Efficacy of different cooling methods for capture-induced hyperthermia in antelope

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The capture of wild animals is a stressful event which may cause a capture-induced hyperthermia, resulting in morbidity or mortality. We investigated whether various cooling techniques were effective at lowering the body temperature of hyperthermic animals. To achieve this, we implanted miniature temperature-sensitive data loggers into the abdomens of 12 blesbok (*Damaliscus pygargus phillipsi*). Five animals were cooled by dousing with water of different temperatures (4°C, 17°C, 28°C) and fanning after dousing with 28°C water. Seven animals were cooled by ice-packs, a fine mist spray of 28°C water, intravenous (IV) infusion of one litre of 4°C saline solution or 28°C water-dousing. The body temperature after capture was significantly elevated to as high as 41°C to 42°C. Water-dousing interventions significantly decreased minimum body temperature but there was no difference in the minimum body temperature reached or the magnitude of cooling between the different water temperatures or by the addition of fanning. The ice-packs also lowered body temperature, whereas mist spraying did not. The use of ice packs and dousing with water between 4°C and 28°C were the most effective techniques to reduce capture-induced hyperthermia in blesbok. Water-dousing, when done appropriately, is the most practical and effective method to cool an animal with capture-induced hyperthermia.

Key words: water-dousing, blesbok, ice-packs, stress, body temperature, hyperthermia.

INTRODUCTION

Capture is a necessary practice in the management and conservation of wildlife but often elicits adverse physiological changes in animals (Foster 2005). These physiological changes, which include alterations in body temperature, acid-base balance, tissue growth and maintenance of immunity (Kock, Jessup, Clark & Franti, 1987; Cattet, Christison & Caulkett, 2003), may result in morbidity and/or mortality (Ganhao, Hattingh & Pitts, 1988). A precipitous body temperature increase, termed capture-induced hyperthermia (Meyer, Hetem, Fick, Mitchell & Fuller, 2008a; Meyer, Hetem, Fick, Mitchell & Fuller, 2008b), is probably the most conspicuous and consistent adverse effect of capture in wildlife.

The severity of the capture-induced hyperthermia, as reflected by the magnitude and duration of the body temperature increase, is associated with the likelihood of organ damage, rhabdomyolysis, alterations in electrolyte balance, increased oxidative

stress and possible death (Kosaka *et al.*, 2004; Kock & Meltzer, 2006). Capture-induced hyperthermia 'is one of the primary indications for the development of capture myopathy' (Drew, 1996), a potentially lethal condition associated with capture.

The mechanisms underlying the increase in body temperature during capture-induced hyperthermia are not fully understood, but a primary factor appears to be the sympathetic stress response; even animals engaging in low levels of activity during capture, and at mild ambient temperatures, may develop severe hyperthermia (Meyer, Hetem, Fick, Mitchell & Fuller, 2008a). The consistent finding of elevated body temperatures in captured animals supports the idea that psychological stress has a major role in the development of capture-induced hyperthermia (Meyer, Hetem, Fick, Mitchell & Fuller, 2008a). While there are efforts to reduce stress during capture, for example by the use of rapidly acting chemical immobilizing agents, most capture events, by their nature, are likely to induce an

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acute stress response, and therefore some degree of hyperthermia, in captured individuals (Meyer, Hetem, Fick, Mitchell & Fuller, 2008a).

Given that capture-induced hyperthermia in some individuals may be severe, one way to improve animal welfare is to physically cool captured animals. Recommendations for cooling captured animals include placing the animals in the shade and dousing with water (Meltzer, Burroughs & Morkel, 2006b), using portable mist sprayers and rapid intravenous (IV) fluid therapy (Meltzer, Hofmeyr & Fivaz, 2006a), and applying water or snow to the animal's neck, belly, axilla and groin regions (Foster, 2005). In animals with body temperatures greater than 41°C, the use of cold water enemas (Foster, 2005) and intravenous infusion of cold Ringer's lactate (Arnemo & Fahlman, 2008) has been recommended. Fanning the animal and application of ice-packs may also be useful methods to reduce body temperature. Whole body fanning (Barwood, Davey, House & Tipton, 2009) and the application of ice-packs to skin areas with large superficial blood vessels (Clements *et al.,* 2002) effectively cooled hyperthermic humans, while ice- packs on the dorsal body surface cooled dogs (*Canis lupus familiaris*) after exercise (Kruk, Kaciuba-Uscilko, Nazar, Greenleaf & Kozłowski, 1985).

For its convenience and ease of use in a field situation, water-dousing is the cooling method used most often in capture (Kock & Meltzer, 2006; Meltzer, Burroughs & Morkel, 2006b). While its efficacy has not been investigated systematically in capture-induced hyperthermia, its use is advocated. Cold water (9°C to 16°C) dousing has been shown to cool horses (*Equus ferus caballus*) with exercise-induced hyperthermia (Kohn, Kenneth & Kenneth, 1999). In the field it is impractical to carry large volumes of cold water, so the temperature of water used to douse wild animals varies and typically is close to that of ambient temperature. It is not known how effective warm (above ~25°C) water is, in comparison to cold water, in cooling hyperthermic animals.

