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Determining thermal stress during the transport of mammals

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1 INTRODUCTION

My dissertation is about determining practical methods of measuring the body temperatures of large mammals during actual capture and transport operations. The capture and transportation of wild animals is carried out routinely for the purposes of nature conservation and commercial game farming, while livestock are transported for use in agriculture. In 2001, there were about 80 000 wild animal captures throughout South Africa (Michler, 2002). For both livestock and wild animals, these capture and transport procedures are associated with morbidity and mortality. A case in point is a recent example of 30 roan antelope dying during transport out of an initial capture of 106 (Wiggett, 2002). The antelope (mostly calves and cows) died due to capture-related stress, worsened because the cows were pregnant, and apparently because holding facilities were inadequate and offered no protection from extreme variations in temperature (Wiggett, 2002). Knottenbelt (1990) reported that the most common causes of death during the capture of impala were due to stress or injuries occurring while they were being captured. Similarly Openshaw (1993) blamed stress, temperature extremes and injury as the main causes of mortality of wild mammals during transportation.

The above reasons may explain the mortality of livestock during capture and transport. Gardiner and Craig (1970) reported that the average mortality rate of sheep transported by ship seems to increase with longer voyage times (0.75% to 3.6%), because the increased time at sea increases the effects of high temperature and relative humidity, crowding and nutritional stress. On land, lambs had a higher mortality rate during transport when the sheep came from auctions (0.0310

%) than when they were transported directly from farms (0.0068 %) (Knowles *et al.*, 1994). Pigs, on the other hand, had a 0.07% mortality rate out of about 400 000 pigs being transported annually in Great Britain (Allen *et al.*, 1974). The mortality rate was strongly correlated with environmental conditions, as it almost tripled when the pigs were transported in summer (Allen *et al.*, 1974). High mortality during the capture and transport of wild animals and livestock not only leads to a needless loss of animals, but it also has large financial implications for the operators involved in the moving of these animals. Research is therefore needed to reduce future mortalities.

1.1 Stress of capture and transport

1.1.1 Causes of stress

Selye (1973) defined stress as a threat to the internal environment of an animal. Stressors can be psychological (e.g. human presence), physical (e.g. thermal extremes) and/or physiological (e.g. pregnancy) factors that could shift a physiological variable or function from normal (Cheney, 1987; Goss and Siegel, 1993; Grandin, 1997). Both capture and transport are considered stressful procedures for livestock and wild animals (Waas *et al.*, 1997; see review by Knowles and Warriss, 2000; von Borell, 2001). Stressors during capture and transport include the loss of a familiar environment, exposure to foreign smells, sights and touch and also to unusual muscle activity (van Logtestijn *et al.*, 1982; also see Ebedes, 1993). There are also various thermal stressors, such as very high or low air temperatures and humidity, exposure to wind, extreme physical

exertion, the restraint techniques used (Fowler, 1978) and the immobilizing drug used (Hofmeyr and de Bruine, 1975).

1.1.2 Responses to stress

An animal's stress response is therefore an attempt to keep the internal environment stable by compensating with voluntary actions (behavioural changes) and involuntary actions (physiological changes) (Cheney, 1987; Ewing, 1999). If the animals' physiological mechanisms were unable to maintain homoeostasis, due to the intensity and prolonged time of the stressor (Selye, 1973), stress could result in the animals dying (Knowles and Warriss, 2000). Involuntary actions include responses from the hypothalamic-adrenal medullary stress response system by which catecholamines are released into the blood, which in turn increases blood flow to muscles and raises metabolic and heart rates (Fowler, 1978; Ewing, 1999). Meanwhile, the activation of the hypothalamic adenohyophyseal adrenalocorticol pathway produces an initial rapid release of cortisol and a longer-term increased production and release of cortisol (Fowler, 1978; Ewing, 1999). The metabolic consequences of this response take a long time to become apparent (Fowler, 1978; Ewing, 1999). All stress responses are stressor and individual specific (Moberg, 1985) as they are affected by the animal's experience and genetics (Grandin, 1997).

1.1.2.1 Changes in blood and faecal constituents

Several studies have investigated the stress response during the capture/restraint and transportation of wild mammals and livestock, by examining the changes in

the concentration of blood constituents known to be affected by stress. For example Hofmeyr *et al.* (1973) investigated the effects of capture on zebra by comparing glucose, lactate, creatine kinase, plasma osmolality and haematocrit of these captured zebra with zebra that were not chased, but after both groups were immobilized. The chased zebras had elevated concentrations of all these blood variables compared to the non-chased zebras. A study by Hattingh *et al.* (1988) showed that by re-capturing impala that were already in a boma, the impalas' haematocrit, cortisol, glucose, lactate and a few other blood constituents increased compared to the concentrations of these blood constituents in brain-shot impala (controls).

In the case of transport, most studies have looked at the changes of stress variables only before and after transport, such as the study by Anderson *et al.* (1999) that showed an increase of cortisol in alpacas after transport. Hattingh (1988) also showed that haematocrit and cortisol increased in roan antelope after they were transported. However, battery powered remote blood samplers have been used to investigate the responses to stress by measuring the changes in various blood constituents before, during and after transport in red deer (Waas *et al.*, 1997). This study has shown that transport increased haematocrit and the concentrations of magnesium, sodium and cortisol and had little effect on glucose. Using the same protocol, Nwe *et al.* (1996) showed that plasma adrenaline and cortisol concentrations increased immediately in Japanese native goats after the start of transport, while noradrenaline did not increase. Packed-cell volume can also be

used as an indicator of the response to stress, as some animals will release red blood cells from a reserve in their spleens (Knowles and Warriss, 2000).

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Because blood sampling in itself causes stress (Dehnhard *et al.*, 2001), only measures the concentration of a blood constitute at a specific time (Harper and Austad, 2000) and is often a dangerous procedure (Palme and Möstl, 1996), other non-invasive methods of sampling physiological variables may be more useful when working with wild animals. Measuring the amount of cortisol found in faeces has been shown to be an appropriate substitute, as an animal's stress responses include the high production of glucocorticoids (Dehnhard *et al.*, 2001). Glucocorticoids are metabolised in the liver and then excreted in urine and faeces (Palme and Möstl, 1996). Faecal sampling showed that the amount of excreted cortisol metabolite increased during transport in roe deer (Dehnhard *et al.*, 2001) and cattle (Möstl *et al.*, 2002). To examine the effects of transport on these metabolites, the difference in intestinal passage times have to be taken into account (Möstl and Palme, 2002). For instance, ruminants take 10-12 hours for maximum concentrations of cortisol to be measured in their faeces after a stress event (Möstl and Palme, 2002).

1.1.2.2 Thermal responses

Thermal stress occurs under the conditions in which mammals have difficulty in maintaining constant body temperature (Ewing, 1999). Responses to thermal stress include hyperthermia and hypothermia, where a large mammal's body temperature can increase or decrease by about 6^{o}C relative to the normal range of

temperature (Schmidt-Nielson, 1990). Hypothermia occurs when the heat loss from the body is greater than the heat gain, whereas hyperthermia results when the heat gain by the mammal is greater than the heat loss. Thermal stress can result in the mammal dying, as normal body functions depend on a relatively stable core body temperature (Drew, 1996). What follows are examples of thermal stressors and the responses to these stressors.

The environment can provide an important stressor that could easily overload the animal's thermoregulatory efficiency (Wenzel, 1983). If the air temperature is equal to that of the animal's body temperature, the normal avenues of heat loss (namely radiation, convection and conduction) cannot occur, resulting in the heat gained by the animal being greater than the heat loss (Dukes, 1955). Therefore the animal can only lose heat by the vaporisation of water, occurring mainly through the conduction of water from the respiratory passages or by water evaporation from the skin (Dukes, 1955). The latter will only occur in those mammals that have well-developed sweat glands (Dukes, 1955). On the other hand, if air temperatures decrease below the animal's body temperature, vasoconstriction in the skin and erection of the animal's hairs are not always enough to prevent heat loss from the animal, and the animal consequently shivers (Dukes, 1955).

It is a well-known phenomenon that there is an increased mortality of animals during transport in summer as compared to winter, because of the higher air temperature and water vapour pressure (van Logtestijn *et al.*, 1982). Therefore there are guidelines as to when to capture animals, such as during the cooler

months of the year, preferably when there is low humidity and generally only in the early morning or late afternoon, when the air temperature is below 25^{o}C (Openshaw, 1993; Ebedes *et al.*, 1996; South African Bureau of Standards, 2001). Capture operators have also been told to place the animal where environmental temperatures are lower than the body temperature (namely in the shade), so that the animal can lose heat to the environment (Burroughs and McKenzie, 1993).

These extremes in body temperature from environmental stressors can be exacerbated by fear. Fear motivates animals to avoid predators (Grandin, 1997) and during capture and transport operations there are unusual smells and sounds made by the capture operators, which are probably seen as potential danger by the animals. Fear creates an even greater stress when the animals are unable to escape from this potential danger by being confined in bomas and in transport containers (Ebedes, 1993). A study by Meyer *et al.* (2004) showed that fright increased core temperature in impala more than the muscle activity associated with chasing. During exercise, the increased muscle activity causes an increased rate of blood flow through the skeletal muscles of up to 80/ml/min/100g of muscle compared to 3 ml/min/100g of muscle at rest (Spraker, 1993). This increase in heat production is rapid from the start of exercise (Schönbaum and Lomax, 1991). Therefore when animals are captured, the animals' prolonged running while being chased and their attempted escape behaviour during restraint, produces excessive heat (Fowler, 1978). The animals' body temperatures will continue to increase until heat loss is the same as this heat gain or the animal dies (Schönbaum and Lomax, 1991). Frightened animals that are restrained have contracted muscles that cause a

decrease in blood flow into the muscles and in turn decrease the ability of these animals to lose heat (Spraker, 1993). This inability to lose heat is exacerbated by conditions of high environmental heat load and chemical immobilization.

Capture drugs can affect animals by increasing their metabolic rate and disrupting the ability of the thermoregulatory system to regulate, so that immobilized animals have no control over how much heat they gain or lose (Burroughs and McKenzie, 1993). Drugs used during the chemical restraint of wild animals include anaesthetics, opioids, sedatives and tranquillizers (Swan, 1993). Out of this list, the opioids, such as etorphine hydrochloride (M99) and long-acting tranquillizers, such as perphenazine enanthane (Trilafon) are known to inhibit the animal's thermoregulatory system by making animals susceptible to chilling or overheating during transport (Swan, 1993). Hypothermia can occur, as chemical immobilization can reduce the ability of the animal to shiver to increase its body temperature (Fowler, 1978). On the other hand, since etorphine hydrochloride slows respiratory rate in ruminants, animals that dissipate heat primarily by panting might easily become hyperthermic (Cheney, 1987). Since an increase or decrease in the body temperature of animals undergoing capture and transport can show the effects of thermal and non-thermal stressors during these procedures, the measurement of body temperature can provide useful insights into the extent of an animal's response to these stressors.

1.2 Measurement of body temperature

1.2.1 Rectal thermometry used during the capture and transport of mammals

Many capture and transport deaths have been ascribed to overheating (Perry, 1996; Knowles *et al.*, 1998). However, many studies investigating thermal stress during capture and transport have measured the animal's temperature intermittently using rectal mercury-in-glass thermometers (Gardiner and Craig, 1970; Jacobson and Cook, 1998), which result in an additional disturbance and stress to the animals (Ingram *et al.*, 2002). Often the animals' temperatures were measured only before and immediately after transport (von Mickwitz, 1982; Martucci *et al.*, 1992; Friend *et al.*, 1998 and Knowles *et al.*, 1998), which resulted in incomplete body temperature records. Lastly, body temperatures have been known to exceed the available scale on the rectal mercury-in-glass thermometer (Gericke *et al.*, 1978).

Since mercury-in-glass thermometers are problematic to use, some studies have used data loggers or telemeters to examine the thermoregulatory responses of animals. Telemeters modulate the frequency of the carrier radio waves. A simple way of measuring that modulation is using beats detected on a radio receiver. The beat frequency depends on the temperature of the telemeter and so temperatures can be instantly obtained, but need calibration curves to convert the values obtained from the receiver to body temperature. Data loggers, on the other hand, have an on-board memory storage capacity and so the temperature data have to be downloaded onto a computer before the data can be seen (see section 2.1.1).

Radio-telemetry has been used to measure the body temperature of animals in outdoor paddocks (Bligh and Harthoorn, 1965; Harris *et al.*, 2001). However, the telemetry system used was cumbersome: the animals had harnesses (often with an aerial or signal booster) around their bodies and Bligh and Harthoorn (1965) used a temperature probe crudely placed in a stab wound made on the necks of the animals. Lefcourt and Adams (1996) and Prendiville *et al.* (2002), however, have used telemeters surgically implanted into the abdomens of livestock that did not need any attachments on the animal to measure their body temperatures.

Implanted data loggers have been used to record body temperatures of wild animals (Mitchell *et al.*, 1997; Fuller *et al.*, 1999). Recently, miniature data loggers have been successfully used by Kamerman *et al.* (2001b) in impala. Data loggers are thought to have more advantages over telemeters as thermometric devices because they do not need additional equipment or people to obtain the data measurements; they have high sampling rates and can be used to measure multiple variables; and they are extremely accurate with a temperature resolution of about 0.05^{o}C (Kamerman *et al.*, 2001a). One drawback of using data loggers, however, is that temperature data can be evaluated only once the logger has been removed from the animal and downloaded, and they should therefore not be used when an animal's temperature needs to be monitored constantly (Kamerman *et al.*, 2001a). Telemeters therefore seem to be the better option to data loggers in measuring body temperature during capture and transport operations, where body temperatures are needed in real time to determine the welfare of the animal. I have found only one paper (Barnes *et al.*, 2003) that implanted both data loggers and

telemeters into the abdomens of cattle, but the authors did not compare the temperatures obtained by the two devices.

1.2.2 Sites of temperature measurement during the capture and transport of mammals

To properly identify the thermoregulatory status of an animal, one needs to measure the core body temperature. Brengelmann's 1987 paper states that core body temperature is an index of the thermal balance of the body and in humans it is the heat measured at the pulmonary artery, while Goodwin (1998) states that the temperature of the hypothalamus or deep body sites, such as the chest or abdomen, in mammals are representative of core temperature. However, in the circumstances surrounding real-life capture and transport operations it is not practical to measure the pulmonary artery's temperature or to surgically implant temperature-measuring devices, so one needs to use other body sites as substitutes. Brengelmann (1987) has suggested that temperature measurements made in the oesophagus and in the mouth were the best substitutes, but these body sites are not practical to use in large non-human mammals.

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In both humans and large mammals, temperature measurements have been made by a telemeter or data logger pill (that is swallowed). Although Nevill and Friend (2003) fed circus tigers miniature data loggers to measure body temperatures during transport (see next section), they did not compare these body temperatures with another body site. This comparison has been done in humans, where temperatures obtained from a swallowed telemetry pill have been compared to

temperatures measured in the rectum and in other areas. Both Kolka *et al.* (1993) and O'Brien *et al.* (1998) found that rectal temperatures were higher than those measured by the telemetry pill and that the temperatures from the oesophageal site were lower than the other two sites. The oesophageal temperature also had the shortest time to stabilise as well as the biggest change in temperature and the greater rate of increase in temperature (Kolka *et al.*, 1993).

Another study on humans measured temperatures in the rectum, oesophagus, gastrointestinal tract and other body sites. Livingstone *et al.* (1983) showed that at normal ambient temperature the following body sites gave comparable estimates of the core body temperature in humans (within about 0.5^{o}C): rectum, oesophagus, auditory canal, gastrointestinal tract (measured using a radio pill) and sublingual. During exposure to cold, however, the auditory canal and sublingual sites gave temperatures that were below the limit of the thermometer, because of facial cooling, while oesophageal temperatures fluctuated due to the person swallowing cold saliva. Both rectal and gastrointestinal temperatures had similar high temperatures, because the radio pill landed up near the rectum and both sites responded to the cold by the local production of heat (Livingstone *et al.*, 1983). A recent study by McKenzie and Osgood (2004) showed that temperatures measured by a telemetry pill and a rectal probe were similar in humans, but that during strenuous exercise in hot (36^{o}C) environments, rectal temperatures were about 1.79^{o}C higher than those measured by the pill. McKenzie and Osgood's study had problems occasionally losing the telemeter signal (resulting in missing data points), as well as differences in passage times of the pill in different people and

the expense of losing the telemeter when it was naturally voided by the human subject. Body temperatures measured by the pill can also be affected by the heat released by fermenting food (affected by eating habits), drinking cold water, and the position of the telemeter in different parts of the body, especially if the telemeter reaches the stomach or is close to the liver or the rectum (Mackay, 1965; Livingstone *et al.*, 1983 and O'Brien *et al.*, 1998).

Ruminants have different stomachs than humans, so that if the telemetry pill was used in the ruminants, the pill would respond very slowly to changes in blood temperature as well as measuring the temperature produced by the masses of bacteria found in the rumen (Schmidt-Nielson, 1990). The above-mentioned studies seem to show that the oesophagus and the gastrointestinal tract are not practical body sites to measure the body temperature of large animals while they are being captured and/or transported.

In a study using large animals (goats, horses and sheep), Goodwin (1998) measured the following temperatures: tympanic, by using infrared thermometry; subcutaneous with an implantable microchip transponder (together with a hand held scanner); and rectal temperature using a digital thermometer. Goodwin found that in goats, rectal and subcutaneous temperatures did not differ, but both were significantly higher than tympanic temperatures. However, in horses and sheep, rectal temperatures were significantly higher than subcutaneous and tympanic temperatures. Subcutaneous temperatures were the most variable compared to the other temperature measurements and Goodwin suggests that the transponders

should have been implanted deeper or in another body area, as the current site was too peripheral. On the other hand, some animals in the study reacted adversely to having their tympanic temperatures measured, which was done using an infrared thermometer instead of the commonly used thermistor probe, resulting in insufficient time to obtain temperature readings (Goodwin, 1998). Lastly, it would have been better for Goodwin to randomise the order of temperatures taken, as a possible reason for the rectal temperature being higher in all cases is that this was the last measurement to be taken. Therefore, the animals could already have an increased temperature due to the handling to obtain the other temperature measurements.

In another large animal, bighorn sheep, Drew (1996) also measured tympanic temperatures (obtained by an infrared scanner) and rectal temperatures (using a mercury-in-glass thermometer). Similar to Goodwin, Drew found that mean tympanic temperatures were significantly lower than mean rectal temperatures. Two years later, Drew used the same methods for measuring temperature and found that tympanic temperatures were again significantly lower than rectal temperatures, but this time the study was on fallow deer (Drew, 1998). However this study obtained the temperature measurements from wild animals recovering from anaesthesia, which means that the animals were more approachable to obtain their body temperatures.

Tympanic and rectal temperatures were measured in cattle, together with temperatures measured in two sub-dermal sites (neck and flank), in a study by Hahn *et al.* (1990). These authors concluded that the tympanum should be used

instead of the rectum to measure temperatures, because the temperature time lag of the rectum is too great. However, it seems that the data that these authors used were from only two animals and they also do not mention how the probes for temperature measurements were placed or where the data logger (used to record temperature) was positioned on the animal. For a once off measurement I am sure that tympanic temperatures can be used, but I am not sure that body temperature will be unaffected by having to handle the animal to obtain tympanic temperature, as well as having to manually measure rectal temperatures. Brengelmann (1987) on the other hand, suggests that tympanic temperatures should not be used as a substitute for measuring core body temperature, as these temperatures do not respond quickly to quick changes in temperature (great time lag).

Ingram *et al.* (2002) used temperature-logging ear tags with sensors glued onto the under-surface of the ear, to obtain pinna temperatures, and sensors incorporated into an outer-ear-canal plug, to obtain ear-canal temperatures of sheep. They also inserted a mercury-in-glass thermometer into the rectum of these animals during transport (see next section). However, the ear temperature measurements cannot be used to examine the thermal stress on the animal, as the ear provides a peripheral measurement of body temperature that is affected by vasodilation or constriction. Furthermore, rectal temperatures cannot be compared to peripheral temperatures, as the rectal temperature readings were intermittent (see next section). Geers *et al.* (1997), in another study on pigs, compared body temperatures measured by a transponder in the base of the ear to rectal temperatures, while the pigs were held in indoor housing. These authors showed

that rectal temperatures were higher than ear base temperatures (Geers *et al.*, 1997). However these authors could only use 30% of their temperature data because of poor reception of the transponder, and again the validity of ear temperature measurements is questioned. Ear canal temperature measurements can therefore be discounted, as they do not measure core body temperatures.

To summarise, the temperatures measured by a telemeter or data logger pill (too much variation) and temperatures measured in the tympanum (too invasive), sub-dermal site (too invasive) and the ear canal and pinna (peripheral temperature) do not seem adequate substitutes for measuring core body temperature of mammals in a capture and transport situation. Since rectal temperature measurement is still the most commonly used method of obtaining core body temperature during the capture and transport of large mammals (Hicks *et al.*, 2001), the rectum would be the closest substitute to measuring core body temperature.

Rectal temperature could be used as an index of the core body temperature (Dukes, 1955), although due to thermal inertia, temperatures measured in the rectum respond slowly to quick changes in thermal stress (Brengelmann, 1987). To judge whether rectal temperatures can be used as a measure of core temperature, rectal temperatures must be compared to temperatures measured in proposed body core sites, namely the pulmonary artery (Brengelmann, 1987), hypothalamus (Goodwin, 1998) or surgically implanting temperature-measuring devices in the chest or abdomen (Schmidt-Nielson, 1990). Hetzel *et al.* (1988) and Prendiville *et al.* (2002) have both shown that rectal temperatures were significantly lower than abdominal temperatures in cattle. Hetzel *et al.* (1988)

showed that telemeters implanted into the muscles of cattles' abdomens gave temperatures that were on average 0.2^{o}C higher than rectal temperatures (measured using digital thermometers). However, the authors acknowledged that the telemeter placed in the muscles of the abdomen would have overestimated thermal stress experienced by the animals, as activity would have increased local body temperature. Prendiville *et al.* (2002) placed the thermometric devices inside the cattle's rumen, which could have influenced the results, due to the temperatures produced by the bacteria in the rumen (Schmidt-Nielson, 1990).

Contrary to the findings by Hetzel *et al.* (1988) and Prendiville *et al.* (2002), other studies have found significant correlations (and similarities) between temperatures measured in the rectum and the abdomen of animals. One such study is that by Barnes *et al.* (2003) on cattle. Another study is by Hicks *et al.* (2001) that used telemetry pills and rectal mercury-in-glass thermometers to measure body temperatures in cows, but instead of feeding the pills to the cows they used a cannula to manually place the pill in the lower rumen of a rumen fistulated cow. As mentioned previously, the high activity of the bacteria present in the rumen would generate all the heat that was measured by the pill (Schmidt-Nielson, 1990). In this study, pills were also surgically implanted into the abdomen of cows. Temperatures measured from both sites did not differ significantly to the rectal temperatures. However, the results are questionable as the sample size was very small (only four animals) and the authors used a mercury-in-glass thermometer to measure rectal temperature. Finally, Bligh and Harthoorn (1965) found similarities in temperature measurement from deep body sites and rectum of

camel, buffalo and eland. However, these authors measured the rectal temperatures intermittently, and more importantly, they may not have measured deep body sites, but appear more likely to have measured sub-cutaneous sites as they placed the temperature-sensitive probes into stab-wounds in the lower neck, hump, back or behind the scapula (depending on the species) of the animals.

Although several studies that have compared rectal to core body temperatures, there is still a lack of knowledge on how well rectal temperature reflects core body temperature during the capture and transport of large mammals.

1.2.3 Consequences of capture and/or transport on body temperature

Very few studies have measured the body temperatures of large animals continuously throughout capture and transport procedures. Sometimes rectal temperature was measured only to determine when to cool the animal down (Martucci *et al.*, 1992) or to determine if the animals were fit to continue transport (Friend *et al.*, 1998). Studies done by Kock (Kock *et al.*, 1987; Kock *et al.*, 1990a; Kock *et al.*, 1990b) have mentioned that body temperatures of bighorn sheep and black rhinoceros were measured during transport, but nowhere have they disclosed how the temperatures were measured and so their conclusions cannot be validated.

Some studies, however, have used thermometry to measure the body temperatures of livestock in climate-controlled rooms that were used to mimic the transport conditions. Barnes *et al.* (2003) used telemeters and data loggers implanted into

the abdomen of cattle and revealed an increase in the cattle's body temperature in high heat and humidity conditions. More importantly, some studies have used thermometry to measure the temperatures of livestock during actual transport. Telemeters were implanted into the abdomen of pre-pubertal pigs and showed that body temperatures initially rose about 0.5^{o}C in response to transport and then after about 30 minutes the pigs' body temperatures decreased to similar temperatures to what they had been at the start of transport (Parrott *et al.*, 1998). However, this change in temperature was not significant compared with the natural changes in body temperatures obtained from pigs in a stationary vehicle. The authors did not measure air temperature to determine the extent of ambient cooling on body temperature, and furthermore, they subjected the animals to a vehicle, or indomethacin injection before transport, with the injection procedure itself possibly increasing body temperature. Indomethacin blocks the synthesis of endogenous prostaglandins and was used to determine whether the pigs' developed a fever in response to transport (Parrott *et al.*, 1998).

A later study by Parrott *et al.* (1999) using implanted telemeters into the abdomen of sheep to record body temperatures during transport showed that the body temperatures of females increased significantly during transport compared to the body temperature of sheep that were not transported, whereas male body temperatures increased only after transport. They concluded that psychological variables during loading and transport increased the animal's temperature, but no environmental variables were measured in this study and so they cannot be ruled out as having had an influence on the temperatures.

A study by Ingram *et al.* (2002) showed that ear-canal, pinna and rectal temperatures of sheep decreased during transport, reflecting the decrease in air temperature during transport. However, temperatures measured in these peripheral body sites are questionable, because these temperatures are affected by vasodilation or constriction of the blood vessels (see previous section). Rectal temperatures increased during transport, but these temperatures were only measured before and after transport, or when transport was stopped in an effort to measure temperature "during" transport.

Compared to the number of studies done on livestock, only a few studies have measured body temperatures during the transport of wild mammals. Nevill and Friend (2003) fed circus tigers miniature data loggers and demonstrated that for one group of tigers, the exertion due to their last performance increased their body temperature during transport. For another tiger group, transport started some time after their performance and their increase in temperature coincided with instances of pacing inside the vehicle. In the previous section, however, I discussed the problem with temperatures measured by the telemetry pill. Roe deer had telemetric recording devices inserted into their rectums to record their temperatures during transport after they were injected with acepromazine (short-acting antipsychotic) or with saline (control) (Montané *et al.*, 2002). The animals' body temperatures decreased during transport from their pre-transport temperatures and this decrease was significantly faster in acepromazine treated animals (Montané *et al.*, 2002). The authors did not mention whether the animals

injected with the drug and the animals with saline were transported under similar conditions, since the study took place in two parts, two years apart. Another concern regarding the Montané *et al.* study is similar to that mentioned above for the Parrott *et al.* (1998) study, as the injection of the drug/saline could have affected the animals' body temperatures.

