‘Heat Stress in Racing Greyhounds’

by

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Abstract

Heat related illness has been recorded in dogs undertaking strenuous exercise in high temperatures. In South Australia, summertime daily maximum temperatures may reach 50°C. This study aimed to determine if a safe maximum ambient temperature for racing in greyhounds can be established and if particular environmental or phenotypic factors increase the risk of greyhounds developing hyperthermia.

A preliminary study compared four temperature recording devices to determine their suitability for use in a racing environment. Digital rectal thermometry was the most reliable and convenient method of recording greyhounds' body temperature. An observational study was then undertaken at racetracks in South Australia, during which, environmental temperature and relative humidity were recorded and greyhounds' body temperatures measured on arrival, pre- and post-race. A mean increase of 2.1 ± 0.4 °C in greyhounds’ (n=239) post-race rectal temperature was recorded. No association was found between environmental temperatures and greyhounds' temperatures on arrival or pre-race. However, post-racing there was a small but significant relationship between shade temperature and both rectal temperature ($r^2 = 0.023, P = 0.027$) and the increase in rectal temperature ($r^2 = 0.033, P = 0.007$). No association between environmental relative humidity and body temperature was detected.

The influence of sex, bodyweight and coat colour on body temperature increases were investigated. There was a small but significant relationship ($r^2 = 0.04, P = 0.009$) between
bodyweight and post-exercise rectal temperature. Greyhounds of dark colours developed higher temperatures than light coloured greyhounds (P <0.05).

Animal housing at racetracks was examined and temperature and relative humidity levels in enclosed environments were recorded using data loggers and ibuttons. A significant relationship was found between kennel house temperatures and body temperature changes of greyhounds during racing ($r^2 = 0.03$, P = 0.009).

Temperature and relative humidity levels in dog transport vehicles were monitored with ibuttons when vehicles were stationary and moving in both laden and un-laden states. The effects of an air conditioning system on conditions within a vehicle were measured and responses of dog body temperatures to transport were assessed. In ambient temperatures <33°C the air conditioning system maintained internal trailer temperature below 26°C. Between ambient temperatures 33-37°C, although the internal temperature in the air conditioned trailer rose above 26°C, dogs were able to maintain normal body temperature. Following journeys of approximately 50 minutes in a trailer without air conditioning, mean dog rectal temperature increased by 0.5°C ± 0.2.

Results of these studies have identified a number of factors which may increase the risk of greyhounds developing a potentially hazardous level of hyperthermia after exercise. Following racing in external environmental temperatures ≥38°C, 39% of greyhounds developed rectal temperatures ≥ 41.5°C. Large, dark coloured greyhounds are at greater risk of developing hyperthermia. Conditions within kennel houses and transport vehicles may influence dog body temperature as a kennel house temperature ≥ 27°C and transport in temperatures ≥32°C are both associated with an increase in body temperature. These
findings will be important in the development of evidence-based guidelines to protect the welfare of greyhounds racing in hot conditions in Australia and other countries.

Declaration of Originality

I declare that this work contains no material which has been accepted for the award of any degree or diploma in my name in any university or other tertiary institution and to the best of my knowledge and belief contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work, will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution, without the prior approval of the University of Adelaide.

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Glossary

Ambient temperature $T_A$ = the air temperature of the environment.

Body temperature $T_B$ = the temperature of the animal’s body.

Core temperature $T_{\text{CORE}}$ = the temperature of the animal’s body core measured physiologically in the spinal cord and areas of the brain or by an internal device such as an ingested sensor travelling though the digestive tract or a sensor implanted within the abdomen, oesophagus or pulmonary artery.

Heat strain = physiological or pathological effects resulting from heat stress

Heat stress = environmental or metabolic factors impacting on the body

Heat stroke = pathological condition occurring when the body’s heat dissipating mechanisms are overwhelmed

Rectal temperature $T_r$ = the temperature measured against the rectal wall.

Shade temperature = the air temperature measured outdoors in a shaded area.
Chapter 1: Background

This thesis focuses on heat stress and its significance in the greyhound racing industry in Australia. Organized greyhound racing is conducted world-wide and is expanding rapidly in some areas, such as South East Asia (Greyhounds Australasia 2014). Australia is one of the world’s major producers of greyhounds, with racing conducted in all States and Territories (Greyhounds Australasia 2003). Sports involving animals are coming under increased scrutiny by animal welfare bodies and the community in general (Animals Australia 2008; RSPCA 2015a) and in early 2015, the greyhound industry in Australia attracted particularly adverse publicity (Meldrum-Hanna & Clark 2015). Greyhounds are expected to race in a broad range of climatic conditions and heat stress is considered a risk factor for greyhounds undertaking strenuous exercise, particularly during the summer months in Australia. A considerable body of work exists on the risks of heat stress and heat strain in human and equine athletes (Brotherhood 2008; Coris, Ramirez & Van Durme 2004; Geor 2005; Geor & McCutcheon 1996; Gosling et al. 2008; Howe & Boden 2007; Jeffcott, Leung & Riggs 2009), however, there has been little research on the effects of heat on dogs engaged in brief periods of intense exercise.

Studies examining the responses of greyhounds to the stresses of racing and associated road transport, under hot conditions, are required to document the effects on greyhound health and welfare. These studies can provide data on which to base formulation of appropriate hot weather policies for greyhound racing.
1.1 Community attitudes towards animals

Cultural attitudes towards animals have varied widely throughout history. Cultures of hunter-gatherers generally have a system of beliefs which place man as a component in nature’s scheme and which also acknowledge a spiritual component in geographical features, weather patterns, celestial bodies, plants and animals (Bulliet 2005). Amongst such cultures may be found aspects such as totemism in which human individuals or families share spiritual links with certain species of animals (Passariello & Passariello 1999). Although past hunter-gatherer cultures had rules and rituals regarding many facets of life, such as defining limits of interaction between groups, Kung (1987) suggests that as humans moved to a more settled, agricultural lifestyle, more regulation became necessary in order for society to remain stable and functional. Most early religions lacked a moral code and Russell (1961)
postulates that, as governments or rulers sought to gain control over their subjects by developing laws, they utilized the influence of religion to enhance their power and thus the connection between religion and morality became established. Belief in an afterlife or reincarnation provides incentive to lead a good life on earth and some of the well-established religions, such as Buddhism, espouse a philosophical position of shared spirituality between man and animals, which induces a sense of responsibility towards other living things (Masson 2010).

Within modern western societies, there exists a broad spectrum of attitudes towards animals which ranges from exploitative to protective and there are many discrepancies within group and individual belief systems (Bulliet 2005). For example, in Australia there is a general acceptance of the eating of herbivores such as cattle and sheep but widespread revulsion at the eating of horseflesh (Duckworth 2001). Australian society has, until very recently, condoned the confinement of swine in very crowded, mass production facilities (Animal Welfare Working Group (AWWG) (2008) but has condemned equivalent treatment of dogs (RSPCA 2015b) despite the physiological and cognitive similarities between the species.

Bulliet (2005) proposes that a new phase of human-animal relationships which he calls “postdomesticity” is emerging in western societies, within which attitudes towards, and treatment of animals are changing markedly from those of the traditional farming or herding societies. He notes this paradigm shift involves a greater sensitivity to animals in the general population and this may be reflected in an increase in the incidence of vegetarianism in developed countries (Leahy, Lyons & Tol 2010).
1.2 Animals in recreation and sport

In this climate of consciousness, the treatment of animals in recreation and sport has emerged as a contentious issue. Sports such as rodeo and hunting with hounds (Baily's Hunting Directory 2015), which were widely supported (particularly in rural communities) until late in the 20th century are now subject to intense criticism and scrutiny from an increasingly urbanized population (Animals Australia 2008). In response, the controlling authorities of many sports have adopted codes of practice, regulations and guidelines for the management of their sports. In 2005, the Australian Federal Government Department of Agriculture, Forestry and Fisheries (DAFF) implemented the Australian Animal Welfare Strategy (AAWS) which developed Model Codes of Practice for some livestock industries and established a working party to develop guidelines for the use of animals in sport and recreation (Australian Animal Welfare Strategy 2009). However, the process was not completed as the AAWS was disbanded by the federal Australian government in 2013 (Vidot 2013).

The Australian Racing Board (ARB) and Greyhounds Australasia (GA), the national umbrella organizations overseeing thoroughbred and greyhound racing, respectively, have broad position statements relating to animal welfare (Australian Racing Board 2015; Greyhounds Australasia 2015). In addition, the individual, state-based controlling authorities of the horse and greyhound racing industries have developed Codes of Practice such as those of Greyhound Racing Victoria (GRV), Greyhound Racing South Australia (GRSA) and Thoroughbred Racing South Australia (TRSA) which include detailed specifications relating to the care and management of racing animals (Greyhound Racing Victoria 2008; Greyhound Racing SA 2009; Thoroughbred Racing South Australia 2009).
1.3 Greyhound racing

In Australia, greyhound racing is conducted in all the states and territories, each of which has a governing body which administers and regulates racing. Greyhounds Australasia (GA) is the peak body for the industry in Australia and New Zealand, having as members, the various state regulatory organizations. In 2005, Greyhounds Australasia adopted a set of national rules governing racing (Greyhounds Australasia 2005) which have since been adopted by the member jurisdictions, which may also have local rules, enforceable within their states. In 2011 there were 43,259 races organized in 4068 race meetings and over $82,000,000 (AUS) prize money was distributed: the greyhound industry had 12,280 greyhounds registered for racing for a total of 330,429 starters (Greyhounds Australasia 2011). In South Australia greyhound racing is controlled by Greyhound Racing South Australia (GRSA) and the industry represents over 15.96% of Totaliser Agency Board (TAB) market share and distribution, which in 2010-2011 was $10m (Greyhound Racing SA 2011).

1.4 Animal welfare and the greyhound Industry

Since the middle of the last century there has been a steady increase in awareness of, and moves to address, the welfare of greyhounds. The World Greyhound Racing Federation (WGRF) was founded in 1969 with fourteen members. Although it performed no regulatory function, its charter nominated as its objectives: the exchange of information, the improvement of greyhound racing and the development of new technologies. In 1995, pursuant to Section 22 of the Animal Welfare Act 1992 of the Australian Capital Territory
(ACT), a Code of Practice for the Welfare of Greyhounds in the ACT was approved (Australian Capital Territory Government 1995). In 2005, Greyhounds Australasia adopted a policy framework to provide the regulatory bodies with guidance on welfare and in 2006 a Code of Practice for the operation of Greyhound Establishments was released by the Department of Primary Industries in Victoria (The State of Victoria, Department of Primary Industries 2006). In the same year, Greyhounds Victoria (GRV) developed a more detailed document for industry participants, which, with minor modifications, was also adopted by Greyhound Racing SA (GRSA) in 2006 (Greyhound Racing South Australia 2011).

Subsequently, Greyhounds Queensland released a Welfare Policy with broadly stated aims of enhancing greyhound welfare and Greyhound Racing NSW adopted a Greyhound Animal Welfare policy which provided good practice guidelines for all the stages of a greyhound’s life.