While there is evidence to support the use of various cooling methods in hyperthermic humans and animals, usually under laboratory conditions, there has been no investigation or comparison of the efficacy of various methods for reducing capture-induced hyperthermia in wild animals. Using implanted temperature-sensitive data loggers to continuously and accurately measure core body temperature, we compared cooling by water-dousing at various temperatures, fanning, ice-

pack application, mist spraying, and IV saline infusion, in captured hyperthermic antelope.

MATERIALS AND METHODS

All experimental and surgical procedures were approved by the Animal Ethics Screening Committee of the University of the Witwatersrand (clearance number 2008/34/04). Fourteen adult blesbok (*Damaliscus pygargus phillipsi*) at the National Zoological Garden's Biodiversity Conservation Centre in Lichtenburg (26°06′55″S, 26°09′50″E), South Africa, were captured using a passive boma-capture technique (Kock & Meltzer, 2006) a month before surgery. After capture the animals were housed in bomas (small enclosures of 10 m × 5 m), in groups of two to three animals per boma.

Surgery

During surgery, eight male (49.0 ± 10.0 kg) and six female (46.6 ± 7.0 kg) blesbok were surgically implanted with miniature temperature-sensitive data loggers (StowAway XTI, Onset Computer Corporation, Pocasset, Massachusetts, U.S.A.). Etorphine hydrochloride (3.0–3.5 mg intramuscularly, M99, Novartis, Johannesburg, South Africa) and azaperone (40–60 mg intramuscularly, Stresnil, Kyron Laboratories, Johannesburg, South Africa) were administered within a Pneu-dart (Type P, 3 cc, 13 gauge, 25 mm long wire barbed needle, Pneu-Dart, Williamsport, Pennsylvania, U.S.A.) projected by a dart gun (Sabi 500, SABI Werkswinkel t/a Magnum Arms, Nelspruit, South Africa) to induce anaesthesia (immobilization) in the blesbok for surgery. Once the animals were immobilized, anaesthesia was maintained with isoflurane (1–4% in 100% oxygen, Isofor, Safe Line Pharmaceuticals, Johannesburg, South Africa), *via* a facemask. The site for data logger implantation was shaved and sterilized with chlorhexidine gluconate (Hibitane, Astra Zeneca, Johannesburg, South Africa) and 1 ml of a local anaesthetic (Lignocaine Injection 2%, Centaur Labs, Johannesburg, South Africa) was injected subcutaneously into the incision line area.

The miniature temperature-sensitive data logger was implanted, without tethering, into the abdomen through an incision in the left para-lumbar fossa. During surgery each animal received an injection of a long-acting penicillin (5–6 ml IM Peni La Phenix, 150 mg/ml procaine benzylpenicillin + 168 mg/ml benzathine benzylpenicillin, Virbac Animal Health, Centurion, South Africa), an analgesic anti-inflammatory (1 ml IV Phenylarthrite

injectable solution, 200 mg/ml phenylbutazone, Bayer Animal Health, Centurion, South Africa), a Vitamin B injection (4 ml IM Rucenta Vitamin B Complex, Rucenta Medical Supplies, Johannesburg, South Africa) and a parasiticide (0.5 ml Dectomax subcutaneously, 1% m/v doramectin, Pfizer Laboratories, Sandton, South Africa). Coloured and numbered ear-tags were attached to each animal for individual identification. After surgery, the wounds were sprayed with a topical antiseptic spray (Necrospray, Centaur Labs, Johannesburg, South Africa) and covered with an ectoparasiticide grease (Tick Grease, 0.025% m/m cypermethrin, Bayer Animal Health, Centurion, South Africa).

After surgery, the pharmacological action of etorphine was reversed with diprenorphine hydrochloride (M5050 7.2–8.4 mg IV, Novartis, Johannesburg, South Africa), the animals were released back into the bomas and their health was monitored closely for three days, and regularly thereafter. The blesbok were allowed one month to recover from the surgery before the commencement of our cooling experiments. A similar surgical and anaesthetic procedure was used to remove the loggers at the end of the study. After post-surgical recovery the blesbok were released back into the reserve.

Body temperature measurements

Core body temperature was measured with implanted miniature ($40 \times 40 \times 20$ mm) StowAway XTI temperature-sensitive data loggers. The data loggers recorded temperature continuously at 6-min intervals throughout the study, had a resolution of $0.04°C$ and a measurement range of $+32°C$ to $+46°C$. The loggers were calibrated against a high accuracy thermometer (Quat 100, Heraeus, Hanau, Germany), in an insulated water-bath, to an accuracy of $0.05°C$. The loggers, covered in an inert wax (Sasol wax EXP987, Sasol, Johannesburg, South Africa), were sterilized with formaldehyde vapour (Paraformaldehyde, Kyron Laboratories, Johannesburg, South Africa) in a sealed drum before implantation.

Experimental procedure

To reduce the number of interventions per animal, blesbok were divided into two groups, a 'water-dousing' group ($n = 7$) and an 'alternative methods' group ($n = 7$). The animals were darted at a weekly interval, during the southern hemisphere summer (January to February), on five occasions. The time of day at which chasing, darting and the cooling

interventions took place was kept the same for each individual to reduce variability that may have occurred as a result of the animal's 24-h rhythm or body temperature. All interventions took place between 08:00 and 15:00.