By examining the previous work done on temperature measurement of large mammals during capture and transport, I have concluded that there still seems to be the need for more information on this topic, especially for wild mammals.

1.3 Consequences of environmental conditions on body temperature

Although there are guidelines as to the best time to capture animals, there is limited scientific work behind them. Only a few studies have measured environmental variables, such as air temperature and humidity during the capture and transport of large animals and even fewer studies have combined these measurements with measurements of the body temperature of the animals (von Mickwitz, 1982; Friend *et al.*, 1998; Knowles *et al.*, 1998; Nevill and Friend, 2003). What two of these studies have shown is that the body temperature of animals after transport is influenced by ambient temperature during transport, such that lambs experience hypothermia in cool environmental temperatures (Knowles *et al.*, 1998) and pigs experience hyperthermia in hot environmental temperatures (von Mickwitz, 1982).

Some researchers have developed indices to estimate the influence of environmental conditions on thermal comfort and physiological ability, which range from effective temperature scales to rational heat scales (Moran *et al.*, 2003). Unfortunately, there seems to be little agreement as to which is the right index to use under which circumstances, as well as to which parameters to use. These indices have to be calculated using equations, so they are of little use outside experimental procedures. As a result, I suggest the use of a black globe thermometer, which was developed to determine mean radiant temperature, with incorporated air temperature and wind speed (Yaglou, 1968). A study by Seely *et al.* (1990) on lizards has provided evidence that globe temperature, and not air temperature, can be used effectively to determine the thermal stress experienced by the animal in the particular environment. Globe temperatures have already been used in studies examining the thermoregulation of free-ranging animals in their natural environments, such as in the case of springbok (Mitchell *et al.*, 1997), eland (Fuller *et al.*, 1999) and wildebeest and eland (Mitchell *et al.*, 2002). However, only one study on horses has measured globe temperature during a capture and transport operation, but without measuring body temperature (Smith *et al.*, 1994).

1.4 Aims

The overall aim of my study, which is reported in four parts, is to provide information directly relevant to those involved in capture and transport operations of wild mammals and livestock. I have confined my measurements to reality

situations, where I operated within actual capture and transport situations, opportunistically using animals that were being captured and transported. However, in some situations I was able to mimic reality by using my own animals that were surgically implanted with data loggers in their abdomens specifically for the study. The methods of data collection used in this study necessitated small sample sizes, as data collection from these actual game operations was not consistent, but depended on when animals were commercially moved. The variety of animal species allowed me to examine general species differences to capture and transport.

During capture and transport operations there is very little time to measure animals' body temperatures, which means that the thermometric devices used have to be suited for this time frame. Therefore, the first part of my study (described in chapter 2) was to determine how accurate data loggers and telemeters are as thermometers intended for use in animals during capture and transport (see section 1.2.1). The temperatures measured by the two devices were compared by joining the devices together (to form a module) and placing the module into the rectums of three tsessebe, one black buck, two elephants and one white rhinoceros. Besides examining the differences or similarities in temperature measurement by the two devices, I also measured the accuracy of each device and the time it took for each device to stabilise when placed in a waterbath and in the rectum.

Because there is minimal time available to measure body temperatures of animals during capture and transport operations, it is also impractical to obtain core body

temperatures of the animals by surgically implanting thermometric devices into their abdomens before they are captured. I chose rectal temperature as the best compromise between a site that is known to reflect core temperature reasonably and what site would be accessible in a captured animal. Therefore the second part of my study (examined in chapter 3) was to determine how practical it is to use data loggers or telemeters to measure rectal temperature in animals during capture and transport (see section 1.2.2). The answer to this part of the study will be examined in three ways, namely by determining how well the rectal temperature reflects true core temperature, which was done by comparing the rectal temperatures of animals to the animals' abdominal temperatures (using surgically implanted animals). Secondly, I measured the amount of time that the thermometric devices remained in the rectum. Lastly, I examined what information would be missed in real life situations, as one is able to measure rectal temperatures only after an animal is captured, irrespective of the device used (data loggers or telemeters). Therefore I examined the consequences of any differences between rectal and true core temperature and the consequences of missing events, picked up by measuring true core temperature, that occur before a rectal thermometer can be inserted. The animals that were used for this part of the study were three tsessebe, three blesbok and seven goats (Angora and mixed breed).

The third part of my study (discussed in chapter 4) looks at what the typical body temperature reactions are for mammals to capture and transport stress in the mimicked and real-life operations (see section 1.2.3). In mimicked operations, I measured body temperatures of animals during capture and transport using

animals that were surgically implanted with data loggers (impala, tsessebe, blesbok and Angora goats). During real-life operations I measured body temperature in animals in which I inserted data loggers in their rectum (blesbok, white rhinoceroses, elephants). Body temperatures were measured in nine impala to assess the effects of “fright” (on the response to being handled and transported) and thermal stress (by being transported on a hot and cold night and day) on the ability to maintain body temperature. The impala were transported from and to the same boma for all transports. The body temperatures of three blesbok were used to determine the influence of different ambient conditions, because they were transported on two cold days and one hot day, as well as whether there were any inherent temperature differences between the animals. Three tsessebe were surgically implanted before being captured and released back into a game reserve. Body temperatures subsequently were measured during a standard capture and transport operation and showed the responses of these animals to “fright” stress.

Five Angora goats were the only livestock transported in this study and they were used to determine how transport influences the animals’ daily temperature rhythms and again how much of a change in body temperature is a response to thermal stress (they were transported on hot and cold day) or “fright” stress. The elephants, blesbok and white rhinoceroses with a rectal thermometric device only allowed me to examine how much of an influence different capture and transport operations have on the animal’s body temperatures.

Since only a few studies have measured environmental conditions together with the body temperature of animals (section 1.3), I will also discuss the influence of environmental conditions, especially globe temperature, on the body temperature of animals during capture and transport, in Chapter 4. Globe temperature gives a better indication of the thermal stress on an animal compared to air temperature, as not only do globe temperatures reflect air temperature, but also radiant temperature and wind speed.

The fourth part of my study (discussed in chapter 5) examined whether there is evidence of a stress response to capture and transport to corroborate thermal measurements (see section 1.1.2.1), namely by measuring cortisol and haematocrit concentrations in the blood plasma of Angora goats and blesbok that had thermometric devices implanted into their abdomens. Catecholamines (adrenaline and noradrenaline) also were measured in Angora goats to examine whether all the animals had similar catecholamines responses to the stress of transport. Another way of finding evidence of stress to corroborate thermal measurements was to take pooled faecal samples from blesbok and impala (also with abdominal thermometric devices) before and after the animals were transported (see section 1.1.2.1).

2. COMPARISON OF TEMPERATURES MEASURED BY TELEMETERS TO TEMPERATURES MEASURED BY DATA LOGGERS IN THE RECTUM OF MAMMALS

To obtain the temperature of animals undergoing actual capture and transport procedures, I needed a remote-sensing device that replaces the need to be in close proximity to the animals. I also needed to measure the temperature in real time using radiotelemetry. To examine how well the intermittent temperatures measurements made by the telemetry accurately reflected the animal's actual temperature, I compared these temperatures to those obtained using a data logger, which gives continuous measurements. Before doing this comparison in animals, I compared the temperatures obtained from the thermometric devices in a controlled physical environment, namely in a laboratory. Subsequently I have chosen the rectum as the body site to compare the temperatures, as it is the most likely site at which telemetry can be used in actual capture and transport operations (refer to section 1.2.1). The following animals were used in this assessment: a white rhinoceros (*Ceratotherium simum*), two elephants (*Loxadonta africana*), a black buck (*Antilope cervicapra*) and three tsessebe (*Damaliscus lunatus*).

2.1 Methods

2.1.1 Equipment used to measure body temperature

I used narrow-range miniature thermometric data loggers (StowAway TidbiT, Onset Computer Corporation, Pocasset, MA, USA) and thermometric telemeters (Datamet, Potchefstroom, South Africa and Mini-Mitter Company, Inc., Sunriver, USA), to measure temperatures in my study. Both thermometric devices have sensors in the form of onboard thermisters.

I used inert waterproof wax (EXP 987, Sasol, Johannesburg, South Africa) to cover the telemeters and data loggers before they were calibrated (see next section) and before they were implanted (see Chapter 3) or inserted into the animals. The added wax resulted in the final dimensions of the telemeter being 13 x 13 x 5 mm (length x width x height) with a total mass of about 11 g, with the connected battery responsible for most of this weight. The signal range of the telemeters was approximately 50 m and they have a temperature range of 10^{o}C to 45^{o}C. Telemeter signals were received on hand-held portable radio receivers: the TRC-221 (Mini-Mitter Co. Inc., Sunriver, USA), the AR8000 (AOR Ltd, Tokyo, Japan) or the FT-29OR II (Yaesu Musen Co. Ltd, Tokyo, Japan), with the signal being detected as beats between the carrier wave frequency and a fixed frequency generated in the receiver. Refer to Figure 2.1 for a picture of a telemeter (Datamet) with a radio receiver (Mini-Mitter). The FM frequency band that the Datamet telemeter operates on is 148 MHz, while for the Mini-Mitter telemeter the band is 27 MHz.

The frequency of the beats depends on the temperature measured by the telemeter. This frequency was determined by measuring the duration of 30 beats, both by





Figure 2.1: The top picture shows a telemeter (Datamet) with a radio receiver (Mini-Mitter) and the bottom picture shows a data logger (StowAway TidbiT).

using a hand-held stopwatch, and by connecting the output of the radio with a remote control interface (CU8232, AOR Ltd, Tokyo, Japan) to a computer fitted with AR8000 software (Spiney Norman Systems). This software detects the signals emitted from the telemeter and measures the duration of 30 beats. The results from these two methods were identical (Figure 2.2) and this means that the choice of method depended on which was easier to measure temperature in the various experimental situations.

Compared to the telemeter, adding the wax to the data logger resulted in its final dimensions being 40 x 25 x 15 mm with a mass of approximately 19 g (refer to Figure 2.1 for a picture of a data logger). The data loggers store temperature-over-time information locally onto an on-board memory with 32 kb of storage capacity. They have a temperature range of 33^{o}C to 45^{o}C. The temperature data from the loggers were downloaded to a computer using Boxcar 4.3 software (Onset Computer Corporation, Pocasset, MA, USA) by means of optic communication through an Optic Base Station.

For this chapter, I combined a data logger and a telemeter into a single module by wrapping the devices together in cling plastic and self-amalgamating tape (RS Components, U.S.A) so that I could determine whether the devices could be used interchangeably to measure body temperature.

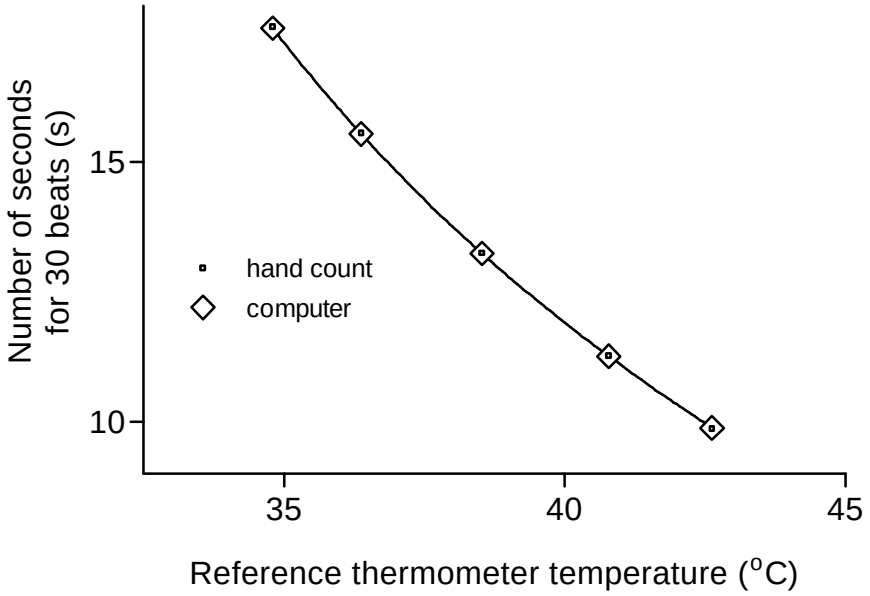


Figure 2.2: Example of output from a telemeter (Mini-Mitter) detected during calibration by simultaneously using hand counts and automated counting via radio receiver and computer. Time for 30 beats was identical, for hand counts, and automated counts. The best-fit least-squares regression line was $y=253.1-15.02x+0.3201x^2-0.002382x^3$, $r^2=1.000$.

2.1.1.1 Calibration

The thermometric devices were calibrated against a quartz thermometer (Quat 100, Heraeus, Hanau, Germany) to an accuracy of 0.2°C or better, by immersion into a controlled-temperature circulating water-bath. The devices then were calibrated using five data points between 34°C and 45°C, which included the normal body temperature range of the animals used in this study. A calibration equation was derived by regression, using TableCurve 2D software (Jandel Scientific Software). Figure 2.3.a is an example of a calibration curve for a telemeter (Mini-Mitter). Figure 2.3.b is an example of a calibration curve for a StowAway Tidbit data logger.

Before I used the combined module to measure the body temperatures of animals, I calibrated the two thermometric devices together, to ensure that the radio signal from the telemeter did not interfere with the temperature recordings of the data logger. Figure 2.4 shows that during calibration, the temperature recordings of a data logger were not affected when the logger was placed in conjunction with a telemeter (Mini-Mitter). Similar tests showed that the telemeter output was not affected by a data logger in close proximity.

2.1.1.2 Time constant

Thermometric devices take some time to stabilize at a given temperature. To distinguish temperature changes of physiological origin from those resulting from the thermal inertia of the thermometric devices (physical inertia), I measured the time constant of each device. The time constant is the time it takes for a variable

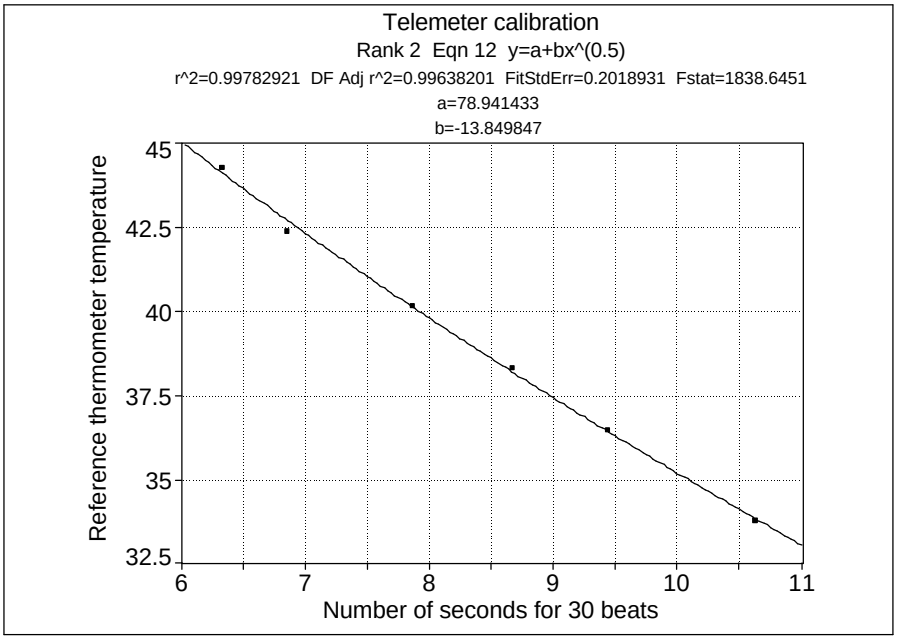


Figure 2.3.a: An example of a calibration curve for a telemeter (Mini-Mitter). The fit standard error is an index of the accuracy of the calibrated instrument and was 0.2^{o}C.

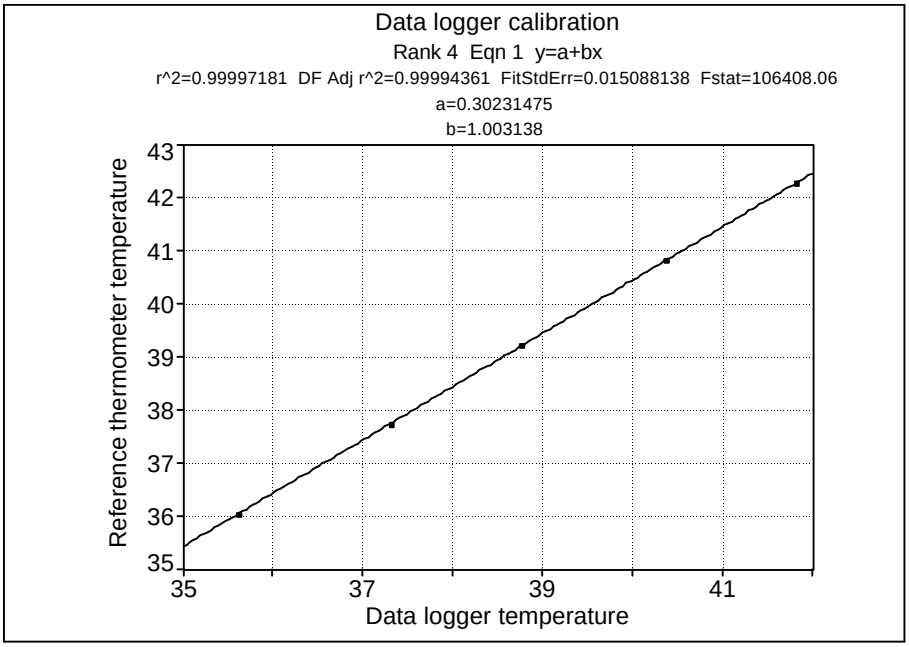


Figure 2.3.b: An example of a calibration curve for a StowAway TidbiT data logger. The fit standard error was 0.02^{o}C.

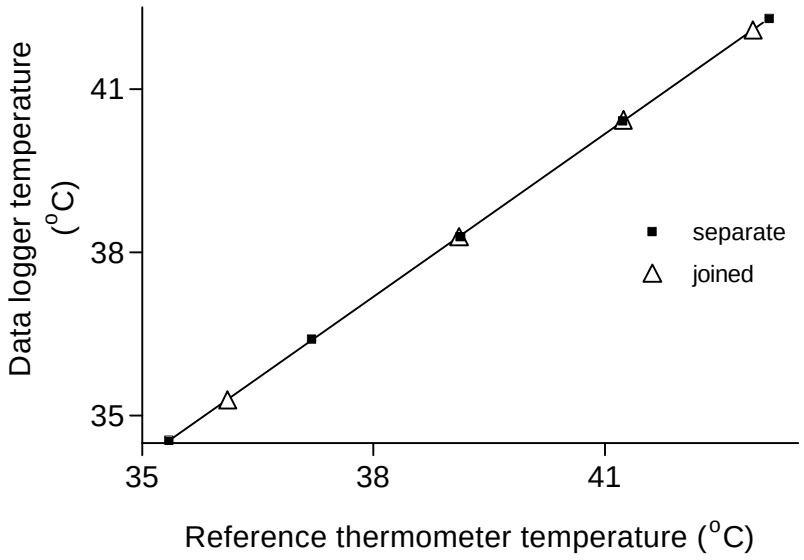


Figure 2.4: Calibration of a data logger (StowAway TidbiT) separately, and joined, in a module, to a telemeter (Mini-Mitter). The presence of the radio signal from the telemeter did not interfere with the operation of the data logger.

(in this case the indicated temperature) to reach 63% of a new value (Crabtree, 2001). By multiplying the time constant by three, one is able to estimate the time to steady state. This constant was obtained by inserting the waxed devices into a waterbath with a temperature of 42^{o}C and recording the temperature at one min intervals. The time constants for the two telemeters tested were the same at approximately 1 minute. Those for the two data loggers, however, varied between 1.2 and 1.8 minutes and so the time to stabilization was about 6 minutes. Therefore, when I made physiological measurements using data loggers and telemeters I excluded temperatures recorded within the first ten minutes of inserting a device to be certain that the temperatures were not compromised by inertia.

2.1.2 Rectal insertion of the combined module

The Animal Ethics Screening Committee of the University of Witwatersrand approved the project for each species (Appendix 1). Permission was granted by the capture teams who allowed me to measure the rectal temperatures of the animals that were being captured and transported (refer to Appendix 1 and Table 2.1). Data collection for my study took place between May 2002 and August 2003, throughout South Africa.

Telemeter-logger modules were inserted into the rectums of one white rhinoceros, two elephants and one black buck as well as into the rectums of three tsessebe that also had data loggers implanted in their abdomens (see section 3.1.1). I inserted

Table 2.1: Capture and transport conditions of one white rhinoceros, two elephants, one black buck and three tsessebe, used in Chapter 2. "Pre-transport" refers to the time after the animal was captured and before it was transported, but included the period of loading the animal into the transport vehicle.

Species	Capture sites	Capture team	Weather conditions*	Transport time (Pre-transport)
White rhinoceros (*Ceratotherium simum*)	Pongola (31.5 ^{o}S, 27.5 ^{o}E)	Catchco Africa	Hot day (36^{o}C)	1 h (0.5 h)
Elephants (*Loxadonta africana*)	Pongola (31.5 ^{o}S, 27.5 ^{o}E),	Catchco Africa	Hot day (29^{o}C)	1 h (1.5 h)
	Phalaborwa (24.0 ^{o}S, 31.0 ^{o}E)		Mild day (23^{o}C)	0.2 h and 10 h (0.8h)
Black buck (*Antilope cervicapra*)	Johannesburg Zoo (26.1^{o}S, 28.0^{o}E)	Johannesburg Zoo	Hot day (32^{o}C)	10 h (2.5 h)
Tsessebe (*Damaliscus lunatus*)	Mdlala game reserve in Mpumalanga (29.0 ^{o}S, 25.3 ^{o}E)	Afrivet	Hot day (36^{o}C)	2.5 h (4 h)

Note: * The temperatures given are the mean globe temperatures measured during the time of the experiment.

the rectal devices after the animals had been captured and sedated (before animals were transported), at a depth of approximately 100 mm. The animals in this part of the study were transported only once. The body temperatures of the animals were measured at intervals of about five minutes until the battery ran out or the experiment ended. The device was recovered when it was naturally voided by the animal, or via a nylon string attached to the device, so that the device could be extracted before the animal was released into the wild.

2.1.3 Capture and transport

Appendix 2 gives a detailed description of the general capture and transport methods used in my study. The species-specific capture and transport conditions are presented in Table 2.1 and the pharmacological procedures used are given in Table 2.2. Species-specific capture and transport procedures were as follows: the rhinoceros (*C.simum* 3) was captured using a dart-delivered immobilizing drug and given a dose of opioid antagonist that enabled it to be walked to the transport vehicle. The two elephants (*L.africana*) were darted before they were loaded onto the back of an open-back truck (with a crane) and then were transported to an enclosed transport vehicle, where they were given an opioid antagonist and transported further. All the tsessebe (*D.lunatus*) were chased at the same time, using a helicopter, but they were caught at different times. The tsessebe that was caught first was chased with a helicopter into a net, where it was injected with an immobilizing drug and placed inside a transport vehicle. The other two tsessebe were captured using a dart-delivered immobilizing drug and then carried to the

Table 2.2: Pharmacological procedures used during the transport of animals in Chapter 2. "Pre-transport" refers to the time after the animal was captured and before it was transported, but included the period of loading the animal into the transport vehicle.

Species	Pre-transport	Transport
White rhinoceros (*C.simum* 3[#])	3mg etorphine hydrochloride, 40mg azaperone	30mg nalorphine hydrobromide, 20ml Peni la Phenix*
Elephant (Pongola) (*L.africana* 1[#])	17mg etorphine hydrochloride, 60mg azaperone	34mg diprenorphine hydrochloride, 20ml Peni la Phenix*
Elephant (Phalaborwa) (*L.africana* 2[#])	13.5mg etorphine hydrochloride, 40mg azaperone	27mg diprenorphine hydrochloride, 20ml Peni la Phenix*
Black buck (*A.cervicapra*)	2mg etorphine hydrochloride, 25mg azaperone	0.5ml doramectin, 3ml Peni la Phenix*, 5mg haloperidol, 10mg perphenazine enanthane, 3mg diprenorphine hydrochloride
Tsessebe-in net (*D.lunatus* 1[#])	3mg thiafentanyl oxalate	37.5mg naltrexone hydrochloride, 10mg haloperidol, 5ml Biosolamine*, 10ml Peni la Phenix*
Tsessebe-with dart (*D.lunatus* 2[#] and 3[#])	4mg thiafentanyl oxalate, 2mg medetomidine	50mg naltrexone hydrochloride, 2ml-10mg atipamezole, 10mg haloperidol, 200mg ketamine hydrochloride, 5ml Biosolamine*, 10ml Peni la Phenix*

Note: *Brand names given for drugs made up of mixtures, while generic names are given for drugs that are pure agents (refer to Appendix 4 for full drug details). [#]This number indicates the order in which the animals were investigated.

transport vehicle. The tsessebe were then given an opioid antagonist. All the animals except for the black buck were captured while in a game reserve. The black buck was caught in a boma at the Johannesburg Zoological Gardens.

The elephants and rhinoceroses were placed individually inside compartments in containers on top of the transport vehicles, as shown in Appendix 3.a. The bottom picture of Appendix 3.b shows an elephant being loaded into the transport container. The tsessebe were placed inside a trailer as seen in the top picture of Appendix 3.c, while the black buck was placed inside a wooden crate, as seen in the bottom picture.

2.1.4. Data analysis

Before calculating any differences between the thermometric devices, I measured the time it takes for the data loggers to stabilize once inserted into the rectum of the animals. Compared to the intrinsic time constants of the devices in the controlled-temperature circulating waterbath (section 2.1.1.2), when the devices are inside an animal there will be physiological inertia added to this time. The devices are therefore dependent on the heat transfer within the animal. I measured the time constants for the data loggers only, because when placed into a waterbath, the data loggers took a longer time to stabilise (about 6 minutes) compared to the telemeters (which stabilised in 3 minutes).

After excluding the temperature data that fell within the time taken for the data logger to stabilize, I compared the rectal temperatures that were measured using a

telemeter to those measured with a data logger. I used the telemeter temperatures measured within one minute of the data logger temperatures. To determine whether there were any differences in the two thermometric devices, the temperatures from the telemeters were subtracted from the temperatures obtained from the data loggers. The mean difference of temperatures from the two thermometric devices obtained from multiple temperature readings was calculated for each animal. I used the mean difference from each animal to determine by how much temperatures measured using a telemeter would differ from temperatures measured using a data logger, using the limits of agreement analysis (Bland and Altman, 1986). For the temperatures measured by the two devices to be in agreement, the range of agreement had to be equal to or less than 1^{o}C. Although this range seems high, the devices would be used for a clinical assessment, to determine whether an animal's temperature is too high or low, during capture and transport operations. The mean values were also used to determine whether there are any differences in the temperature measurements that were particular to certain animals or certain transports.