Recent events in Australia have illustrated that ill treatment of animals, or poor governance in sport organisations, may have enormous impact on industries if given extensive media coverage. In early 2015, a television documentary on illegal activities in the greyhound industry, which aired on the Australian Broadcasting Corporation *Four Corners* programme (Meldrum-Hanna & Clark 2015), stimulated vigorous debate and led to several inquiries in the eastern states of Australia. Greyhounds Australasia promptly instigated a review of all national and local rules relating to the use of lures and appointed an independent auditor to assess the industry’s greyhound welfare and integrity rules and policies (Greyhounds Australasia 2015). Racing Queensland launched a Commission of Inquiry which recommended changes in governance of the sport with increased emphasis on animal welfare (MacSporran 2015). Greyhound Racing NSW (GRNSW) announced implementation
of a new Welfare and Integrity Fund to support a range of welfare and integrity measures in NSW to be funded through reductions in prizemoney and GRNSW also commissioned a study into best practice rearing, socialising, training and education of greyhounds (Greyhound Racing NSW 2015). In Victoria, the Racing Commissioner and the Chief Veterinary Officer investigated a range of issues in the industry and provided reports to parliament and Greyhound Racing Victoria (GRV) (Greyhound Racing Victoria 2015). Although no evidence of illegal activities relating to the use of live animals was revealed in South Australia or Western Australia, the governing authorities of the greyhound industry in both states increased investment in personnel and resources to monitor and inspect registered persons and properties. The State Government of South Australia (SA), in consultation with GRSA and the Royal Society for Prevention of Cruelty to Animals (RSPCA), created new offences relating to live baiting (Greyhound Racing South Australia 2015).
Chapter 2: Review of Literature

2.1 Thermoregulation

A considerable amount of research into thermoregulation was conducted in the middle years of the 21st century (Baker 1974; Baker 1984; Crawford 1962; Dorn 1981; Hammel, Wyndham & Hardy 1958; Iampietro et al. 1966; Jackson & Hammel 1963; Jensen & Ederstrom 1955; Kozlowski et al. 1985; Magazanik et al. 1979; Magazanik, Shapiro & Sohar 1978; Shapiro, Rosenthal & Sohar 1973). Under current standards of ethical research, it is unlikely that many of the experimental procedures, particularly those conducted on dogs, would be approved today (Australian Government National Health and Medical Research Council 2013). Consequently, many of the references cited in his review are not recent.

Regulation of body temperature is essential for maintenance of life. Vertebrates are now classified as endotherms or ectotherms, terms which have replaced the former descriptors of homeotherms and poikilotherms (Bicego, Barros & Branco 2007). Vertebrates regulate body temperature by both behavioural and physiological means; ectotherms rely primarily on behavioural thermoregulation but endotherms employ both behavioural and physiological means, the latter through the autonomic nervous system (Bicego, Barros & Branco 2007). In mammals, cutaneous thermal sensors measure surface temperature, while core temperature ($T_{core}$), is measured in the spinal cord and areas of the brain (Boulant 1998; Morrison & Nakamura 2011). The normal range of canine body temperature has been given as 37.5-39.2°C (Blackwell 2007) and 38.3-38.7°C (Orpet & Welsh 2011): dogs are able to maintain their temperature over a broad range of environmental and climatic conditions. Body temperature in canines is controlled by the pre-optic, anterior hypothalamus which can
have an adjustable set point and varying sensitivity (Hellstrom & Hammel 1967; Klir & Heath 1994).

Marvin and Reese (1986) concluded from a study on female pointers that, unlike some other species, dogs do not display a circadian fluctuation in core body temperature. However, Refinetti & Piccione (2005) found a diurnal pattern of variation of 0.6° in rectal temperature ($T_{re}$) in beagles and recent work by Hynd, Czerwinski & McWhorter (2014) demonstrated a regular fluctuation in core body temperature of greyhounds and Labrador retrievers. Different methods of temperature measurement were used in these studies which may account for the varied conclusions. Marvin and Reese (1986) utilised intra-peritoneal transmitters and external recording antennae whereas Hynd, Czerwinski & McWhorter (2014) utilised indigestible sensors which travelled through the gastro-intestinal tract.

When ambient temperature ($T_A$) exceeds body temperature ($T_s$) some species of mammals allow body temperature to rise during daylight hours and then disperse accumulated heat during the hours of darkness. This process is known as heterothermy and was first reported in camels (Schmidt-Nielsen et al. 1956) and has since been described in Arabian Oryx (Ostrowski, Williams & Ismael 2003), cattle (Gaughan et al. 2008) and Asian elephants (Weissenböck, Arnold & Ruf 2012). Brown-Brandl, Eigenberg & Nienaber (2006) note that when the $T_A$ first exceeds the core temperature ($T_{core}$) of cattle, there is an initial drop in heat production (HP) but as heat loss becomes more difficult $T_{core}$ increases. This in turn results in increased HP due to the Q$_{10}$ effect which refers to the increased rate of chemical reactions as a result of an increase in core temperature (Hill, Wyse & Anderson 2008). However, most animals can only function effectively within a fairly narrow range of body temperature which is described as the thermoneutral zone.
2.1.1 Thermoneutral zone

The thermoneutral zone (TNZ) has been defined as “the range of ambient temperature within which metabolic rate is at a minimum and within which temperature regulation is achieved by non-evaporative processes” (Bligh 1973, p 958). For most species there is a range of about 10°C, over which animals can maintain a basal metabolic rate (BMR) (Currie 1988). Animals increase their metabolic rate in environments both below and above their TNZ (Hill, Wyse & Anderson 2008). The TNZ varies between species and within a species it may be influenced by factors such as breed, age and condition (Ames 1980). Gender differences in thermotolerance have been demonstrated in humans (Gagnon, Crandall & Kenny 2013; Wyndham, Morrison & Williams 1965). Wyndham, Morrison & Williams (1965) concluded that, during an acclimatisation study, female humans suffered greater physiological and psychological stress than their male counterparts and Gagnon, Crandall & Kenny (2013) demonstrated that compared to males, female humans exhibit less sudomotor activity and lower thermosensitivity of the sudomotor response during exercise. Hanada et al. (2009) using genetically modified mice, demonstrated sex differences in thermoregulation by identifying the receptor-activator of NF-kB ligand (RANKL) and its receptor RANK as key thermoregulators of female, but not male, body temperature. As dogs demonstrate a greater variation in phenotype than any other domestic species, it might be expected that they would also have a greater range of body temperature or a broader comfort zone. Although the National Research Council (2006) gives the TNZ for dogs as -25°C - +30°C, different thermoneutral zones have been estimated for dogs by a number of researchers using a variety of methods and various types of dog. Hammel, Wyndham and Hardy (1958) described a range of 23-27°C as neutral for three mixed breed
dogs with bodyweights 8.5-10.5 kg: these authors measured O₂ consumption and heat production in a calorimeter and determined that metabolic rate increased below 23°C and that respiratory heat loss increased above 27°C. Hales and Dampney (1975) estimated the TNZ for greyhounds to be 16°- 24°C by measuring the temperature of the extremities when they were in an intermediate state of vasoconstriction/vasodilation as described by Hales and Hutchins (1971), and Gerth et al. (2010) estimated the TNZ for Inuit dogs to be -25°- 10°C. It can therefore be concluded that thermotolerance may vary between breeds and sizes of dogs and sex-based differences may also exist.

2.1.2 Heat gain

Body heat may be gained through metabolic processes and by radiation, conduction and convection.

2.1.2.1 Metabolic processes

The basal metabolic rate (BMR) is the rate of an animal’s metabolism when the animal is in its thermoneutral zone and is resting, in a fasting state (Hill, Wyse & Anderson 2008b). It may be influenced by factors such as age, sex, reproductive state and body size (Ferraro et al. 1992; Król, Johnson & Speakman 2003; Nagy 2005; Speakman, van Acker & Harper 2003). In 1975, Kleiber proposed that the metabolic rate of mammals and birds could be calculated by the equation:

\[ M = 70 \times W^{3/4} \]

Where M = metabolic rate in kilocalories per day and W = animal’s mass in kilograms (Kleiber 1975). However, the ‘3/4-power scaling law’ for metabolic rate is not invariable across animal species (Glazier 2005); although the BMR increases with bodyweight, it does
not do so proportionally. Hill, Wyse and Anderson (2008) propose an allometric equation by which the metabolic rate per gram of animal decreases as the animal’s mass increases. This may be particularly relevant to dogs due to the great range of bodyweights between breeds.

The work of Max Rubner (1883) cited by Hill and Scott (2004) demonstrating proportionality between dog body surface area and metabolic rate, was an early attempt to establish an accurate way of estimating the relationship. However, that work was subsequently discredited, due to the difficulty of accurately measuring body surface area (Kleiber 1947).

More recently Speakman, van Acker and Harper (2003) were able to demonstrate a significant breed effect on metabolic rate for three dog breeds of very different size, Papillons (mean body mass 3.0kg), Labradors (mean body mass 29.8 kg) and Great Danes (mean body mass 62.8kg).

Metabolic rate has been estimated by a variety of methods by different researchers. Early researchers, Hammel, Wyndham and Hardy (1958) when investigating heat production and heat loss for three dogs of bodyweight 8.5 -10.5 Kg expressed the metabolic rate as heat production both per square metre of body surface and per kilogram of bodyweight, obtaining a mean metabolic rate of 31Cal/m²/hr and 1.64Cal/kg/hr. Using rate of oxygen consumption as an indicator of metabolic rate, Schmidt-Nielsen (1997), illustrated that the rate of O² consumption per gram of body weight decreases with increases in body size. He applied the formula:

\[
\frac{V\,O^2}{M_b} = 0.676 \times \frac{V\,O^2}{M_b}
\]
where $V_02/\text{Mb} = \text{oxygen consumption in litres per kilogram of body mass per hour and } \text{Mb}$ is body mass in kilograms. A combination of open flow respirometry, doubly labelled water, and heart rate recording was used by Gerth et al. (2010) to estimate energy metabolism in Inuit dogs. Recent developments in data recording facilitate the use of heart rate monitoring (with appropriate calibration) as an indirect means of estimating metabolic rate which may be particularly suited to field studies (Green 2011; Green et al. 2008).

Following ingestion, an animal’s metabolic rate increases, a process known as specific dynamic action, during which part of the energy of the food consumed is released as heat (Hill, Wyse & Anderson 2008). In dogs, the sight and smell of food may cause an initial increase in metabolic rate, preceding that resulting from the physiological process of digestion (Diamond, Brondel & LeBlanc 1985). Metabolism produces considerable quantities of heat (Kowi 2014) and the muscular activity of exercise demands an increase in metabolic rate (Chappell et al. 2013). In athletic species, the proportionally greater volume of mitochondria and capillaries is associated with an elevation of metabolic rate (Weibel & Hoppeler 2005) and although Hill, Wyse & Anderson (2008) suggest that the maximal aerobic metabolic rate induced by exercise is approximately ten times the BMR, short term increases in metabolic rate up to 25 times BMR have been recorded in some canine species (Gerth et al. 2010; Gorman et al. 1998) which indicates great anaerobic capacity (Snow & Harris 1985).

2.1.2.2 Conduction

Standing or moving animals have little contact with solid surfaces, which conduct heat effectively. Air is a poor conductor and animals will only gain heat if the air surrounding them is above body temperature (Stockman 2006). This may be of particular relevance when
dogs are confined in small spaces such as trailers, as Hammel, Wyndham and Hardy (1958) were able to show an initial increase in body heat content in dogs held in a calorimeter at 35°C. Behavioural and conductive thermoregulation, through positioning next to a warm surface, has been demonstrated in neonatal dogs (Jeddi 1970). However, heat gain by conduction may be restricted by the type and density of pelage (Schmidt-Nielsen 1997c).

2.1.2.3 Convection

Convection depends upon the mass transfer of liquids or gases (Schmidt-Nielsen 1997c). Whilst the temperature of surrounding air or water is higher than skin temperature, heat will be gained (Stockman 2006). Movement of air or fluid will influence both the rate and quantity of heat transfer and when $T_A$ exceeds $T_B$, heat may be gained from inspired air passing through the respiratory tract (Seymour 1972). Localized systems of parallel arterial and venous vessels, facilitating counter current flows and local heat transfer, are utilized by many animals to reduce heat loss from extremities (Henshaw, Underwood & Casey 1972; Schmidt-Nielsen 1997c; Scholander & Krog 1957).