To induce hyperthermia before the start of the cooling interventions, the blesbok from one boma (2–3 animals) were chased into a larger, adjoining enclosure (10×30 m) where they were encouraged by people on the perimeter of the enclosure to run at a moderate pace for 10 min. Thereafter, the animals were herded back to their boma. Following this 'chase', the animals were immediately darted (with 3.0–3.5 mg etorphine and 40–60 mg azaperone) and immobilized for the cooling intervention. Time to recumbency was 208 ± 54 seconds in the 'water-dousing' group and 273 ± 146 min in the 'alternative methods' group.

After darting, each blesbok was immobilized for 30 min. The blesbok were placed in sternal recumbency with the head held up and the nose pointing downwards. The animal was orientated with its head facing the sun so that the sun's rays fell on the animal's back evenly. Care was taken to ensure animals were not shaded by the researchers or the boma walls, and animals lay on the same sandy substrate for each trial. Skin temperature was measured by placing a thermistor (bead diameter 1.5 mm, 27 10K4A801, Onset Computer Corporation, Pocasset, Massachusetts, U.S.A.), attached to a washing-line peg, on the inside of the ear of the blesbok. Skin temperature was logged at a 2-min interval by a temperature-sensitive data logger (StowAway XTI, Onset Computer Corporation, Pocasset, Massachusetts, U.S.A.) at a resolution of $0.4°C$.

Within each group, all animals received five interventions, in a randomized cross-over design, at a weekly interval. Cooling interventions were initiated 5 min after immobilization, to allow for the monitoring equipment to be placed on the blesbok. Animals in both groups received a control intervention (no cooling) and a $28°C$ water-dousing intervention (to allow comparison between groups, and to evaluate the most common cooling practice of using water at ambient temperature). Testing before experimental trials, under our environmental conditions, revealed that water held in containers exposed to the environment had a mean temperature of $28°C$.

For animals in the 'water-dousing' group we compared the cooling efficacy of water at temperatures of $4°C$, $17°C$, $28°C$ and fanning following

dousing of water at 28°C to a control intervention of no cooling. Animals were doused with 10 l of water over the dorsal and lateral body surface (from the middle of the neck down towards the tail). The first 5 l was poured slowly over the animal and rubbed into the skin, from 5–10 min after the animal had been immobilized. The remaining 5 l was poured, and rubbed into the skin, 15–20 min after the start of immobilization. In this group of animals, we also examined if the addition of fanning to an animal doused with 28°C water (28°C + fanning) improved the efficacy of cooling with 28°C water-dousing. Fanning was done by manually using a rigid plastic tray (530 mm × 380 mm), which was waved up and down to produce a wind speed of about 1.2 ± 0.6 m/s (measured with a portable anemometer – Alnor GGA-65, Turku, Finland) from the start of dousing until the end of the immobilization.

For animals in the 'alternative methods' group we investigated effects of mist spraying, cold intravenous (IV) saline infusion, and ice-pack application. For the mist spray intervention, the animal received a fine mist spray of 28°C water, from a manual hand-held garden sprayer (0.435 l/min, Premium Pressurised Sprayer, Model G-2317, Shih Kuo, Taiwan) from a distance of about 100 mm from the body. The mist spray was applied to the dorsal and lateral body surface (from the middle of the neck down towards the tail) of the animal from 5–10 min and 15–20 min after the animal had been immobilized. For the IV infusion, 1 l of sterile isotonic saline (Adcock Ingram Critical Care, Johannesburg, South Africa) at 4°C was infused as fast as possible (over 12.8 ± 1.5 min) *via* an 18-gauge Jelco catheter (BD Insyte IV catheter, 1.3 × 30 mm, 105 ml/min, BD, New Jersey, U.S.A.) into the cephalic vein of the blesbok. For the ice-pack application, an 'ice-pack blanket' (Techni-Ice, Reusable Dry Ice Packs, HDR Model, Victoria, Australia) was placed over the dorsal and lateral body surface of the blesbok (from the middle of the neck down towards the tail) and in the groin and axilla areas (where there is less fur and good superficial blood supply), for 25 min. The 'alternative method' group also contained a 28°C water-dousing intervention (same procedure as for the water-dousing group) and a control intervention (no cooling).

Microclimate measurements

Wet-bulb, dry-bulb and black globe temperatures (HO-007-02, Onset Computer Corporation, Pocasset, Massachusetts, U.S.A.) were measured in the bomas. Wind speed (portable thermo-anemometer, Alnor GGA-65, Turku, Finland) was measured by holding the sensor both at 1.5 m above the ground and 100 mm above the animal. Vapour pressure was determined from a psychrometric chart (Barenbrug 1974).