2.2 Results

2.2.1 Time to stabilisation

The times to stabilisation calculated for the data loggers once inserted into the rectums of animals (Table 2.3) were much longer than the times calculated for the data loggers in the waterbath (less than 10 minutes). Therefore, there was a substantial physiological inertia added to the physical inertia so that the period of

Table 2.3: **Stabilisation and voiding times for data loggers.** Times for data loggers (joined with a telemeter in a module) to stabilise after being inserted into the rectums of animals used in Chapter 2 and the times for the modules to be voided naturally by the animal, pulled out of the animal via a nylon string attached to the module or when the animal died. These times shown for the devices to come out are not necessarily the time that the comparisons were made between the thermometric devices. The times to stabilisation include the time taken for data loggers to stabilise in a waterbath (section 2.1.1.2). The species used were: tsessebe (*D.lunatus*), black buck (*A.cervicapra*), white rhinoceros (*C.simum*) and elephants (*L.africana*). The mean (± standard deviation) stabilisation for tsessebe was 20.5 ± 6.1 minutes and for the elephant it was 10.5 ± 2.1 minutes

Individual animals	**Time to stabilisation (min)**	**Time for thermometric device to come out (h)**	**Termination event**
D.lunatus 1	15.0	4.4	Naturally voided
D.lunatus 2	19.5	1.4	Died
D.lunatus 3	27.0	0.6	Died
A.cervicapra	12.0	18.7	Naturally voided
C.simum 3	22.5	1.3	Manually extracted
L.africana 1	12.0	1.7	Manually extracted
L.africana 2	9.0	0.7	Naturally voided

data exclusion was longer than that calculated from the physical inertia. I also had to take into account that the animal's temperature could be increasing or decreasing and so the stabilisation time calculated is actually the time needed to track the body temperature of each animal.

2.2.2 Temperature differences between the thermometric devices

Figure 2.5 shows an example of the kind of measurement I made on each animal, using a tsessebe as a case study. After capture and during transport the tsessebe's temperature varied over an approximate range of 5 ^{o}C and the temperatures measured by the telemeter followed those measured by the data logger over the full range.

Temperatures were compared between data loggers and telemeters until the module was naturally voided by the animal or removed using a nylon string attached to the module. The times taken for the modules from insertion to expulsion or removal varied between individual animals. Table 2.3 shows these times (that range from 38 minutes to about 18 hours), but not necessarily the time that the comparisons were made between the thermometric devices.

The average differences between data logger and telemeter temperature measurements for each animal during the capture and transport procedures are shown in Table 2.4.a. Also shown in this table are the conditions of measurement, the number of measurements taken and the average difference for tsessebe and elephants. Table 2.4.b is a further analysis of the data from Table 2.4.a and it

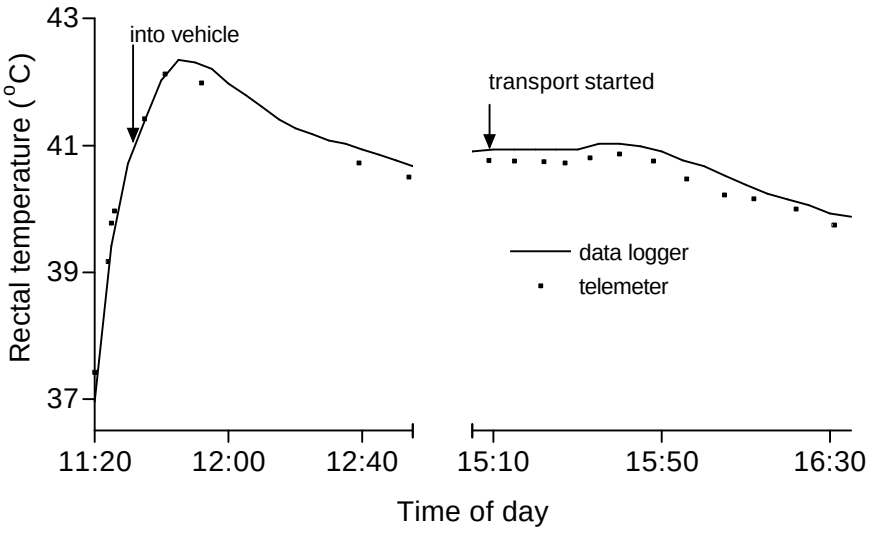


Figure 2.5: **Tsessebe rectal temperature measured with two devices.** A tsessebe's (*D.lunatus* 1) rectal temperature after capture and during transport was obtained from a module containing both a telemeter (signals were hand-counted) and data logger. This tsessebe was chased with a helicopter from about 30 minutes prior to the time depicted as the start of the x-axis on the graph, and caught in the net approximately 20 minutes later. It was then injected with an immobilizing drug (See Table 2.2) and the module was then inserted into its rectum (about seven minutes before the times depicted as the start of the x-axis on the graph). Mean globe temperature of capture conditions was 40 ± 4°C, while the temperature during transport was 33 ± 3°C.

Table 2.4.a: Rectal temperature difference (data logger minus telemeter). The average differences of body temperatures obtained by subtracting temperatures measured by a telemeter from temperatures measured by a data logger in the rectum of each animal during the capture and transport procedures. Included are the number of measurements taken for each animal. The mean (± standard deviation) difference for tsessebe is: 0.06 ± 0.15°C and for elephants: 2.44 ± 2.88°C. Refer to Table 2.4.b for further analysis of the data from this table.

Individual animals and species name	**Conditions of measurement for species with mean ± SD globe temperature at site**	**Mean ± SD difference of each individual (and number of measurements)**
D.lunatus 1	Before transport (inside vehicle) with	0.16 ± 0.12°C (11)
D.lunatus 2	40 ± 4°C and during transport with	-0.05 ± 0.14°C (4)
D.lunatus 3 (tsessebe)	33 ± 3°C, in Mpumalanga	Too few values
A.cervicapra (black buck)	Before transport (inside vehicle) with 32 ± 2°C, at the Johannesburg Zoological Gardens	-0.25 ± 0.17°C (4)
C.simum 3 (white rhinoceros)	During transport with 36 ± 1°C, in Pongola	3.75 ± 4.65°C (9)
L.africana 1 (elephant)	Before transport (being lifted with crane onto open-back truck) and during transport with 29 ± 2°C, in Pongola	4.47 ± 0.82°C (21)
L.africana 2 (elephant)	During transport (on open-back truck) with 23 ± 1°C in Phalaborwa	0.40 ± 0.22°C (12)

Table 2.4.b: (further analysis of data from Table 2.4.a) Maximum positive and negative deviations of the differences in temperature measurements of data loggers and telemeters inserted into the rectums of animals. The following animals were used: tsessebe (*D.lunatus*), black buck (*A.cervicapra*), white rhinoceros (*C.simum*) and elephants (*L.africana*). Included are whether there was an agreement between temperatures measured by two devices, based on my range of limits (equal to or less than 1^{o}C).

Individual animals	**Maximum positive and negative deviation of individual**	**Agreement between temperatures?**	**Limits of agreement**
D.lunatus 1	0.31, -0.09	Yes	-0.08, 0.40
D.lunatus 2	0.10, -0.24	Yes	-0.12, 0.20
D.lunatus 3	Too few values		
A.cervicapra	N/A, -0.48	Yes	-0.59, 0.09
C.simum 3	7.58, -7.27	No	-5.55, 13.05
L.africana 1	5.99, N/A	No	2.83, 6.11
L.africana 2	0.81, N/A	Yes	-0.04, 0.83

shows the maximum positive and negative deviations of the differences in temperature measurements as well as the limits of agreement. Note that the highest positive deviations of temperature differences for each animal were obtained from the first temperature measurements after the time to stabilisation has been excluded from the data.

Data loggers generally measured a higher estimate of body temperatures than telemeters, except for the data loggers in one tsessebe and the black buck (based on mean differences). Using the limits of agreement analysis (Bland and Altman, 1986), it is likely that the data loggers will always measure a higher estimate of body temperatures than telemeters in one elephant (*L.africana* 1). This elephant, as well as a rhinoceros (*C.simum* 3), were the only animals where temperatures measured by the two devices showed no agreement, based on my limits. Although there was agreement between the temperatures measured by the devices in tsessebe (as a species) (limits of agreement: -0.06, 0.26^{o}C), there was no such agreement in the elephants (-3.32, 8.2^{o}C). The large differences and lack of agreement in temperatures between the two devices in an elephant (see Figure 2.6) and rhinoceros were probably due to external factors that will be described in the discussion.

2.3 Discussion

Data loggers are thought to have more advantages over telemeters as thermometric devices, but the temperature measurements are stored locally and

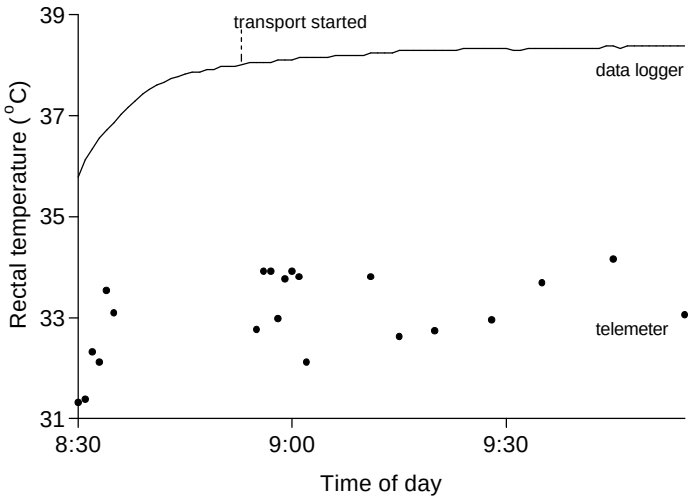


Figure 2.6: **Elephant rectal temperature measured with two devices.** An elephant's (*L.africana* 1) rectal temperature during transport, obtained from a module containing both a telemeter (signals were hand-counted) and a data logger. At about the time that is depicted at the start of the x-axis on the graph was when the elephant was being lifted onto an open-back truck, using a crane. The elephant was darted twice with an opioid and a tranquillizer (see Table 2.2) from a helicopter, the first dart shot about 45 minutes before the time that is depicted as the start of the x-axis on the graph. The mean globe temperature at the capture site and during transport was 29 ± 2°C.

can be retrieved only once the loggers are removed from the animal and the data has been downloaded. Telemeters, however, provide instantaneous temperature readings allowing for minute-by-minute monitoring of an animal's body temperature, which is more useful during actual capture and transport operations.

Besides examining whether there are differences in temperature measurements made by the two thermometric devices, any differences between the devices in the way that they record temperature had to be examined. Temperature measurements made by telemeters took a shorter time than data loggers to reach a steady state in a waterbath (3 minutes compared to about 6 minutes) as well as when inserted into the rectums of animals (mean time for telemeters: 11.7 ± 1.4 minutes, mean time for data logger: 16.8 ± 4.9 minutes). This difference in times to stabilisation is probably due to the lower mass of the telemeter compared to the data logger (Crabtree, 2001). My results show that the temperature of a device in the rectum of a large wild animal does not give a reliable measurement for at least 20 minutes after insertion.

However, it seems that the times to stabilisation actually were longer (about 5 or 10 minutes) than what I estimated, based on the high positive deviations of the first few temperatures after I excluded the time I estimated. Therefore, either the time to stabilisation must be made longer or it may help to use devices with better heat transfer characteristics. Clinical thermometers may have better heat transfer than waxed devices, but tests have shown that the clinical thermometer took 3 minutes to stabilise (Mitchell and Laburn, 1985), which is similar to that of the

telemeter in my study and experiments still need to be done to determine how long the clinical thermometer would take to stabilise in the rectum of an animal. Currently veterinary surgeons insert a clinical thermometer into a darted animal's rectum and take immediate temperature readings, but because the time to stabilisation is unknown they may be given false information. The available scale on the clinical thermometer would present problems, as a study by Gericke *et al.* (1978) showed that the body temperature of captured animals would often exceed the scale.

Using a data logger and a telemeter (in a combined module) in a laboratory setting made no difference in their temperature measurements compared to when the devices were separately in a waterbath. Therefore the two devices do not interfere electrically with each other and if there are any differences in temperature measurements made by the two devices, then these must be due to the fact that they are being used outside of a controlled waterbath environment. When both a data logger and a telemeter (in a combined module) were inserted into their rectums, all the animals, except one elephant (*L.africana* 1) and a rhinoceros (*C.simum* 3), exhibited temperatures measured by the telemeter similar to the measurements made by the data logger, as the range of agreement was less than 1^{o}C. Therefore, the devices can be used interchangeably.

Dealing with the issue of big differences in the temperature measurements made by the data logger and telemeter in the rhinoceros and elephant (Table 2.6), a reason for possible error in temperature measurements is that using telemetry and

beat counting cannot be accurate if the observer cannot hear every beat clearly or if there are extraneous noises (such as wind and engine noise) that could be counted as a beat. Conditions for measuring beats are not fulfilled when the observer is sitting on an open vehicle transporting the animal, as I found in my study. Good agreement between the devices in the other animals supports this conclusion that the big difference arose from a noise problem. The error did not occur when I used earphones and a bigger aerial, attached to the radio receiver, when measuring the temperature of the tsessebe, so that extraneous noise was lessened and signal reception was improved. In addition, I measured temperatures in the black buck only before it was transported, so that earphones and a bigger aerial were not needed. A possible reason why the temperatures measured by the telemeter in the elephant *L.africana* 2 did not show such a big difference to the data logger (compared to the other elephant) was that transport time was very short (about 10 minutes) and the transport speed was much slower than during the transport of *L.africana* 1. Therefore, even without a bigger aerial or earphones there was less extraneous noise when measuring the temperature.

Only one study other than my own has used temperatures measured by data loggers and telemeters, both placed in the same body site, namely the abdomen. However, the authors assumed that the two thermometric devices measured similar temperatures and used the telemeter to provide instantaneous readings of temperatures of cattle in a climatic chamber (Barnes *et al.*, 2003).

I believe that it is possible to use a remote sensing device to measure the rectal temperature of large mammals after capture and during transport, once the technical problems that I encountered, have been resolved. First, the devices stay in the rectum for a sufficiently long time and can be recovered before the animal is released. Secondly, the intrinsic accuracy of both devices (data logger: 0.02^{o}C, telemeter: 0.2^{o}C) is more than sufficient to measure variable temperatures of large mammals.

Radiotelemetry is a preferred method for use by game capture operators, as it provides instantaneous temperatures that can be used to make management decisions. However, the technique used for radiotelemetry needs development so that it can be used in the noisy environment of a transport vehicle, such as earphones and a large aerial. Once these developments have been taken into account, I suggest that rectal radiotelemetry should be used in conjunction with the continuous measurements made possible by a data logger. However, although I decided to have a fixed depth of insertion, it has not been tested whether the depth to which telemeters are placed in the rectum could affect the temperature readings. Care should also be taken to allow time for the devices to stabilise, taking account of the physical and physiological inertia.

However, in the following chapter, I will investigate the relationship between rectal and abdominal temperatures, taking abdominal temperatures to be a measure of core body temperature.

3 COMPARISON OF TEMPERATURES MEASURED IN THE RECTUM TO TEMPERATURES MEASURED IN THE ABDOMEN OF MAMMALS

In this part of my study I investigated whether a remote sensing device placed in the rectum of a large mammal gave temperature measurements related to abdominal temperatures of that mammal and so could be used to estimate body core temperatures (see section 1.2.2). The following animals were used as I could implant and recover abdominal devices from them: three blesbok (*Damaliscus dorcus phillipsi*), three tsessebe (*Damaliscus lunatus*), five Angora goats (*Capra aegagrus*) and two mixed breed goats (*Capra hircus*). I compared rectal and abdominal temperatures in a controlled thermal environment of a climatic chamber, using tame livestock (goats) because they were comfortable in this chamber. Secondly, the comparison was done in game animals, under actual transport conditions.

3.1 Methods

3.1.1 Surgical implantation of data loggers into abdomen

The Animal Ethics Screening Committee of the University of Witwatersrand approved the project for each species (Appendix 1). Permission was granted by the zoological gardens to have their animals surgically implanted with data loggers. Data collection for my study took place between May 2002 and August 2003, throughout South Africa.

3.1.1.1 Surgical procedures common to all species

What follows is a general description of the surgical procedures that were performed on all the animals used in my study. The subsequent section describes species-specific surgical procedures that differ from this general outline (Refer to Table 3.1 for the feeding and housing conditions for each of the species used in this chapter). At least 24 hours before surgery, the data loggers that were to be implanted into the abdomen were sterilized in a sealed drum with formaldehyde tablets. On the day of surgery, animals were injected with an immobilizing drug by a veterinarian or the game capture operator (see Table 3.2). Once the animals were immobilized they were blindfolded and cotton wool was placed into their ears to prevent external stimuli from causing additional stress to the animal. They were then carried to a nearby temporary operating theatre set up in the field and placed in sternal recumbency with their heads elevated. They were injected with an anaesthesic and a veterinarian implanted the data loggers into the peritoneal cavity through a small insertion in the paralumbar fossa. During the surgical procedure, the animal's rectal temperature was measured using an electronic thermometer (Physitemp BAT-12, Physitemp Instruments Inc., NJ, USA) and oxygen saturation and heart rate were monitored using a pulse oximeter (Nonin 8500AV, Kyron Laboratories (Pty) Ltd., Johannesburg South Africa). The respiration rate was monitored by recording the number of inhalations in one minute.

The wound was sutured closed and the skin suture line treated with a topical antiseptic spray (Necrospray, Centaur Labs, Johannesburg). The animals then received intra-muscular injections of antibiotics, anti-inflammatories and drug

Table 3.1: Experimentation sites and animal care for animals that had intra-abdominal data loggers for Chapter 3.

Species	**Number of individuals**	**Sites**	**Animal care**
Tsessebe (*Damaliscus lunatus*)	3	Mdlala game reserve in Mpumalanga (29.0^{o}S, 25.3^{o}E)	They had free range of the reserve
Blesbok (*Damaliscus dorcus phillipsi*)	3	A small camp (25 x 45 m) with scattering of wild grasses and trees, at the Rietvlei breeding centre of the Johannesburg Zoo (26.1^{o}S, 28.0^{o}E)	They were fed antelope cubes, teff and lucerne every day. They also had a permanent vitamin and mineral lick block, as well as water
Angora goats (*Capra aegagrus*)	6	Hopedale farm near Steytlerville (24.5 ^{o}S, 33.3 ^{o}E), Eastern Cape and in the indoor pens at the Central Animal Service, University of Witwatersrand (26.1^{o}S, 28.0^{o}E), Johannesburg	At Hopedale they were free-ranging and had no supplementary feeding. At the Central Animal Service, they were fed with ground hay and lamb and ewe cubes and had water *ad libitum*
Mixed breed goats (*Capra hircus*)	2	Central Animal Service at the University of Witwatersrand, Johannesburg	They were fed with ground hay and lamb and ewe cubes and had water *ad libitum*

Table 3.2: Pharmacological procedures used during surgical implantation of data loggers in the abdomen of animals, in Chapter 3.

Animal	**Anesthetic/ immobilizing drug**	**Local anesthetic**	**Other §**
Blesbok	2-3mg etorphine hydrochloride, 20mg fentanyl citrate, 60mg azaperone	20ml lignocaine hydrochloride, 120-200mg ketamine hydrochloride	8-11mg diprenorphine hydrochloride, 10ml Peni la Phenix*
Tsessebe	4mg thiafentanyl oxalate, 1-2mg medetomidine	8ml Lignocaine/ Adrenaline* mix, 50-150mg ketamine hydrochloride	10ml Peni la Phenix*, 10ml Biosolamine*, 1ml/50kg doramectin, 10mg atipamezole hydrochloride, 50mg naltrexone hydrochloride
Angora goats	0.5mg medetomidine, 0.5mg ketamine hydrochloride	4ml lignocaine hydrochloride	2.5mg atipamezole hydrochloride
Mixed breed goats	1mg medetomidine, 1mg ketamine hydrochloride	4ml lignocaine hydrochloride	5mg atipamezole hydrochloride

Notes: *Brand names given for drugs made up of mixtures, while generic names are given for drugs that are pure agents (Refer to Appendix 4 for full drug details).

§ “Other” includes anti-inflammatories, antibiotics and drug antagonists

antagonists (see Table 3.2) before being left to recover in their enclosure. All animals were allowed at least a week of recovery from surgery before being subjected to experimentation. At the end of the experiment, the data loggers were removed from the animals using a similar procedure. These capture and surgical procedures have been used previously in studies of thermoregulation in eland (Fuller *et al.*., 1999) and oryx (Maloney *et al.*., 2002).

3.1.1.2 Species-specific surgical procedures

For both the blesbok and the tsessebe, the only difference to the general description of surgical procedures given in the previous section was that the blesbok were immobilized while inside a boma in a Zoological Garden using a dart gun, and the tsessebe were darted while in a reserve from a helicopter.

The livestock were hand held while injected with an anaesthetic. Angora goats had surgery in a nearby temporary operating theatre set up in the field at the Hopedale farm, while the surgery for the mixed breed goats took place in a sterile operating theatre in the Central Animal Service at the University of the Witwatersrand.

3.1.2 Rectal insertion of thermometric devices

The animals used in this study were first surgically implanted with data loggers in their abdomens and allowed to recover before I was able to insert a thermometric device into their rectums for specific measurements. Subsequently, only after the animals had been captured and sedated for transport was I able to insert telemeter-

logger modules into the rectums of three tsessebe and data loggers into three blesbok. I also inserted telemeters into the rectums of seven goats (Angora and mixed breed). The size of the animals determined whether telemeter-logger modules or just telemeters or data loggers were inserted into the rectums of these animals.

3.1.3 Measurement of rectal and abdominal temperatures

3.1.3.1 Measurement of temperatures in livestock

I measured the rectal and abdominal temperatures of the Angora goats and mixed breed goats while they were inside climatic chambers (2700 x 2240 x 2370 mm), with air temperature ranging from 27^{o}C to 40^{o}C.

3.1.3.2 Measurement of temperatures in wild animals

I measured the temperature of wild animals during transport, which was planned and carried out specifically for this study. Refer to Appendix 2 for a more detailed description of general capture and transport methods used in this study. As described in Chapter 2, all the tsessebe were chased at the same time, with a helicopter, but they were caught at different times. Two tsessebe were darted from a helicopter, while the third one was caught using net-capture, where it was then injected with an immobilizing drug (Table 3.3). The tsessebe were carried to the transport vehicle. The time that the animals were chased until the start of transport (loading) lasted about 4 hours. The tsessebe were transported for about 2.5 hours on a hot day (36^{o}C). On the other hand, the three blesbok were darted while they were inside a boma at the Zoological Gardens and only once they were

Table 3.3: Pharmacological procedures used during capture and transport procedures of the animals in Chapter 3. "Pre-transport" refers to the time after the animal was captured and before it was transported and included the period of loading the animal into the transport vehicle.

Species	**Pre-transport**	**Transport**
Tsessebe-in net (*D.lunatus* 1)	3mg thiafentanyl oxalate	37.5mg naltrexone hydrochloride, 10mg haloperidol, 5ml Biosolamine*, 10ml Peni la Phenix*
Tsessebe-with dart (*D.lunatus* 2 and 3)	4mg thiafentanyl oxalate, 2mg medetomidine	50mg naltrexone hydrochloride, 2ml-10mg atipamezole, 10mg haloperidol, 200mg ketamine hydrochloride, 5ml Biosolamine*, 10ml Peni la Phenix*
Blesbok (*D.d. phillipsi* 1,2,3)	2-3mg etorphine hydrochloride, 40mg azaperone, 20mg fentanyl citrate	10-15mg haloperidol, 3mg diprenorphine hydrochloride, 5ml Peni la Phenix*

Note: *Brand names given for drugs made up of mixtures, while generic names are given for drugs that are pure agents (refer to Appendix 4 for full drug details).

immobilized (Table 3.3) were they carried to the transport vehicle. Loading and transport lasted about 1 hour each on three transport days, namely a hot day (39^{o}C) and two cold days (15^{o}C and 20^{o}C). These temperatures given are the mean globe temperatures measured during the time of the experiment. The tsessebe and blesbok were placed inside a trailer, as seen in the top picture of Appendix 3.c, where they were injected with an opioid antagonist and injected with penicillin into the dart wound (Table 3.3). The top picture of Appendix 3.b shows a blesbok being loaded into a trailer.

3.1.4 Data analysis

Rectal temperatures that I measured using a telemeter or a data logger were compared to the abdominal temperatures measured with a data logger. I excluded temperature data within the time that each device took to stabilize (once inserted into the rectum of an animal) before using the data for comparisons (refer to section 2.1.4).

I determined whether there was a difference in the temperatures measured in the abdomen and rectum by subtracting the temperatures obtained in the rectum from the temperatures obtained in the abdomen. The mean difference of temperatures obtained from multiple temperature readings was calculated for each animal. I then calculated whether this difference was statistically significant by examining whether zero was included in the confidence limits of the mean difference. The mean values were also used to determine whether there were any differences in

the temperature measurements that were particular to certain animals or certain transports.

3.2 Results

This section is presented in two parts: First, I describe the comparison of temperatures measured by a telemeter in the rectum and a data logger in the abdomen of livestock (Angora goats and mixed breed goats) in climatic chambers. This comparison is also described for tsessebe during actual transport. Second, I describe the comparison of temperatures measured by a data logger in the abdomen and in the rectum of wild animals (blesbok and again tsessebe) during transport.

3.2.1 Rectal temperatures measured by telemeters

3.2.1.1 Time to stabilisation

The average times for the telemeters to stabilise in the rectum of animals was 11.7 ± 1.4 minutes with individual times as follows: tsessebe *D.lunatus* 1 in 12 minutes, tsessebe *D.lunatus* 3 in 9.6 minutes and mixed breed goats (*C.hircus* 1 and *C.hircus* 2) in both 12.6 minutes. The time to stabilisation of the telemeter in a waterbath (section 2.1.1.2), of about three minutes, was included in these times. For some animals I was unable to obtain the times to stabilisation, as there was not enough data. I therefore used 10 minutes (as I suggested in section 2.1.1.2) as the time to stabilisation and excluded data gathered before this time from further

analysis. For the rest of the animals, their specific stabilisation times were used to exclude data.

3.2.1.2 Temperature differences between the two body sites

Comparisons between temperatures from the telemeters in the rectum and data loggers in the abdomen were made until the telemeter was naturally voided by the animal or when the animal died (in the case of the tsessebe, see Table 3.5 in section 3.2.2.1). The times for the devices to be naturally voided by the goats were on average approximately 15 minutes, but could vary between 5 and 30 minutes.

