North Pole Marathon Laboratory Lessons and Field Success

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BACKGROUND: This case study documents the training, laboratory preparation, and in-race performance data from Great Britain's top finisher in the 13th edition of the UVU North Pole Marathon.

CASE REPORT: We report data from a preparatory laboratory test in simulated cold conditions (−15°C) with and without wind chill during high- and low-intensity expected 'race pace' running. These tests examined the adequacy of the selected clothing assembly and provided recommendations for the race. The tests established that there was no risk of hypothermia, as the clothing assembly provided too much insulation; terminal rectal temperature was 39.25°C. Skin temperature (T_{sk}) data revealed no impending risk of frostbite; nadir T_{sk} was 20.2°C at the hamstring. Oxygen consumption data revealed the self-selected high intensity was potentially not sustainable based on estimates of substrate utilization. We recommended: 1) a maximum running speed; 2) some of the clothing base layers could be removed pre-race; 3) vents and/or zips could be used to offload or retain heat; and 4) an even pacing profile should be adopted.

DISCUSSION: The participant completed the race in 6:55:24 (h:mm:ss) in temperatures of −41°C. GPS data revealed a positive pacing template (i.e., marginally quicker in the first half). Neither hypothermia nor frostbite occurred. Peak pace from the laboratory tests was not consistently exceeded. Marathon performance can be undertaken in one of the world's most inhospitable environments when careful consideration is given to clothing insulation and exercise intensity by planning for the dynamic thermal changes that may occur as the race ensues.

KEYWORDS: Arctic running, North Pole, pacing, frostbite.

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Recreational, military, and sporting activities are increasingly taking place in hazardous and hostile thermal environments. Humans are not adapted to cope with these extremes and, therefore, must rely on intelligent solutions to combat the physiological and psychological stressors that are evoked when prolonged exposures take place. Failure to account for the likely demands of a given event or deployment may precipitate failure and, in the worst case, injury, illness, or death.

The North Pole is one such environment which reaches an average air temperature of −40°C in the winter months and does not exceed 0°C in the summer.[8] With the addition of the 16 to 25 mph average wind speed that occurs at the Pole,[8] exposed flesh would be expected to freeze within 5 to 10 min[7] in the coldest conditions. Without adequate protection and heat production in the long-term, hypothermia may result.

The North Pole Marathon takes place each year in April in the Arctic Circle and combines the challenge of long distance running with the rigors of doing so in extreme cold conditions. This case study documents the training, laboratory preparation, and in-race performance data from Great Britain's top finisher in the 13th edition of the UVU North Pole Marathon.

The 2015 geographic North Pole marathon marked the 13th edition of the race series, which began in 2002.[10] Guinness World records recognize the event as the world's most northerly marathon and the only certified marathon that is run exclusively on water. The men's record of 3:36:10 (h:mm:ss) was set in 2007 by Irishman Thomas McGuire and the women's record of 4:52:45 was established by a German lady, Anne-Marie Flammersfeld, in 2014. Notable nadir temperatures of −37°C

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and −32°C were achieved in 2009 and 2011, respectively.[10] The environmental conditions have a profound effect on the competitive times that are achieved each year and bear little comparison to road running.

The race logistics typically require competitors to undertake three flights to arrive at the Pole from Longyearbyen in Svalbard, Norway, landing on a temporary runway fashioned by Russian airborne military forces; the runway eventually comprises part of the running course. Competitors must be ready at short notice to compete, as the environmental conditions do not always allow for a set schedule. Up to a third of competitors may not finish the race through withdrawal due to injury, and the potential for frostbite and hypothermia. Polar bears are also a potential threat. The health threats are mitigated by participants undertaking a voluntary medical examination after each completed 2.62-mile loop; armed military personnel guard the course as the race ensues.