Data analysis

Complete data sets were retrieved from 12 animals. In the 'water-dousing group' two data loggers failed prematurely, reducing the sample size to five animals. For analyses, the time of the start of the cooling intervention was taken as time zero. The peak body temperature elicited after the chase procedure was the absolute maximum temperature within 30 min after time zero; this peak temperature always occurred just after the capture and the start of cooling in the recumbent blesbok. The minimum body temperature was calculated as the absolute minimum reached within 60 min from time zero. The change in body temperature after cooling (the magnitude of cooling) was calculated as the difference between the body temperature at time zero and the body temperature at 30 min and 1 hour later. The rate of cooling was calculated as the change in body temperature from the peak to the minimum body temperature (within 30 min) divided by the time between these two points.

Results are reported as mean ± standard deviation (S.D.) and $P < 0.05$ was considered statistically significant. A paired Student's *t*-test for pairwise comparisons was used to compare body temperatures, as well as temperature differences between the skin and core, before and after darting. An unpaired Student's *t*-test was used to compare peak mean body temperatures between the two different groups. Repeated measures analysis of variance (RM-ANOVA) was used to compare peak, minimum and change in body temperature and rate of cooling in each group and a Newman-Keuls multiple comparisons test was used to detect significant differences between the interventions. We used GraphPad Prism version 6 for Windows (GraphPad Software, San Diego, U.S.A.) for statistical analyses.

RESULTS

Environmental conditions

Dry-bulb temperature, over all interventions, was 27.4 ± 0.7°C for the 'water-dousing' group and

28.4 ± 0.8°C for the 'alternative methods' group, while black globe temperature was 38.0 ± 2.5°C for the 'water-dousing' group and 40.0 ± 3.3°C for the 'alternative methods' group. Wet-bulb temperature was 22.8 ± 0.8°C for the 'water-dousing' group and 23.1 ± 0.4°C for the 'alternative methods' group. Wind speed in the boma, 1 m above the ground, was low and similar for both groups (0.3 ± 0.0 m/s for the 'water-dousing' group, and 0.3 ± 0.1 m/s in the 'alternative methods' group). Vapour pressure was 2.5 ± 0.2 kPa for the 'water-dousing' group, and 2.6 ± 0.1 kPa in the 'alternative methods' group.

Normal body temperature rhythm

In undisturbed blesbok in the bomas (over 23 capture-free days), mean 24-hour body temperature was 38.8 ± 0.4°C, with a minimum body temperature of 37.9 ± 0.1°C at about 08:30 each day and a maximum of 39.4 ± 0.1°C at about 18:00.

Body temperature changes in response to capture

The chase and darting to mimic a capture procedure consistently induced a precipitous rise in body temperature (Fig. 1), above that of the body temperature before capture (peak body temperature was significantly higher than body temperature before capture ($t_{(11)}$ = 10.79, P = 0.0001). The peak body temperatures reached after capture were not different between individuals within the 'water-dousing' ($F_{(4,16)}$ = 2.280, P = 0.106) and those in the 'alternative methods' group ($F_{(4,16)}$ = 0.365, P = 0.831). These peak body temperatures were in the range of 41–42°C and were on average 41.4 ± 0.5°C in the 'water-dousing' group and 41.2 ± 0.4°C in the 'alternative methods' group; they were not different between the groups ($t_{(10)}$ =

1.56, P = 0.54). The mean time for the occurrence of the peak in body temperature after darting was 12.8 ± 4.8 min in the 'water-dousing' group and 15.7 ± 3.3 min in the 'alternative methods' group.

Body temperature changes in response to cooling interventions

In the control interventions, without any cooling method applied, the minimum body temperature exceeded 40°C in both groups of blesbok more than an hour after capture (Fig. 2A and Fig. 2B). Minimum body temperatures after all water-dousing interventions were significantly lower than minimum body temperature in the control intervention ($F_{(4,16)}$ = 14.87, P < 0.0001, Fig. 2A). The minimum body temperature, however, was not influenced by water temperature; minimum body temperature of the blesbok did not differ between the 4°C, 17°C and 28°C water-dousing interventions. Minimum body temperature after 28°C water-dousing with fanning also was lower than that of the control, but did not differ from the water-dousing interventions alone ($F_{(4,16)}$ = 14.87, P < 0.0001, Fig. 2A).

In the 'alternative methods' group, only the ice-packs and the 28°C water-dousing interventions significantly ($F_{(4,16)}$ = 7.431, P = 0.0005, Fig. 2B) lowered minimum body temperature in comparison to the control. There was no difference between the minimum body temperatures in the blesbok after ice-pack application and 28°C water-dousing. However, the ice-packs significantly lowered body temperature compared to IV infusion and mist spray, while 28°C water-dousing resulted in a lower minimum temperature than did IV infusion.