2.1.2.4 Radiation

Heat transfer by radiation occurs by electromagnetic waves in the intermediate range of the spectrum (Howell, Siegel & Menguc 2010). In their natural environment, animals are exposed to solar radiation from the sun during daylight hours and to thermal radiation from their surroundings in both daylight and dark (Stockman 2006). In Adelaide, South Australia (34° 56’ South, 138° 36’ East) the estimated insolation is 17 MJ/m²/day, 5.75 kW/h/m²/day (Australian Government Bureau of Meteorology, 2012). The quantity of heat acquired by animals from radiation in the visible spectrum may be influenced by pelage colour and
structure: the dark coloured plumage of birds absorbs more radiative heat than light
coloured plumage (Hamilton & Heppner 1967) and on mammals, dark coloured hair absorbs
more radiation than equivalent light coloured hair (Gaughan et al. 2008; Kay 1998;
McManus et al. 2009; Schmidt-Nielsen 1997a). The fur structure of mammals may also
influence radiative heat transfer (Fratto & Davis 2011; Walsberg 1988). However, Walsberg
et al. (1978) showed that wind velocity significantly affected radiative heat gain and that for
birds flying at 16m/sec there was little difference in the radiative heat transmission between
black and white plumages. As racing greyhounds travel at 16-18m/sec (Usherwood 2005),
there may be little difference in heat absorption by different coloured coats during racing.

2.1.3 Heat loss

In order to maintain body temperature mammals must balance heat gained by heat loss.
The rate of heat loss by dry heat transfer is proportionate to the difference between the body
temperature $T_B$ and ambient temperature $T_A$ (Hill, Wyse & Anderson, 2008). In addition to
heat transfer by conduction, convection and radiation, dogs employ evaporative heat loss by
panting (Blatt, Taylor & Habal 1972). Unrestrained dogs may also utilise behavioural means,
such as immersion in water or lying on cool surfaces, to facilitate heat loss (Flournoy, Wohl
& Macintire 2003).

2.1.3.1 Conduction

The amount of heat lost is determined by the contact area and the thermal gradient from the
body surface to the in-contact surface (Schmidt-Nielsen 1997). Mammals and birds make
seasonal adjustments to pelage density and depth to alter the insulative property of the skin
covering as increased thickness of coat reduces conductive heat transfer (Berglund 2009;
Henshaw, Underwood & Casey 1972). Some species produce subcutaneous fat deposits to reduce heat transfer in cold (Schmidt-Nielsen 1997; Scholander et al. 1950). Animals can, to some extent, control heat transfer from the body surface by making postural adjustments, thus altering the area of body surface in contact with air or substrate (Baldwin 1973). Richards (1970) considers this to be of particular relevance to animals which pant. Wetting hair can increase heat transfer by conduction and reduce the insulative capacity (Webb & King 1984).

2.1.3.2 Convection
Heat loss by convection may be influenced by air or water currents surrounding an animal and the area of the animals’ surface which is exposed (Chappell 1980; Schmidt-Nielsen 1997). Vasomotor responses to increased $T_B$ result in increased peripheral circulation and dilation of superficial blood vessels which permits an increase in blood flow to and from the skin, thereby facilitating heat loss by convection (Cooper, Randall & Hertzman 1959). An example of an animal utilising convection for heat loss is the African elephant which increases convective heat loss by fanning of the ears (Phillips & Heath 1992). As dogs utilize panting as the major means of cooling, if $T_A$ is less than $T_B$, movement of air through the respiratory tract represents a method of convective heat loss. Young et al. (1959) demonstrated that, in dogs exercising at high intensity, heat loss by convection is significant.

2.1.3.3 Radiation
The intensity of radiation from an object follows the Stefan-Boltzmann law which states that the total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature (Encyclopædia Britannica 2015). This results in a rapid rise in the emission of heat by radiation as surface temperature increases. Dark coloured coats which
absorb more radiation also emit more heat as thermal radiation (Scharf 2008). A combination of convective and radiative heat loss is responsible for 40% of cooling in dogs exercising on treadmills at temperatures of 76 ±1.5°F (Young et al. 1959).

2.1.3.4 Evaporation

When $T_A$ approaches or exceeds $T_B$, an animal may be unable to readily dissipate the heat generated by metabolic processes and in such circumstances evaporative heat loss is utilised to maintain homeothermy (Schmidt-Nielsen 1997b). Evaporation of 1 kg water requires 580kcal or 2426kJ (Schmidt-Nielsen 1997b). Human and equine athletes evaporate moisture from the skin: humans may lose 300ml/m²/hr (Wyndham, Morrison & Williams 1965) and horses 40ml/m²/min from some areas of the body surface (Hodgson et al 1993). Although canine skin contains sweat glands which may respond to localised heating, the glands are not actively involved in thermoregulation (Aoki & Wada 1951). In dogs, the paw pads are one of the few locations that contain eccrine sweat glands (Carrier, Seeman & Hoffmann 2011). Some differences in foot pad sweating, in response to thermal load, have been demonstrated between coyotes, wolves and dogs, as dogs exhibit foot pad sweating with and without thermal stimulation, whereas wolves do not (Sands, Coppinger & Phillips 1977). Panting is the principal evaporative process used by dogs and they can modify the rate and direction of respiratory airflow in response to changes in body temperature (Schmidt-Nielsen, Bretz & Taylor 1970). Blatt, Taylor and Habal (1972) revealed that in ambient temperatures 30-50°C, 20-40% of respiratory evaporation could be attributed to secretion from the nasal glands. Some early researchers thought that the work of panting would increase $T_B$ but Crawford (1962) showed that, in dogs, panting frequency
corresponded to the resonant frequency of the respiratory tract, thus minimising the work involved.

2.2 Influence of environment on thermoregulation

Wild canids are found in a very broad range of environments from polar to desert. Strains of *Canis familiaris* are associated with both nomadic and settled human communities throughout the world, thus demonstrating canine ability to adapt to a wide range of climatic and weather conditions (Derr 2012).

Most extant wild species of Canis, such as the jackals and the grey wolf, are believed to have evolved in the Old World: coyotes and the group *Dusicyon* (commonly called South American foxes) developed independently (Bradshaw 2011). In their extensive review of data, Ashton, Tracy and Queiroz (2000) found that *Canis lupus* and *Vulpes vulpes* follow Bergman’s rule with positive correlation between latitude and body mass and negative correlation between environmental temperature and body mass, although some other species of Canidae did not. In a further review of BMR in canids from a range of habitats, Careau, Morand-Ferron & Thomas (2007) found that Arctic canids have a significantly higher mass adjusted BMR than desert canids and that a similar intraspecific effect was apparent in species with wide distribution.

2.2.1 Acclimatization /acclimation

Over long time periods, species may make phenotypic or physiological adaptations to their environment (Ley et al. 2008; Storz 2007). However over shorter time periods, when exposed to different thermal conditions, individual animals can make seasonal or short term alterations to their metabolism (Bedrak & Samoilof 1965; Hannon & Durrer 1963; Storey &
Storey 2010). This process is termed acclimatization; when conditions in a laboratory situation are imposed on animals and the animals adjust appropriately, the process is distinguished by being termed acclimation (Schmidt-Nielsen 1997). Acclimatization has been recognized since 1850 (Lindinger et al 2000; Marlin 1998; Nguyen & Tokura 2002). The concept of an adjustable set point for thermoregulation (ie. the point at which body temperature is controlled by the hypothalamus), was proposed by Hammel et al. (1963) and shifting of the TNZ has been demonstrated by other researchers (Marder & Arieli 1988; Sugano 1981). Although the concept of an adjustable set point has since been challenged by some researchers, Cabanac (2006) having reviewed the data, provides a well-founded case for its continued use by illustrating how set points respond to peripheral or genetically programmed signals.

2.2.2 Adaptation to cold environment
Mammals in cold environments may adopt a variety of methods to survive extreme cold.

2.2.2.1 Metabolism
Some species hibernate to reduce metabolic rate, but species which remain fully active in winter may maintain $T_{CORE}$ either by increasing metabolic rate or by reducing heat loss. Localised reduction in heat loss may be achieved by regional heterothermy whereby animals maintain different regions of the body at different temperatures (Kay 1998) and by circulatory counter currents in limbs (Schmidt-Nielsen 1997b). Surprisingly, Klir & Heath (1992) found no significant difference in the metabolic rate (estimated from $O^2$ consumption) of red ($Vulpes vulpes$) or arctic ($Alopex lagopus$) foxes at temperatures between -13°C - 27°C. However, as suggested by Korhonen et al. (1985), measurement of $O^2$ consumption in captive, wild animals may not be a valid means of estimating metabolic rate, due to many
interfering factors. These authors consider the onset of shivering to be a more reliable indicator of cold stress. Using captive bred raccoon dogs and blue foxes, the authors demonstrated an increase in metabolic rate at +10°C and -6°C, respectively, with a linear increase in O\textsubscript{2} consumption as ambient temperature decreased. Therminarias et al. (1979) showed that dogs adapted to cold after ten repeated exposures to one hour periods of immersion in cold water between 8-13°C. The adaptive changes noted were an increase in metabolic rate indicated by 19-50% increase in O\textsubscript{2} consumption and a decrease in the reduction of colonic temperature which was attributed to increased heat production.

2.2.2.2 Fat deposition

Marine mammals which inhabit Arctic or Antarctic regions have thick deposits of subcutaneous blubber which maintains a heat gradient from skin to $T_{\text{CORE}}$ (Schmidt-Nielsen 1997b). There have been very few studies completed on seasonal fat deposition in canines. In an investigation of metabolism in Inuit sled dogs over summer (when the dogs were tethered and fed intermittently), Gerth et al. (2009), discovered muscle atrophy with sparse lipid droplets between myofibrils. Prestrud and Nilssen (1985) demonstrated that although Arctic foxes laid down subcutaneous and visceral fat deposits in autumn, these were not depleted over winter. However, the latter authors concluded that the scavenging habit of Arctic foxes over winter enabled them to gain sufficient nutrition without depleting fat reserves. In contrast, studies by Lindstrom (1983) and Kolb and Hewson (1980) on red foxes in Sweden and Scotland, revealed marked seasonal changes in body condition.
2.2.2.3 Pelage

The density of the fur or hair coats of land mammals varies in relation to environmental conditions and may provide effective insulation in cold climates (Scholander et al. 1950). Seasonal increases of <50% in the winter fur of Canadian mammals have been recorded (Hart 1956) and Walsberg (1991) concluded that despite an increase in reflectivity, the white winter coats of three species of subarctic mammals had greatly increased thermal resistance. Using thermography, Klier and Heath (1992) demonstrated that different species of foxes were able to control heat exchange with the environment, through the thinly haired areas of the body (head, ears and lower limbs) by altering cutaneous blood flow to those regions. Also using thermography, Korhonen et al. (1986) showed that the raccoon dog, which is not native to Arctic regions, was more susceptible to heat loss from head and extremities than the blue fox. These results suggest that there might be differences in heat exchange mechanisms amongst breeds of domestic dogs. One of the most obvious characteristics of breeds from cold climates is the type, length and density of coat. Spitz dogs of Scandinavia, northern America and China all have very dense double coats and short muzzles & ears (De Vito, Russell-Revesz & Forino 2009). Sugano (1981) concluded that dogs reared outdoors in Japan acclimatized to low winter temperatures by both increasing heat production and increasing fur density.

2.2.3 Adaptation to hot environment

Mammals in hot environments may adopt physiological or behavioural strategies in response to arid conditions, food shortages and high \( T_a \).
2.2.3.1 Heat storage

As described above (2.1) some species of large herbivorous mammals use the process of heterothermy, allowing body temperature to rise during daylight hours and then decline during the hours of darkness. Many authors suggest it is an adaptation, particularly suited to desert dwelling species, in order to reduce the water losses which would be incurred by attempts to maintain body temperature by evaporative cooling. Heat storage has also been recorded in African predators (Taylor et al. 1971; Taylor and Rowntree 1973) and in coyotes (Golightly & Ohmart 1983).

2.2.3.2 Metabolism

In a study of two canid species from a common habitat, kit foxes *Vulpes macrotis* (mean bodyweight 1,820g) and coyotes *Canis latrans* (mean bodyweight 10kg), Golightly and Ohmart (1983) showed that the smaller kit foxes had seasonal variations in both metabolism and thermal conductance whereas the coyotes reduced endogenous heat by maintaining a lower than predicted metabolic rate, thus reducing the need for evaporative heat loss. Noll-Banholzer (1979) also concluded that Fennec foxes maintained a lower than predicted metabolic rate as an adaptation to the desert environment.