The average differences between abdominal and rectal temperature measurements of individual tsessebe (during capture and transport) and goats (Angora and mixed breed in climatic chambers) are shown in Table 3.4.a. Also shown in this table are the conditions of measurement, the number of measurements taken and the average difference for each species. Table 3.4.b is a further analysis of the data from Table 3.4.a and it shows the maximum positive and negative deviations of the differences in temperature measurements as well as the confidence intervals. Inside the climatic chamber, out of five Angora goats on the first day of measurement, the goats *C.aegagrus* 4 and *C.aegagrus* 5 did not have significant differences between the temperatures measured in the rectum and abdomen (as seen by the confidence limits). On the second day of measurement, out of the three goats, *C.aegagrus* 4 again did not have a significant difference, but there were not enough measurements to calculate the confidence intervals for *C.aegagrus* 5. Out of the two mixed breed goats, *C.hircus* 2 did not have a

Table 3.4.a: Abdominal minus rectal (telemeter) temperature. The average (± standard deviation) differences of body temperatures obtained by subtracting temperatures measured by a telemeter in the rectum from temperatures measured by a data logger in the abdomen of each animal. Included are the number of measurements (N) for each animal. Temperatures were measured during the capture and transport of tsessebe and while the goats were inside a climatic chamber. The mean (± standard deviation) difference for tsessebe (*D.lunatus*) was: 1.03 ± 0.97°C; for Angora goats (*C.aegagrus*) for the first day of measurement: 0.66 ± 0.51°C and the second day: 0.33 ± 0.19°C; and for mixed breed goats (*C.hircus*): 1.01 ± 0.68°C. Refer to Table 3.4.b for further analysis of the data presented in this table.

Individual animals	**Conditions of measurement for species**	**Mean ± SD difference of each individual (N)**
D.lunatus 1	Before transport with 40 ± 4°C	0.54 ± 0.64°C (11)
D.lunatus 2	(mean globe temperature) and	0.41 ± 0.54°C (4)
D.lunatus 3	during transport with 33 ± 3°C,	2.15 ± 1.47°C (2)
	in Mpumalanga	
C.aegagrus 1	Inside climatic chamber with	0.85 ± 0.07°C (2)
C.aegagrus 3	temperature set at 35°C, at the	1.08 ± 0.22°C (3)
C.aegagrus 4	University of Witwatersrand.	0.07 ± 0.38°C (3)
C.aegagrus 5	First day of measurement	0.17 ± 0.23°C (3)
C.aegagrus 6		1.13 ± 0.91°C (3)
C.aegagrus 3	Same as above, but temperature	0.55 ± 0.07°C (2)
C.aegagrus 4	set at 40°C. Second day of	0.23 ± 0.25°C (3)
C.aegagrus 5	measurement	0.20°C (1)
C.hircus 1	Same as above, but temperature	1.49 ± 0.43°C (3)
C.hircus 2	set at 27°C	0.53 ± 0.57°C (3)

Table 3.4.b: (further analysis of data from Table 3.4.a) Maximum positive and negative deviations of the differences in temperature measurements of data loggers in the abdomen and telemeters inserted into the rectum of animals. The following animals were used: tsessebe (*D.lunatus*), Angora goats (*C.aegagrus*) on two measurement days and mixed breed goats (*C.hircus*). Included are whether these temperature differences were significantly different to zero, as judged by their confidence intervals.

Individual animals (and day of measurement)	**Maximum positive and negative deviation of individual (^{o}C)**	**Significantly different to zero?**	**Confidence interval (^{o}C)**
D.lunatus 1	2.38, N/A	Yes	0.16, 0.92
D.lunatus 2	1.10, -0.10	No	-0.12, 0.94
D.lunatus 3	3.19, N/A	Yes	0.11, 4.19
C.aegagrus 1 (day 1)	0.90, N/A	Yes	0.75, 0.95
C.aegagrus 3 (day 1)	1.23, N/A	Yes	0.83, 1.33
*C.a*egagrus 4 (day 1)	0.50, -0.20	No	-0.36, 0.50
C.aegagrus 5 (day 1)	0.30, -0.10	No	-0.09, 0.43
C.aegagrus 6 (day 1)	1.80, N/A	Yes	0.10, 2.16
C.aegagrus 3 (day 2)	0.60, N/A	Yes	0.45, 0.65
C.aegagrus 4 (day 2)	0.50, N/A	No	-0.05, 0.51
C.aegagrus 5 (day 2)	0.20, N/A	N/A	
C.hircus 1	1.92, N/A	Yes	1.00, 1.98
C.hircus 2	1.12, -0.01	No	-0.12, 1.18

significant difference. As a species, both the mixed breed goats (confidence interval: 0.07, 1.94^{o}C) as well as the Angora goats on the first day of measurement (0.21, 1.11^{o}C) and second day of measurement (0.11, 0.55^{o}C) had significant differences between the temperatures measured in the rectum and abdomen. However, although only one tsessebe (*D.lunatus* 2) out of three did not have a significant difference between temperatures measured in the two body sites, the difference calculated for the species was not significant (confidence interval: -0.07, 2.13^{o}C). All the animals had positive significant differences, therefore the temperatures measured in the rectum were lower than the temperatures measured in the abdomen. As mentioned in section 2.2.2, the highest positive deviations of temperature differences are from the next temperature difference after the time to stabilisation had been excluded.

3.2.2 Rectal temperatures measured by data loggers

3.2.2.1 Time to stabilisation

Figure 3.1 shows an example of the kind of measurement I made on each animal, using two blesbok as a case study and it shows that it took some time before temperatures measured by data loggers stabilised in the rectum these animals. Note that the abdominal temperature increased about 2^{o}C during capture, which was not shown by the rectal temperature, as the device was inserted after this temperature event. A lag in rectal temperatures was seen in all the species tested and the times for the data loggers to stabilize, after being inserted into the rectum are presented in Table 3.5. These times were very similar for all the individuals, with the average time being 18.2 ± 4.0 minutes, compared to a much shorter

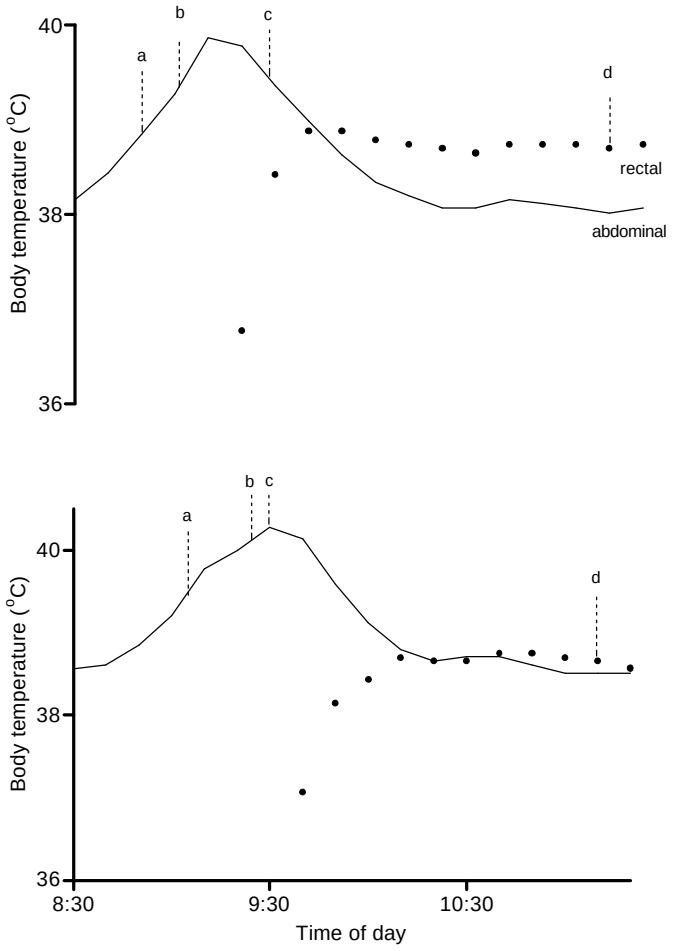


Figure 3.1: **Rectal and abdominal temperatures of two blesbok.** Temperatures measured by data loggers in the abdomen and the rectum of a male blesbok (*D.d.phillipsi* 3, top panel) and of a female blesbok (*D.d.phillipsi* 2, bottom panel) during a capture and transport operation on a cold day (mean globe temperature: 15 ± 1°C). The symbols on the graph indicate: a=darted, b=inserted data logger into rectum and blesbok inside vehicle, c=transport started, d=transport ended back at Johannesburg Zoological Gardens and blesbok offloaded.

Table 3.5 Stabilisation and voiding times for data loggers. Times for temperatures recorded by data loggers to stabilise after being inserted into the rectums of tsessebe and blesbok and the times for a thermometric device to be naturally voided by the animal or when the animal died (*D.lunatus* 2 and *D.lunatus* 3). These times shown are not necessarily the time that the comparisons were made between the thermometric devices. The stabilisation times include the time taken for data loggers to stabilise in a waterbath (section 2.1.1.2). The tsessebe (*D.lunatus*) were transported once on a hot day and blesbok (*D.d.phillipsi*) were transported on one hot day and two cold days. The mean (± standard deviation) stabilisation for tsessebe was 20.5 ± 6.1 minutes and for the blesbok it was 16.8 ± 1.6 minutes.

Individual animal	**Time to stabilisation (min)**	**Time for thermometric device to come out (h)**
D.lunatus 1	15.0	4.4
D.lunatus 2	19.5	1.4
D.lunatus 3	27.0	0.6
D.d.phillipsi 1 (cold day 1)	18.0	9.4
D.d.phillipsi 3 (cold day 1)	15.0	20.8
D.d.phillipsi 1 (cold day 2)	18.0	9.9
D.d.phillipsi 2 (cold day 2)	18.0	6.6
D.d.phillipsi 3 (cold day 2)	15.0	14.2

average for telemeters of 11.7 ± 1.4 minutes (see section 3.2.1.1). The average time to stabilisation of all data loggers (including the times from section 2.2.1) was 16.8 ± 4.9 minutes. The time to stabilisation of the data logger in a waterbath (section 2.1.1.2) was included in these times. Before comparing rectal temperatures to abdominal temperatures, the individual-specific stabilisation times were used to exclude data gathered before this stabilisation time from further analysis.

3.2.2.2 Temperature differences between the two body sites

Temperature comparisons were made until the data logger or module (as in the case of the tsessebe) was naturally voided by the animal or when the animal died. Table 3.5 shows the times specific to each animal, which ranged from about 38 minutes to approximately 20 hours. These times were on average much longer than the times calculated for the goats (see section 3.2.1.2).

The differences in rectal and abdominal temperatures in two blesbok are shown in Figure 3.1, where the rectal temperature in the male blesbok (*D.d.phillipsi* 3, top panel) was about a half a degree higher than that of the abdominal temperature during the transport. This difference in temperatures was greater than the difference shown in the female (*D.d.phillipsi 2*, bottom panel). The average differences between abdominal and rectal temperature measurements of tsessebe and blesbok during the capture and transport procedures are shown in Table 3.6.a. Also shown in this table are the conditions of measurement, the number of measurements taken and the average difference for each species. Table 3.6.b is a

Table 3.6.a: Abdominal minus rectal (data logger) temperature. The average (± standard deviation) differences of body temperatures obtained by subtracting temperatures measured by a data logger in the rectum from temperatures measured by data loggers in the abdomen for each animal during the capture and transport procedures. Included are the number of measurements taken for each animal (N). The mean (± standard deviation) difference for tsessebe (*D.lunatus*) was: 0.11 ± 0.14^{o}C and for blesbok (*D.d.phillipsi*) on the first cold day transport: -0.15 ± 0.16^{o}C and 0.18 ± 0.47^{o}C on the second cold day. Refer to Table 3.6.b for further analysis of the data presented in this table.

Individual animals (and transport trip)	**Conditions of measurement for species with mean ± SD globe temperature at site**	**Mean ± SD difference of each individual (N)**
D.lunatus 1	Before transport (inside vehicle)	0.11 ± 0.27^{o}C
D.lunatus 2	with 40 ± 4^{o}C and during	(71)
D.lunatus 3	transport with 33 ± 3^{o}C, in	0.25 ± 0.28^{o}C (13)
	Mpumalanga	-0.03 ± 0.13^{o}C
		(14)
D.d.phillipsi 1	Before (inside vehicle) and during	-0.04 ± 0.40^{o}C (14)
D.d.phillipsi 3 (male)	transport with 20 ± 2^{o}C, at the	-0.26 ± 0.79^{o}C (13)
(first cold day)	Johannesburg Zoological Gardens	
D.d.phillipsi 1	Before (inside vehicle) and during	0.41 ± 0.67^{o}C (13)
D.d.phillipsi 2	transport with 14 ± 2^{o}C, at the	0.48 ± 1.04^{o}C (10)
D.d.phillipsi 3 (male)	Johannesburg Zoological Gardens	-0.36 ± 0.49^{o}C (11)
(second cold day)		

Table 3.6.b: (further analysis of data from Table 3.6.a) Maximum positive and negative deviations of the differences in temperature measurements of data loggers in the rectum and abdomen of tsessebe (*D.lunatus*) and blesbok (*D.d.phillipsi*). Included are whether these temperature differences were significantly different to zero, as judged by their confidence intervals. Note that temperatures were recorded during two cold transport trips ("1" and "2") for the blesbok and that the tsessebe were transported only once.

Individual animals (and transport trip)	**Maximum positive and negative deviation of individual (^{o}C)**	**Significantly different to zero?**	**Confidence intervals (^{o}C)**
D.lunatus 1	1.49, -0.22	Yes	0.05, 0.17
D.lunatus 2	0.64, -0.16	Yes	0.10, 0.40
D.lunatus 3	0.12, -0.37	No	-0.10, 0.04
D.d.phillipsi 1 *(1)*	1.15, -0.33	No	-0.25, 0.17
D.d.phillipsi 3 *(1)*	2.16, -0.73	No	-0.69, 0.17
D.d.phillipsi 1 *(2)*	2.28, -0.12	Yes	0.05, 0.77
D.d.phillipsi 2 *(2)*	3.08, -0.19	No	-0.16, 1.12
D.d.phillipsi 3 *(2)*	0.94, -0.68	Yes	-0.07, -0.65

further analysis of data from Table 3.6.a and it shows the maximum positive and negative deviations of the differences in temperature measurements as well as the confidence intervals. As mentioned in 2.2, note that the highest positive deviations of temperature differences for each animal were obtained from the first temperature measurement after the time to stabilisation had been excluded from the data.

Out of all the animals, only two tsessebe (*D.lunatus* 1 and *D.lunatus* 2), and two blesbok (*D.d.phillipsi* 1 and *D.d.phillipsi* 3 on the second cold day transport) had significant differences between the temperatures measured in the two body sites. Only the temperatures measured in the abdomen of these two tsessebe and two blesbok (*D.d.phillipsi* 1 and *D.d.phillipsi* 2 on the second cold day) were higher than those measured in the rectum. However, examined as a species, the differences in rectal and abdominal temperatures were not significant for both tsessebe (confidence interval: -0.05, 0.27^{o}C) and blesbok on the first cold day (confidence interval: –0.37, 0.07), as well as on the second cold day (confidence interval: –0.35, 0.71).

I assessed whether the temperatures measured in the rectum were related to temperatures measured in the abdomen of animals, using two different thermometric devices inserted into the rectum. However, rectal temperatures measured by telemeters were much lower than abdominal temperatures in all the animals (Table 3.4), compared to when data loggers were placed in the rectum, where only a few animals had lower rectal temperatures (Table 3.6). In Table 3.4,

four animals had temperature differences between the two body sites of about 1^{o}C, while in Table 3.6 none of the animals had this much of a difference. Interestingly, rectal temperatures measured by telemeters or data loggers in the rectum of tsessebe (as a species) were not significantly different to abdominal temperatures.

3.3 Discussion

In this chapter I have determined whether rectal temperature can be used to predict abdominal temperature, as a practical method of estimating a mammal's core body temperature during actual capture and transport procedures. Rectal temperatures may be used if there is a consistent relationship between rectal and abdominal temperatures, but these temperatures do not necessarily have to be the same.

In a controlled thermal environment (inside climatic chambers), both the mixed breed goats and the Angora goats (as a species) had positive significant differences in temperature between the two body sites, meaning that rectal temperatures were lower than abdominal temperatures. However, in some individuals, the gap between abdominal and rectal temperatures was anomalously high (around 1^{o}C) and these individuals would have biased the mean response for the group. I believe that the high differences probably were due to the short retention time of the thermometric device and I could not be certain when the animals had naturally voided the devices and so I could have been measuring air

temperature. On the other hand, some goats showed no differences in temperature measurements between the two body sites, so that it seems the relationship between abdominal and rectal temperatures is specific to individual animals.

It is a very interesting result that in all the goats and tsessebe (except *D.lunatus* 3, with a data logger in the rectum), rectal temperatures were lower than abdominal temperatures, whereas humans and large animals (such as sheep) are known to have rectal temperatures higher than arterial blood temperatures (Brengelmann, 1987; Maloney *et al.*, 2001) and arterial blood temperatures higher than abdominal temperatures (Fuller *et al.*, 1999). Since goats and tsessebe are ruminants, the abdominal temperature could have been high because the thermometric device was close to the rumen, which has a temperature about 3^{o}C higher (see Mustafa, 2005) than arterial blood temperature. During the transport of tsessebe, one individual showed a significant difference in temperatures measured in the two body sites when rectal temperature was measured by telemetry, but this same individual did not show a significant difference when the rectal temperatures were recorded by a data logger. The reverse was true for another tsessebe, but the third tsessebe did not show any differences between rectal and abdominal temperatures, when another telemeter or data logger was employed to measure rectal temperature.

Contrary to the consistent results obtained from the goats, two blesbok showed no significant differences between rectal and abdominal temperatures on the first day of measurement, but, on the second day, the temperatures were significantly

different. Generally, the temperatures measured in the abdomen of blesbok were lower than the temperatures measured in the rectum.

Although tsessebe and blesbok (as a species) showed no difference in abdominal and rectal temperatures, the goats had significant differences between the temperatures measured in the two body sites. Besides this species difference, there is also high variability in the differences between rectal and abdominal temperatures between individuals. In most cases, the rectal temperature was lower than the abdomen, but the situation was reversed in other animals. Perhaps these discrepancies occurred because the data loggers were situated differently in the abdomen of each animal (as mentioned by Hetzel *et al.*, 1988). The depth of insertion of the thermometric devices in the rectum was probably also not the same in all the animals. Coupled with these problems, there are the issues of improving the use of the radiotelemetry techniques (see section 2.3) as well as the thermometric devices' time constants.

A problem I encountered with using devices inserted into the rectum to measure body temperature is that, in my animals, it took about 20 minutes, on average, for those devices to reach a stable temperature, so that any temperature readings made during 20 minutes were not valid. The 20 minutes included the time for temperature measurements made by the thermometric devices to stabilise in a waterbath. However, as mentioned in section 2.3, the times to stabilisation actually were longer than what I estimated. Therefore there may have been less variability in the relationship between rectal and abdominal temperature if the

temperatures had been measured after a longer stabilisation time. However, the fact that one has to wait so long raises serious doubts about the practicality of using rectal temperatures to predict abdominal temperatures, even if one establishes a better relationship between them. Examining Figure 3.1, one can see that being able to insert a device into the rectum only after the animal has been captured, together with the long time to stabilise, causes one to lose valuable temperature information that is needed for management purposes by the game capture operators. It is apparent from this figure that the two blesbok had an increase in abdominal temperature of about 2^{o}C, which had resolved by the time the rectal temperature had stabilised.

Another problem that I found is that although wild animals retained the thermometric devices in their rectums for as long as 18 hours, goats took as short as five minutes to naturally void the devices. A possible reason for these long retention times in the wild animals is the opioid-induced paralysis of the gastrointestinal tract (Swan, 1993).

Although the time lag before an inserted device validly measures rectal temperature is a major problem, I still suggest that measuring the temperature in the rectum is the most practical, non-invasive, method for capture operators to measure body temperature in wild animals. Capture operators need to discard measurements made in the first 20-30 minutes after insertion. However, other body sites have been suggested to be non-invasive enough to be a substitute for implanted thermometric devices (measurements reflect core body temperature),

such as the tympanum and gastrointestinal tract (measured using a swallowed thermometric pill).

Tympanic (ear canal) measurements could be used only if the large animals were domesticated and in a paddock, and even in this case, Goodwin (1998) stated that some animals reacted badly to this intrusive form of temperature measurement. I believe that body temperature could be affected by having to handle the animal to obtain the temperature. Other authors, such as Ingram *et al.* (2002), measured pinna and ear-canal temperatures of animals, but the ear provided a peripheral measurement of body temperature that was affected by vasodilation or constriction of the blood vessels.

Another non-invasive method to obtain temperatures that reflect core body temperatures is having a large animal or human swallow a telemetry pill (or data logger). However, body temperatures measured by the pill can be affected by the heat released by fermenting food (affected by eating habits), drinking cold water, and the position of the telemeter in different parts of the body, especially if the telemeter reaches the stomach or is close to the liver or the rectum (Mackay, 1965; Livingstone *et al.*, 1983 and O'Brien *et al.,* 1998). If the pill lands up in the rumen of a large animal, then the heat produced by the large amounts of bacteria (Schmidt-Nielson, 1990) could severely compromise the temperatures measured.

Since the non-invasive methods mentioned so far do not seem adequate to use during the capture and transport of large animals, several authors have

recommended that temperatures in the rectum be used to estimate core body temperature. Hicks *et al.* (2001) and Barnes *et al.* (2003) have shown the temperatures measured by thermometric devices placed in the rectum and abdomen were similar in cattle. Barnes *et al.* (2003) gave a correlation with a significance of $p<0.001$ between the rectum and abdomen. Hicks *et al.* (2001) stated that there were no statistically significant differences between the temperatures measured in the abdomen and rectum. However, using the temperature data from Hicks *et al.*'s study, I calculated whether the rectal temperatures were significantly different to abdominal temperatures by determining whether the confidence limits of the mean difference in temperatures for each animal included zero. The temperature differences were significant, as judged by their confidence intervals as follows: -0.64, -0.16 (for two animals) and –0.92, -0.28 (for one animal), with six temperature differences for each animal. Hetzel *et al.* (1988) and Prendiville *et al.* (2002) have both shown that rectal temperatures were significantly lower than temperatures measured in the abdomen of cattle (similar to my results). Hetzel *et al.* (1988) showed that the rectal temperatures were 0.2^{o}C lower than the abdominal temperatures with a correlation coefficient of 0.95, while Prendiville *et al.* (2002) determined an overall correlation coefficient of 0.34 between temperatures measured in the abdomen and rectum of animals in a pen. However, Prendiville *et al.* (2002) placed the thermometric devices inside the cattle's rumens, where bacteria produce vast amounts of heat (Schmidt-Nielson, 1990).

The studies that had previously compared rectal to abdominal temperatures were different to my own study, in the following ways: the authors used mercury-in-glass (or digital) thermometers intermittently placed in the rectum, which could have caused disturbance to the animals, every time they inserted or examined the thermometer. They also did not calculate the time it took for the rectal thermometer to stabilise, or had not mentioned it. Lastly, I have done my measurements on various species and individuals and in a controlled environment (as they have) as well as during actual game capture operations. I believe that my study is the first to compare the two body sites, using continuous measurement from data loggers or telemeters. Since there are currently no alternatives to placing a temperature device into the rectum, one has to be aware of the limitations of the temperatures measured in this body site. In the next chapter, I used rectal temperature to measure the response of animals to stress.

4 BODY TEMPERATURES UNDER THERMAL STRESS

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This chapter examines the typical body temperature reactions in large mammals to capture and transport stress in mimicked and real-life operations (see section 1.2.3). In mimicked operations, I measured body temperatures of animals during capture and transport using animals that were surgically implanted with data loggers (impala, tsessebe, blesbok and Angora goats). During actual operations I measured body temperature in animals by inserting data loggers into their rectums only (blesbok, white rhinoceroses, elephants). Note that I used two different groups of blesbok, namely three blesbok with intra-abdominal data loggers and three different blesbok with data loggers in their rectums only. Environmental conditions, especially globe temperature, were measured to determine the influence of environmental conditions on the body temperature of the animals (see section 1.3).

4.1 Methods

The Animal Ethics Screening Committee of the University of Witwatersrand approved the project for each species (Appendix 1). Permission was granted by the zoological gardens to have their animals surgically implanted. Permission was also granted by the capture teams to measure the rectal temperatures of the animals that were being captured and transported (refer to Appendix 1 and Table 2.1).

4.1.1 Mimicked capture and transport operations

I set up this study to investigate how body temperatures of large mammals would react to transport in different environmental conditions.

4.1.1.1 Surgical implantation of data loggers into abdomen

The surgical procedures used for the tsessebe, blesbok and Angora goats in this study have already been described in section 3.1.1 and the pharmacological procedures used were presented in Table 3.2. Impala (*Aepyceros melampus*) were only used in this study and in the study presented in the following chapter, therefore the specific details of their surgery and transportation are given in more detail here. The nine impala were captured from a reserve at the Lichtenburg Game Breeding Centre of the National Zoological Gardens (26.2 ^{o}S, 26.2 ^{o}E) and placed into a boma at the same Centre, about two weeks before surgery. They were tranquillized on the day of entry to the boma with 50 mg of zuclopenthixol acetate. On the day of surgery, the impala were captured by herding them from their holding boma into an enclosed transport container on the back of a large truck where they were injected with the same tranquillizer and dosage using a pole syringe. Once the animals were tranquillized, each impala was captured by hand in the container and immediately fitted with a face-mask delivering an inhalable anaesthetic (2-8% halothane in oxygen). The impala then were injected with 1.5-2ml Dexa-Tomanol and 3-5ml Peni la Phenix (see Appendix 4 for full drug details).

After surgery, the impala were transported back to the boma before being taken off the anaesthetic. The boma covered an area of 50 x 60 x 2.4 m with well-drained soil, scattered with wild grass species and trees. The impala were fed three times a week with lucerne and concentrated antelope cubes and always had water. Refer to Table 3.1 for the information on the study site and animal care provided for the blesbok, tsessebe and Angora goats.

4.1.1.2 Capture and transport procedures

Refer to Appendix 2 for a more detailed description of general capture and transport procedures used in my study. The mimicked capture and transport conditions are close to what would happen during actual transport of the species used in this chapter. The transport procedures used for the tsessebe and blesbok in this study have already been mentioned in section 3.1.3.2 and the pharmacological procedures used were presented in Table 3.3. Therefore, only the capture and transport procedures specific to impala and Angora goats will be discussed here.

The impala were herded from their holding boma straight into a container on the back of a truck, where they could easily be separated and tranquillized with a pole syringe (Table 4.1). The tranquillizer dosage decreased for successive transports, in the light of the animals' adverse reactions to the initial dose. Consequently, the use of biperiden lactate was also reduced. The impala were then herded using loading chutes into a trailer attached to a towing vehicle (top picture of Appendix 3.c) and randomly separated into two compartments. The adult ram was placed

Table 4.1: Pharmacological procedures used during the mimicked and actual transport of animals in Chapter 4. The animals with intra-abdominal devices (in mimicked transports) are tsessebe (Table 3.3), blesbok (Table 3.3.), impala and Angora goats (they were not sedated for their transport). Animals with devices in the rectum only (actual transports) are blesbok, white rhinoceroses and elephants.