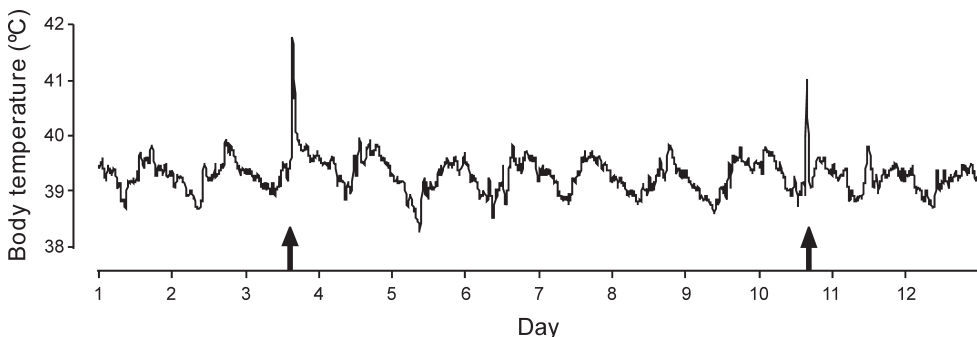Analysis of the magnitude of cooling, calculated as the absolute change in body temperature from

Fig. 1. The body temperature of one blesbok over 11 days in spring. On the third and tenth day the blesbok was chased and chemically immobilized (arrows) to perform cooling interventions. Note the precipitous rise in body temperature, of about 2°C, at the time of the chase and chemical immobilization.
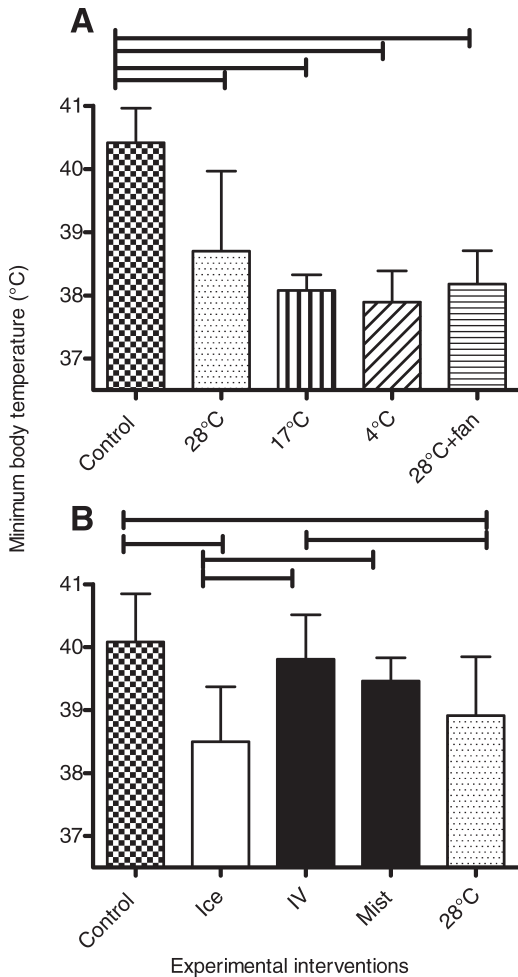
Fig. 2. Mean and S.D. of the minimum body temperatures reached within an hour from the start of cooling interventions. The top panel (**A**) illustrates the minimum body temperature reached following the water-dousing interventions in comparison to the control in lowering body temperature 1 hour after the start of the cooling intervention. The bottom panel (**B**) illustrates the minimum body temperature reached following alternative methods of cooling. The horizontal bars above the columns (⊢——⊣) indicate significant differences between groups ($P <$ 0.05). The term IV refers to intravenous infusion of 4°C saline.

the start of cooling to 30 minutes (Fig. 3 left panels), and 1 hour later (Fig. 3 right panels), revealed similar results as did the patterns of minimum body temperature. After 30 minutes, all the water-dousing interventions led to a significantly greater change ($F_{(4,16)} = 10.45$, $P = 0.0002$) in body temperature in comparison to the control (Fig. 3A). The magnitude of the change in body temperature did not differ between the water-dousing interventions of different water temperatures. A similar pattern occurred after an hour; however the magnitude of cooling was greater, at about 3°C for the water-dousing interventions (Fig. 3A *vs* Fig. 3B). There was no difference in the magnitude of cooling between 28°C water-dousing and 28°C water-dousing with the addition of fanning, at either 30 minutes or 1 hour.

In the 'alternative methods group', ice-packs, IV cold saline infusion and the 28°C water-dousing showed a significantly greater decrease in body temperature after 30 min compared to the control ($F_{(4,16)} = 8.91$, $P = 0.0001$), with body temperature decreasing by about 1°C (Fig. 3C). The mist spray was ineffective in lowering body temperature after 30 min and after 1 hour (Fig. 3C & Fig. 3D). After 1 hour, body temperature was still significantly lower than in the control following the application of ice-packs and 28°C water-dousing ($F_{(4,16)} = 12.12$, $P = 0.0001$, Fig. 3D). The change in body temperature after IV cold saline infusion, however, was no longer different to that of the control, in which body temperature had decreased slowly by about 1°C over the hour (Fig. 3D).

Water-dousing reduced body temperature regardless of water temperature. The minimum body temperature after cooling, and the fall in body temperature after 30 min and 1 hour, were not significantly different among 4°C, 17°C, and 28°C water temperatures (Fig. 2A and 3A & 3B). However, the rate at which the various water temperatures lowered body temperature did differ (Fig. 4A). In the 'water-dousing' group, body temperature fell more rapidly when animals were doused with 4°C water than when they were doused with 28°C water ($F_{(4,16)} = 7.47$, $P = 0.0014$). When animals were doused with cold water (4°C and 17°C) or with 28°C water with fanning, body temperature fell about three-fold as quickly as it did when they received the control intervention.