2.2.3.3 Behaviour

Fennec foxes have a nocturnal pattern of activity and generally retreat into burrows during the day (Noll-Banholzer 1979) and Golightly and Ohmart (1983) concluded that kit foxes avoided hunting during periods of high temperature as a survival strategy. However, burrowing is generally restricted to mammals <1500g (Nevo 1979) and it is not exhibited by larger canines as a strategy to escape heat.
2.2.3.4 Pelage

Most desert living mammals have light coloured fur/hair which absorbs less radiative heat and even those with dark hair may have hair structure which reduces heat absorption or heat transfer (Fratto & Davis 2011). Differences in heat absorbance, body temperature and daily activity in three colour morphs of springbok have been recorded: black springbok show greater daily variation in body temperature with a higher maximum in spring than white springbok and black springbok also exhibit lower foraging activity in winter, which is believed to reflect lower energy requirements (Hetem et al. 2009). In Australia, the predominant colour of dingoes is ginger, with an increasing frequency of dark colouring in southern, temperate areas (Corbett 1995). Dingoes held in cool conditions, increase both the weight and density of coat as an adaptive process (Shield 1972). Dog breeds such as the Basenji (southern Africa), Azawakh (central Africa) and Pariah dogs (India) which have developed in warm to hot climates, have short, thin coats (De Vito, Russell-Revesz & Fornino 2009). Berglund et al. (2011) using computer modelling, demonstrated an improvement in heat tolerance by clipping the coat of a long haired breed. It can be concluded therefore, that both coat density and colour may affect response to heat stress.

2.2.3.5 Estivation

Estivation involving prolonged periods of dormancy has been observed in birds and mammals (Geiser 2010; Macmillen 1965) and Wilz & Heldmaier (2000) concluded from their studies in the edible dormouse, that daily torpor, hibernation and estivation all involved similar physiological processes which differed only in duration. However, estivation is restricted to small mammals (generally <1kg) which are able to retreat underground or into shelter and large mammals adopt other means to survive extreme heat.
2.3 Influence of exercise on thermoregulation

Carnivores must hunt almost daily and the pursuit of prey entails either prolonged medium intensity exercise or short bursts of intense exercise. Intense exercise may cause an increase in metabolic rate of 10-25 times the BMR (Gorman et al. 1998; Schutz 2005), so athletic animals are particularly challenged to dissipate the resultant heat generated.

Increases in both muscle temperature and $T_{\text{CORE}}$ (or rectal) temperature, in response to exercise, have been recorded in dogs (Kozlowski et al. 1985; Phillips, Coppinger & Schimel 1981), horses (Essen-Gustavsson, Gottlieb-Vedi & Lindholm 1999; Hodgson et al. 1993; McConaghy et al. 1995) and humans (Drust et al 2005; Duffield, Coutts & Quinn 2009).

Hodgson et al. (1993) noted that the increase in rectal temperature in horses lagged behind the increase in muscle temperature and they estimated that 80% of the energy utilized during exercise was liberated as heat. Ahlstrom, Redman & Speakman (2011) estimated the energy cost of running to be 32kJ/kg BW $^{0.75}$ per km for dogs hunting in Nordic winter conditions. In sled dogs running at 25km/hr, $T_{r}$ rises rapidly with significant correlation ($r=0.821$) between $T_a$ and $T_r$ in $T_a$ between $-9-25^\circ$ (Phillips, Coppinger & Schimel 1981) and Arctic sled dogs undertaking prolonged exercise in $T_a$ $-35^\circ$--$-10^\circ$C may expend total energy of $47,000\pm5,900$ kJ/day, equivalent to $4,400\pm400$ kJ.kg$^{-0.75}$/d (Hinchcliff et al. 1997).

Such energy expenditure is considerably in excess of that of both active humans in Arctic conditions, $32,029$kJ/day (Stroud, Coward & Sawyer 1993) and Tour de France cyclists, $25,000$kJ/day (Westerterp et al. 1986) and demonstrates the potential heat production by domestic dogs in extreme conditions.

As previously noted (2.1) heat storage is utilised by some African predators, however, heat storage may limit the period of exercise tolerated by sprinting animals (Taylor & Rowntree...
These researchers measured heat production in cheetahs (*Acinonyx jubatos*) on a treadmill and cheetahs refused to run at $T_r > 40.5^\circ C$. It is apparent that, although dogs have great capacity to metabolise energy and have a broad range of $T_A$ tolerance, the heat production from intense or prolonged exercise may exceed the animals’ capacity for heat dissipation.

### 2.4 Heat stress/heat strain/heat stroke

When the body’s thermoregulatory mechanisms are challenged, due either to excessive $T_A$ or extreme heat production, *heat stress* is the term used to describe the environmental or metabolic factors impacting on the body whereas *heat strain* describes the physiological or pathological effects resulting therefrom (Tikuisis, McLellan & Selkirk 2002). *Heat stroke* occurs when the body’s heat dissipating mechanisms are overwhelmed due to exposure to an environmental temperature exceeding body temperature (classic or environmental heat stroke) or when metabolic heat accumulates due to strenuous exercise (exertional heat stroke) (Bouchama & Knochel 2002): heat stroke entails major organ failure and is life threatening (Leon & Helwig 2010; Sucholeiki 2005; Yan et al. 2006). Symptoms considered indicative of heat illness in dogs include panting, dry mucous membranes, prolonged capillary refill time, ataxia and elevated body temperature (Flourney, McIntyre 2003; Johnson, McMichael & White 2006).

#### 2.4.1 Heat stroke

Although heat stroke has been recognised for centuries, until relatively recently, the mechanisms were poorly understood. Shapiro et al. (1973) was able to demonstrate, using dogs (which do not sweat) that heat stroke was due to tissue damage resulting from elevated body temperature and not cessation of sweating as had been previously believed.
A subsequent study by Bynum et al. (1978), in which anaesthetized dogs were heated to a $T_{re}$ of 44.5°C, revealed increased levels of serum enzymes glutamic-pyruvic glutaminase (SGPT), glutamic-oxaloacetic transaminase (SGOT) lactic acid dehydrogenase (LDH) and alkaline phosphatase (Alk Phos) in the terminal stages of hyperthermia. Elevation of these enzyme levels is indicative of tissue damage. The authors also noted necrosis of liver and intestinal epithelium and turbid, brown urine, indicative of impaired renal function. Current understanding is that heat stroke involves impairment of cellular function, denaturing of proteins (both structural and enzymatic) and disruption of lipid membranes and that the syndrome is similar to systemic inflammatory response syndrome (SIRS) (Lugo-Amador, Rothenhaus & Moyer 2004). Hyperthermia induces intestinal ischaemia and increased intestinal wall permeability which permits leakage of endotoxins (Flournoy, Wohl & Macintire 2003; Liu et al. 2011; Shapiro et al. 1986). The recent work by Chen et al. (2012) demonstrating the effectiveness of haemofiltration as a treatment modality for heatstroke in dogs, tends to confirm the pathogenic role of circulating endotoxins. Based on a study of hyperthermia in baboons, microvascular injury, thrombosis, inflammation and apoptosis might also be important in the pathogenesis of heat stroke (Roberts et al. 2008). Although disseminated intravascular coagulation has been proposed as one of the pathogenic mechanisms in heat affected dogs and humans (Bruchim et al. 2006; Flournoy, Wohl & Macintire 2003), cell damage can occur through alternative mechanisms (Bouchama et al. 2012). Cytokines TNF, IL-1 and IL-6 have been implicated as causative factors in the development of heat stroke (Chang 1993; Lugo-Amador, Rothenhaus & Moyer 2004; Shen et al. 2008) and Yan et al. (2006) found a positive correlation between levels of IL-6 and the severity of heat stroke. However, correlation does not prove cause and Leon and Helwig
(2010) proposed that cytokines might, in fact, have a protective role in the resolution of inflammation.

Dehydration has been identified by many authors as a precursor or precipitating factor for heat stroke in humans (Coris, Ramirez & Van Durme 2004; Howe & Boden 2007; Maughan & Shirreffs 2004). It has been widely accepted that dehydration of 2-3% is a major risk factor for heat illness and that a fluid deficit of as little as 1.5-2% may have a negative effect on performance (Maughan & Shirreffs 2004). Assia et al. (1989) demonstrated that a decrease in plasma volume of 6% ± 2% increased the rate of heat accumulation in dogs exposed to high external heat load and there is a significant (P <0.01) elevation in $T_{re}$ in dehydrated dogs exercising on a treadmill at $T_A$ 25°C (Baker 1984).

Dehydration has also been recognised as limiting performance and heat dissipation in equine athletes (Geor 2005). However, although many authors attest that dehydration may predispose to exercise-induced hyperthermia, due to reduced cutaneous circulation, a series of studies in the latter half of last century, on a number of species (Greenleaf et al. 1976; Harrison et al. 1978; Kozlowski et al. 1980) demonstrated that hypovolaemia alone did not contribute to an elevation of body temperature during exercise and that an increase in plasma Na was associated with an elevation of body temperature which could be attributed to a direct effect of Na on the thermoregulatory centres of the brain. Racing greyhounds may lose up to 6% bodyweight, due to dehydration, in the pre-race kennelling period (Blythe & Hansen 1986). Such losses might lead to increased risk of hyperthermia and increased risk of renal damage from myoglobinuria (see 2.6).
2.5 Exertional hyperthermia

Exertional hyperthermia is widely recognised as a risk factor for people engaged in a variety of occupations and sports and has been the subject of extensive research. Howe and Boden (2007) describe a range of heat related illnesses, graded from mild heat oedema to heat stroke, which may affect human athletes and note that heat stroke is the third leading cause of death in athletes in the USA. Although the milder manifestations of heat illness described in humans such as heat rash and heat oedema have not been described in dogs, more significant symptoms such as cramps and fatigue are commonly exhibited by greyhounds following even short periods of strenuous exercise (Blythe, Gannon & Craig 1994; Pemberton 1983).

Most of the studies into exertional hyperthermia in humans and horses have been on subjects exercising for prolonged periods. However, the power output of cyclists exercising in short (15 sec) intervals is reduced in $T_A \ 40^\circ C$ (Drust et al. 2005) and the authors suggest that a high $T_{CORE}$ may affect the central nervous system (CNS). The elevation in rectal and muscle temperature resulting from prolonged exercise by dogs is associated with reduced levels of high energy phosphates (adenosine triphosphate and creatine phosphate) and increased levels of muscle lactate, pyruvate and adenosine monophosphate, which may contribute to fatigue (Kozlowski et al. 1985). The accumulation of such waste products in muscle is now widely accepted as a factor limiting muscular effort, so although elevation of body temperature facilitates an increased rate of metabolism, the work of these researchers suggests that high intensity exercise at high $T_A$ may have adverse effects on both nervous and muscular systems.
There may be some breed variation in tolerance to exertional hyperthermia, as has been shown in non-domestic canids. Taylor et al. (1971) revealed that the African hunting dog (*Lycaon pictus*) had a higher body temperature while running and greater capacity for non-evaporative heat loss than the domestic dog. As greyhounds have been subject to intense selection for athletic performance over several centuries (Banks 1978; Burnell 1973) and 60% of the body mass is muscle (Gunn 1978), the large locomotor muscles may contain high mitochondrial and capillary volumes as found in some athletic marsupials (Webster & Dawson 2012). It could therefore be expected that greyhounds would generate heat at a high rate and may therefore be particularly susceptible to exertional hyperthermia.