Animal	**Pre-transport**	**Transport**
Impala males	Nil	10- 20mg haloperidol, 5mg biperiden lactate#
Impala females	Nil	5-15mg haloperidol, 5mg biperiden lactate#
Blesbok	12-14mg haloperidol and 18mg perphenazine enanthane	Nil
White rhinoceros (Hluhluwe)	3mg etorphine hydrochloride and 30mg azaperone	20ml Peni la Phenix*
White rhinoceros (Pongola)	4mg etorphine hydrochloride, 40mg azaperone, 2500iu hyaluronidase	20ml Peni la Phenix*
White rhinoceros (Pongola)	3mg etorphine hydrochloride and 40mg azaperone	30mg nalorphine hydrobromide, 20ml Peni la Phenix*
Elephants (Pongola and Phalaborwa)	13.5-17mg etorphine hydrochloride, 40-60mg azaperone	27-34mg diprenorphine hydrochloride, 20mg Peni la Phenix*

Notes: # biperiden lactate was given when the welfare of the animal depended on it, in the opinion of the professional game operator, to reduce the haloperidol side effects.

*Brand name given for drug made up of mixture, while generic names are given for drugs that are pure agents (refer to Appendix 4 for full drug details).

alone in a wooden crate (bottom picture of Appendix 3.c). The impala were transported for about five hours (after about one hour taken up by loading) on four different occasions, namely on a hot day (31^{o}C), a hot night (22^{o}C), a cold night (16^{o}C) and a cold day (14^{o}C). These temperatures given are the mean globe temperatures measured during the time of the experiment. The night transports started around 17:00 and the day transports started around 11:00.

Since the Angora goats were domesticated, they were not sedated before transport and the transport vehicle that was used for them was an open pick-up truck. The goats were transported twice for about 10 hours each time, on a hot day, with mean globe temperature of 25^{o}C and on a cold day (18^{o}C). For the first transport, the goats were shorn, but for the second transport their hair length had increased by about 75 mm.

4.1.2 Actual capture and transport operations

I set up this study to investigate whether body temperatures of large mammals would react similarly to transport on an individual level as well on a species level.

In section 2.1.3 I described the capture and transport procedures for the rhinoceros from Pongola (*C.simum* 3) and elephants from Pongola (*L.africana* 1) and Phalaborwa (*L.africana* 2). For this chapter, I used data obtained from these animals, as well as from one more elephant from Phalaborwa (*L.africana* 3), two more rhinoceroses (*C.simum* 1 from Hluhluwe and *C.simum* 2 from Pongola) and three blesbok (with a device only in the rectum). The capture and transport

procedures for *C.simum* 2, as well as *L.africana* 3 were the same as mentioned in section 2.1.3. The rhinoceros *C.simum* 1 from Hluhluwe (28.0 ^{o}S, 32.0 ^{o}E) was darted with an immobilizing drug while inside a boma and lead into a transport vehicle without it being given an opioid antagonist. The capture team was comprised of members of the KwaZulu Natal Parks Board. The three blesbok were caught by chasing them with a helicopter into a boma and then into a transport container, where they were tranquillized. These blesbok were caught on a game reserve in Bronkhorstpruit (25.7 ^{o}S, 28.6 ^{o}E) by the Specialist Game Services capture team. Refer to Table 4.1 for the pharmacological procedures used during the transport of all rhinoceroses, elephants and the blesbok (with a device only in the rectum).

4.1.3 Environmental measurements during capture and transport operations

Environmental conditions were measured during all the capture and transport operations in my study. Environmental air temperature and absolute humidity were measured using a wide-range temperature (-20^{o}C to +70^{o}C) and humidity (25% to 95%) data logger (Hobo, Onset Computer Corporation, Pocasset, MA, USA). This logger was placed inside a ventilated metal box (170 x 170 x 330 mm) that shielded the logger from radiation. In addition to measuring air temperature, I also measured globe temperature using a globe thermometer attached to the exterior top of the box. The globe thermometer consisted of either a standard 150 mm diameter globe, or, where space was limited, smaller globes of 110 mm or 30 mm diameter were used. All globes were painted with matt black paint. I recorded

globe temperatures with a data logger similar to that which I used for air temperature.

I calibrated the data loggers used to measure environmental temperature, against the quartz thermometer, by immersion in latex rubber sleeves in a controlled-temperature circulating water-bath. I used ten data points between 0°C and 50°C, which included the range of environmental temperatures experienced during this phase of the research. I used the manufacturer's calibration for the humidity sensor, as this variable was not crucial to my study.

4.1.4. Data analysis

4.1.4.1 Mimicked capture and transport operations

From the continuous measurements of temperatures measured by the data logger in the abdomen of the following large animal species, for this chapter I only used the temperature data pertaining to the time of the capture and transport procedures.

Nine impala were subjected to four transport trips: hot and cold days and hot and cold nights. To investigate the effects of the conditions prevailing in the four transport trips, I measured the following variables: pre-loading body temperature (the hour before animals were chased), loading body temperature (from time animals were chased to start of transport), peak body temperature during loading, body temperature during transport and the times for the body temperatures to stabilise (three times the time constant). Each result from the mean population

(namely: the mean pre-loading, loading and transport body temperatures and mean time constants) was compared between the four transport trips using repeated measures analysis of variance (RMANOVA, Statistica, StatSoft Inc., U.S.A.) and if significance was found, the post-hoc Scheffe test was used to determine where the significance was evident. I assessed whether the mean pre-loading, loading and transport temperatures, as well as whether the mean time constants correlated with the order of transport or the mean globe temperature for each transport trip. Correlations between the body temperature variables and the order of transport were done using Spearman Rank Correlation, while the correlations between the variables and the mean globe temperatures were done using Pearson Product-Moment correlations. The differences in body temperature between the transport phases and pre-loading phases were analysed using paired t-tests.

Thermal response indices were calculated for the temperatures during loading and transport (refer to Figure 4.1 for an example of this calculation). The thermal response index is the time integral of the change in body temperature from an initial value. Therefore, if there were any differences found between the pre-loading temperatures (initial value) for the different transports, an unpaired t-test with Welch correction was used to calculate differences between transport trips, instead of RMANOVA. Any individuals that showed temperature responses that were unlike the trend in temperatures shown by the majority of the animals (referred to as “outliers”) were excluded from the calculations of the population means. The temperature of the outliers were compared to the results from the

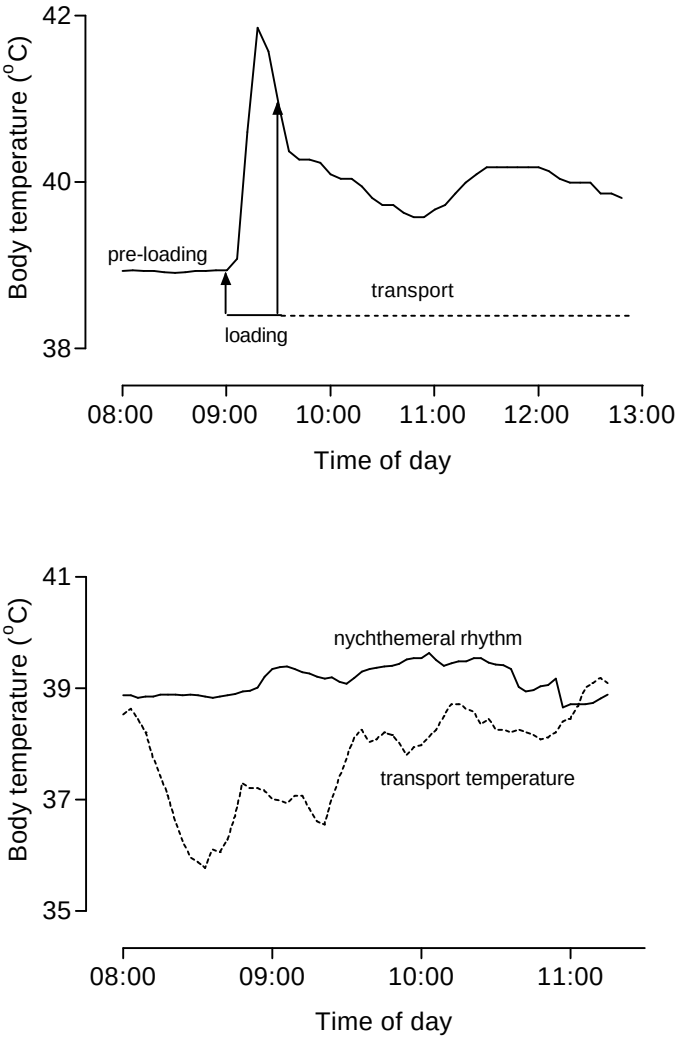


Figure 4.1: How to calculate thermal response indices. Diagrammatic representation of how to calculate thermal response indices using typical temperatures of an animal undergoing capture and transport procedures, as well as an animal showing differences in transport temperatures to its nychthemeral rhythm. Using the top graph, the mean "pre-loading" (initial) temperatures are subtracted from the temperatures during loading as well as during transport. The average difference in loading temperature from the initial temperature (example:

0.4^{o}C) is multiplied by the loading time (in this example: 0.5 h). The average difference in transport temperature from the initial temperature (example: 2.5^{o}C) is multiplied by the transport time (in this example: 3.5 h). Therefore the thermal response index for loading of the individual in this graph is: 0.2 ^{o}C.h and for transport: 8.8 ^{o}C.h. The bottom graph shows that the nychthemeral (initial) temperature (calculated from three days during the time before transport) corresponds to the time that the animal was transported. A thermal response index is calculated from the average of the mean difference in nychthemeral and transport temperature, which is multiplied by the duration of transport (in this case: 3.2 h).

mean population by analysing whether their results fell within the confidence intervals of those results for the mean population.

Similar calculations were done for the three blesbok that were transported three times. The body temperatures of each blesbok were averaged for an hour before the first individual was darted (the pre-loading or “initial” temperature), during the time after darting to the start of transport (loading temperature), during the entire transport, and an hour after they were transported (post-transport). Temperature differences (in the loading, during transport or post-transport temperatures) between the three blesbok were compared within two cold days and a hot day, using RMANOVA with Scheffe post-hoc test if any significance was found. The nychthemeral rhythms were also compared between the blesbok, using RMANOVA with Scheffe post-hoc test. The rhythms were calculated for each animal, from loading to two hours after transport (with the times specific to each transport) from the body temperatures averaged three days before each transport. For each transport trip the differences in temperatures measured between the pre-loading phases and transport phases were analysed using paired t-tests. Thermal response indices were calculated (refer to Figure 4.1 for an example of this calculation), using the pre-loading temperatures (specific to each transport) for each animal, and compared between the hot and the two cold transports, using RMANOVA, with Scheffe post hoc test. These indices were also calculated from the temperatures of the blesbok an hour after transport and compared between the hot and cold days.

Thermal response indices were also calculated for three tsessebe, using the body temperatures of the animals an hour before they were chased (pre-loading). The first index was calculated for the temperatures measured in each animal from the time all the tsessebe were chased until the first tsessebe was caught. The second index was calculated for the temperatures measured in each animal from the time the first tsessebe was caught until the first tsessebe was placed inside the transport vehicle (not necessarily the same animal). Differences between these two indices for each animal and to zero were analysed using RMANOVA, with Scheffe post hoc test. The difference in temperature between the pre-loading and transport phases was analysed using a paired t-test.

From the mean temperatures shown by the only livestock transported in my study (Angora goats), one goat was excluded as the thermometric device had been mistakenly implanted under the skin of the animal for the first transport. The difference in the nychthemeral rhythms of each goat and their body temperatures during the two transports were analysed using a paired t-test. Thermal response indices were calculated for the duration of two transport trips, using the difference in temperature between the nychthemeral rhythm and temperature during transport, for each goat (refer to Figure 4.1 for an example of this calculation). The differences in the indices between the transports were determined by a paired t-test. For each transport trip the differences in temperatures between the pre-loading phases and transport phases were analysed using paired t-tests.

4.1.4.2 Actual capture and transport operations

The rectal temperatures of three rhinoceroses, three elephants and three blesbok (with a data logger only in the rectum) did not have statistical analyses done on them. Instead, the temperatures were used to show the differences in animals' thermal responses to transport between individuals and between species. The rectal temperatures were also compared to normal rectal or abdominal temperatures of the species.

4.2 Results

4.2.1 Mimicked capture and transport operations

Figure 4.2 shows the body temperatures of nine impala for a typical transport (the 22^{o}C night), indicating three animals that showed temperature responses that were unlike the trend shown by the majority of the animals (referred to as "outliers"). Figure 4.2 also shows the mean temperature of six impala for this same transport, excluding the three outliers. For both the mean and outliers, the pre-loading temperatures are shown in Table 4.2.a, the loading temperatures in Table 4.2.b and transport temperatures in Table 4.2.c, for the four transport trips. The six impalas' mean pre-loading body temperatures for the four transports were significantly different ($F_{(3,15)}$=22.28, p<0.01 (exact value not available), RMANOVA). The mean pre-loading temperature on the hot day was significantly lower than the mean pre-loading temperature on the hot night (P<0.01 (exact value not available), Scheffe post hoc test) and the mean pre-loading temperature

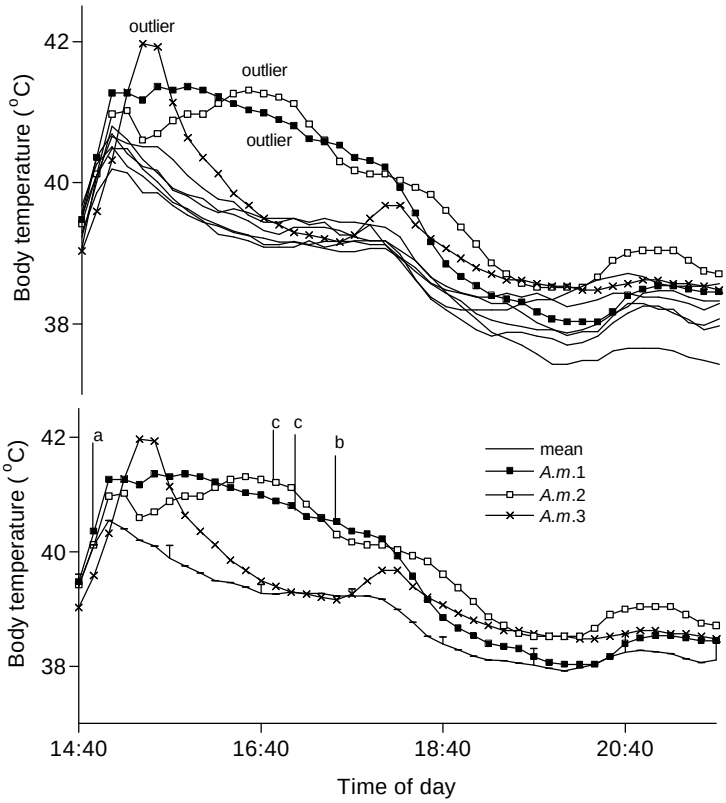


Figure 4.2: **Abdominal temperatures of impala.** Two graphs showing abdominal temperatures of impala during a capture and transport operation on the hot night, with mean globe temperature inside the vehicle of 22 ± 5°C (averaged from three globe temperatures in different compartments). The top panel shows individual body temperatures, indicating the unusual temperature responses of three impala (outliers). The bottom panel shows the mean (and standard deviation) body temperature of six impala and the individual body temperatures of the outliers. The impala were being loaded at the time depicted as the start of the x-axis on the graph. The symbol "a" on the graph indicates when they were injected with haloperidol. The symbol "b" on the graph indicates when transport started and "c" indicates when biperiden lactate was given.

Table 4.2.a: **Pre-loading temperatures for impala.** Mean ± standard deviation pre-loading abdominal temperatures (the hour before loading) of the mean impala (n=6) and for the three outliers, for four impala transports (mean ± standard deviation globe temperatures are shown). Means with different superscripts are significantly different to each other ($p<0.05$). The symbol "X" indicates that this impala had died and the symbol "*" indicates that the pre-loading temperature of the outliers lay outside the 95% confidence intervals of the mean pre-loading temperatures.

Impala	**Mean body temperature (^{o}C) during pre-loading**			
	Hot day (31 ± 2 ^{o}C)	**Cold day (14 ± 3 ^{o}C)**	**Hot night (22 ± 5 ^{o}C)**	**Cold night (16 ± 7 ^{o}C)**
Mean (SD, n=6)	38.65 ± 0.21[a]	38.54 ± 0.44[a]	39.29 ± 0.15[b]	38.97 ± 0.13[a,b]
C.I. (n=6)	38.48; 38.82	38.10; 38.80	39.17; 39.41	38.87; 39.07
A.melampus 1 (outlier)	39.00 ± 0.09[*]	38.86 ± 0.08[*]	39.46 ± 0.15[*]	39.16 ± 0.13[*]
A.melampus 2 (outlier)	38.64 ± 0.19	38.61 ± 0.07	39.18 ± 0.24	38.76 ± 0.07[*]
A.melampus 3 (outlier)	38.43 ± 0.06[*]	X	38.83 ± 0.13[*]	39.14 ± 0.09[*]

Table 4.2.b: **Loading temperatures for impala**. Mean ± standard deviation abdominal temperatures during loading (over the time the animals were chased until the start of transport) of the mean impala (n=6) and for the three outliers, for four impala transports. Means with different superscripts are significantly different to each other ($p<0.05$). The symbol "X" indicates that this impala had died and the symbol "*" indicates that the loading temperature of the outliers lay outside the 95% confidence intervals of the mean loading temperatures.

Impala	**Mean body temperature (^{o}C) during loading**			
	Hot day	**Cold day**	**Hot night**	**Cold night**
Mean (SD, n=6)	40.07 ± 0.21^{a}	39.17 ± 0.45^{b}	$39.69 \pm 0.15^{b,a}$	$39.77 \pm 0.27^{b.a}$
C.I. (n=6)	39.85; 40.29	38.81; 39.53	39.57; 39.81	39.55; 39.99
A.melampus 1 (outlier)	$40.98 \pm 1.19^{*}$	$39.69 \pm 0.42^{*}$	$40.95 \pm 0.48^{*}$	$40.52 \pm 0.59^{*}$
A.melampus 2 (outlier)	$40.41 \pm 1.15^{*}$	$39.73 \pm 0.42^{*}$	$40.84 \pm 0.48^{*}$	$40.47 \pm 0.84^{*}$
A.melampus 3 (outlier)	$40.81 \pm 1.59^{*}$	X	$40.15 \pm 0.95^{*}$	$41.20 \pm 0.89^{*}$

Table 4.2.c: Transport temperatures for impala. Mean ± standard deviation abdominal temperatures during transport of the mean impala (n=6) and for the three outliers, for four impala transports. Means with different superscripts are significantly different to each other ($p<0.05$). The symbol "X" indicates that this impala had died and the symbol "*" indicates that the loading temperature of the outliers lay outside the 95% confidence intervals of the mean transport temperatures.

Impala	**Mean body temperature (^{o}C) during transport**			
	Hot day	**Cold day**	**Hot night**	**Cold night**
Mean (SD, n=6)	39.56 ± 0.38^{a}	37.79 ± 0.16^{b}	$38.41 \pm 0.17^{b,a}$	38.29 ± 0.28^{b}
C.I. (n=6)	39.26; 39.86	37.66; 37.92	38.27; 38.55	38.07; 38.51
A.melampus 1 (outlier)	$40.20 \pm 0.68^{*}$	$38.32 \pm 0.53^{*}$	$38.88 \pm 0.86^{*}$	$38.71 \pm 0.41^{*}$
A.melampus 2 (outlier)	$40.03 \pm 0.59^{*}$	$38.32 \pm 0.53^{*}$	$39.24 \pm 0.66^{*}$	$38.60 \pm 0.26^{*}$
A.melampus 3 (outlier)	39.61 ± 0.72	X	$38.85 \pm 0.39^{*}$	$39.54 \pm 0.47^{*}$

on the cold day was significantly lower than the mean pre-loading temperature on the cold night ($p<0.01$ (exact value not available)) and hot night ($p<0.01$ (exact value not available)). Most of the outliers had pre-loading temperatures that lay outside the confidence intervals of the mean pre-loading temperatures (Table 4.2.a). The mean pre-loading temperatures were not correlated to the order of transports ($r=0.40$, $p=0.60$, Spearman Rank correlation) or to the mean globe temperatures for the different transports ($r=0.00$, $p>0.05$ (exact value not available), Pearson Product-Moment correlation).

There was also no correlation between the order of transports and mean loading temperature ($r=-0.80$, $p=0.20$) and between the mean globe temperatures and mean loading temperatures ($r=0.82$, $p>0.05$ (exact value not available)). The mean loading temperatures were also significantly different between the transports ($F_{(3,15)}=34.52$, $p<0.01$ (exact value not available)), where the mean loading temperature for the hot day was significantly higher than that for the hot night ($p=0.01$ (exact value not available)), cold night ($p=0.04$) and cold day ($p<0.01$ (exact value not available)). The mean loading temperature for the cold day was significantly lower than those for both the hot night ($p<0.01$ (exact value not available)) and the cold night ($p<0.01$ (exact value not available)). The mean loading temperatures of all the outliers were significantly higher compared to the mean loading temperatures (Table 4.2.b).

In a similar trend as that shown by the loading temperatures, the impalas' mean body temperature during transport was significantly different during the four

transports ($F_{(3,15)}$=38.28, p<0.01 (exact value not available)). The mean temperature during the hot day was significantly higher than the mean temperature during the hot night (p<0.01 (exact value not available)), the cold night (p<0.01 (exact value not available)) and cold day (p<0.01 (exact value not available)). The mean temperature during the cold day transport was significantly lower than that for the hot night (p=0.02). Unlike the correlations for the mean pre-loading and loading temperatures, there was a significant negative correlation between the order of transport and mean transport temperature (r=-1.00, p<0.05 (exact value not available)) and a significant positive correlation between mean globe temperature for each transport day and the transport temperature (r=0.97, p<0.05 (exact value not available)). The impalas included in the mean had a significant increase in body temperatures during transport, compared to the pre-loading temperatures, on the hot day (t=-5.04, p<0.01 (exact value not available), paired t-test). However, for the hot night (t=9.60, p<0.01 (exact value not available)), cold night (t=6.46, p<0.01 (exact value not available)) and cold day (t=3.60, p=0.02) there were significant decreases in temperature during transport.

The transport temperatures of the outliers were significantly higher than the mean transport temperature, except *A.melampus* 3 on the hot day (Table 4.2.c). One of the outliers, the male *A.melampus* 1, died 28 days after the fourth and last transport, possibly because he had hyperthermia for a few days, from losing condition. Another male outlier (*A.melampus* 3) died three days after the third transport, after showing only a slight fever (about half a degree) before dying. No post-mortems were done on these animals.

All three outliers had consistently higher peak temperatures for most of the transport trips, compared to the mean peak temperatures for the rest of the impala (Table 4.3). The mean peak temperatures for the transports of the six animals, not considered outliers, were significantly different ($F_{(3,15)}$= 24.93, p<0.01 (exact value not available)). The mean peak temperature on the hot day was significantly higher than the mean peak temperature on the hot night (p=0.03) and cold day (p<0.01 (exact value not available)). The mean peak temperature on the cold day was significantly lower than that for the cold night (p<0.01 (exact value not available)) and hot night (p<0.01 (exact value not available)). There was no correlation between the order of transport trips and the mean peak temperatures (r= -0.80, p=0.20) or between mean globe temperatures and mean peak temperatures (r = 0.76, p>0.05 (exact value not available)).

Thermal response indices were calculated for the outliers, as well as the rest of the impala, during both loading and transport and are shown in Figure 4.3. The thermal response index for the group of six animals was significantly higher on the hot day loading than the index for the cold day loading (t=10.00, p<0.01 (exact value not available), paired t-test). The mean index for the hot day transport was also significantly higher than the index for the cold day transport (t=5.74, p<0.01 (exact value not available)). The index for the cold night loading was significantly higher than the index for the hot night loading (t= -4.16, p=0.01), but there was no difference in these indices for the hot night and cold night transports (t= -2.41, p=0.06).

Table 4.3: **Peak temperature of impala.** Peak abdominal temperature of three outlier impala and the mean peak temperature (± standard deviations and 95% confidence intervals) for the rest of the animals (n=6) occurring during loading of each transport trip. Means with different superscripts are significantly different to each other ($p<0.05$). The symbol "X" indicates that this impala had died and the symbol "*" indicates that the loading temperature of the outliers lay outside the 95% confidence intervals of the mean.

Impala	**Peak temperature (^{o}C)**			
	Hot day	**Cold day**	**Hot night**	**Cold night**
Mean ± SD (n=6)	41.09 ± 0.55^{a}	39.78 ± 0.59^{b}	$40.56 \pm 0.21^{b,a}$	40.77 ± 0.56^{a}
C.I. (^{o}C), n=6	40.65; 41.53	39.31; 40.25	40.39; 40.73	40.32; 41.22
A.melampus 1 (outlier)	42.14^{*}	40.12	41.36^{*}	41.03
A.melampus 2 (outlier)	41.88^{*}	40.40^{*}	41.31^{*}	41.45^{*}
A.melampus 3 (outlier)	42.40^{*}	X	41.97^{*}	42.50^{*}

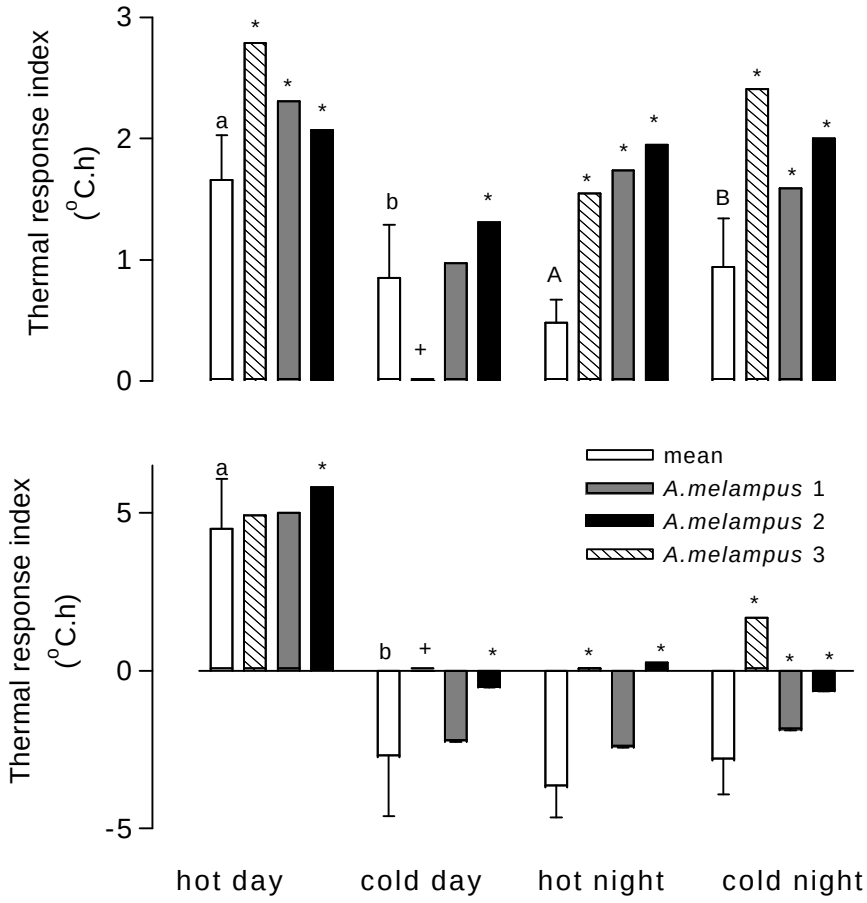


Figure 4.3: Thermal response indices for impala. Mean (± standard deviation) thermal response indices for the six impala (with intra-abdominal data loggers) and indices for three outliers, for four transport trips. Refer to Figure 4.1 for an example of this calculation. Note different scales used for indices during loading (top panel) and transport (bottom panel). The symbols "a" and "b" indicate significance ($p<0.05$) between mean day temperatures, while the symbols "A" and "B" indicate significance between the mean night temperatures. The symbol "+" indicates that the impala died. The symbol "*" indicates that the indices for the outliers lay outside the confidence intervals of the mean indices.