CASE REPORT

The case study is of a 52-yr-old British man with a competitive background of endurance events such as marathon, endurance cycling, Ironman triathlon, and ultra-endurance events, but with no prior experience of extended running on ice. He was 1.69 m tall, weighed 75.85 kg, and had an estimated body surface area of 1.86 m^2.[4] In order to prepare for the event the participant undertook approximately 8-10 h of running training sessions per week on a range of undulating and uneven surfaces such as local beaches and sand dunes. The participant had a lifetime best road marathon time of 2:48:15 (h:mm:ss) and a recent completion time of 3:26:30. The beach environment also enabled the potential strong winds that may be experienced at the North Pole to be included within the training. The extreme cold expected at the Pole was partially simulated in tests undertaken at the Laboratory of Extreme Environments at Northumbria University.

The participant visited the laboratory on one occasion in order to undertake one 2-h treadmill based (Woodway ELG, Woodway World, Waukesha, WI) exercise test in simulated cold (−15°C) and cold plus wind conditions (peak wind speed 6.71 mph) as simulated by an industrial fan (75 cm Drum Fan, DF30S, 430 W, EHS, Manchester, UK). The primary aim of the protocol was to assess the thermal insulation provided by the full clothing assembly selected by the participant at the slowest [10.5 min/mile (5.7 mph)] and fastest [9.5 min/mile (6.3 mph)] expected speeds during the race. These speeds are relatively modest in the context of road running, but were selected in order to account for the likely slower running speeds that would be caused by the slippery uneven ice conditions expected in the race. Unrealistically high speeds would have resulted in more heat being produced than was feasible in the race itself. The participant completed four blocks of exercise. One at the low intensity in the cold only, with the addition of wind, then at the high intensity without wind followed by the addition of wind.

Upon arrival at the environmental chamber the participant was weighed naked (behind a privacy screen) and then holding the clothing intended for use during the exercise test (see itemized list below). This was to enable the estimation of sweat production when combined with fluid consumption measurements. The participant then self-inserted (in private) a calibrated rectal thermistor [Grant Instruments Ltd, Cambridge (Shepreth), U.K] 15 cm beyond his anal sphincter. He then partially dressed and was instrumented with skin thermistors (Squirrel 1000/1250 series, Grant Instruments Ltd, Cambridge, UK) at eight different body sites to enable a mean skin temperature to be estimated;[6] a further thermistor was attached to the index finger of the right hand to enable the risk of peripheral cold injury to be quantified. Temperature data were logged every 30 s by a data logger (Squirrel 1000/1250 series, Grant Instruments Ltd, Cambridge, UK). The participant also donned a heart rate monitor (Team Polar Electro OY, Kempele, Finland).

Toward the end of each block the participant provided a sample of expired air through a two-way mouthpiece (Hans-Rudolph, Shawnee, KS) connected to respiratory tubing and a Douglas bag for subsequent gas analysis (Servomex MiniMP 5200, Zoetermeer, Holland). The participant also provided a rating of his thermal sensation and thermal comfort on a 13-point and 7-point scale, respectively,[1] for the whole body and the hands. Between exercise blocks the participant straddled the treadmill band and took a 3-min rest to enable fluid and nutritional intake. This was also included as a break to undertake medical assessment as well as taking in refreshment since this is enforced as a compulsory part of the race format. Once the final exercise block was complete, the participant exited the environmental chamber, removed all of the measurement instruments, and was reweighed.

Throughout the test the participant wore the full clothing assembly, which included: trail shoes (Solomon Spikecross 3, Metz-Tessy, France), socks (Smartwool Merino thick socks, Steamboat Springs, CO), calf compression tights (Skins AW15, calf compression tights, Steinhausen, Switzerland), long johns, base layer top, pullover midlayer, outer shell trousers, outer shell marathon jacket, balaclava, running mits (All Montane, Ashington, UK), and ski goggles (Oakley, Foothill Ranch, CA).