### 2.6 Rhabdomyolysis/myoglobinuria

Rhabdomyolysis may be a consequence of strenuous exercise and/or heat strain. Exercise induced muscle fibre damage has been reported in humans (Chatzizisis et al. 2008; Ebbeling & Clarkson 1989; Milne 1988; Moghtader, Brady & Bonadio 1997; Schiff, Macsearraigh & Kallmeyer 1978; Sinert et al. 1994) and animals (Amelink & Bar 1986; Beech, Lindborg & Braund 1993; Freestone & Carlson 1991; li, Hodgson & Bayly 1995). Differences exist in the susceptibility of male and female rats to disruption of the sarcolemma following exercise (Komulainen et al. 1999) and several authors, Amelink and Bar (1986) and Tiidus and Bombardier (1999), have demonstrated apparent protective effects of oestrogen against exercise-induced muscle damage in rats and humans. These findings are in contrast to results from equine studies, as female horses are reported to be more frequently affected by exertional rhabdomyolysis than males (MacLeay et al. 1999; Upjohn et al. 2005). Sex differences in susceptibility to exertional rhabdomyolysis in dogs have not been reported.
Following muscle breakdown there is rapid release of cell breakdown products, such as the enzymes creatine kinase, lactate dehydrogenase, aldolase and aspartate transferase; ions such as potassium and phosphate and muscle proteins such as myoglobin and troponin (Brancaccio, Lippi & Maffulli 2010.; Cervellin, Comelli & Lippi 2010). Myoglobin is recognised as being nephrotoxic (Cervellin, Comelli & Lippi 2010) and in humans, elevated levels of myoglobin in serum or urine have been associated with a risk of acute renal failure and subsequent mortality (Brancaccio, Lippi & Maffulli 2010). Knochel (1990) describes rhabdomyolysis associated with exertional heat stroke as one of the most devastating clinical illnesses affecting humans.

Post-exercise myoglobinura has been widely reported in human (Knochel 1990; Schiff, Macsearraigh & Kallmeyer 1978; Sinert et al. 1994) and equine (Freestone & Carlson 1991) (van Oldruitenborgh-Oosterbaan, van den Boom & Grinwis 2006) athletes. It has also been reported in greyhounds (Ferguson & Boemo 1998) but the incidence is unknown and the levels of myoglobin excreted have not been quantified. Shelton (2004) remarked that there was little information available on the occurrence of rhabdomyolysis and myoglobinuria in companion animals and that further investigation should be undertaken.

**2.7 Transport**

Road transport has been reported to be stressful to many animal species (Gregory 2008; Pilcher et al. 2011; Schmidt et al. 2010; Tateo et al. 2012; von Borell 2001). Behavioural and physiological indications of stress occur in dogs transported by air (Leadon and Mullins, 1991; Bergeron et al, 2002) and major physiological and muscle changes occur in goats transported at high temperatures (Kadim et al. 2006). Fisher et al. (2008) identified thermal
comfort, hydration and physical integrity as risks to animals being transported and all of these factors could represent significant challenges to animals being transported specifically for athletic performance.

The Greyhound Board of Great Britain (GBGB), in its Rules of Racing, outlines specific requirements for the road transport of greyhounds, including a temperature range of 10-26°C which must be monitored (Greyhound Board of Great Britain 2011). The Australian Animal Welfare Strategy (AAWS) did not develop a Model Code of Practice for land transport of dogs and although the controlling authorities of greyhound racing have policies relating to the care of greyhounds, they are not consistent between states and lack specific recommendations in relation to transport. No studies have been conducted on road transport of greyhounds in Australia and such a study is warranted to ensure the welfare of greyhounds.

2.8 Temperature recording methods and devices

Researchers working in the field of thermal relations have used a wide variety of methods and devices for measuring both environmental conditions and $T_B$.

2.8.1 Thermistors/thermocouples

Many of the studies on hyperthermia in humans and dogs have been conducted on subjects which were either sedated or anaesthetized (Bynum et al. 1977; Bynum et al. 1978; Oglesbee et al. 2002; Shuman et al. 1988) and researchers used implanted thermistors in sites such as the rectum (Bynum et al. 1977) or tympanic membrane, oesophagus and pulmonary artery (Oglesbee et al. 2002). Studies on conscious dogs have been conducted using rectal thermistors (Iampietro et al. 1966) and chronically implanted thermocouples in
the brain, carotid artery and rectum (Baker 1974). Thermistors inserted in the rectum were used to monitor body temperature ($T_b$) in exercising, harnessed sled dogs (Phillips, Coppinger & Schimel 1981) and a microcontroller-based system for collecting blood, which permitted simultaneous measurement of temperature, in running greyhounds was used effectively by Schmalzried et al. (1992). However, the latter system required surgery to relocate the carotid artery and had an approximate weight of 2kg, both of which would preclude its use in field studies. The recent development of ingestible and implantable sensors, has facilitated the monitoring of body temperature of many species in field conditions and they may be suitable for use in racing greyhounds.

2.8.2 Implantable/ingestible sensors
The accuracy of implantable and ingestible and systems may vary between species. Variations have been recorded in the correlation of readings provided by a tympanic infra-red thermometer, a subcutaneously implanted microchip transponder and a rectal thermometer in goats, sheep and horses (Goodwin 1998). However, there is good correlation between readings obtained with an ingestible sensor-telemetric system and readings obtained from thermistors implanted in the jugular vein and rectum of horses, and Green, Gates and Lawrence (2005) concluded that the telemetric system was a valid means for monitoring $T_{CORE}$ in that species.

Ingestible sensors have been validated as means of measuring $T_{CORE}$ in exercising humans (Easton, Fudge & Pitsladis 2007; Lim, Byrne & Lee 2008) and in Australia, ingestible sensors have been utilised to record thermoregulatory responses in Australian Football players, in warm conditions (Duffield, Coutts & Quinn 2009). Angle and Gillette (2011) evaluated ingestible sensors with telemetry as a method of recording $T_{CORE}$ in exercising
Labrador dogs and concluded the system offered potential for field studies in working and sporting dogs. Ingestible sensors and telemetry may therefore be suitable for monitoring body temperature in racing greyhounds.

2.8.3 Infrared thermography

Infrared thermography has been used in non-domestic species since 1940 and in veterinary medicine since 1950 (Hilsberg-Merz 2008). The technique permits measurement of surface temperature from a distance and therefore enables assessment of factors such as differences in coat temperatures in different species in a shared environment (Kotrba et al. 2007) and heat loss mechanisms in horses and elephants (Autio et al. 2006; Weissenböck et al. 2010). In the field of veterinary medicine, thermography has enabled detection of foot and mouth lesions in cattle (Rainwater-Lovett et al. 2009) and febrile responses in calves (Schaefer et al. 2004). Thermographic imaging has been widely used in equine veterinary medicine to aid diagnosis of lameness and identification of localised inflammatory responses (Bathe 2011; Soroko & Jodkowska 2011) and Johnson et al (2011) validated thermographic eye temperature measurement as a means of detection of elevated body temperature in ponies. Differences in the surface temperature of some greyhound muscles have been demonstrated thermographically (Vainionpaa et al. 2012) however the relationship between surface temperature and core or rectal temperature has not been determined.

2.8.4 Infra-red thermometers

The use of aural infra-red thermometers has become commonplace in human medicine and a number of studies have indicated that they may be appropriate for thermal studies or clinical use (Chamberlain et al. 1995; Kocoglu et al. 2002; Rotello, Crawford & Temdrup 1996). However, systematic reviews by Craig et al. (2002) and Dodd et al. (2006) of studies
utilising aural and rectal thermometers in children, found poor levels of agreement between rectal and ear temperature measurements and consequently it was concluded that aural infra-red thermometers were not reliable for use in young children. The review authors did not identify factors to explain the discrepancies however, it is possible that body mass may be one explanatory which would indicate that use of aural thermometers in dogs may not be reliable.

Veterinary aural thermometers have been available since the early 1990s and Rexroat, Benish & Fraden (1999) (in a study supported by the manufacturer) validated the use of the Vet-Temp™ aural thermometer for use in cats and dogs. However, Kunkle et al. (2004) found poor correlation between temperatures recorded with a digital rectal thermometer and a veterinary aural infra-red thermometer in cats and the authors concluded that the devices could not be used interchangeably in that species. It may therefore be concluded that factors such as species, body mass or anatomy of the ear canal influence the accuracy of aural infra-red thermometers.

2.9 Heat indices

As heat stress has been recognised as a health hazard for both humans and animals in a broad spectrum of situations, heat stress indices have been developed in attempts to monitor environmental conditions and obviate heat strain in at-risk groups (Malchaire et al. 2001; Moran et al. 1999). The Wet Bulb Globe Temperature (WBGT) index was developed by the US military in the 1950s in an attempt to estimate hazardous conditions for military recruits undergoing training (Budd 2008). It has since been widely used to predict the risk of heat
illness in both work and sporting situations. However, it was developed for estimating the comfort of humans (that sweat) and may not be applicable to animals such as dogs, that do not. In addition, as elucidated by Budd (2008), it is limited in its suitability to estimate heat stress in situations of high humidity or low air movement. Prior to the Atlanta Olympics, Schroter and Marlin (1995) argued that the existing Fédération Equestre Internationale (FEI) comfort index was inadequate in estimating thermal load as it failed to account for solar radiation and was merely a figure derived from the addition of different parameters, i.e. ambient temperature and relative humidity. They proposed an index based on ambient temperature, atmospheric humidity, wind and solar radiation and recommended adoption of the WBGT index with an upper limit for equestrian activity of approximately 32.5°C. Whereas many authors advocate the use of WBGT, this measurement may not always be readily available for sites and Stull (2011) proposed a method of deriving $T_w$°C (wet bulb temperature) as a function of $T_A$ and RH% plotted on a graph. This might offer a means of estimation of WBGT from $T_A$ and RH% data which may be readily obtained from simple recording devices. Steadman (1979) developed a table to indicate apparent temperature from a combination of dry bulb temperature and relative humidity. However, the author noted that the table was applicable to clothed humans and was not suitable for application to non-human animals.

A number of organisations worldwide have developed Heat Stress Indices for production animals, such as cattle. Gaughan, Mader et al. (2008) devised a formula which incorporates breed and colour of cattle, availability of shade and current environmental conditions. The formula is recommended to operators of cattle feedlots by Meat and Livestock Australia (MLA) and is available online at [www.mla.com.au](http://www.mla.com.au). The Temperature Humidity Index (THI) is
used quite extensively in the dairy industry (Dikmen & Hansen 2009) and panting score has been used to estimate heat stress in sheep (Hales & Hutchinson 1971) and cattle (Gaughan et al. 2008). Heat Stress Indices have also been developed for humans in a variety of situations. Bates and Miller (2002) validated a heat stress index for application in the workplace and Coris et al. (2006) developed a 13 item scale for symptoms exhibited by athletes in the early stages of heat illness.

Using some or all of these models it may be possible to develop a heat stress index which could be adopted by the greyhound industry to aid decision making, relative to the conduct of racing in hot weather.

2.10 Summary of literature

A large body of literature exists on thermoregulation in mammals. Variations in the mechanisms of heat conservation and dissipation have been documented in different species and adaptations to a broad range of climatic conditions occur. However, extremely hot conditions may lead to failure of the thermoregulatory system and heat induced illness may result. Heat stress is recognised as a significant risk for livestock and for human, equine and canine athletes.

Although competition between greyhounds and intensive selection for athletic performance has occurred over centuries, there has been limited investigation of the effects of strenuous exercise under extreme conditions. There are conflicting opinions regarding the pathogenesis of heat stroke and in addition to the variation in methods of thermoregulation between species, there may also be differences between breeds of domestic dogs. Heat
Stress indices have been developed for some livestock industries and human sporting organizations and it may be possible to develop a suitable model for the greyhound racing industry. The greyhound industry provides a structured and regulated framework in which to conduct research and findings from this study may be extended to other activities involving canine athletes.