All the thermal response indices for the group of six animals, both during loading and transport, were significantly different to zero, as judged by their confidence intervals as follows: hot day (loading: 1.36 to 1.95^{o}C/h and transport: 3.22 to 5.74 ^{o}C/h), cold day (loading: 0.50 to 1.19 ^{o}C/h and transport: -4.23 to –1.27 ^{o}C/h), hot night (loading: 0.32 to 0.63 ^{o}C/h and transport: -4.44 to –2.93 ^{o}C/h), cold night (loading: 0.61 to –1.26 ^{o}C/h and transport: -3.71 to –1.98 ^{o}C/h). The thermal response indices for the outliers were also significantly different to zero, as they lay outside the confidence intervals of the mean (see Figure 4.3).

I estimated how long it took for the body temperature of the impala to adjust to the events of loading and transport by calculating the time constant of the stabilisation of temperature, from the temperature prevailing at the moment of the animals being loaded into the vehicle. For these calculations, I employed the individual body temperature records of the impala finally included in the group of six, that is I excluded the outliers. The mean time constants were significantly different between the transports ($F_{(3,15)}$= 10.80, $p<0.01$ (exact value not available)), where the mean time constant for the hot day was significantly lower to the mean time constant for the hot night ($p<0.01$ (exact value not available)) and the cold night ($p=0.01$). There was no correlation between the mean time constants and the order of transports ($r=0.20$, $p=0.80$) or the mean globe temperatures ($r=-0.60$, $p>0.05$ (exact value not available)). The time constant for the outlier *A.melampus* 1 was higher than the time constant for the mean on the hot day (confidence intervals: 18.40; 24.93 minutes), hot night (45.86; 80.80 minutes) and cold day (31.65; 51.68 minutes) and lower than the time constant for

the mean on the cold night (44.97; 66.69 minutes). The time constant for *A.melampus* 2 was lower than the mean time constant for the cold night and higher than the mean time constant for the cold day. The time constant for *A.melampus* 3 was higher than the mean time constants for the hot day and lower than the mean time constants for both the hot night and cold night. The mean time constants, together with the prevailing globe temperatures, are shown in Figure 4.4.

The longest time for the body temperatures to stabilise occurred during the hot night transport. Given that it takes three time constants to reach within 95% of the full change of body temperature, I predict that for impala transported in conditions similar to those prevailing on my hot night, in a similar vehicle, it would take about three hours before body core temperature could be considered to have stabilised.

The measurements I have reported on the body temperatures of impala during loading and transport were derived from a study I conducted specifically for that purpose. I also had the opportunity to make similar measurements in tsessebe, during a translocation. All of the tsessebe were chased at the same time, but they showed individual peaks in body temperature, the magnitude of which depended on when each animal was captured (Figure 4.5). Tsessebe *D.lunatus* 1 was darted first and had a peak in body temperature that was the lowest as compared to the other two tsessebe (Table 4.4). Globe temperatures were measured externally at the capture site, where temperatures reached 44^{o}C, and inside the vehicle, where

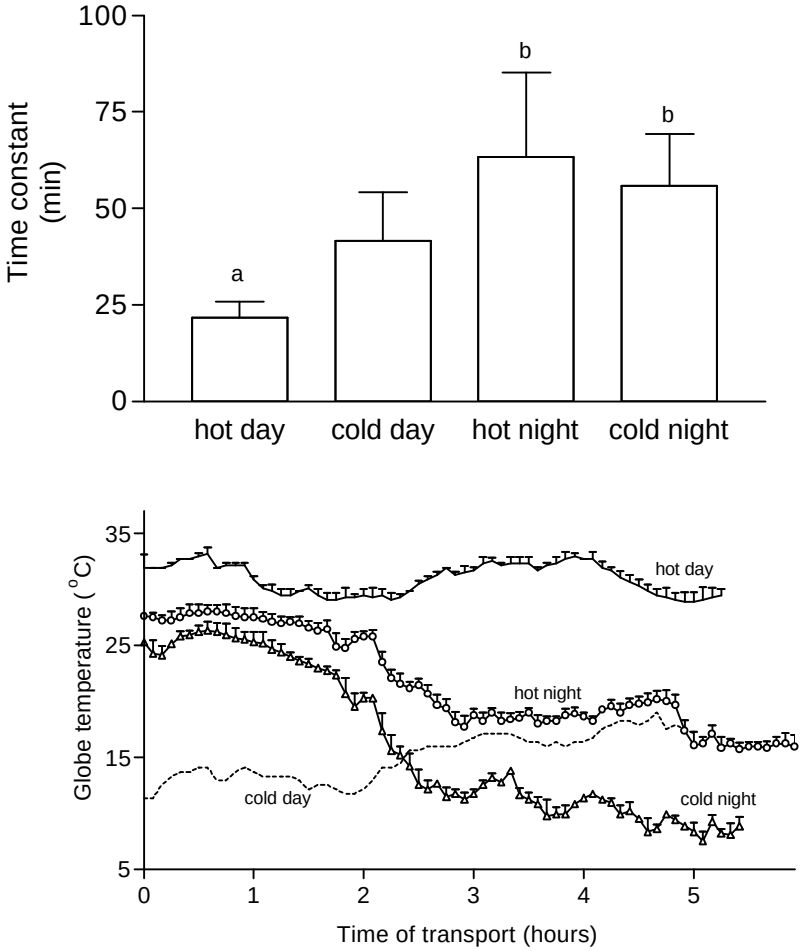


Figure 4.4: Time constants for impala. Mean time constants for temperatures of six impala (with intra-abdominal data loggers) are shown for four different transport trips (top panel). The error bars indicate standard deviations. The time to steady state is three times the time constant and the means with different letters are significantly different to each other ($p<0.05$). The bottom panel shows the mean globe (30mm diameter) temperature for the duration of each transport trip. This mean temperature was obtained from three globe thermometers placed inside different compartments for the duration of this transport.

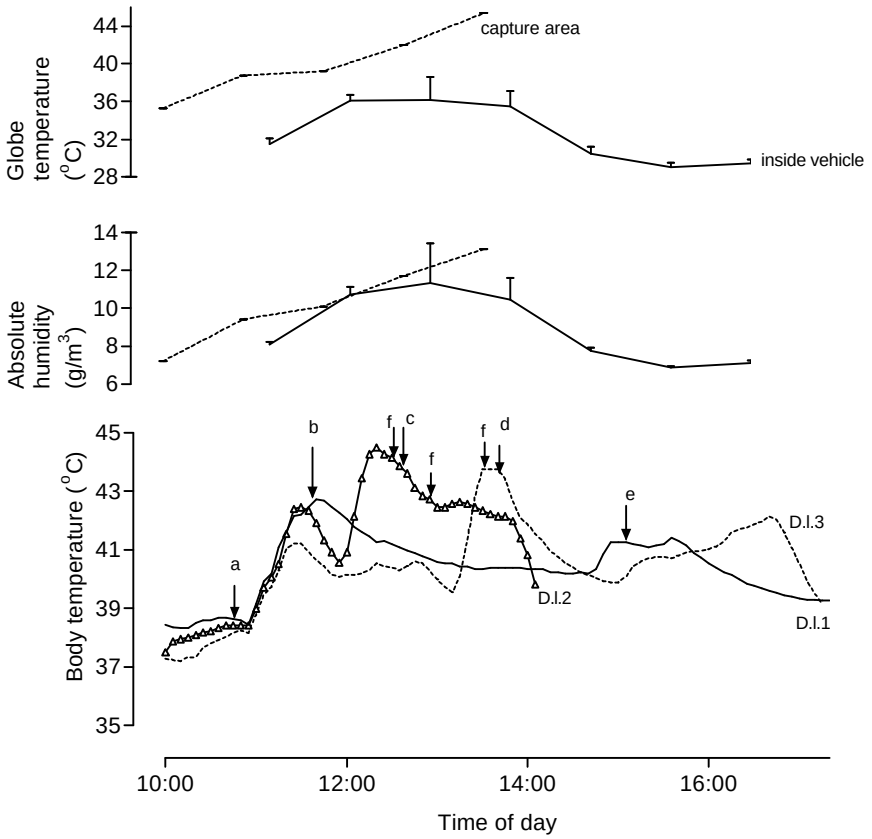


Figure 4.5: Environmental conditions and temperature of tsessebe during transport. Abdominal temperatures and environmental conditions during the loading and transport of three tsessebe. The bottom panel shows the body temperatures of the individual animals. The top panels show mean globe (30mm) temperature and absolute humidity in the capture area and inside the two compartments of the transport vehicle over the same time period. Error bars indicate standard deviations. The symbols on the graph indicate: a=all animals chased, b=*D.lunatus* 1 into vehicle, c=*D.lunatus* 2 into vehicle, d=*D.lunatus* 3 into vehicle, e=transport started, f= water was put onto the animal. All three animals died, two during this transport operation and the third two weeks later.

Table 4.4: Peak abdominal temperatures of three tsessebe in a capture and transport operation and time of death, relative to peak temperature reached, together with mean (± standard deviation) body temperature during transport. Included are the number of measurements taken (N).

Tsessebe	Peak temperature (^{o}C)	Mean ± SD (N)	Died (time since peak)
D.lunatus 1	42.7	40.66 ± 0.90^{o}C (77)	2 weeks later
D.lunatus 2	44.5	42.04 ± 1.56^{o}C (36)	85 minutes
D.lunatus 3	43.7	40.68 ± 1.15^{o}C (59)	130 minutes

the temperatures reached 36^{o}C (Figure 4.5). As the animals were brought into the vehicle both globe temperature and absolute humidity inside the vehicle increased, but once transport began, the temperature and humidity decreased.

For each tsessebe, two thermal response indices were calculated (see Table 4.5). The first index was calculated from the time all the tsessebe were chased, until the first tsessebe was captured. The second index was calculated from the time each tsessebe was caught until the first tsessebe was inside the transport vehicle. There was a significant difference between the indices and zero ($F_{(2,4)}$=19.96, p=0.01), where the first index was not significantly to zero (p=0.30), but the second index was significantly greater than zero (p=0.01) and the first index (p=0.03). The body temperatures of the tsessebe increased significantly during transport from their pre-loading temperatures (t=-5.73, p=0.03).

The measurements I made of the body temperatures of the tsessebe turned out to have forensic importance, because all three tsessebe died (Table 4.4). The deaths of the first two animals were the result of heat stroke, according to the post-mortem report, while no post-mortem was done on the animal that died about two weeks later

Compared to tsessebe (with only one transport), three blesbok were transported on three days: on a hot day (39 ± 1^{o}C), nearly as hot as the day of tsessebe transport, and on two cold days (15 ± 1^{o}C and 20 ± 1^{o}C). The body temperature profiles for the blesbok during the hour before loading, during loading, during transport and

Table 4.5: Thermal response indices for tsessebe. Two thermal response indices calculated for each tsessebe (with intra-abdominal devices). The first index (calculated from time the tsessebe were chased until the first tsessebe was captured) was compared to the second index (calculated form the time each tsessebe was caught until the first tsessebe was inside the transport vehicle). Both indices were also compared to zero. Indices were calculated using pre-loading temperatures as initial values (see Figure 4.1 for an example of this calculation).

	Thermal response indices (^{o}C.h)	
Tsessebe	**chase to capture**	**capture to inside vehicle**
D.lunatus 1	0.25	0.69
D.lunatus 2	0.37	1.53
D.lunatus 3	0.42	1.32

an hour after transport on the hot day and on the second cold day (15^{o}C) are shown in Figure 4.6.

The body temperatures of the blesbok on the first cold day (20^{o}C) are not shown, as the body temperature profile was similar to that shown by the blesbok on the 15^{o}C day. Refer to Table 4.6.a for the statistical differences between the average body temperatures of three blesbok during loading for each transport trip, as well as between the average nychthemeral rhythms. The nychthemeral rhythms were calculated from temperatures three days before each transport trip, over the time from loading until two hours after transport, to establish whether there are any inherent differences in the body temperatures between the three blesbok. Table 4.6.b. shows the differences in the average temperatures between blesbok during transport and the hour after transport (post-transport) for all transport trips.

The blesbok's temperatures did not increase significantly during transport (from pre-loading temperatures) on the hot day ($t=-0.28$, $p=0.80$), the first cold day ($t=-0.36$, $p=0.75$) and the second cold day ($t=-0.27$, $p=0.82$). The thermal response indices between the three blesbok were not significant for all three transports trips: during transport ($F_{(2,4)}=0.40$, $p=0.69$) and post-transport ($F_{(2,4)}=0.84$, $p=0.50$). The mean thermal response indices of the transport and post-transport temperatures of each day were not significantly different to zero, as judged by their confidence intervals (Table 4.7).

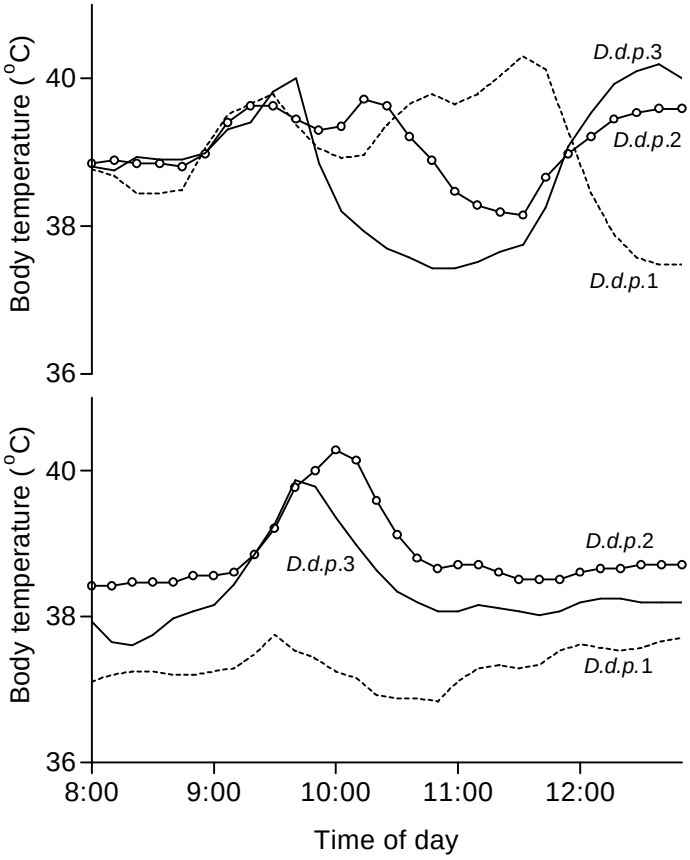


Figure 4.6: Abdominal temperature of three blesbok on two days. Abdominal temperature profiles of three blesbok, one male (*D.d.phillipsi* 3) and two females, during a capture and transport procedure on a hot day (top panel, mean globe temperature: 39 ± 1°C) and a cold day (bottom panel, 15 ± 1°C). The blesbok were chased and loaded into the transport vehicle at around 09:00. Transported started around 10:00 and ended around 11:00. The body temperatures for blesbok on the first cold day (20 ± 1°C) transport is not shown on the graph as the temperature profiles were similar to that shown by the blesbok during the second cold transport. Refer to Table 4.6 for the statistical results when the body temperatures were compared between the three blesbok for each transport trip.

Table 4.6.a: Differences in nychthemeral rhythms and loading temperature between three blesbok. Significant differences between the abdominal temperatures of two female blesbok (*D.d.phillipsi* 1, *D.d.phillipsi* 2) and one male (*D.d.phillipsi* 3) during loading on three different transport days. Nychthemeral rhythms were also compared between the blesbok, during the time of loading until two hours after transport, which was specific to each transport trip. Significant differences were determined using RMANOVA and if any significance was found, the Scheffe post hoc test was used.

Temperatures	**Day of transport**	**Where significant?**
Nychthemeral rhythms	Hot	$F_{(2,38)}$=119.06, p<0.01. *D.d.p.*1 higher than *D.d.p.*2 (p<0.01) and *D.d.p.*3 (p<0.01).
	First cold	$F_{(2,46)}$=7.05, p<0.01. *D.d.p.*2 higher than *D.d.p.*3 (p<0.01).
	Second cold	$F_{(2,44)}$=7.72, p<0.01. *D.d.p.*2 higher than *D.d.p.*1 (p<0.01) and *D.d.p.*3 (p=0.01).
Loading	Hot	$F_{(2,10)}$=1.72, p=0.23
	First cold	$F_{(2.12)}$=19.56, p<0.01. *D.d.p.*2 higher than *D.d.p.*1 (p<0.01). *D.d.p.*3 higher than *D.d.p.*1 (p<0.01).
	Second cold	$F_{(2,8)}$=46.91, p<0.01. *D.d.p.*2 higher than *D.d.p.*1 (p<0.01). *D.d.p.*3 higher than *D.d.p.*1 (p<0.01).

Table 4.6.b: Differences in transport and post-transport temperatures between three blesbok Statistical analyses were done between the abdominal temperatures of two female blesbok (*D.d.phillipsi* 1, *D.d.phillipsi* 2) and one male (*D.d.phillipsi* 3) during transport and an hour after transport on three transport days. Significant differences were determined using RMANOVA and if any significance was found, the Scheffe post hoc test was used.

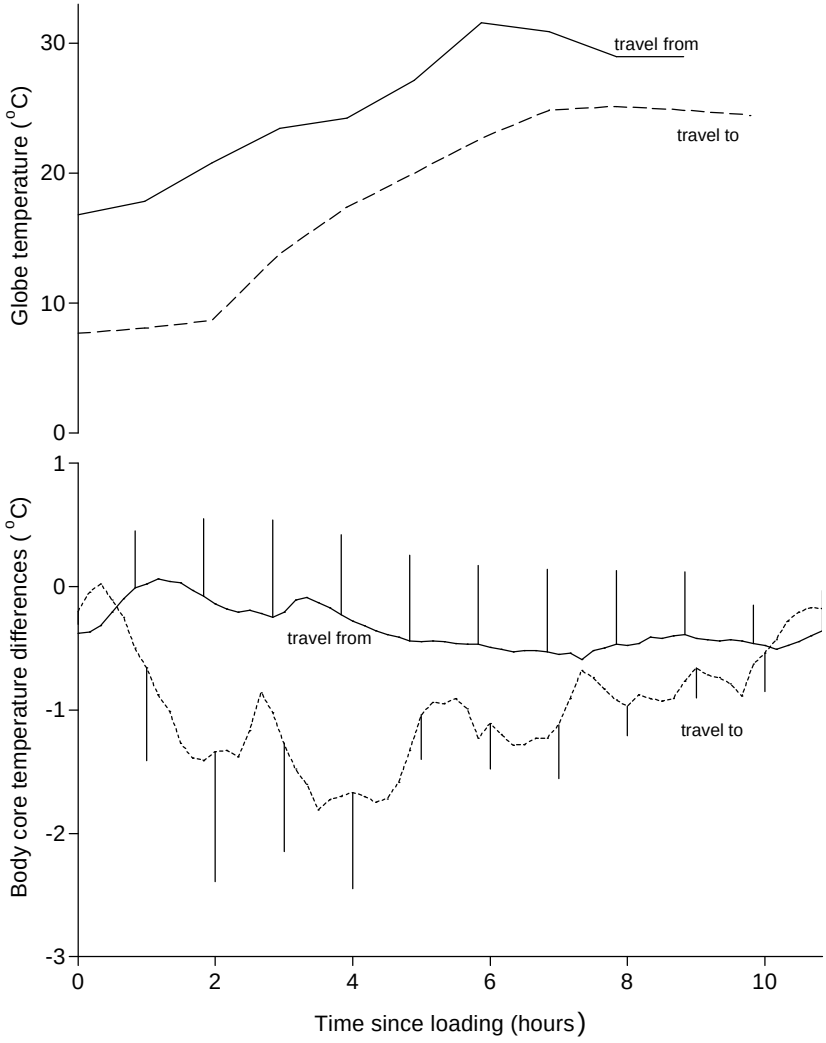
Temperatures	Day of transport	Where significant?
Transport	Hot	$F_{(2,12)}$=46.58, p<0.01. *D.d.p*.1 higher than *D.d.p*.2 (p<0.01) and *D.d.p*.3 (p<0.01). *D.d.p*.2 higher than *D.d.p*.3 (p<0.01).
	First cold	$F_{(2,18)}$=86.09, p< 0.01. *D.d.p*.2 higher than *D.d.p*.1 (p<0.01) and *D.d.p*.3 (p<0.01).
	Second cold	$F_{(2,20)}$=82.60, p<0.01. *D.d.p*.2 higher than *D.d.p*.1 (p<0.01) and *D.d.p*.3 (p<0.01). *D.d.p*.3 higher than *D.d.p*.1 (p<0.01)
Post-transport	Hot	$F_{(2,12)}$=3.63, p=0.06.
	First cold	$F_{(2,12)}$=155.56, p<0.01. *D.d.p*.2 higher than *D.d.p*.1 (p<0.01) and *D.d.p*.3 (p<0.01). *D.d.p*.3 lower than *D.d.p*.1 (p<0.01).
	Second cold	$F_{(2,12)}$=836.98, p<0.01. *D.d.p*.2 higher than *D.d.p*.1 (p<0.01) and *D.d.p*.3 (p<0.01). *D.d.p*.3 higher than *D.d.p*.1 (p<0.01).

Table 4.7: Thermal response indices for blesbok. The thermal response indices of the abdominal temperatures during the transport (T) and post-transport (P) phases of three blesbok, one male (*D.d.phillipsi* 3) and two females, for each transport trip. Mean (± standard deviations, n=3) thermal response indices of transport and post-transport temperatures are also shown for each transport day, together with the 95% confidence intervals (C.I.) of the means.

Individual animal	**Thermal response indices (^{o}C.h)**					
	Hot day		**First cold day**		**Second cold day**	
	T	**P**	**T**	**P**	**T**	**P**
*D.d.p.*1	1.03	-0.45	-1.17	-0.17	-0.15	0.39
*D.d.p.*2	-0.25	0.35	1.30	0.13	0.96	0.17
D.d.p 3	-1.37	0.63	-0.63	-0.21	0.81	0.32
Mean ± SD	-0.20 ± 1.20	0.18 ± 0.56	-0.17 ± 1.30	-0.08 ± 0.19	0.54 ± 0.60	0.29 ± 0.11
C.I.	-1.56; 1.16	-0.46; 0.81	-1.64; 1.30	-0.29; 0.13	-0.14; 1.22	0.17; 0.42

The Angora goats were transported for a much longer duration than the blesbok and are the only livestock transported in my study. The same five Angora goats were transported twice, first from Steytlerville to Johannesburg and then back to Steytlerville from Johannesburg, a distance each way of approximately 1000 km. There was a higher globe temperature during the second transport, and the goats' had a longer fleece. I calculated the mean deviation of body temperature from the goats' nychthemeral rhythm during transport, by subtracting the temperatures during transport from the same animals' nychthemeral temperatures over the time of transport (Figure 4.7). I calculated this difference in temperatures, because the body temperature of the goats during transport were much lower than the temperatures of these same animals not undergoing transport (refer to Figure 4.1 for an example of the differences in these temperatures). The mean deviation of body temperature for the first transport was significantly greater than that for the second transport ($t= 3.04$, $p=0.04$). The mean deviation of the body temperatures during the first transport was significantly different to zero (confidence intervals: 0.64; 1.32^{o}C.h), but not during the second transport (-0.02; 0.74 ^{o}C.h).

Using the differences between transport temperature and the nychthemeral rhythms, the thermal response index (Table 4.8) for the first transport was significantly greater than the index for the second transport ($t=3.26$, $p=0.03$). The mean index for the transport to Johannesburg was significantly different to zero (confidence interval: 6.37; 13.73^{o}C.h), while mean index for the transport from Johannesburg was not significantly different to zero (confidence interval: -0.06; 7.06^{o}C.h). The body temperatures of the Angora goats did not increase



F**igure 4.7: Angora goat body temperature with globe temperature.** Abdominal temperature differences and globe temperature during two transports of the same five Angora goats. The top panel shows the mean globe (150mm) temperature during two transports (to and from Johannesburg). The bottom panel shows the mean deviation in body temperature from the nychthemeral rhythm, measured before transport (see Figure 4.1). Error bars indicate standard deviations.

Table 4.8: Thermal response indices for Angora goats. Thermal response indices for five Angora goats (with intra-abdominal devices), calculated from the difference in their body temperatures during transport and their nychthemeral rhythms. Angora goats were transported to Johannesburg (from Steytlerville) and then from Johannesburg, back to Steytlerville. Note than one goat was excluded from the analysis, as the data logger was implanted underneath the skin.

Individual animal	Thermal response indices (^{o}C.h)	
	Travel to Johannesburg	**Travel from Johannesburg**
C.aegagrus 1	0.87	-0.42
C.aegagrus 2	1.60	0.76
C.aegagrus 4	0.98	0.57
C.aegagrus 5	0.39	0.33
C.aegagrus 6	1.45	0.61

significantly during transport from pre-loading temperatures (an hour before loading) on the transport to Johannesburg (t=2.33, p=0.08) or the transport from Johannesburg (t=-0.26, p=0.81).

4.2.2 Actual capture and transport operations

The rectal temperatures of three blesbok with data loggers in their rectums (two females (*D.d.phillipsi* 4, *D.d.phillipsi* 5) and one male (*D.d.phillipsi* 6)) are shown in Figure 4.8, together with the air temperature during transport. Although the blesbok were caught at the same time and transported together, the male had a much higher peak temperature and lower body temperature during transport than the females and than the normal abdominal temperature (obtained from the blesbok implanted with data loggers in section 4.2.1). The female *D.d.phillipsi* 5 had a higher peak than the other female and similar to the male, had a lower body temperature during transport than the other female and to the normal abdominal temperature.