Lab data results showed that the deep body temperature data (**Fig. 1A**) indicated that there was no evidence that hypothermia would ensue at either the lower (blocks 1 & 2) or higher (blocks 3 & 4) work intensities either without (i.e., blocks 1 & 3) or with (i.e., blocks 2 & 4) the addition of light wind. The deep body temperature profile was stable, with evidence of thermoregulation at the lower intensity, but showed evidence of uncompensable heat gain at the higher intensity with a terminal rectal temperature of 39.3°C. Overall, the mean skin temperature (T_{msk}) profile (**Fig. 1B**) indicated a mean decline in temperature across the whole trial (T_{msk} start was 30.1°C vs. T_{msk} end of 26.6°C). However, there was evidence of greater stability in the skin temperature that was achieved when exercise was undertaken without wind chill compared to with, which showed evidence of progressive decline. This may have been due to a greater effect of the wind chill on areas of the body that were less well insulated by clothing;

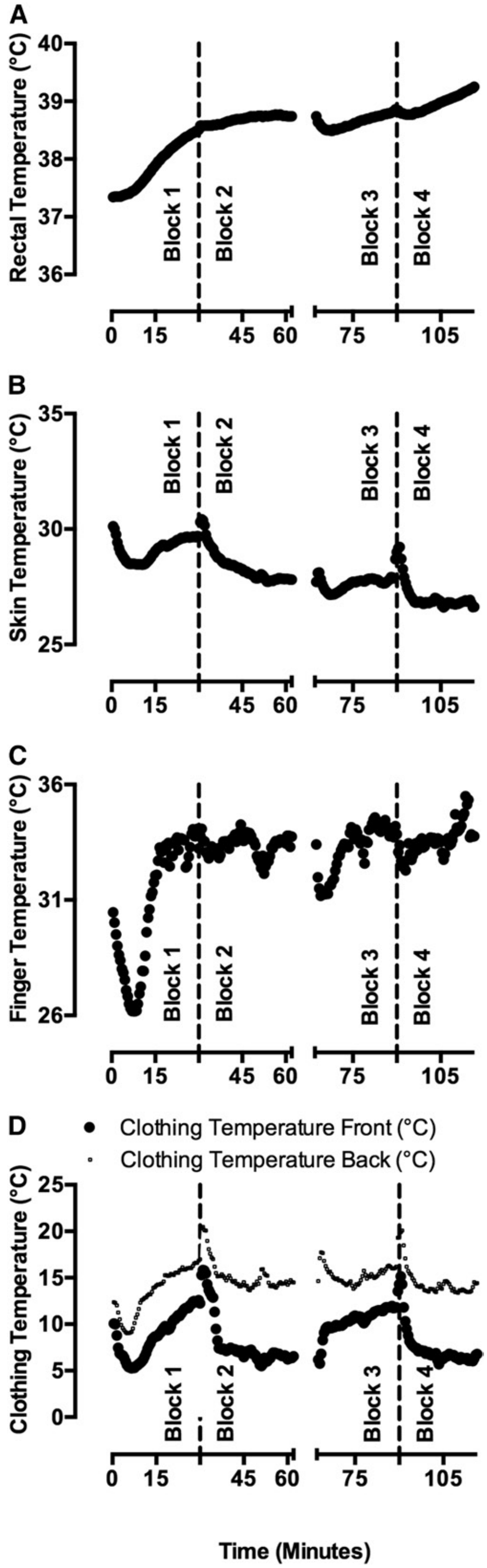

Fig. 1. A) Rectal temperature, B) mean skin temperature, C) finger temperature, and D) clothing temperature of the participant during laboratory tests in cold (−15°C) conditions at low (blocks 1 & 2) and high intensities (blocks 3 & 4) without (blocks 1 & 3) and with wind chill (blocks 2 & 4).