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Chapter 3: Determination of effective means to measure greyhound body temperature

3.1 Introduction

As much of the study was to be implemented at racetracks and in a restricted time frame, it was necessary to firstly identify the most suitable method of greyhound body temperature measurement. Although the most widely accepted method of body temperature measurement in clinical veterinary practice is the rectal thermometer, the use of such devices in a competitive environment might not be acceptable to trainers and might not be tolerated by some dogs. As racing greyhounds are accustomed to having their ears closely examined by stewards for the purpose of reading identification tattoos, it was considered that the use of an infra-red aural thermometer might be a suitable and acceptable alternative method of determining body temperature. Even preferable to both aural and rectal thermometers would be a non-contact method of temperature measurement and two modalities utilizing infra-red technology have been employed in biological research, infra-red thermometry (Saegusa & Tabata 2003) and infra-red thermography (Kastberger & Stachl 2003). Hilsberg-Merz (2008) advocates thermography as a non-invasive means for estimating body temperature in zoo animals. However, thermography equipment is relatively expensive and financial constraints precluded its use in this study. Two alternative methods of temperature measurement were selected for assessment, a hand held infra-red thermometer and ingestible sensors. This preliminary study aimed to determine which temperature recording device would be most suitable for use in a racetrack situation.
3.2 Materials and methods

3.2.1 Study 1 design

Laboratory validation of the instruments was performed to establish levels of agreement between the instruments at the limits of the expected range of dog body temperature. Field work was then carried out to test animal acceptance and ease of use of the different devices. For the field work, operators of seven greyhound breeding and training establishments, located on the Adelaide Plains and Barossa Valley, South Australia, (Figure 3-1) were approached to co-operate in the study. Owner/trainer consent was obtained for each visit (see Appendix 1; consent form). Animal ethics approval was provided for this study by the University of Adelaide Animal Ethics Committee.
Figure 3-1 Map of South Australia showing locations of field studies

3.2.2 Temperature recording devices

3.2.2.1 Aural thermometer

A veterinary aural infrared thermometer, Vet-Temp VT-150 (Advanced Monitors Corporation, San Diego, California, USA) was selected. The manufacturer states this device
has a clinical range of 34 – 43°C with an accuracy ± 0.10 °C and that it provides a digital readout within one second, signified by a short beep.

3.2.2.2 Rectal thermometer
A commercially available clinical veterinary digital rectal thermometer, DT-K01A (Provet, Adelaide, South Australia) was selected. The manufacturer states an accuracy ± 0.10° C and that it provides a digital readout within 60 seconds, signified by a short beep.

3.2.2.3 Infra-red thermometer
A hand-held, infra-red thermometer (ZyTemp TN408LC HsinChu, Taiwan 300) was used which has a manufacturer stated operating range of 0-50°C, accuracy of ± 0.10° C and instant display readout. An inbuilt laser beam indicates the point of heat source.

3.2.2.4 Ingestible sensors
The CorTemp™ core body temperature monitoring system (HQ Inc, Palmetto, FL, USA) comprises an externally mounted data recorder measuring 120x60x25mm and weighing 200gm and battery powered, ingestible sensors measuring 12mmX19mm which wirelessly transmit core body temperature as they travel through the digestive tract (Figure 3-2).
3.2.3 Environmental monitoring

Ambient temperature and humidity were recorded using a weather station (La Crosse technology, wireless 433MHZ Weather Station). The device comprises two components: an indoor unit with LCD screen displaying humidity, temperature, time and calendar information and an outdoor thermo-hygro transmitter which provides remote transmission of outdoor temperature and humidity by 433 MHz signals to the weather station (Figure 3-3).
3.2.4 Animals

One hundred and two greyhounds (49 female, 53 male) were enlisted. Ages ranged from 6 months to 14 years (mean 3 years ± 2.6 SD). Weights were estimated based: a) for animals currently racing (N=43), on the most recent recorded racing weights and b) for non-racing animals (N=59), by close observation by the researcher and handlers, all of whom had many years of experience in greyhound management. Weights ranged from 26-40 kilograms (mean 30 ± 3.8kg).

3.2.5 Statistical analysis

Data was analysed using GraphPad Prism version 5 (GraphPad Software, San Diego, CA, USA) using the plotting method advocated by Bland and Altman (1986). A Bland Altman plot compares two assay methods, plotting the difference between the two measurements on the Y axis, and the average of the two measurements on the X axis. The plots permit visual assessment of the agreement of measurements obtained with the two methods. The mean difference between the methods is then calculated (bias) and 95% limits of agreement set as 2 standard deviations (SD). In the current study a bias of <0.5 was considered acceptable.

3.2.6 Procedures

3.2.6.1 Laboratory validation

The temperature of water baths (Type JB2, Grant Instruments (Cambridge) Pty, Cambridge, UK) set to 37°C and 42°C was recorded with the veterinary aural infrared thermometer, rectal thermometer and hand held infra-red thermometer. Measurements by each device were recorded six times simultaneously with an electrical thermometer (Ecoscan EC-TEMP6/01, Eutech Instruments) and a mercury thermometer. Readings from the electrical
thermometer were considered the gold standard. The rectal thermometer was immersed to a depth of 1cm in the water bath and both the aural thermometer and the hand-held infra-red thermometers were positioned approximately 1cm above the water surface. All readings were made by the same observer.

3.2.6.2 Field validation

Each dog was brought from its individual kennel and held for examination by its owner/trainer. All measurements were made by one operator and in the same sequence, aural, rectal and skin temperatures. All the dogs in each location were checked on the same occasion. Visits occurred during spring and summer 2009-2010. Seven kennel visits were made - September (one location, 6 dogs), October (three locations, 52 dogs), December (two locations, 33 dogs) and January (one location, 11 dogs). Time at recording ranged from 10.00 to 14.00 hours.

3.2.6.3 Aural Thermometer

A new probe cover was fitted for each measurement. The pinna of the ear (randomised left or right) was held and extended dorso-laterally to expose the ear canal while the probe was inserted and directed towards the opposite jaw to measure tympanic membrane temperature.

3.2.6.4 Rectal Thermometer

A clinical veterinary digital rectal thermometer DT-K01A (Provet, Adelaide, South Australia) was used to measure rectal temperature. For each measurement the probe was lubricated with Vaseline and inserted 2-3 cm into the rectum.
3.2.6.5 *Infra-red Thermometer*

The hand held infra-red thermometer was positioned 20-40 centimetres from the target surface, the skin overlaying the femoral artery (groin) as illustrated below (Figure 3-4).

![Figure 3-4 Positioning of hand-held infra-red thermometer over femoral artery.](image)
3.3 Results Study 1

3.3.1 Laboratory validation

In the water bath at 37°C both the aural thermometer and the hand-held infra-red thermometer provided readings lower than the rectal thermometer (mean difference -0.4°C and -2.5°C respectively). In the water bath at 42°C the aural thermometer provided readings higher than the rectal thermometer (mean difference + 0.9°C) and the readings by the infra-red thermometer were all lower than the rectal thermometer (mean difference – 2.6°C). At the higher temperature, an increase in scatter in readings by the hand-held, infra-red thermometer was noted (Figure 3-5).

![Figure 3-5 Temperature recorded with four thermometers in water baths at 37°C and 42°C.](image)
In six paired readings of the rectal thermometer and the electrical thermometer, in both water baths, there was close agreement with a bias of 0.05 for the difference against the average using the method of Bland and Altman. Results for the electrical vs aural thermometers showed a bias of 0.25 for difference vs average and for the aural vs rectal the bias was 0.20, however, this level of bias was considered acceptable. The hand-held infra-red thermometer produced erratic readings which varied significantly as the laser pointer was moved over different portions of the bath. Most consistent readings were obtained by aiming the laser pointer at a steel plate immersed approximately 1cm beneath the water surface, indicating that the device was not effective in measuring the temperature of a fluid surface. It was not considered that this would preclude its use for measuring body surface temperature. All temperature measurements obtained with the hand-held, infra-red thermometer were lower than those obtained with the other instruments. Mean difference from the electrical thermometer was -2.4°C (Figure 3-6).
Figure 3-6 Bland-Altman plots of the differences vs averages of (a) aural and rectal, (b) electrical and aural, (c) electrical and rectal and (d) electrical and infra-red thermometers with the mean and limits of agreement (mean ± 1.96 SD) indicated.

3.3.2 Field validation

Environmental conditions on each occasion are summarized in Table 3-1. Average daily maximum temperature in Adelaide for spring (September – November) is 20°C and for summer (December – February) is 31°C and average humidity at 3pm during both seasons ranges from 30 - 40% (Australian Government Bureau of Meteorology). Ambient temperature on examination days ranged from 15.0°- 35.8°C and relative humidity ranged from 12% - 70% (Table 3.1).
### Table 3-1 Environmental conditions at kennel locations

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Time</th>
<th>Ambient Temp °C</th>
<th>Relative humidity%</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/09/09</td>
<td>Barossa</td>
<td>10.00-11.00</td>
<td>15.0</td>
<td>67-70</td>
</tr>
<tr>
<td>07/10/09</td>
<td>Plains</td>
<td>10.00-12.00</td>
<td>16.0-17.0</td>
<td>40-42</td>
</tr>
<tr>
<td>21/10/09</td>
<td>Barossa</td>
<td>10.00-12.00</td>
<td>16.0</td>
<td>56</td>
</tr>
<tr>
<td>27/10/09</td>
<td>Plains</td>
<td>13.00-14.00</td>
<td>27.0</td>
<td>35</td>
</tr>
<tr>
<td>11/12/09</td>
<td>Plains</td>
<td>12.00-13.00</td>
<td>24.0</td>
<td>34-40</td>
</tr>
<tr>
<td>18/12/09</td>
<td>Plains</td>
<td>12.00-13.30</td>
<td>20.0-24.0</td>
<td>43-50</td>
</tr>
<tr>
<td>22/01/10</td>
<td>Plains</td>
<td>10.00-11.45</td>
<td>35.0-38.5</td>
<td>12-20</td>
</tr>
</tbody>
</table>

Mean body temperatures recorded by the aural, rectal and infra-red thermometers are displayed in Table 3-2 and the range of temperatures illustrated in Figure 3-7. Mean difference between temperatures recorded by the rectal and aural methods was -0.1° ± 0.5°C: mean difference between temperatures recorded by the rectal and infra-red thermometers was 1.2° ± 1.0°C. Readings by the hand-held, infra-red thermometer displayed the greatest range (33.3-39.4°C) whereas readings by the rectal thermometer showed the narrowest range (37.2-39.7°C).
Table 3-2 Mean body temperature recorded with three thermometers

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Male</th>
<th>Female</th>
<th>Mean Body Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Aural</td>
</tr>
<tr>
<td>24/09/2009</td>
<td>Barossa</td>
<td>3</td>
<td>3</td>
<td>38.4</td>
</tr>
<tr>
<td>7/10/2009</td>
<td>Plains</td>
<td>3</td>
<td>12</td>
<td>37.7</td>
</tr>
<tr>
<td>21/10/2009</td>
<td>Barossa</td>
<td>11</td>
<td>5</td>
<td>37.8</td>
</tr>
<tr>
<td>27/10/2009</td>
<td>Plains</td>
<td>10</td>
<td>11</td>
<td>37.6</td>
</tr>
<tr>
<td>11/12/2009</td>
<td>Plains</td>
<td>8</td>
<td>8</td>
<td>38.6</td>
</tr>
<tr>
<td>18/12/2009</td>
<td>Plains</td>
<td>11</td>
<td>6</td>
<td>38.0</td>
</tr>
<tr>
<td>22/01/2010</td>
<td>Plains</td>
<td>6</td>
<td>5</td>
<td>38.0</td>
</tr>
</tbody>
</table>

Mean (all dogs) ± SD 38.01±0.6 38.03±0.5 37.0±1.1

Figure 3-7 Range of body temperature recorded with three thermometers.

Bland Altman plots were used to assess agreement between readings obtained with aural and rectal thermometers and with infra-red and rectal thermometers. Temperature
recorded with aural and rectal thermometers showed good agreement but readings from the body surface over the femoral artery (groin) utilizing the infra-red gun thermometer revealed poor agreement with rectal measurements (Figure 3-8).

