	**40.0**	**80.0**	**38.0**	**194.0**
WBGT (°C)	**28.0** (0.7) [28.7, 27.1]	**25.9** (3.7) [28.9, 21.8]	**20.7** (1.3) [22.8, 19.1]	**22.9** (0.3) [23.1, 22.7]	**24.0** (3.6) [28.9, 19.1]
n	*5*	*4*	*4*	*4*	*4*

Results by 24 hour period throughout the march.

[2] WBGT = 0.7 (wet bulb temperature) +0.2 (150mm globe temperature) +0.1 (air temperature).

2



The volume of water that was consumed and urine excreted during the march. Data have been summed for every 4 hour period throughout the march and plotted for each subject (spheres that are connected by a solid line describe the group mean at the end of each 4 hour period).

The pattern observed in the consumption of water, the excretion of urine, and relative cardiovascular strain is shown in figures 2 and 3. The mean environmental heat stress to which the subjects were exposed during the march was 24.0 (3.6)°C WBGT (table 3). However, figure 4 illustrates the pattern in WBGT data at 4 hourly intervals.

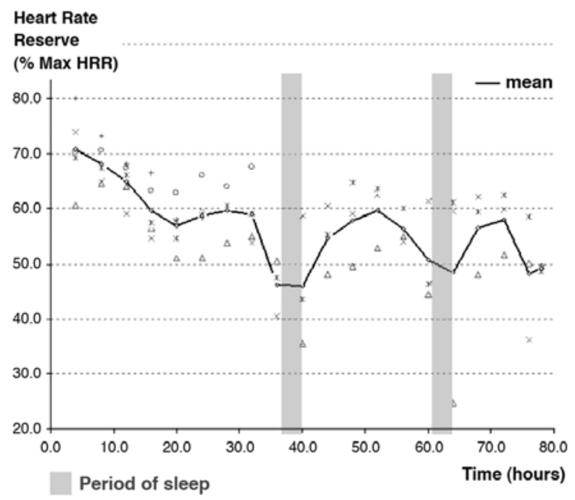
An estimated mean total of 46.0 (10.5) MJ was consumed (table 3) by each subject during the march. Mean total water intake (per subject) was 34.7 (6.4) litres, with only 2.9 (0.6) litres of urine excreted in this period. TBW increased by 0.3 (0.4) litres (range of 0.8 to 1.5%) compared with pre-march values ($p<0.05$). Mean Tgi was 38.1 (0.6)°C but occasionally it exceeded 39.3°C. Estimated fat mass was found to decline ($p<0.05$) by 3.4 (1.0) kg, accounting for the loss in total body mass of 3.3 (1.6) kg.

Discussion

Water policy

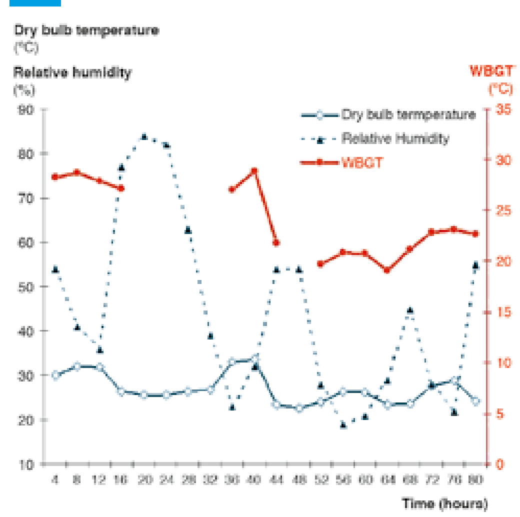
During the study, each subject was provided with 50 litres of water to consume *ad libitum*. The subjects ensured that this water allocation was used only for drinking and for no other purpose (eg pouring water over the head to attempt to cool the skin, maintaining personal hygiene or to clean equipment). At the end of the march, having consumed 34.7 (6.4) litres of water each, the total body water of the subjects was found to have increased above starting levels. In the absence of any further

3



The relative cardiovascular strain during the march (as described by the HRreserve). Mean data for each 4 hour period have been plotted for each subject throughout the march. (spheres that are connected by a solid line describe the group mean data for each 4 hour period).