the coldest average (21.2°C) and nadir (20.2°C) skin site was the hamstring, with the warmest being the foot on average (33.9°C), and the highest peak temperature was seen at the fingertip (35.5°C). Despite a transient reduction in fingertip temperature at the onset of exercise (**Fig. 1C**, block 1), there was an increase in temperature as the trial ensued before a plateau was reached at approximately 35.5°C. These data suggest a sustained extremity blood flow despite the cold conditions and no evidence of a risk of peripheral cold injury. The clothing temperature data suggested lower surface temperatures at the back of the clothing relative to the front (**Fig. 1D**). This may have been due to greater convective cooling at the front of the garment due to locomotion (blocks 1 & 3) and wind chill when the fan was switched on (blocks 2 & 4).

The sweat production data suggested a high level of thermal strain with 2.04 L of sweat produced, 0.34 L of which was estimated to be evaporated (i.e., approximately 16%). Heart rate during the low-intensity exercise was 143 ± 4 bpm and was 159 ± 8 bpm at the higher intensity; 85% and 95% of an age-predicted maximum. The oxygen consumption and respiratory exchange ratio data suggested the lower intensity was sustainable for an extended period (2.56 ± 0.30 $L \cdot min^{-1}$ and 0.95 ± 0.01 or 9.6 metabolic equivalents; MET), but the higher intensity (3.06 ± 0.40 $L \cdot min^{-1}$ or 11.5 METs) was likely to use a higher proportion of carbohydrates, as indicated by an RER > 1,[5] to sustain the higher intensity (RER 1.01 ± 0.02).

Hand and whole body thermal sensation progressively declined throughout the trial from hot and very hot to slightly warm and neutral, respectively, yet this did not culminate in significantly disturbed thermal comfort, which was predominantly rated as comfortable. Despite the relatively modest environmental conditions by comparison to those expected during the race, it was evident that the clothing that was selected was too substantial in the face of the heat gained through the raised metabolism during exercise. Retaining this level of clothing insulation may have resulted in substantial sweating, raised deep body temperature, and hyperthermia. Hence it was recommended that some of the initial clothing assembly could be jettisoned prior to the race or that it could be adapted to enable the user to vent heat from areas of the garment if a high exercise intensity was achieved, particularly upon the torso, to enable air circulation. The present test showed no evidence that hypothermia or peripheral cold injury would result at either work rate. The participant remained generally comfortable throughout. However, it was recommended not to exceed the higher exercise intensity given that this resulted in high respiratory exchange rates indicative of an increased dependence upon carbohydrates as a fuel source and approached 95% of an age-predicted maximum heart rate. Lastly, we also recommended that an even pace should be adopted to avoid large fluctuations in heat production between the start and the end of the race.

The 13th edition of the North Pole marathon commenced at 12:15 GMT on Saturday 11th April 2015. The ambient temperature at the start of the race was −29°C with winds of 11.2 mph producing a wind chill temperature the equivalent of −41°C and a predicted tissue freezing time of 10 to 30 min.[7] There were 45 competitors from 22 different countries who started the race. One participant failed to complete the distance, having succumbed to hypothermia. The race was won in a time of 4:22:24 (h:mm:ss).

An identical clothing assembly to that of the laboratory tests was used, with the exception of the midlayer pullover, which was not worn. The participant's race pace and exercise intensity were recorded by a global positioning system (GPS; Garmin 310XT Forerunner, Garmin ltd, Schaffhausen, Switzerland) with integrated heart rate monitor.

The participant completed the race in a time of 6:55:24 (h:mm:ss) with a peak running speed of 8.12 min/mile in the fifth mile of the race and an average of 15.47 min/mile. Peak heart rate was recorded in the first mile of the race at 194 bpm. When the estimated total time lost for six medical checks taken was subtracted from the overall race completion time (i.e., 66 min equals 9 min 25 s per stop), a total running time of 5:49:24 results (i.e., 13.20 min/mile). There were no signs of hypothermia developing or evidence of peripheral cold injury during this time. In-race heart rate and pace are reported in **Fig. 2A** and **Fig. 2B**, respectively. For the miles which were completed without a medical stop, the pace averaged 12.35 min/mile and heart rate averaged 146 ± 16 bpm. This intensity was well below that estimated to be near maximal after the laboratory tests.