While 28°C water-dousing did not lower body temperature more rapidly than the control in the 'water-dousing group', it did do so in the 'alternative methods' group (Fig. 4B). However, the rate of cooling in this group of animals always was slow. After ice-pack application and 28°C water-dousing, body temperature of the blesbok decreased at a rate of about 0.05°C/min, significantly quicker than the rate of cooling in the control, which was about 0.03°C/min ($F_{(4,16)} = 7.31$, $P = 0.0021$, Fig. 4B), but much less than the cooling of about 0.1°C/min seen in animals after 4°C water-dousing (Fig. 4A). The rate of fall in body temperature after the mist
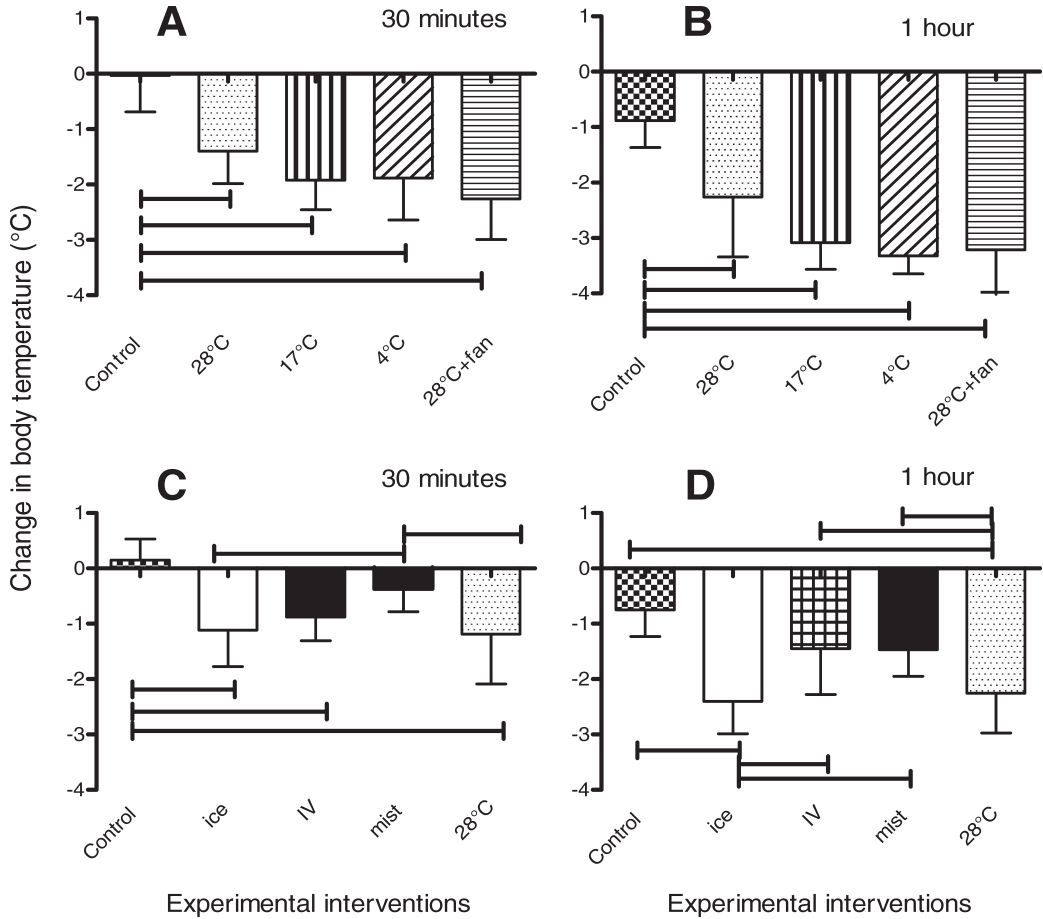
Fig. 3. Mean and S.D. of the magnitude of the change in temperature within 30 min (panels **A** and **C**) and 1 hour (panels **B** and **D**) following the start of the intervention. The solid horizontal bars above the columns (├───┤) indicate significant differences between groups ($P < 0.05$). The term IV refers to intravenous infusion of 4°C saline.

spray and the IV infusion was not different to that of the control.

Temperature difference between core and ear skin temperature

The difference between the core (abdominal) and ear skin temperature at the end of cooling was 5.16 ± 3.09°C in the 'water-dousing group' and 3.5 ± 5.52°C in the 'alternative methods group' and these differences were no different to that at time zero ($t_{(4)} = 1.73$, $P = 0.098$ 'water-dousing'; $t_{(6)} = 0.23$, $P = 0.824$ 'alternate methods'). The area under the curve for the temperature difference between the core and the ear skin from time zero to the end of cooling was also not different among the interventions in both the 'water-dousing interventions' ($F_{(4,16)} = 0.149$, $P = 0.96$) and the 'alternative methods group' ($F_{(4,16)} = 1.446$, $P = 0.25$).