Three elephants and three white rhinoceroses were transported on six different occasions and their rectal temperatures were measured. The globe temperature of the capture site and the rectal temperatures of the rhinoceroses and the elephant from Pongola were higher than those of the other rhinoceroses (Figure 4.9) and the other elephants (Figure 4.10). The mean globe temperatures experienced by the rhinoceros at Hluhluwe was 19 ± 1^{o}C and at Pongola it was 36 ± 1^{o}C, while for elephants the mean globe temperatures were 29 ± 3^{o}C (Pongola), 23 ± 1^{o}C and 29 ± 1^{o}C (Phalaborwa). The rhinoceros *C.simum* 1 showed a body temperature

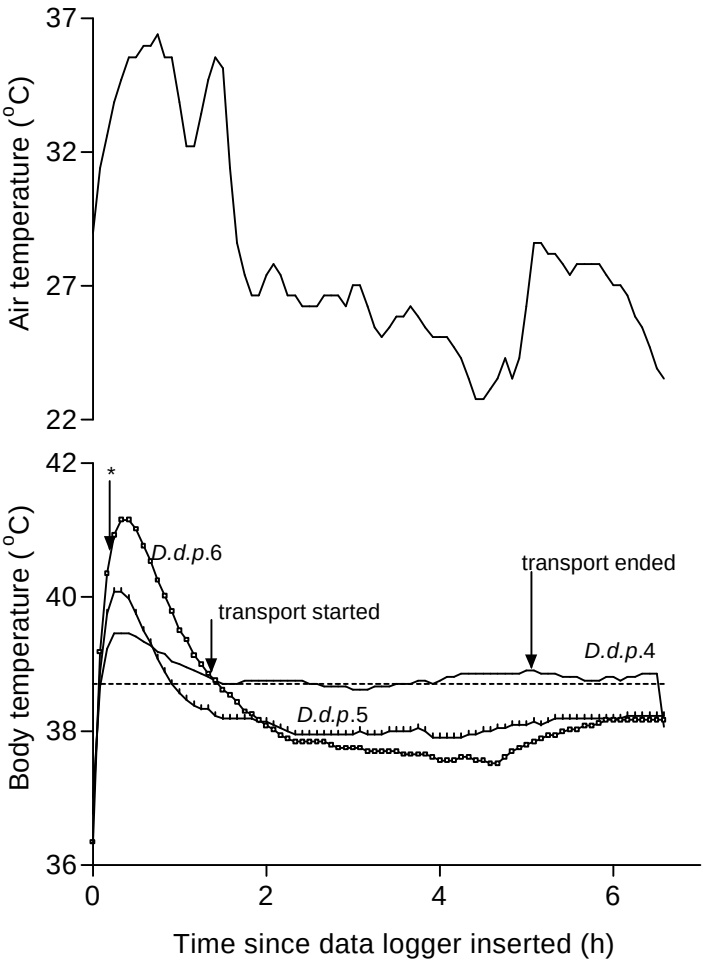


Figure 4.8: Blesbok rectal temperature and air temperature. Air temperature (top panel) inside transport vehicle and rectal temperatures (bottom panel) of three blesbok (with only a rectal device inserted): one male (*D.d.phillipsi* 6) and two females, from the time that they were inside the transport container. The dotted line represents the normal abdominal temperature obtained from the three blesbok implanted with data loggers in my study. The symbol "*" indicates when I believe the temperatures have stabilised, based on the average time (about 17 minutes) that the data loggers took to stabilise in the blesbok with intra-abdominal loggers.

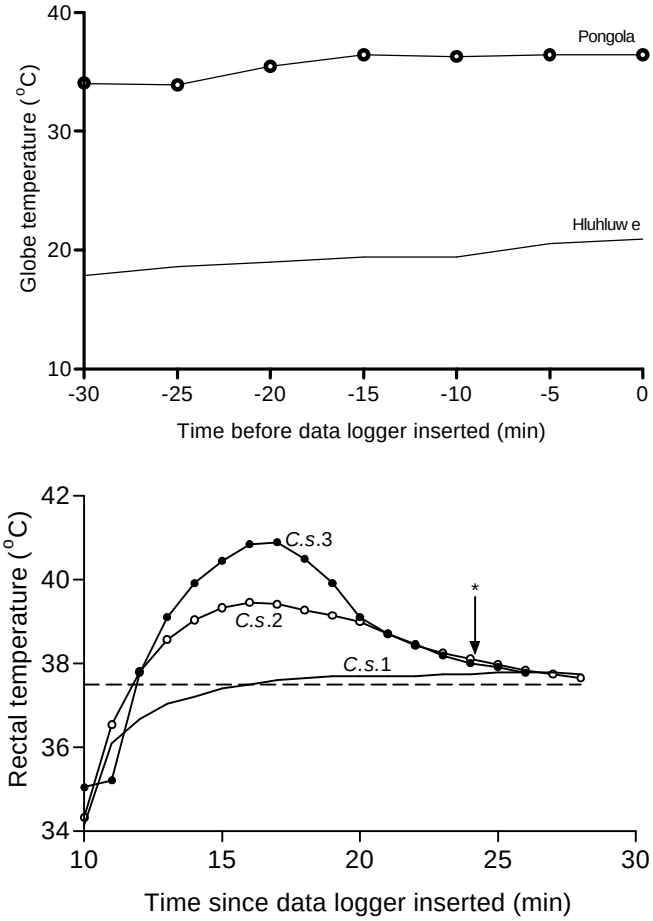


Figure 4.9: Rectal temperatures of white rhinoceroses and globe temperature. Globe temperatures (150mm) of the capture areas (top panel) and rectal temperature (using data loggers) of three white female rhinoceroses during three transport trips (bottom panel). The rhinoceroses *C.simum* 2 and *C.simum* 3 were transported in Pongola, while *C.simum* 1 was transported in Hluhluwe. The dotted line represents the normal rectal temperature of a rhinoceros (Trendler, pers.comm. in Rogers, 1993). It took about 22.5 minutes for the data logger to stabilise (the symbol "*" on the graph) once inserted into the rectum of *C.simum* 3, so the peaks shown in the graph are probably underestimates of true peaks.

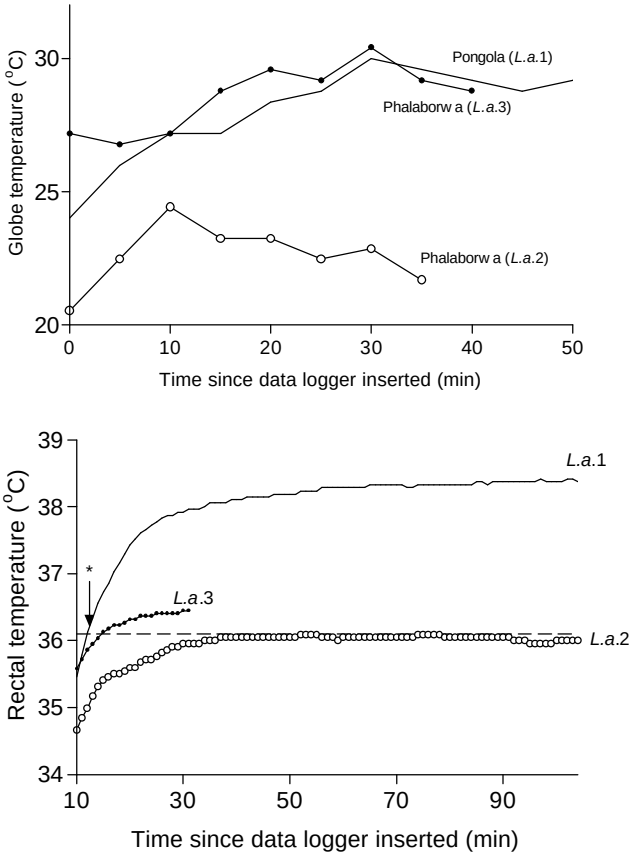


Figure 4.10: **Rectal temperatures of elephants and globe temperature.** Rectal temperatures (using data loggers) and globe temperatures during the transport of three male elephants. Globe (110mm) temperatures during the different transport trips in Phalaborwa and Pongola are shown in the top panel. The bottom panel shows rectal temperature for three elephants from different transport trips in Phalaborwa (*L.africana* 2 and *L.africana* 3) and Pongola (*L.africana* 1). The dotted line represents the normal rectal temperature of an elephant (Raath, 1993). It took about 12 and 9 minutes (the symbol "*" on the graph) for the data logger to stabilise once inserted into the rectum of *L.africana* 1 and *L.africana* 2 respectively.

profile that was similar to that shown by the elephants, as it did not show a clearly defined peak in temperature after capture. The other two rhinoceroses' body temperatures showed a peak (up to 41^{o}C), but after about ten minutes after the beginning of transport their temperatures decreased to that of *C.simum* 1. On the other hand, the elephants' temperatures did not decrease before data collection ended, but only one elephant's (*L.africana* 1) body temperature was higher than the normal rectal temperature of elephants.

4.3. Discussion

I examined the body temperature responses of animals to capture and transport stress in mimicked operations using data loggers that were implanted in the abdomen of various animals, as well as in actual operations using inserted thermometric devices into the rectum of animals. Although temperatures were not measured during capture in actual operations, I was still able to compare these temperatures to the temperature patterns measured in the experimental study with temperatures in actual operations. Since animals with data loggers implanted in their abdomens show the temperature during capture, these results will be discussed first.

There were several differences in the four transports that impala were subjected to. Firstly, the mean pre-loading body temperatures between the two day transports and the two night transports were not different, but the pre-loading temperatures were significantly higher for the night than the day. Kamerman *et al.*

(2001b) has also shown that body temperatures of impala were higher at night than during the day. Studies by Mitchell *et al.* (1997) on springbok and Mitchell *et al.* (2002) on wildebeest and eland have both shown that arterial blood temperature was higher at night (around 17:30) than during the day. However, animals are generally captured in the early morning or late afternoon, when ambient temperatures are cool (such as recommended by Openshaw, 1993), on the false assumption that the animals' temperatures would also be low. Perhaps these guidelines of when to capture should be re-evaluated.

Secondly, compared to the pre-loading temperatures, during loading and transport, the mean body temperature during the hot day (first transport) was significantly higher than the mean temperature on a hot night (second transport), cold night (third transport) and cold day (last transport). The mean temperatures on the cold day were significantly lower than the mean temperatures on the hot night (during transport only) and cold night. These differences in temperature seem to indicate that a higher globe temperature, as well as the order of transport, affects body temperature. However, only the mean transport (and not loading) temperatures had a significant correlation with mean globe temperatures and the order of transport. Therefore, as mean globe temperatures increased, so did the mean animals' temperature during transport and the mean transport temperature decreased with successive transport trips. The animals seemed to be adapting to the capture and transport procedures (reacting less to "fright" stress). It seems possible that the correlation between the mean globe temperatures and animals' temperatures during transport was only an indication of the correlation of animals'

temperatures and the order of transport, as mean globe temperatures decreased with successive transports.

Since transport temperatures were correlated with the order of transport trips, it seems to explain why the mean body temperatures of the impala increased significantly due to transport for the first transport, but decreased significantly due to transport for the second, third and last transports. However, although animals on the hot day did have a higher increase in body temperature than on any other transport trip and the mean peak temperatures generally decreased with successive transport trips, there was no correlation between the mean peak temperatures and the order of transports or mean globe temperature.

Thirdly, during both capture and transport procedures the thermal response index for the mean group of animals was the highest for the hot day. This indicates that during the hot day the animals had the highest positive thermal load imposed on them and so the heating events of the animal exceeded cooling events. All animals, however, exhibited an increase in thermal load during loading on all transport trips, which could be due to excessive heat produced by muscle activity and/or the stress of capture ("fright" stress) (van Logtestijn *et al.*, 1982, Meyer *et al.*, 2004). During the four transport trips, all the mean thermal response indices decreased, except on the hot day, possibly because the transport procedure involved less physical exertion, the animals were sedated, ventilation inside the vehicle was increased during transport and there were lower globe temperatures. Possible reasons for the high body temperatures during the hot transport were that

the globe temperature was the highest for this transport and the haloperidol doses given to tranquillize the impala were still being adjusted and many animals needed biperiden lactate to reverse the haloperidol's side-effects. Since the lowest thermal response indices were significantly higher than if no change in temperature occurred, it indicates that capture and transport both affected the thermal load imposed on the animal, but that loading was more thermally stressful than transport.

Finally, it took a significantly longer time for the body temperatures of the impala to stabilise when transport occurred at night than during the day. The longest time to stabilisation was about three hours. It is therefore important that in real-life capture and transport procedures, if the operators are making intermittent checks of body temperature, then they have to do so for several hours before they can be sure that the animal is in equilibrium.

Those animals excluded from the mean (referred to as "outliers") generally had their pre-loading, loading and transport temperatures higher than the temperatures of the mean population of impala. The outliers also showed higher positive or lower negative thermal loads during capture and transport, which was indicated by their thermal response indices, as well as significantly longer or shorter times for their temperatures to stabilise. These individuals generally had temperature peaks that were higher than the mean peaks for all transports. The unusual body temperature responses of the "outliers" show temperatures measured in some animals in a group will not necessarily reflect the response of all animals.

Two of the outliers died soon after the last time they were transported. *A.melampus* 1 seemed to have died from hyperthermia, but it is unclear what happened to *A.melampus* 3. *A.melampus* 3 was the adult male and so was transported in isolation in a wooden crate. Perhaps as a herd animal, this isolation increased the animal's stress (Grandin, 1997). This animal was constantly kicking and rubbing his horns during transport, which could easily explain the higher temperatures. However, I think that his death was due to his last transport (namely the cold night), as it took about an hour for him to get out of the crate. It was during this transport that the male was the only animal that showed a positive thermal load. It is interesting that both animals that died were males, which might indicate that males experience more stress than females during transport.

The three tsessebe used in my study, two of which died during the study and the third died two weeks later, had much higher temperatures and peak temperatures than any other animals subjected to capture and transport. Body temperatures also increased significantly due to transport from pre-loading temperatures. The high peak temperatures occurred during the time between capture and placement inside the transport vehicle and the thermal response index calculated for this same time frame was significantly higher than zero, and higher than the index calculated for the time the animals were chased until they were caught (which was not different to zero). Therefore it seems that the "fright" stress experienced by the animals due to handling had a greater impact on the animal's body temperature than the stress of increased muscle activity due to being chased (as shown by Meyer *et al.*, 2004).

Interestingly, the individuals with higher peak temperatures (with higher increases in body temperature) died sooner and the two animals that died on the same day showed two peaks in temperature, the second peak occurring just before the animal died (Figure 4.5). Since it is common practice in game capture operations to capture animals by chasing them all at the same time, these results indicate the dangers, as those caught later were running around for a longer period of time. These tsessebe had to deal with a long period of exercise and exertion, coupled with their responses to the "fright" stress when they were caught, and on top of this there was the high globe temperatures of the capture environment. I believe that these factors could have caused the hyperthermia that eventually killed the animals. Two important findings from procedures used by actual game operators are as follows: water that was used to cool animals down did decrease the animals' body temperatures; and possibly due to air movement provided by the ventilation in the transport vehicles, the high globe temperature and absolute humidity that resulted when the tsessebe entered the transport vehicle, decreased during transport.

Instead of high ambient temperatures, Angora goats had to deal with cold temperatures. During their first transport, the globe temperatures were low (a range of about 8 to 25^{o}C) and the animals were shorn, which resulted in the animals showing large decreases in body temperature, of up to 2^{o}C relative to their nychthemeral rhythm. The thermal response index for the first transport was also significantly greater (higher negative index) than the index for the second transport. For their second transport, the animals' hair had grown and the globe

temperatures were much higher (about 10^{o}C), which resulted in hardly any body temperature differences from the nychthemeral rhythm. Although the transport vehicle was an open pick-up truck and the wind-chill factor would have been important in the cold-stress experienced by these animals, the body temperatures did not increase or decrease due to transport from pre-loading temperatures, for both transport trips.

Unlike the previous species, where temperature responses seem to be affected by ambient temperatures, the results from the blesbok (with intra-abdominal devices) seem to indicate that the differences in body temperature patterns that were shown by these animals were independent of ambient temperature, over the range of my measurements. Firstly, the thermal response indices between the temperatures measured during transport and post-transport were not different between the hot and two cold transports. There were also no significant changes in temperature due to transport from the pre-loading temperatures for all the transport trips. Secondly, there were inherent differences in body temperatures between the three blesbok. Before the hot day transport, the female *D.d.phillipsi* 1 had a significantly higher nychthemeral rhythm than the other two animals. However, before the first cold transport, the female *D.d.phillipsi* 2 had a higher nychthemeral rhythm than the male. By the third transport, *D.d.phillipsi* 2 had a higher nychthemeral rhythm than both the male and *D.d.phillipsi* 1. The procedures of loading and transport did little to change the order of the blesbok that had the highest temperatures to begin with.

The female *D.d.phillipsi* 1 was pregnant (gestation day about 135) at the time of the hot day transport, which could have accounted for her higher temperature. Once she had given birth (about three months before the first cold transport), she was always darted first in the group, resulting in her having a lower temperature and displaying no peak compared to the other animals. As mentioned before, once the first animal is darted the others run around until they are caught, probably increasing their body temperatures.

Another group of blesbok, along with white rhinoceroses and elephants, had temperatures measured by a rectal device only. A similarity in the temperatures measured in the species is that the animals showed a high rectal temperature immediately after being caught and then a stable temperature was reached during transport. Transport seems to be less thermally stressful than capture. However, the species varied in whether they showed a pronounced peak in temperature after capture and they varied in the temperatures reached during transport, possibly due to the differences in species' sizes.

Differences in temperature between individuals (within a species) could be due to differences in sexes, ambient temperature and/or capture methods. Firstly, the one male blesbok showed a distinctly high peak in temperature, which was higher than the two females, although all the blesbok were caught and transported at the same time. As mentioned with the impala results, perhaps males experience more stress than females. Secondly, although all the rhinoceroses were female, one rhinoceros (*C.simum* 1) did not show a peak in temperature and the rectal temperature was

not different to the normal rectal temperature of rhinoceroses, compared to the other two rhinoceroses. Though the differences in globe temperature experience by the animals (lowest for *C.simum* 1) also may have contributed to differences in body temperature, my observations are consistent with boma capture (*C.simum* 1) being less stressful thermally than field capture (*C.simum* 2 and *C.simum* 3). *C.simum* 3 had a higher peak temperature than *C.simum* 2, probably because it was caught later in the day, when globe temperatures were higher.

Different capture methods and ambient temperature could also be used to provide explanations for the differences in body temperatures shown by three elephants. *L.africana* 1 had a much higher rectal temperature than the others as well as than the normal rectal temperature for elephants. *L.africana* 1 was caught when the globe temperature was much higher than it was for the other two elephants, although *L.africana* 1 was caught in the early morning, compared to afternoon captures of the other two. It also took about an hour after *L.africana* 1 was darted for transport to begin, compared to only ten minutes for the others. Peaks in temperature, as well as decreases in body temperature were not observed in elephants. It seems that their body temperatures gradually rose due to capture and then stabilised during transport. Perhaps the rise in body temperature was related to the elephants' body sizes and the confined container.

The completeness and construction of my data are nothing like what one would expect from laboratory studies or controlled field studies, because they were largely opportunistic. Although I tried to randomise the samples, such as the

placement of impala into the containers, in some situations it was not possible. The male impala was always placed inside the crate and he was the last to be offloaded. Due to management procedures, the male could not be placed with the other animals or offloaded with the group, but it might have increased the stress of this animal. The darting order of the blesbok was not randomised, because of the difficulties of darting the animals. Therefore, the animals were darted in the same order for all three transports. A small sample size for all of the data collection presents a big problem. Although this study used several species, no definite comparison can be made between them with regards to thermal stress. It is however important to note the similarity in the responses to stress of all the species. In the following paragraph I will discuss the relevance of other studies to this chapter on thermal stress, where these studies have used a greater sample size.

The results from my study show that capture is generally more thermally stressful to animals than transport and that temperatures even decrease during transport. A study by Parrott *et al.* (1998) in pigs showed that body temperatures during transport were not different to temperatures at the start of transport, but Montané *et al.* (2002) showed that in Roe deer, the body temperatures during transport decreased from their pre-transport temperatures. However, the results from both these studies could have been compromised, because the animals were subjected to a vehicle or drug injection before transport. On the other hand, many authors (such as Ingram *et al.*, 2002) have reported increases in body temperature, but they have used rectal temperatures that were intermittently measured using mercury-in-glass thermometers and/or they continuously measured peripheral

sites (that are affected by ambient temperatures and not stress). Perhaps there are species-specific or individual-specific reactions to transport, such as shown by some of the impala in my study. The impala that were excluded from the calculation of the mean (the outliers) generally had higher temperatures during the capture and transport procedures, as well as higher peak temperatures than the temperatures for the mean population. These outliers also had higher or lower thermal response indices than the mean index. Knox (1992) in her PhD thesis had similar results, where the animals that did not survive her experiments had responses that were outside the range of the surviving animals.

I suggest that the high ambient temperature and long chase time could have been responsible for the tsessebe dying in my experiment. The globe temperatures during the capture of tsessebe was around 40^{o}C, but Murray *et al.* (1981) mentions a cut off for capture at 30^{o}C (air temperature), as capture would then exacerbate the high body temperatures of the animals. Perhaps the increased absolute humidity in the transport container, due to the animals being wet in this hot confined container, could have added more stress to the animals. A study done by Barnes *et al.* (2003) showed cattle indicated clinical heat stress during high absolute humidity and high wet globe temperatures, while inside a climatic chamber. Although several authors (such as Ebedes *et al.* 1996) have raised concerns with high environmental conditions having a negative impact on the temperatures of animals during capture and transport, only a few studies have been done on the effect of air temperatures (and some of the studies have also measured absolute humidity) on body temperatures of animals during transport.

The results of two studies have shown that the body temperatures of animals after transport (using intermittent rectal temperatures) were influenced by ambient temperatures during transport, where lambs experienced hypothermia in cool environmental temperatures (Knowles *et al.*, 1998) and pigs experienced hyperthermia in hot environmental temperatures (von Mickwitz, 1982). However, Nevill and Friend (2003) measured body temperature continuously during transport and showed that the environmental conditions had no affect on body temperature of tigers.

There are still not enough studies on the thermal stress of animals during capture and transport procedures that measure body temperature and environmental conditions continuously. I believe that my results have added to this field. I also suggest that globe temperature should be used because it takes into account more variables than just air temperature, and that it is just as easy to use.

Besides the affect of ambient temperature on body temperature, several authors (such as Swan, 1993) have mentioned that etorphine hydrochloride (M99) can also play a role in increasing body temperature. However, I could not detect any trends in body temperature responses that could be attributed to different doses of opioid, or indeed to the use of any other immobilizing or tranquillizing agent.

5 COMPARING PRE- AND POST-TRANSPORT VALUES IN BLOOD AND FAECAL CONSTITUENTS OF MAMMALS

In this part of the study I examine whether there is evidence of a hormonal stress response to capture and transport procedures to corroborate thermal measurements (see section 1.1.2.1), which will be examined in two ways. First, I measured the cortisol and haematocrit concentrations in the blood plasma of Angora goats and blesbok that had thermometric devices surgically implanted into their abdomens (see chapter 4). Catecholamines were also measured in Angora goats. Second, I measured the changes in cortisol found in the faeces of blesbok and impala (both species had intra-abdominal data loggers) after transport.

5.1 Methods

5.1.1 Sample collection

Blood samples were taken from Angora goats and blesbok before and after the first transport, and analysed for cortisol. The blood samples taken from the Angora goats were also analysed for catecholamines. However, before this analysis could be done on the blood samples taken from the blesbok these samples were lost. Faecal samples were taken from the impala before and after four transport events as well as from the blesbok before and after the last two transports and analysed for cortisol.

5.1.1.1 Blood

About 10ml of blood was taken from the jugular veins of the unsedated Angora goats and the sedated blesbok both during loading and after being transported. Blood sampled from each animal was analysed immediately for haematocrit, using a haematocrit centrifuge (Heraeus, Separation Scientific CC., Johannesburg, South Africa). The remainder of the blood sample of each animal was centrifuged and the plasma stored at –80 ºC for further analysis.

5.1.1.2 Faeces

Faeces were collected before loading, during transport and in the morning after transport for both impala and blesbok. As there were many animals in the boma and in the transport vehicle, faecal droppings were taken from about three of the freshest middens (those that were wet) throughout the boma and inside the vehicle, to render a representative sample for the entire group. Samples taken in the boma before transport were combined with those from inside the vehicles, to be used as the control because it takes 12 hours for cortisol to appear in the faeces of ruminants (Möstl and Palme, 2002). Samples were immediately stored at –20^{o}C after collection.

5.1.2 Faecal cortisol extraction

Faecal cortisol was extracted according to the protocol developed by Wasser *et al.* (2000), which is not species-specific. In brief, the faecal samples were freeze-dried and 0.2 g of each sample were weighed and placed into a test tube. Six aliquots were used to determine the coefficient of variance of the measured cortisol concentration. To each test tube, 5 ml of 100% ethanol were added, and

the test tubes were placed into a waterbath and boiled for twenty minutes. The test tubes then were centrifuged for 15 minutes, after which the supernatant was recovered and the pellet suspended again in 5 ml of ethanol and vortexed for one minute. The tubes were centrifuged one last time. The supernatant was again removed, added to the previous supernatant, and placed under air to dry. Once the samples were dry, 1 ml methanol was added and vortexed. The extraction efficiency of this procedure was not determined, but was assumed to be the same for all the samples.

5.1.3 Analysis of cortisol in blood and faeces

Cortisol concentrations were determined using a Coat-A-Count® Cortisol kit (Diagnostic Products, South Africa). The radioimmunoassay procedure consisted of pipetting 30 µl of the plasma/extracted faecal supernatant (resuspended in methanol) or standard into polypropylene tubes coated with anti-cortisol antibodies. One ml of radiolabelled cortisol (about 0.1 microcuries of radioactive ^{125}I cortisol) was added to all tubes and incubated at 37ºC for 45 minutes. The tubes were emptied and a gamma counter (Cobra auto-gamma, Packard, B5002, Netherlands) was then used to determine the amount of bound cortisol in the tubes. Reference curves were produced using the standard solutions supplied by the manufacturer.

5.1.4 Analysis of catecholamines in the blood of Angora goats

Plasma catecholamines were extracted and then assayed by standard techniques (see Ganhao *et al.*, 1991; Ganhao *et al.*, 1992). In brief, the extraction procedure

was based on the principle that plasma catecholamines are selectively absorbed on acid-washed alumina at pH 8.6. The adsorbed catecholamines were eluted at a low pH (between 1.0 and 2.0). Plasma samples (500 µl) were then mixed for 15 minutes with 50 mg alumina (WA-4, Sigma) in 1.0 ml TRIS buffer (pH 8.6, 1.5 M). After the alumina was washed, the adsorbed catecholamines were eluted into 200 µl perchloric acid (pH 1.2, 0.1 M). The eluant was then put through a high performance liquid chromatography (HPLC) system in which the catecholamines of interest were separated by a reversed-phase ion-pair. The separated molecules then passed between electrodes of an electrochemical detector (ECD). An applied voltage of 650 mV oxidised the molecules and the resulting current was compared to that generated by standard solutions of noradrenaline and adrenaline (1-5 µM).