4



The environmental heat stress reported by the Meteorological Office (UK) for the desert area of northern Doha (Qatar) during the period of the march.

measurement to assess their hydration status this would suggest that the quantity of water that was consumed had in fact been sufficient to avoid any significant levels of dehydration (perhaps even to maintain or restore euhydration). The latest UK military guidelines suggest that for the conditions that were experienced in this study (mean 24.0 (3.6)°C WBGT) and the intensity of the work that was conducted (moderate to low intensity) each subject should have consumed water at a rate of approximately 0.5 litres.hour^{-1} (or a total of 37.0 litres of water for the 74 hours of physical activity [11.4 litres.person^{-1}.day^{-1}]). Previous UK military guidelines [1] had suggested that an upper limit of 12 litres of water per person per day should be provided for such a scenario. This study showed that four subjects were able to increase their total body water whilst consuming water at an approximate rate of 10.7 litres per person per day, during a prolonged desert march.

However, it was found (in general) that the rate at which water was consumed during the march, was not constant, but indeed reflected the Tapparent cardiovascular strain (as determined by the HRreserve).he march was essentially completed in two distinct phases: (a) the soft sand of the dunes; and (b) the harder surface of the rock paths (figure 5). The sand dunes (soft sand) occurred at the start of the march and the subjects were seen to work very hard in an attempt to

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Top: Negotiating the soft sand dunes with two separate carts during the first 32-km of the march. **Bottom**: In the latter stages of the march the terrain was much firmer under foot and the subjects chose to join the two carts in tandem.

transport the wheeled carts at this stage. The carts were at their heaviest as very little of the water cargo had been consumed at this stage, and the wheels of the carts often needed to be lifted out of the sand. Furthermore, the environmental heat stress apparent at this time was greater than at any other period during the march. Subjects appeared to self-select a work rate that was sustainable under such conditions (figure 3), and which has seemingly been established by other researchers as achievable for prolonged periods [15].

Initially, subjects added a carbohydrate-electrolyte powder ('High5 energy source', High5 Ltd, UK) to their water with a view to replacing the essential electrolytes that may be lost under conditions of high rates of sweat loss. This beverage had been used similarly during pre-study training sessions in the UK with good success, and optimal subject compliance (as they were considered to be highly palatable). However, during the initial phase of the march in the sand dunes, one subject reported that he actively stopped consuming water in response to the feeling of nausea which had followed the consumption of this beverage. It wasn't until he was able to work at a lower relative intensity, that he felt able to tolerate consuming plain water in the necessary quantities, supplemented with brief snacks of food items which contained high levels of salt and were savoury in flavour (eg peperami sausage sticks, and salted peanuts). Interestingly the food items that were consumed during the march included: High5 energy bars, salted peanuts, peperami sticks, yoghurt bars, Pringles™ potato chips, apricot flavoured pop-tarts and mixed fruit with plain nuts.

The greatest quantities of urine that were excreted during the march occurred in the latter stages of the second phase, when the terrain was perceived to be 'easier going', the work rate was moderate to low, and the environmental heat presented a lesser stress than had previous been observed. This increased excretion of urine occurred with a concomitant rise in the consumption of water (ingestion). Subjects reported a perceived inability to consume water at any greater rate than was evident at each stage during the march. They had ensured that they drank water at every opportunity and that they did not rely on the feeling of thirst to determine their need [16]. The observed loss in total body mass at the end of the march could be accounted for by the estimated loss in fat mass. Therefore, it was believed that the hydration status of the subjects had been maintained effectively on the water budget that was allocated.

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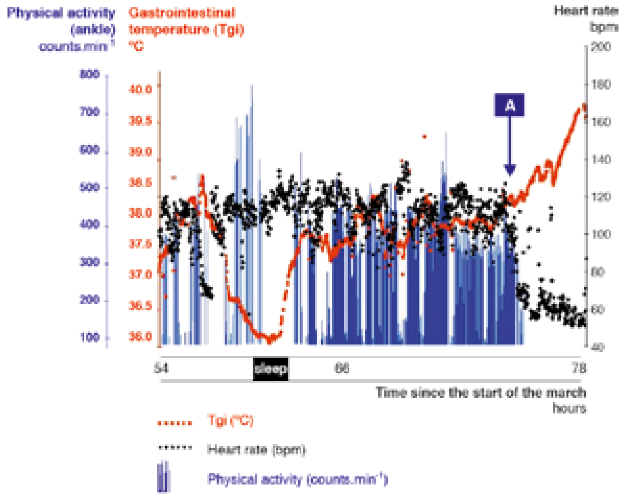
6a

The onset of symptoms of heat illness occur in one of the subjects during the final 4 kilometres of the march.