DISCUSSION

As far as we are aware, this is the first study to compare the efficacy of various cooling techniques in lowering body temperature in captured hyperthermic antelope. We have shown that ice-pack application and water-dousing, with water temperature varying from 4°C to 28°C, or with fanning added to 28°C water, were effective in returning the body temperature of hyperthermic blesbok, within an hour, to pre-capture levels. Intravenous infusion of 1 l of cold saline also reduced body temperature but was less effective than were the water-dousing and ice-pack methods. Spraying 28°C mist over the animal had no effect; cooling was similar to that in the control in which no cooling method was applied.

One potential concern associated with cooling hyperthermic animals is the risk of hypothermia if
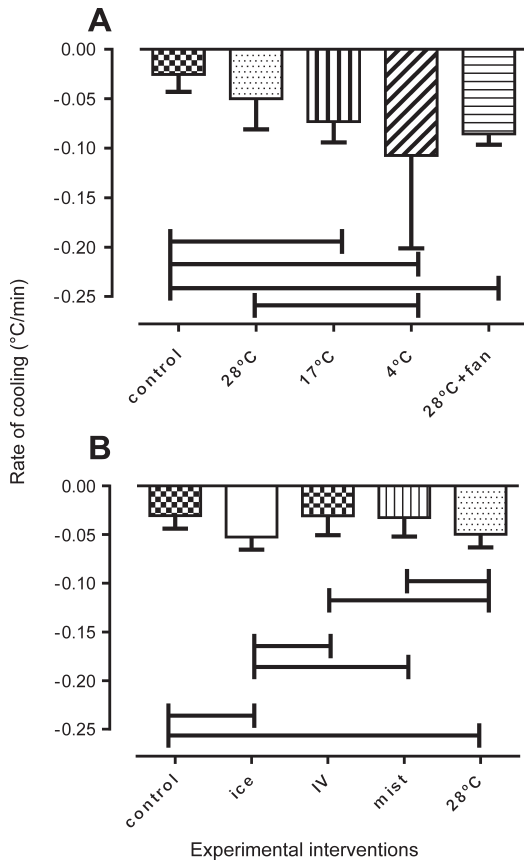
Fig. 4. Mean and S.D. of the rate of cooling within 30 minutes by each experimental intervention. The top panel (**A**) illustrates the rate of cooling following water-dousing and the bottom panel (**B**) illustrates the rate of cooling following alternative cooling methods. The solid horizontal bars above the columns (├────┤) indicate significant differences ($P < 0.05$). The term IV refers to intravenous infusion of 4°C saline.

body temperature continues to fall after the cooling intervention has ended. The cooled blesbok's body temperatures typically returned to normal within an hour after capture and there was no overshoot of body temperature to levels lower than normal. It is important, however, given the need to reduce morbidity and mortality in captured animals, that hyperthermic animals be cooled rapidly after capture. In most capture situations, animals are unlikely to be held or monitored for more than 30 min. We have shown that body temperature of blesbok returned to normal after 1 hour following water-dousing, water-dousing with fanning, and ice-pack application. However, these cooling interventions also elicited significant decreases in body temperature 30 min after the start of cooling,

resulting in body temperatures below 39°C, close to the normal 24-h average body temperature of 38.8°C for blesbok. While the minimum body temperature reached after cooling with 28°C and 4°C did not differ, 4°C water-dousing lowered body temperature more rapidly than did the tepid 28°C water. Often it may be impractical in the field to carry cold water; however, where rapid cooling of an animal is required, we have shown that water at 4°C, or even 17°C, was more effective than was water at 28°C. However, the rate at which 28°C water-dousing lowered body temperature was improved, and was similar to that of cold water, if convective cooling through fanning was added. Our water-dousing interventions, which effectively and rapidly lowered body temperature (by 0.05 to 0.1°C/min), were applied for 10 min during the immobilization. Whether cooling applied over a shorter period, and through use of smaller volumes of water, is as effective in reducing body temperature as in our study remains to be determined. Similarly, whether our cooling protocols are effective when hyperthermia exceeds that experienced by our blesbok, or whether the cooling effect is dependent on the mechanisms resulting in the hyperthermia (*i.e.* stress-induced *vs* exertional-induced) needs to be elucidated.

Body temperatures that exceed 41–42°C are known to cause cellular damage in most mammals (Grint, Gorvy & Dugdale, 2007; Haskins, 1995), and temperatures greater than 43°C are believed to result in death of wildlife during capture procedures (Kock & Meltzer, 2006). The extent of tissue damage and physiological malfunction depend not only on the magnitude of the hyperthermia but also on its duration (Proulx, Ducharme & Kenny, 2003). In humans, the primary objective of treatment for hyperthermia is to reduce body temperature to a safe level as quickly as possible (Proulx, Ducharme & Kenny, 2003). At present, there are no data to indicate what duration of hyperthermia is harmful to an animal with capture-induced hyperthermia, or the magnitude, or rate of cooling that is required to reduce the pathophysiological consequences of this hyperthermia. Therefore, we believe the premise should be that the most effective cooling method should be instituted as soon as possible and should be applied until body temperatures approach near normal values.