The extent of variation in peak height was established by injecting the standard solutions through the HPLC system a number of times and on a number of separate occasions. Figure 5.1 depicts a typical standard curve. To account for the variation in the extraction process, a known amount of an internal standard DHBA (3,4-dihydroxybenzylamine) was added to each sample before the extraction procedure began and was injected repeatedly through the HPLC system. The amount of DHBA recovered in the samples was then compared to the value from the standard. The ratio of recovered DHBA to the standard DHBA indicated the efficiency of extraction process.

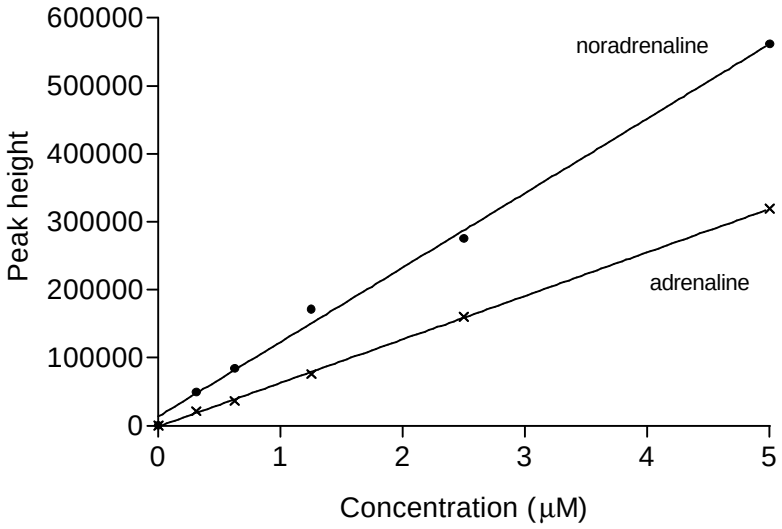


Figure 5.1: Standard curve for the adrenaline standard (y=640.65808x-1073.27, R^2=0.9997) and noradrenaline standard (y=1096.762x+13334.61, R^2=0.9963) used to determine the concentrations of the unknown catecholamines. Peak height has arbitrary units.

5.1.5 Data analysis

5.1.5.1 Analyses of catecholamines, cortisol and haematocrit in the blood of Angora goats and blesbok.

Changes in cortisol and haematocrit from before and after transport were analysed for both blesbok and Angora goats, using paired t-tests (Statistica, StatSoft Inc., U.S.A). The mean cortisol values found in the plasma before blesbok were transported were compared to the mean cortisol values found in the plasma before Angora goats were transported and analysed using unpaired t-test with Welch correction. The mean haematocrit values before transport were also compared between the two species. The mean changes in the cortisol from before and after transport was compared between the species using an unpaired t-test with Welch correction. The mean changes in the haematocrit before and after transport was also compared between the species. Changes in catecholamine concentrations (noradrenaline and adrenaline) from before and after transport were analysed for Angora goats using a paired t-test.

5.1.5.2 Analysis of cortisol in the faeces of impala and blesbok

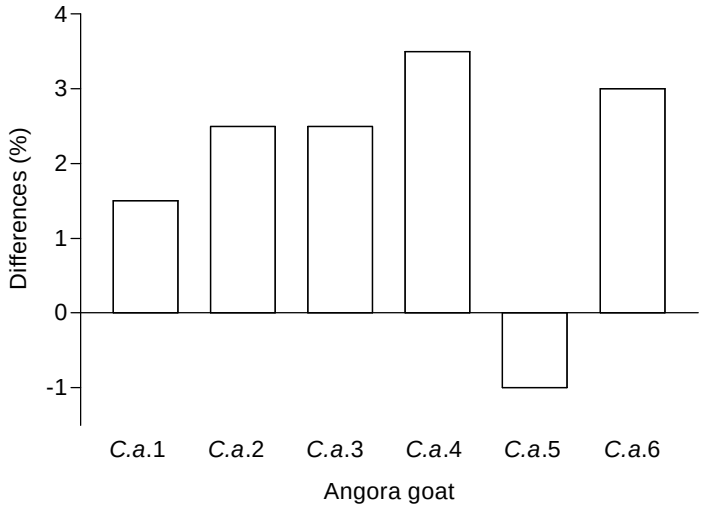
For both impala and blesbok, no statistical tests were done to determine the increases in cortisol values due to transport, as the faecal cortisol was obtained from pooled faecal samples.

5.2 Results

5.2.1 Analyses of catecholamines, cortisol and haematocrit in the blood of Angora goats and blesbok

The differences in pre-transport haematocrit values from values after transport for blesbok and Angora goats are shown in Figure 5.2.a. For Angora goats there was a significant increase in haematocrit after transport ($t=3.04$, $p=0.03$, paired t-test), but the increase was not significant for blesbok ($t=2.67$, $p=0.12$). Note that one goat (*C.aegagrus* 5) did not show an increase in haematocrit. Figure 5.2.b shows the differences in blood cortisol concentration after the transport of blesbok and Angora goats. Cortisol concentration increased significantly after transport for Angora goats ($t=6.52$, $p<0.01$ (exact value not available)), but not for blesbok ($t=2.76$, $p=0.11$).

In Table 5.1 the pre-transport values and the differences in haematocrit, cortisol and catecholamines between before and after transport phases are given for Angora goats and blesbok. The mean pre-transport haematocrit values were significantly higher for the blesbok than the Angora goats ($t=-2.63$, $p=0.03$, unpaired t-test with Welch correction). On the other hand, the pre-transport concentrations of cortisol for blesbok and Angora goats were not statistically significant from each other ($t=1.81$, $p=0.17$). The mean cortisol increases after transport were not significantly different between the species ($t=0.67$, $p=0.55$), which is also the case for the mean haematocrit increase ($t=1.95$, $p=0.19$). However, the mean increases in cortisol and haematocrit after transport were different to zero, as judged by their confidence intervals.



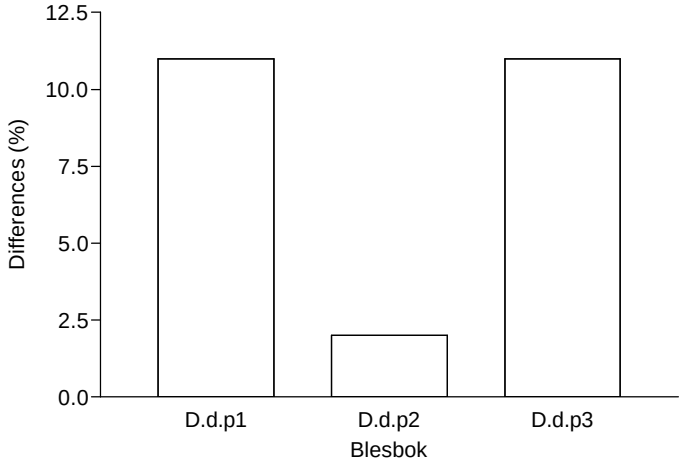


Figure 5.2.a: Changes in haematocrit after transport, from pre-transport values, for individual Angora goats (top panel) and blesbok (bottom panel). Refer to Table 5.1 for the mean haematocrit for the Angora goats and blesbok before transport (loading).

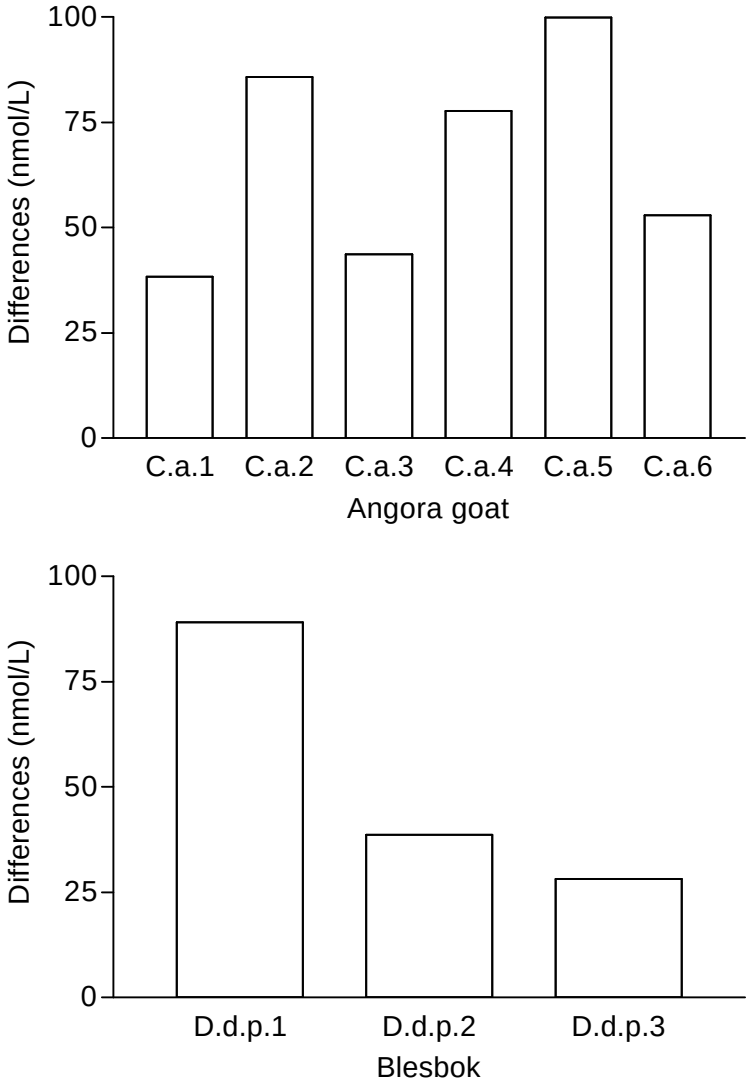


Figure 5.2.b: Increase in cortisol after transport, for individual Angora goats (top panel) and blesbok (bottom panel). Refer to Table 5.1 for the mean cortisol for the Angora goats and blesbok before transport (loading).

Table 5.1: **Blood variables for Angora goats and blesbok**. Mean (± standard deviation) pre-transport values and mean differences of haematocrit and blood cortisol concentrations during transport, from pre-transport values, for Angora goats (n=6) and blesbok (n=3). Catecholamine concentrations are also shown for Angora goats. Means with different superscripts are significantly different to each other ($p<0.05$). The 95% confidence intervals (C.I) are given for the mean values.

Animal	**Blood variable**	**Pre-transport value**	**C.I**	**Differences**	**C.I**
Angora goats	cortisol (nmol/l)	63.2 ± 19.5	48, 79	66.4 ± 25.0	46, 86
Blesbok	cortisol (nmol/l)	37.3 ± 20.6	14, 61	52.0 ± 32.6	15, 89
Angora goats	haematocrit (%)	25.0 ± 1.4[a]	24, 26	2.0 ± 1.6	1, 3
Blesbok	haematocrit (%)	36.7 ± 3.1[b]	33, 40	8.0 ± 5.2	2, 14
Angora goats	adrenaline (mmol/l)	2.0 ± 0.7	1, 3	0.1 ± 0.8	-1, 1
Angora goats	noradrenaline (mmol/l)	1.9 ± 1.8	0, 3	-0.7 ± 1.4	-2, 0

The differences for Angora goats in the concentration of blood catecholamines between before and after transport phases are shown in Figure 5.3. Adrenaline values increased after transport for all goats, except *C.aegagrus* 4, while noradrenaline increased after transport for all goats, except in goats *C.aegagrus* 1, *C.aegagrus* 4 and *C.aegagrus* 6. Neither adrenaline (t=0.37, p=0.72, paired t-test), nor noradrenaline (t=1.31, p=0.25) increased significantly in their concentration. The pre-transport adrenaline and noradrenaline concentrations were significantly different to zero, but this was not the case for the increases in these variables after transport, as judged by their confidence intervals.

5.2.2 Analysis of cortisol in the faeces of impala and blesbok

Faecal cortisol concentrations were obtained from pooled faecal samples taken before and after transport, for both impala and blesbok (Figure 5.4). The first transport trip for both blesbok and impala appeared to exhibit higher cortisol concentrations than subsequent transports, even before transport started. Although I was unable to perform any statistical tests, because the cortisol was obtained from pooled samples, there was no evidence for faecal cortisol increasing after transport. The cortisol values were uncorrected for extraction efficiency, but the coefficient of variance for the cortisol concentration from six aliquots was 0.06% (n=6).

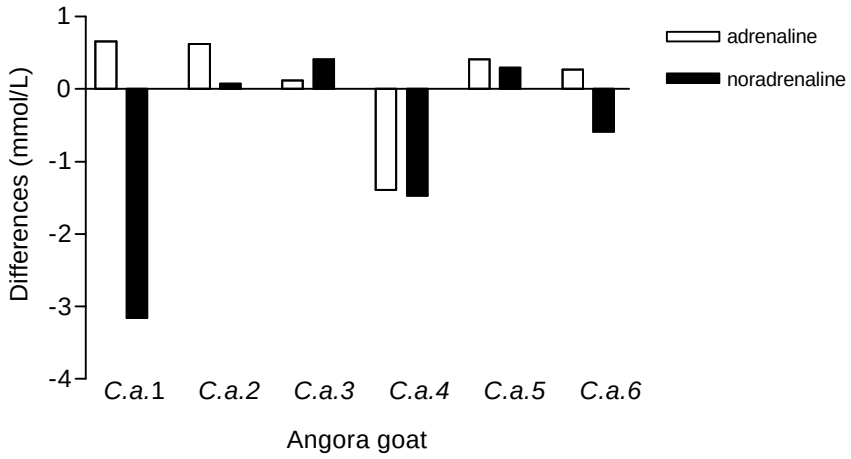


Figure 5.3: Changes in catecholamine (noradrenaline and adrenaline) concentrations after transport, from pre-transport concentrations, for individual Angora goats. Refer to Table 5.1 for the mean adrenaline and noradrenaline for the Angora goats before transport (loading).

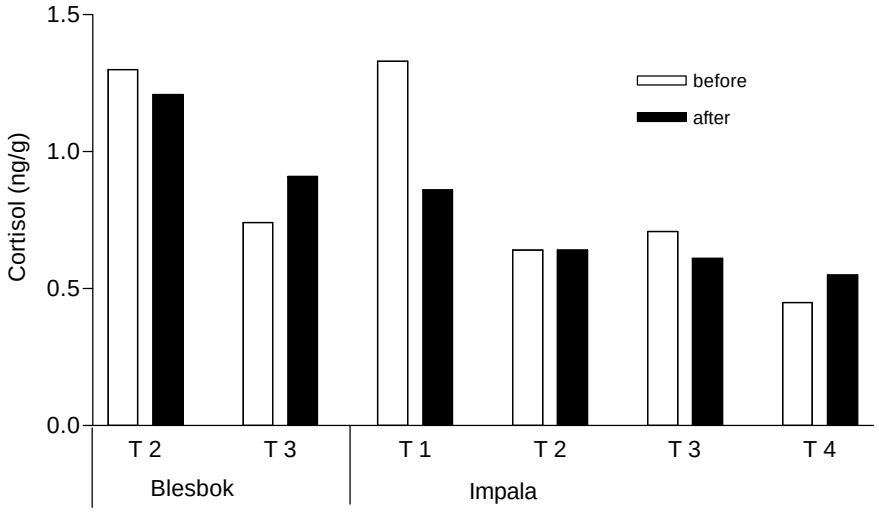


Figure 5.4: Faecal cortisol concentrations from pooled samples before and after two transport trips (T2 and T3) for blesbok (no faecal samples were taken on the first transport trip) and four transports (T1 to T4) for impala. The cortisol concentrations were uncorrected for extraction efficiency.

5.3 Discussion

The stress responses of animals to capture and transport not only involves changes in body temperature, but also certain variables that are found in the blood and faeces. Although animals were stressed before transport and the stress variables obtained in the blood were used as the starting value for animals before normal commercial transport, any further measurable stress due to transport would be evident as a further increase in the stress variable.

The cortisol and haematocrit concentrations for both blesbok and Angora goats increased after transport, except for the haematocrit value of one goat, which decreased. This decrease does not seem consistent with the other data and may have been due to the sample not being mixed properly. The increases in these variables demonstrate that both species experienced stress due to transport. Although cortisol and haematocrit increased due to transport, the body temperatures of the Angora goats for the same transport trip that blood was taken did not change significantly due to transport and even decreased compared to the pre-loading temperatures. The body temperatures of blesbok also did not increase during transport from the pre-loading temperatures.

There was no difference in the stress response (of cortisol and haematocrit) shown by the two species, although the blesbok were wild and the Angora goats were domesticated. This could be due to the blesbok being tranquillized, which probably resulted in very reduced hypothalamic responses, reflected in the

production of cortisol (Morton *et al.*, 1995). Meanwhile the Angora goats were domesticated and so did not show a response to the novelty of handling, which can be seen in the starting values for haematocrit in the goats (about 25%) being similar to the normally accepted haematocrit values for goats of about 24.3% (Altman and Dittmer, 1974). It is interesting that the female blesbok (*D.d.phillipsi* 2) had a much lower haematocrit than the other blesbok and a low cortisol value, although she was not caught first. A possible explanation for these results is that she was the only blesbok that had been hand reared and so did not react excessively to human presence. However, this female generally had the highest body temperature compared to the other blesbok.

Cortisol obtained from the faeces of impala and blesbok was generally lower after transport, which is opposite to the results from cattle transport (Möstl *et al.*, 2002). The cortisol concentrations in my study also seem to decrease with subsequent transports, indicating that the animals adapted to the stress of transport. This decrease in concentration for subsequent transports would possibly have been seen in the blood cortisol if blood was drawn for more than one transport.

The adrenaline and noradrenaline values also generally decreased after the Angora goats were transported, possibly because of the quick response (between one and two minutes) of catecholamines to stimulation (Guyton, 1986). It seems the catecholamines were not continuously released and so the animals were not additionally stressed during transport. The difference in adrenaline or

noradrenaline being released is thought to be due to the type of stress experienced by the animal. Both adrenaline and noradrenaline are released in response to physical stressors, but Dimsdale and Moss (1980) stated that only adrenaline is released in response to mental stress. Therefore, in my study, the greater decreases in noradrenaline after transport, compared to adrenaline, could be due to the decrease in physical activity after loading. A reason for the large decrease of noradrenaline in *C.aegagrus* 1 could be that it was caught first and so would have had more time to adjust to the stress. Although there seem to be slight increases in adrenaline after transport, I believe that it was probably due to the arrival and offloading of the goats, than actual psychological stress during the transport, because these animals were domesticated.

The problems in this section include that I only had blood samples from one transport (both for blesbok and Angora goats) and catecholamines were only measured in the blood of Angora goats. Blood samples were also only taken before and after transport, as it was difficult to obtain blood during the transport. Therefore, I was unable to notice any quick changes in the blood variables, but could rather only assess how stressed the animals were at the end of transport. Nwe *et al.* (1996) was able to take blood repeatedly during transport and so was able to provide specific times for the increases in cortisol and catecholamines. Perhaps more blood variables should have been measured, as suggested by Hattingh (1988). However Morton *et al.* (1995) states that cortisol is a good indicator of the stress of transport and Ewing (1999) continues by saying that if

cortisol is not present when the animal is severely stressed, then there is no sustained metabolic response and the animal is less able to cope with a stressor.

Regarding the faecal cortisol results, there were two main problems: the faecal cortisol values were uncorrected for extraction efficiency; and it was impossible to determine the specific individual that produced the faecal samples. From the random samples collected, it was possible that some of the faeces were obtained from individuals that showed a greater or lesser response to stress and so would have biased the results for the entire faecal sample. However, even so, my results do not show an increase of faecal cortisol after transport, as shown by Möstl *et al.* (2002) using pooled faecal samples from cows. Since it takes about 11 hours for maximum concentration of cortisol to be measured in the faeces of ruminants after a stress event (Möstl and Palme, 2002), it was not possible to obtain cortisol during the relatively short transports of blesbok and impala.

Although it seems that the animals in my study adjusted to transport, as seen from the faecal samples collected before and after transport trips, other studies have taken blood samples after repeated captures and have shown that animals adapted to the procedure. Knox (1992) in her PhD thesis and a study by Hattingh *et al.* (1988) both show that blood variables such as cortisol, were higher for animals that were repeatedly caught and bled in a boma, compared to blood from impala in the wild (after being brain-shot). Therefore, it seems that the animals in the boma had an anticipatory response to the procedure, but with repeated captures (about a

week apart) adaptation occurred and the blood variables showed a non-significant decrease.

Since I obtained blood samples only before and directly after a single transport, I was unable to determine whether the animals' had adapted to this procedure. However, as in my study, cortisol increased after one transport trip in a study by Anderson *et al.* (1999) in alpacas. My study on Angora goats also shows similar results to that shown by Nwe *et al.* (1996) on Japanese native goats, where noradrenaline exhibited no change with transport, but adrenaline increased immediately thereafter.

6 CONCLUSION

My study explored practical methods of measuring the body temperatures of large mammals during actual capture and transport operations. I believe I have succeeded in doing this as well as adding information to the field of animals' responses to the stress of capture and transport.

I recommend that telemeters should be used to measure the temperatures of animals after they have been captured and during transport. Telemeters provide on-line measurements of temperature, while data loggers give off-line measurements. For many thermometric applications in free-living large animals, it is not a problem to use data loggers, but it is a problem during the dangerous procedure of capture. For management purposes, game capture operators need to know the temperatures of the animals in the moment, which is not possible when using a data logger. Currently, veterinarians use a clinical thermometer to measure an animal's temperature after it has been captured. However, the time that the clinical thermometer takes to stabilise once inside an animal has not yet been determined. In addition, monitoring body temperature of an unsedated animal or an animal that is being transported is not only impractical, but also dangerous. The addition of earphones and a large aerial inside the transport vehicle improves the results obtained from the telemeter.

Capture and transport operators do not have the time or the money to have their animals surgically implanted with a thermometric device. Non-invasive

techniques to obtain temperature, other than the rectum, do not seem feasible during actual transport. However, there are two main problems with using the rectum to obtain temperature measurements. First, it takes about 30 minutes for thermometric devices in the rectum to stabilise. Allowing for this stabilisation, there is close agreement between the temperatures measured in the body sites if one averages the temperatures from more than one individual, to limit the effect of differences in the placement of thermometric devices in the abdomen and rectum. However, there could be significant differences in temperatures measured in the two body sites, as shown by the goats in my study. Goodwin (1998) found that in goats, rectal and subcutaneous temperatures do not differ, but in horses and sheep, rectal temperatures were higher than subcutaneous temperatures.

Currently there are no better substitutes, than the rectum, to measure core body temperatures during actual game capture and transport. Therefore, I believe that the rectal temperatures from one animal will give at least some indication of whether the animal is experiencing thermal responses to stress, so that a veterinarian is able to take decisive actions if concerned with the welfare of the animal. The second problem in using the rectum is that animals such as livestock, that are generally not tranquillized, are likely to naturally void the devices within 10 minutes. I am not sure therefore that the rectum can be used as an alternative body core temperature measurement site in these animals. Bearing in mind these limitations, a telemeter is again useful in measuring temperature, as it can be left inside rectum of the animal to measure post-transport temperature and when the

telemeter is voided, it can be found by tracking it's signal. To make finding the telemeter easier, the wax covering the device can be dyed red.

Temperature measurements from actual game capture and transport procedures show similar results to those from the experimental studies. One such result is that capture increases body temperature and often results in a peak in temperature. This increase is then followed by a decrease in temperature during transport. During capture, the likelihood of animals dying may depend on the peak temperature reached, the amount of time an animal spends running around (while others are being caught) and lastly the globe temperature. Those animals that are darted first have a shorter time of running around and so have a lower body temperature (e.g. blesbok, tsessebe). Perhaps there should be a cut-off time for the duration of the chase, such as the time taken for the first tsessebe to be caught in my study (about 15 minutes). Different ways of capturing also seem to influence temperature. Darting an animal in a reserve, compared to a smaller enclosure, seems to delay the time before the animal can be transported and so is likely to cause more stress for the animal.

High globe temperatures increase the animal's temperature during most captures. Although several authors have repeatedly highlighted this concern, the majority of these studies have not measured ambient temperatures in conjunction with continuously measuring the body temperature of the animals being transported. There also has not been enough concern on the influence of low ambient temperatures on an animal's temperature. In my study, low globe temperatures

decreased the animal's body temperature during transport (e.g. Angora goats) as well as increasing the time it took for body temperatures to stabilise (e.g. impala), therefore globe and body temperature must be constantly monitored. I find it disappointing that only one study measured globe temperature during transport (Smith *et al.*, 1994), as globe temperatures incorporate radiant temperature, air temperature and wind speed (Yaglou, 1968) and have been used to determine the thermal stress experienced by an animal (Seely *et al.*, 1990). I therefore recommend its use during future studies examining the thermal stress of animals during transport.

I also suggest that one has to debunk the guidelines of capturing animals late in the day, so as to avoid the heat of the midday sun. My results on impala show that body temperatures are highest at the end of the day, as also shown by Mitchell *et al.* (1997) on springbok, Kamerman *et al.* (2001b) on impala and Mitchell *et al.* (2002) on wildebeest and eland. Therefore, I believe that animals should only be captured in the morning; or when ambient temperatures are low, they could be captured around noon.

Although in real life situations the same animals are not subjected to capture and transport in close procession, animals are captured and transported more than once in their lives, such as from a game farm to a game auction and then back to a farm. It is interesting, therefore, that the animals in my study showed adaptation to repeated captures and transports, where temperatures during transport decreased, as well as faecal cortisol, for successive transports. However, it would have been

better if I were able to obtain faeces from identified animals, as well as blood samples for more than one transport, so that these values could match up with individual body temperatures, to allow for a conclusive correlation. It is also interesting that the differences in cortisol and haematocrit values after transport from those established prior to transport were not different between a domesticated animal (Angora goats) and a tranquillized wild animal (blesbok). This result seems to indicate the importance of tranquillizers on decreasing the stress of wild animals, but it also shows that animals will experience stress due to transport, although it was not seen in body temperature measurements. Because I obtained blood variables only before and after transport, I concede the increase in variables may have been due to offloading the animals at the end of the transport. It would be interesting to see what changes occur in the blood variables of domestic animals if they are transported after being tranquillized. It would also be worth looking at the changes in catecholamines in blesbok during transport, to see whether there would also be similarities to the Angora goats.

I believe that my study will enable practical monitoring of animal's body temperature after capture and during transport, with using a telemeter inserted into the animal's rectum. Although my samples sizes are small, the variety of species and different capture and transport techniques that I collected my data from, enables me to make good deductions of the general thermal stress experienced by the animals during these procedures and so will further the current field of study.