![Figure 3-8 Bland-Altman plots for (a) aural vs rectal and (b) infra-red vs rectal thermometers.](image)

### 3.4 Study 2 (ingestible sensors)

A limited study was conducted to assess the suitability of a system utilising ingestible sensors and an externally mounted data recorder.

#### 3.4.1 Location

Three kennels participated in this study, two on the Adelaide plains and one in the Barossa region.

#### 3.4.2 Animals

Nine animals (four male, five female) were selected for this trial. Ages ranged from 2-5 years, with estimated body weights 25-35kg.

#### 3.4.3 Procedure

The CorTemp™ core body temperature monitoring system (HQ Inc, Palmetto, FL, USA) was programmed according to manufacturer's instructions, using CorTrack™ II software.
The data recorder was programmed to record body temperature at one minute intervals, in real time. The data recorder was inserted into a pocket on the upper side of the jacket (Figure 3-9).

![Figure 3-9 Dog wearing jacket with data recorder.](image)

Following activation of each sensor, function was confirmed by immersion in a water bath at 37°C and data recorder readings were validated against an electrical thermometer. Each ingestible sensor was then administered to the subject in a ball of minced meat (approx. 50gm). Each subject was offered three balls of meat with the sensor secreted in the third ball. The data recorder was removed from each animal either when no signal was detected or when a sensor was seen to be excreted. Animals were housed in their normal home kennel locations and undertook daily activities as usually scheduled. Owners were requested to record dog activities and to record rectal temperature several times over 24 hours (see Appendix 2 for owner recording sheet).
3.5 Results Study 2

Sensors were administered to nine animals and data recordings for >12 hours were obtained from six subjects. The initial temperature recorded was influenced by the temperature of the meat in which the sensor was administered. Passage time was measured as the time from administration to excretion (see Table 3-3). Time elapsing from administration to stable temperature recording (three consecutive equal readings) varied from 13 to 55 minutes. A marked drop in core temperature was noted within minutes after the dog(s) were observed to drink cold water and maximum temperatures were recorded immediately after periods of exercise (Figure 3-10).

Table 3-3 Summary of data recorded by ingestible sensors.

<table>
<thead>
<tr>
<th>Dog</th>
<th>Time to stabilization (mins)</th>
<th>Maximum temperature °C</th>
<th>Minimum temperature °C</th>
<th>Passage time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ja</td>
<td>55</td>
<td>40.11</td>
<td>36.90</td>
<td>52</td>
</tr>
<tr>
<td>Lil</td>
<td>50</td>
<td>39.06</td>
<td>37.29</td>
<td>23</td>
</tr>
<tr>
<td>Con</td>
<td>42</td>
<td>39.66</td>
<td>37.48</td>
<td>19</td>
</tr>
<tr>
<td>Bu</td>
<td>25</td>
<td>39.24</td>
<td>34.30</td>
<td>17</td>
</tr>
<tr>
<td>Pan</td>
<td>70</td>
<td>38.87</td>
<td>37.40</td>
<td>20</td>
</tr>
<tr>
<td>Lis</td>
<td>13</td>
<td>39.24</td>
<td>37.84</td>
<td>39</td>
</tr>
</tbody>
</table>
Figure 3-10 Temperature recorded with CorTemp ingestible sensors (a) in dog JA over 23 hours (b) in dog Lil over 22 hours.
Bland-Altman analysis generally showed good levels of agreement between temperatures recorded by the rectal thermometer and the ingested sensors, with a bias of 0.001 (Figure 3-11). One outlier of rectal temperature of 41.0°C vs core 39.7°C was noted.

Figure 3-11 Bland-Altman analysis of temperature recorded by ingestible sensors and rectal thermometer with the mean and limits of agreement (mean ± 1.96 SD) indicated.

Technical problems affected the CorTrack II software at times, thus preventing communication between sensors and data recorder. One dog exhibited discomfort wearing the data recorder, demonstrating reluctance to lie down in its kennel. When greyhounds were exercising vigorously, secure positioning of the data recorder proved difficult and readings were not recorded. Bland–Altman analysis of temperature recorded by CorTemp and digital rectal thermometer revealed good agreement at lower body temperature with an acceptable bias of 0.0014. However, divergent readings were recorded when rectal temperatures exceeded 40°C which was within the post-exercise range expected.
3.6 Discussion

This preliminary study revealed acceptable levels of agreement between measurements by aural and rectal thermometers and between ingested sensors (core) and rectal temperature at temperatures ≤40°C. Poor levels of agreement were found between readings by the hand-held infra-red thermometer and rectal thermometer in both laboratory and field situations. Use of the rectal thermometer was tolerated by all dogs. The time lag to obtain a reading sometimes exceeded the manufacturer’s estimate of 60 seconds and the flexible tip was occasionally difficult to position accurately against the rectal wall.

Use of the hand-held, infra-red gun thermometer was well tolerated by all dogs, however, accurate positioning of the laser beam on the femoral artery occasionally required several attempts. The maximum temperature recorded with this device was 39.4°C. The presence of hair overlying the artery resulted in low temperatures being recorded in six dogs (33.3-36.8°C). Four of these dogs were retired from racing and one was in early training.

The Vet-Temp aural thermometer had been assessed (in a study supported by the manufacturer) as providing acceptable accuracy of readings within 0.1° F of rectal temperature (Rexroat, Benish & Fraden 1999). However, a subsequent study into use of an aural thermometer in cats, found that the device could not be used interchangeably with a rectal thermometer, due to poor levels of agreement (Kunkle, Nicklin & Sullivan-Tamboe 2004). During the current study, field use of the aural thermometer presented some difficulties both to the operator and some subject dogs. Accurate positioning of the probe was not readily achieved at the first attempt in all dogs and six of 102 dogs vocalized, indicating discomfort, on deep insertion of the probe. However, as the operator became more experienced, the incidence of adverse reactions decreased. A reading was not obtained at the first attempt for
every dog and the presence of any debris such as sand or cerumen in the aural canal, prevented a reading being obtained. These findings were in accord with those of Daanen (2006) who assessed two types of aural thermometer in humans and concluded that the morphology of the aural canal or presence of cerumen affected measurements. A number of studies have shown a trend for aural infra-red thermometers to underestimate body temperature. Aural temperature is lower in healthy, adult humans both when resting (Daanen 2006) and post-exercise (Easton, Fudge & Pitsladis 2007; Yeo & Scarbough 1996) and a recent meta-analysis by Huggins et al. (2012) found that aural temperature in hyperthermic humans was consistently lower than rectal temperature, with the difference increasing as rectal temperature increased. Although there is good agreement between aural and rectal temperature in anaesthetized, hypothermic dogs, as body temperature reaches the normal range, the aural thermometer provides lower readings than a rectal thermometer (Southward et al. 2006). In the current study the mean difference between rectal and aural temperature of 0.1°C was less than that recorded by Huggins et al. (2012) in humans, and was not considered significant. Although the subject dogs in the current study were co-operative, positioning the aural thermometer presented some difficulties and the adverse response (withdrawal and vocalization) from six dogs indicated that, at times, the process was uncomfortable.

A non-contact method of measuring skin temperature, as an indicator of core temperature would be most useful for the racetrack. Hand-held infra-red thermometers have been used for the measurement of human forehead temperature in hospitals (Ng, Kaw & Ng 2004) and for the measurement of limb temperature in sheep (Colditz et al. 2011). Martello et al. (2010), using an aural thermometer, found good correlation between rectal temperature and the surface temperature at the ear, tail and vulva of dairy cattle and concluded that body surface
temperature offered potential as an indicator of thermal stress. However, in the current study the divergence from rectal temperatures recorded by the hand-held, infra-red thermometer indicated that such a device could not be considered reliable for body temperature measurement in greyhounds.

Telemetric core temperature monitoring systems utilizing ingestible sensors have been widely used in human studies of thermal stress in sporting and occupational activities (Duffield, Coutts & Quinn 2009; Easton, Fudge & Pitsladis 2007; Lim, Byrne & Lee 2008). Ingestible sensor/telemetric systems have been validated in horses (Green et al. 2008) and in exercising Labrador dogs (Angle & Gillette 2011). Post-exercise rectal temperatures higher than core temperature may result from the heat generated by the major muscles of the hind quarters (Robertson 2012) and this trend was revealed in the current study. Although, in a previous study of exercising Labrador dogs the CorTemp system was satisfactory (Angle & Gillette 2011), the current study found it was not reliable in greyhounds. Due to the weight (200g) and dimensions (120x60x25mm) of the data recorder it was difficult to stabilise on the relatively narrow, dorsal thoracic surface of greyhounds, when they were exercising at speed. The Labrador dogs studied by Angle and Gillette (2011) exercised at speeds of 2.6 metres/second whereas galloping greyhounds travel at >15metres /second (Usherwood 2005) with vigorous flexion and extension of the torso. If miniaturisation of the data recorder could be achieved, the CorTemp system might offer potential for monitoring body temperature in greyhounds and other sporting dogs.

Infrared thermography has been used in non-domestic species since 1940 and in veterinary medicine since 1950 (Hilsberg-Merz 2008) and thermal imaging has been used during human epidemics, for screening crowds to identify individuals with elevated temperatures (Chan et al.
2004; Chiu et al. 2005). Thermography has also been used as a diagnostic modality for detecting musculoskeletal injuries in horses (Bathe 2011; Soroko & Jodkowska 2011; Turner 2001) and as a predictive tool for identifying febrile calves (Schaefer et al. 2004) and ponies (Johnson et al. 2011). As thermography has been proposed as a suitable method for assessing skin temperature in human athletes (Costello et al. 2013), and has been used to detect differences in greyhound muscle temperature (Vainionpaa et al. 2012), a thermographic scanner at racetracks might offer an effective, non-contact method of body temperature measurement of greyhounds.

It was concluded from this preliminary study that a digital rectal thermometer with a rigid structure would provide the most reliable method of body temperature measurement in a racetrack environment. This finding is in accord with that of Moran and Mendal (2002) who described the use of rectal temperature as the gold standard for human athletes. However, as it was anticipated that to trainers, in a racetrack situation, use of an aural thermometer might be more acceptable than a rectal thermometer, further usage of the aural thermometer was planned.

### 3.7 References


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Chapter 4: Influence of environment at racetracks on body temperature of greyhounds.

Introduction
Muscular activity generates heat as a by-product of ATP production and utilization. When the ambient temperature nears or exceeds body temperature, heat can only be lost by evaporation, which in dogs is achieved via the respiratory tract (Schmidt-Nielsen, Bretz & Taylor 1970). During strenuous exercise the respiratory rate increases, thus facilitating heat transfer, however, high levels of humidity may restrict the amount of heat lost. As heat stress has been identified as a risk for human and equine athletes (Geor, McCutcheon & Lindinger 1996; Howe & Boden 2007; Lindinger 1999), it is probable that canine athletes are also at risk. Increases of up to 2.1°C in the surface temperature of some leg muscles of greyhounds, after exercise in moderate ambient temperatures (13.1–23.3°C) have been recorded (Vainionpaa et al. 2012) and although Bjotvedt, Weems and Foley (1984) concluded that greyhounds racing in environmental temperatures of 42°C were at risk of heat stroke, there has been no further investigation into the effects on greyhounds, of exercising in high ambient temperatures (Ta).

Rhabdomyolysis may be a consequence of both strenuous exercise (Brancaccio, Lippi & Maffulli 2010) (Chatzizisis et al. 2008) and heat strain (Nichols 2014). Severe heat strain (heat stroke) comprises multi-organ failure which involves impairment of cellular function, denaturing of proteins (both structural and enzymatic) and disruption of lipid membranes: the syndrome
resembles systemic inflammatory response syndrome (SIRS) (Lugo-Amador, Rothenhaus & Moyer 2004). Exercise-induced muscle fibre damage has been reported in humans (Knochel 1990; Moghtader, Brady & Bonadio 1997; Sinert et al. 1994) and animals (Freestone & Carlson 1991; Lopez-Rivero 2000; Piercy et al. 2001; Wilberger et al. 2015). Muscle fibre damage may be detected by the presence of myoglobin in urine (myoglobinuria) (Cervellin, Comelli & Lippi 2010; Shelton 2004)

Post-exercise myoglobinuria has been widely reported in human (Knochel 1990; Schiff, Macsearraig & Kallmeyer 1978; Sinert et al. 1994) and equine (Freestone & Carlson 1991) (van Oldruitenborgh-Oosterbaan, van den Boom & Grinwis 2006) athletes. It has also been reported in greyhounds (Ferguson & Boemo 1998) but the incidence is unknown and the levels of myoglobin excreted have not been quantified. As myoglobinuria may result from both strenuous exercise and heat illness it was hypothesized that greyhounds exercising in hot conditions would produce high levels of myoglobinuria.