DISCUSSION

Marathon running performance is achievable even in one of the world's most inhospitable climates in conditions in which

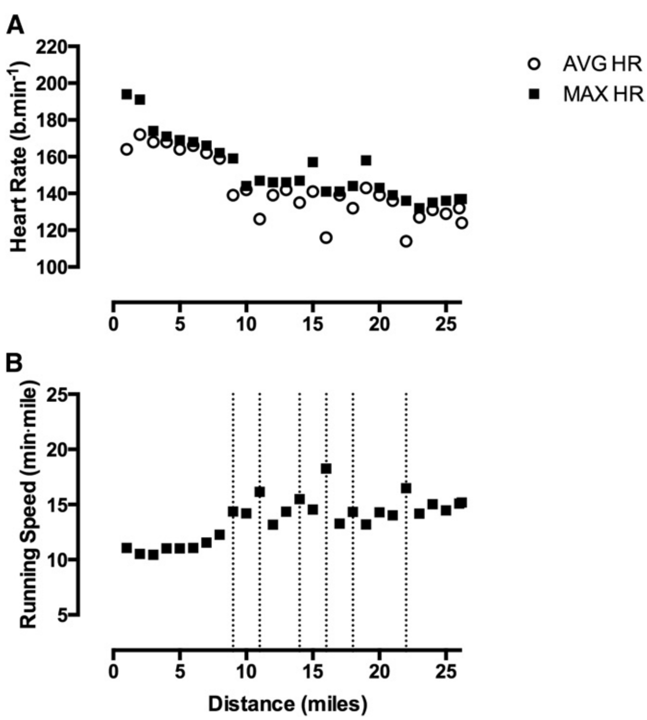

Fig. 2. A) Average and peak heart rate and B) running pace in the case study participant during the 2015 North Pole Marathon; vertical dashed lines denote the points at which stops for medical checks were undertaken (panel B only).

humans would normally develop hypothermia and frostbite without adequate protection at rest. Burton and Edholm[3] described the positive relationship between the required mitten size and exposure duration before frostbite would ensue at rest. Yet they concluded that mittens were not necessary in the presence of strenuous exercise at −29°C, ambient temperatures similar to the 2015 North Pole race. Part of that protection is provided by heat production through raised metabolism as a consequence of physical activity. In the conditions under foot at the North Pole Marathon, it is likely that the mechanics of running will be even less efficient, thereby contributing more heat production to this scenario by comparison to road running. Indeed, the consequence of competing on ice at the North Pole by contrast to the road was an approximate 40% longer completion time, even accounting for stops. This is closer to 50% slower when medical stop checks are included (i.e., 3:26:15 vs. 6:55:24 and 5:49:24 with and without stops at the North Pole). Our laboratory tests confirmed that too much insulation, even in more modest cold conditions, could result in heat gain, sweat production, and an elevated cardiovascular strain. Despite the extremely cold conditions, the event organizers have consistently observed some competitors overdressing for the conditions and becoming too hot at the start of the race when combined with an overly aggressive early running speed (Mr. Richard Donovan, Race Director, North Pole Marathon; personal communication; Sept. 2015).