In addition to the difficulty of keeping water cold in the field, a potential limitation of applying cold water to an animal's surface is that the cold stimulus may elicit vasoconstriction (Daanen, 2003), lead-

ing to an attenuated fall in body temperature. Such vasoconstriction may be reflected by an increased difference between core body temperature and skin temperature. We found, however, that the difference between core temperature and ear skin temperature remained constant, at about 5°C, throughout the cooling interventions and did not differ across the various cooling interventions. It appears unlikely, therefore, that cold water dousing led to a change in vasomotor tone that altered the efficacy of the cooling. Azaperone, used in the dart to immobilize the animals, has alpha$_1$ adrenergic receptor antagonist properties that may have elicited vasodilation (Meltzer, Burroughs & Morkel, 2006b), potentially countering any cold-induced vasoconstriction, but any drug effects would have been similar in all interventions.

The finding that water-dousing effectively lowered body temperature supports the common practice in field conditions of pouring water over captured animals and rubbing the water into the hair (Foster, 2005; Meltzer, Hofmeyr & Fivaz, 2006a; Arnemo & Fahlman, 2008). Non-anaesthetized hyperthermic horses have been effectively cooled with 6°C and 15°C water-dousing (Marlin *et al.,* 1998; Kohn, Kenneth & Kenneth, 1999). In the field it is not always possible to regulate the temperature of water, or to keep water cold. In southern Africa, where we worked, water stored in a container exposed to the environment is likely to be warm, even in winter, as a result of high solar radiation. Importantly, we have shown that even water at 28°C can be used to lower the body temperature of hyperthermic antelope after capture.

Our findings were similar to our expectations that colder water (4°C and 17°C) would decrease the body temperature quicker than would 28°C water because of an increased conductive cooling power resulting from a greater temperature difference between the water and the animal (Jessen, 2001; Willmer, 2005). We also predicted that dousing the blesbok with 28°C water with fanning would be more effective in cooling the animals than would 28°C water-dousing alone, because fanning increases heat loss through convection and evaporation of water off the animal (Jessen, 2001). However, we found no difference when we doused the animals only with 28°C water compared to when we fanned the animals while dousing them with 28°C water. We fanned the blesbok with a rigid sheet of plastic to simulate field practice, and generated a wind speed of about 1.2 m/s over the animal. This wind speed was possibly too low; the

recommendation for alleviating heat stress in cattle (*Bos taurus*) is a wind speed of 2 to 4 m/s (Gaughan, Binns & Lott, 2004). Generating such high wind speeds to improve convective cooling may be impractical in the field, although situations where animals are subsequently translocated in ventilated vehicles may facilitate additional convective cooling.

Guidelines for cooling captured animals also recommend the use of cold IV infusions, mist sprays and packing of ice under the axilla, groin and tongue (Foster, 2005; Meltzer, Hofmeyr & Fivaz, 2006a; Arnemo & Fahlman, 2008). We investigated some of these methods as alternatives to water-dousing. Because the placement of ice-packs to only the axilla and groin is ineffective in decreasing body temperature in humans (Smith, 2005), we placed ice-packs over the body surface as well as ice-packs in the axilla and groin and found that these cooled the animals effectively by decreasing body temperature in a manner similar to that of water-dousing.

Cold IV fluids also have been used in the field to cool wild animals (Foster, 2005; Meltzer, Hofmeyr & Fivaz, 2006a; Arnemo & Fahlman, 2008). In humans, 4°C isotonic saline has been used to reduce body temperature by between 1°C (Moore, Callaway & Hostler, 2008) and 2.5°C (Rajek *et al.,* 2000). Infusion of 1l of cold saline in blesbok led to a fall in body temperature after 30 min of about 1°C. The infusion of cold saline was not as effective in lowering body temperature as were water-dousing and ice application. Increasing the volume of infused saline is likely to improve cooling, but infusing a higher volume is impractical and increases the risk of pulmonary oedema (Bouchama, Dehbi & Chaves-Carballo, 2007). Rather than being used as a first-line cooling approach, IV infusion may be useful in situations of severe hyperthermia, where it could be used in combination with other cooling techniques, such as water-dousing, to cool an animal more rapidly.

The only method that was completely ineffective in lowering body temperature of our blesbok was mist spraying. Mist sprays have been recommended for cooling hyperthermic animals, on the basis that spraying allows better soaking of the animal's pelage than does dousing, and because of an erroneous belief that sprayed water is cooled by evaporation once the water droplets are expelled from the sprayer. Our study does not support these ideas; even though spraying did soak the animals pelage, spraying water at 28°C was less effective

than was the more practical method of dousing an animal with 28°C water. Ice-packs also restored body temperature of hyperthermic animals to pre-capture levels but carrying water is far less cumbersome and difficult than is transporting and maintaining ice-packs in the field. We therefore recommend, at least in species of similar size and pelage to blesbok, that water-dousing is the most practical and effective method to cool an animal with capture-induced hyperthermia. Although no more effective than tepid water in cooling an animal over 30–60 min, cold water will cool an animal quicker. In circumstances where it is diffi-cult to carry cold water, and where there is a need to cool an animal rapidly, the addition of convective cooling through fanning is likely to be beneficial if adequate air movement is generated.

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