6b



Heart rate, Tgi and physical activity observed in this subject prior to, and following the onset of symptoms of heat illness (which occurred at 'A').

Although it cannot be concluded as a finding of this study, it did appear that the total increase in heat strain was associated with a greater perceived intolerance of water and sweet-flavoured foods [3] [17]. It may be that the contribution to the total heat strain of the relatively high work rate in the early stages of the march was one of the most important factors in determining the subjects' perceived intolerances.

Heat illness

On a number of occasions subjects felt that they required a rest as a consequence of their increased Tgi, or an opportunity to obtain shelter from the sun. Despite a brief and mild case of prickly heat in one subject during the early stages of the march, the incidence of symptoms of heat illness were few. However, at the end of the march, having successfully reached the end point, the condition of one of the subjects was found to deteriorate suddenly and quite rapidly. This subject was physically among the fittest, he had maintained a good sense of humour during the event, coping very well with the burden of the task before him, and was a very stable and strong character. At this point his Tgi had increased above 39.8°C, and he reported feeling 'cold'. Immediate action was taken by a fellow subject who had extensive medical experience, and intravenous fluids were administered (this explains why fewer than 4 data sets were available for bioimpedance analysis post-march) and cold water was poured over his head and body. His body was observed to commence mild convulsions prior to being evacuated by helicopter to the nearest military hospital. Fortunately this subject was treated in a very timely fashion and was released from hospital later that same evening.

Interviewing this subject subsequently identified a number of early 'warning signs of heat illness' which had been evident during the march but which also appeared not to have been noticed by his fellow subjects at that time. In the last few hours of the march this subject reported feeling unwell, lethargic and heavy with fatigue. He had felt nauseous when consuming the carbohydrate-electrolyte beverage, and had decided to drink just plain water. He became quiet, withdrawn and less able to take the role of pulling the cart. At a point only a few kilometres from the end of the march (the end point was clearly visible to the subjects) this subject began to take regular rest stops which increased in duration. He was bent at the waist as he sought rest (figure 6), and in the last 2 kilometres he stopped drinking water (due to an increased feeling of nausea). This stage can be seen in figure 6 as the area on the curve where physical activity was very low (point 'A'). Soon after this point the subject recognised that he was no longer evaporating sweat from his arms. He managed to reach the finish successfully, before becoming a casualty.

All of the subjects appeared to manage their levels of physical activity during the march in an attempt to regulate their own body temperature. The march was conducted in repeated bouts of low to moderate levels of physical activity (relative to maximum physical capability) often lasting less than 45 minutes. By rotating the role of each subject during the march it was possible to share the burden without unduly stressing any given individual (this also complemented effective team dynamics and compliance at times when fatigue and sleep deprivation were perceived by the subjects to be very high). It was the aim of the subjects to work hard during the cooler, darkness hours of each night. However, it was not possible to sleep under the intense, unsheltered heat of the sun during the day, and so two brief 2 hour naps were used (providing a total of 4 hours sleep during the 78 hours of the march) as a strategy to alleviate the effects of fatigue. The temperature in the darkness hours (22:00 hours to 04:30 hours) was perceived to be 'cold', which was reflected by a dry-bulb temperature of approximately 18°C. The example in figure 6 shows how the body's autonomic control ensured that this subject did not become hypothermic when he took a nap in the final 'sleep' period before completing the march. The sustained heart rate at a time when this subject was physically inactive and lying on the ground could possibly be explained by the onset of shivering thermogenesis which avoided this subject's body temperature (Tgi) falling below 36°C.

Conclusion

Daily consumption of up to 11 litres of water per man was sufficient to maintain hydration (on the basis that total body water was increased at the end of the march when compared with pre-march levels) when working at up to 58% HRreserve during this prolonged, self-sufficient desert march. These data support the existing UK military guidelines for the provision of potable water [18].

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