Hence our recommendation was to reduce the extent of some of the clothing layers that were worn for the race and enable some venting of well-insulated areas of the body; for example, the torso. From a practical perspective, this would enable the athlete to respond to any dynamic changes in the environmental conditions or exercise intensity to maintain thermal balance and lower the risk of thermal injury. Although the clothing insulation of the clothing assemblies worn is not clear, it is likely that the work intensity selected in both the laboratory and the race itself were more than enough to reduce the required insulation to a manageable level to avoid impairing gait because of added clothing bulk. Indeed, predictive models would suggest that a clothing insulation of a minimum of 1 for either of the present scenarios (i.e., laboratory or field) both with and without wind chill would be sufficient to enable thermal protection when combined with the relative high heat production.[2] Thereafter, the primary role of the clothing assembly would be to protect against freezing injury.[2]

Our laboratory tests also informed the likely feasible maximal sustainable exercise intensity for the race itself. Despite transient deviations above the pacing threshold identified in the laboratory tests, especially in the first 10 miles of the marathon, the athlete selected an exercise intensity that was sustainable from the perspective of heat gain and running speed. GPS data suggest a positive pacing template was adopted, with a fast start and steady reduction in running speed, particularly toward last 10 miles of the race. The difference between the first half and second half of the race was marginal and within an approximate 10% difference in pace. Given the fluctuations in speed that could have occurred due to fatigue or environmental strain, this is a relatively small margin; 12.08 min/mile vs. 13.51 min/mile. However, it is generally acknowledged that an even pacing template is optimal for endurance events and that fluctuations beyond 5% are linked to high RPE and poor performance.[9] This may be particularly prudent in the present scenario as high heat production during an initial higher intensity bout of activity may result in sweat production followed by subsequent sweat freezing in exposed areas as heat production drops in line with intensity. Evidently this did not result in the present case study, but competitors in future North Pole marathons may wish to carefully consider their pacing profile on this basis.

In a post-race debrief, the participant reported that the laboratory tests gave him confidence in his approach to the race and resulted in a similar global RPE rating in the laboratory scenario compared to the race itself. However, the source of that exertion was different with the extreme cold, slippery conditions, and slower running pace matching the exertion required to continue exercise in the more temperate and permissive laboratory scenario. This case study shows that marathon performance can be undertaken in one of the world's most inhospitable environments when careful consideration is given to clothing insulation and exercise intensity by planning for the dynamic thermal changes that may occur as the race ensues.

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REFERENCES

1. American Society of Heating Refrigerating and Air-Conditioning Engineers. Thermal environmental conditions for human occupancy. Atlanta (GA): American Society of Heating Refrigerating and Air-Conditioning Engineers; 1992. ASHRAE standard 55.
2. Anon. Prevention and management of cold-weather injuries. Washington, DC: Headquarters, Department of the Army; 2005. Technical Bulletin: Medical 508.
3. Burton AC, Edholm OG. Man in a cold environment, 1st ed. London: Edward Arnold Ltd; 1955.
4. DuBois D, DuBois EF. The measurement of the surface area of man. Arch Intern Med (Chic). 1915; XV(5_2):868–881.
5. McArdle WD, Katch FI, Katch VL. Energy expenditure at rest and during physical activity. In: Harris JM, Stead L, Lukens R, editors. Essentials of exercise physiology. Baltimore (MD): Lippincott Williams & Wilkins; 1999:78–113.
6. Olesen BW. How many sites are necessary to estimate a mean skin temperature? In: Hales JRS, editor. Thermal physiology. New York: Raven Press; 1980:33–38.
7. Osczevski R, Bluestein M. The new wind chill equivalent temperature chart. Bull Am Meteorol Soc. 2005; 86(10):1453–1458.
8. Polar Discovery. Woods hole Oceanographic Institution - weather. 2015. [Accessed Sept. 2015.] Available from: http://polardiscovery.whoi.edu/poles/weather.html.
9. Thomas K, Stone MR, Thompson KG, St Clair Gibson A, Ansley L. The effect of self, even, and variable pacing strategies on the physiological and perceptual responses to cycling. Eur J Appl Physiol. 2012; 112(8): 3069–3078.
10. UVU North Pole Marathon. Race Info & Results. 2015. [Accessed Sept. 2015.] Available from: http://www.npmarathon.com/html/race-info/.