The hypotheses tested in this study were; 1) that body temperature would increase more when greyhounds raced in hot environmental conditions than in cool conditions; 2) that elevated humidity would also result in higher body temperature; and 3) that use of cooling jackets would reduce the degree of post exercise hyperthermia in greyhounds.

This study also sought to determine the incidence and levels of post-exercise myoglobinuria in racing greyhounds and to determine if associations existed between ambient temperature, race distance, dogs' level of fitness, sex, bodyweight or post-exercise body temperature and the levels of myoglobin excreted in urine.
It is acknowledged that, as the studies described in this and the following chapters were conducted in a commercial environment, it was not possible to control study conditions and access to animals and time available to measure parameters were often restricted.

4.1 Background

The climate of the more populated districts of South Australia is described as Mediterranean with cool wet winters and hot dry summers (Atlas of South Australia). In summer, mean maximum daily temperature for the capital city, Adelaide (Latitude 34° 50’S – Longitude 138° 30’E) is 29°C (Australian Government Bureau of Meteorology 2013).

The pool of racing greyhounds in South Australia fluctuates, as dogs commence or terminate their racing careers and move between states. Greyhounds are privately owned and may be trained by their owners or by professional trainers and are transported to racetracks for meetings. Owners and trainers must be licensed by Greyhound Racing South Australia (GRSA) and their kennels must comply with the Code of Practice issued by GRSA (Greyhound Racing South Australia 2011). Racing is conducted throughout the year. At the time of commencement of this study there were eight racetrack venues (Figure 4-1), three of which Barmera, Port Augusta and Virginia, did not conduct race meetings during January and February. All racetracks with the exception of Virginia were oval tracks. The Virginia track was straight and only held lure coursing events. Race meetings were conducted three times per week at both Angle Park and Gawler but at approximately fortnightly intervals at other tracks.
Figure 4-1 Map of South Australia showing locations of racetracks attended.

On oval tracks, seven to twelve races were programmed per meeting and eight greyhounds (plus two reserves) were drawn to compete in each race. At lure coursing meetings six to ten
events were held, each of which included from 4 to 32 runners which were drawn to run off in pairs. Winners of each course proceeded to the next round until the surviving pair contested a final. Race fields were published three to four days prior to a meeting and could be viewed online at http://sa.thedogs.com.au. At the Virginia straight track, lure coursing meetings were only held between April and October and meetings commenced at 9.30am and finished by 2pm. At other tracks, races were scheduled between 12 noon and 11 pm and all greyhounds engaged at a meeting were presented for inspection prior to kennelling and required to be kennelled at least thirty minutes prior to the first race on the programme.

Pre-kennelling inspection entailed an identity check of each greyhound by colour, markings, ear tattoo and/or microchip number. Every greyhound was then weighed and underwent a brief veterinary inspection for health and racing suitability. Each oval racetrack had a kennel house which contained 80-120 individual kennels arranged in blocks of 8 to accommodate the runners in each race. Following inspection each greyhound was confined in an allocated kennel until approximately ten minutes prior to its race start time. At the Virginia racetrack, greyhounds were confined in their transport vehicles for the duration of the meeting.

4.2 Materials and methods
An observational study was commenced in 2010 to record temperature and humidity at racing venues around South Australia and to record body temperature changes of greyhounds competing in races. The effect of cooling jackets on greyhounds’ body temperature was investigated and urine samples from greyhounds were subjected to urinalysis for the presence of myoglobin. Animal ethics approval was provided for this study by the University of Adelaide Animal Ethics Committee.
4.2.1 Venues

Forty-six race meetings were attended at seven different venues and at different times of the year as listed in Table 4-1. One track was straight (Virginia) and the other six were oval with various radii and circumferences. Races were conducted over distances from 295-731 metres.

<table>
<thead>
<tr>
<th>Track</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle Park</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Gawler</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strathalbyn</td>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barmera</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Pirie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Port Augusta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Two race tracks (Port Augusta and Virginia) had grass surfaces and five (Angle Park, Barmera, Gawler, Port Pirie and Strathalbyn) had sand/loam surfaces (Figure 4-2).
Environmental monitoring

Ambient conditions inside the kennel houses and trackside were monitored with a weather station (La Crosse technology, wireless 433MHZ Weather Station) as described in Chapter 3. Kennel house conditions were measured by the monitor placed approximately 1.2m above ground level in the kennel area. Trackside conditions were measured by the outdoor monitor placed 1.2-1.8m above ground level adjacent to the track, at a readily accessible location. Temperature and relative humidity were manually recorded at the start time of each race in which a selected greyhound was competing. Cloud cover was recorded in oktas on a scale 0-8 on which 0=nil cloud and 8=complete cloud cover (Rakesh, Stallings & Reifman 2014). Some races were conducted after dusk which was recorded as 10.
4.2.3 Thermometers

Temperatures were measured as described in Chapter 3 (3.2.6) using an aural veterinary thermometer (Vet-Temp VT-150; Advanced Monitors Corporation, San Diego, California, USA), a hand held infra-red thermometer (ZyTemp TN408LC HsinChu, Taiwan 300) and a rectal clinical veterinary thermometer (Vicks Speed Read digital thermometer).

4.2.4 Cooling jackets

The use of cooling jackets on greyhounds at racetracks, in temperatures >30°C, has been encouraged by GRSA for over four years (P. Marks, personal communication, January 2014). The jackets used during this study (Cool Champions, Silver Eagle Outfitters http://www.coolweave.com.au) are composed of a layer of batting (containing both hydrophilic and hydrophobic fibres) sandwiched between a thermally conductive inner layer and light outer layer (Figure 4-3). The jackets were soaked in iced water for 30 minutes prior to initial use and also between uses. The use of jackets was optional, ie at the discretion of trainers, prior to or after races.
4.2.5 Animals

The population of racing greyhounds in South Australia was approximately 1200 animals (G. Barber, GRSA personal communication, January 2010). On the day prior to a race meeting, the fields were accessed online at http://sa.thedogs.com.au and greyhounds were selected by random draw using Excel RANDBETWEEN function. If two greyhounds in the care of one trainer at one meeting were selected, for diplomatic reasons, a draw was repeated to select an alternative greyhound. Details of the age, sex, colour, sire, dam and previous race history of each greyhound was recorded from the published race fields (Appendix 3 Racetrack record sheet for greyhound).

For the purpose of this study, greyhounds were assigned a fitness score expressed in metres from 300–700m in 100m increments. The fitness score was based on the mode of the distance of the greyhound’s last three races or trials to the nearest 100m. From 246 races, 238 greyhounds were selected to participate in the study (134 male, 104 female) aged 18 months.
to 5 years (mean 2.6 years). One greyhound was selected three times and six greyhounds were selected twice. For the purpose of analysis each of these greyhound’s race starts was treated as a separate data point.

4.2.6 Procedure
At each race meeting, approximately 30 minutes prior to the commencement of greyhound admission, a list of the selected greyhounds was provided to the stewards officiating at the meeting and a copy was posted in a prominent position at the kennel house entrance. As the selected greyhounds were presented for identification checks, the trainer was advised of the selection and permission was sought for inclusion in the study. Some trainers declined to include some of the pre-selected greyhounds because of perceived temperamental unsuitability. All participating trainers read and signed a consent form (Appendix 1). Each participating greyhound was weighed and its weight recorded to the nearest kilogram and then had its temperature recorded as arrival temperature. Greyhounds were subsequently confined in their allocated kennels up until approximately ten minutes prior to their race start time.

Each greyhound was then collected from its allocated kennel and had a racing vest fitted, underwent identity check by stewards and was then taken outdoors to relieve itself. Urine samples were collected by voluntary voiding from 182 greyhounds at this point. Rectal temperature was then recorded (pre-race temperature). After completion of a race, greyhounds were collected by their handlers and returned to the kennel house and each greyhound’s temperature was again recorded (post-race temperature). This time point was between two and three minutes after greyhounds ceased to run. All greyhounds then underwent hosing with cool/cold water and were allowed to drink from a hose prior to being returned to their allocated kennels. An attempt was made to follow up each greyhound to collect a second urine sample.
before the greyhound left the racetrack. Post-race urine samples were collected from 203 greyhounds. Rectal temperature before and after racing was obtained for 229 dogs (131 male, 98 female).

4.2.7 Urinalysis

Matched pre- and post-race urine samples were collected by voluntary voiding from 177 greyhounds, 104 male, 73 female: (a) in the immediate pre-race exercise period: and (b) as the greyhounds were leaving the track. Post-race samples were obtained between 30 minutes and three hours after racing, time dependent on the trainer’s schedule. Urine samples were transferred from the collecting ladle into specimen containers immediately after collection and placed on ice for transport, then refrigerated for up to 12 hours prior to screening. Screening was conducted in the laboratory where 3 ml aliquots of urine were centrifuged at 3000rpm for 5 minutes to remove red blood cells. Reagent strips (Siemens Multistix 10 SG) were then immersed in the supernatant urine and read following the manufacturer’s protocol. Results for blood/haemoglobin are expressed as trace, 1+, 2+, 3+ (1+ equivalent to 0.030-0.065mg/Dl). The manufacturer states that the test is equally sensitive to myoglobin as to haemoglobin. Samples were then stored frozen at -20° C for up to 12 months. Subsequently, 87 urine samples (77 which tested positive for blood/haemoglobin, 7 which tested negative and 3 unknown) were thawed and subjected to enzyme linked immunosorbent assay (ELISA) using Dog Myoglobin (Life Diagnostics, Inc.) according to the manufacturer’s procedure and the microplates were read with a spectrophotometer (Benchmark Plus BIO-RAD) at 450nm. Duplicate ELISA tests were conducted on 100 samples (same plate) and triplicate tests (different plates) were conducted on 5 samples.
4.2.8 Statistical analysis
Data was analyzed with GraphPad Prism 6. Linear regression analysis was conducted to
determine the association between shade temperature and relative humidity on rectal
temperature at three time points: a) on arrival; b) pre-race; and c) post-race. Linear regression
analysis was also used to determine any association between ambient temperature, race
distance, dogs' level of fitness, bodyweight or post-exercise body temperature and post-
exercise urine levels of myoglobin. Residuals were inspected for normality in distribution using
the D'Agostino-Pearson test. Unpaired t-tests with Welches correction were conducted to
determine sex based differences in urine myoglobin and the effects of cooling jackets worn
post-race. A Wilcoxon matched-pairs, signed rank test was used to assess significance of
rectal temperature increases. A level of significance of $P < 0.05$ was used throughout.

4.3 Results

4.3.1 Environmental conditions.
Ambient (shade) temperature was recorded at each dog race start and the temperature ranged
from 11.0°- 40.8°C. Relative humidity was also recorded at each dog race start and ranged
from 17-92%. Climatic conditions for all race starts are summarised in Figures 4-4, 4-5.
Figure 4-4 Ambient temperature and relative humidity recorded at racetracks.

Figure 4-5 Relationship between ambient temperature and relative humidity recorded at racetracks.
4.3.2 Body temperature.

In the first 56 greyhounds, body temperature was taken with aural and rectal thermometers. Six of those greyhounds expressed discomfort by flinching and vocalizing at use of the aural thermometer, so its use was discontinued and results are not presented. Mean rectal temperature on arrival was $39.15^\circ C \pm 0.46$ ($38.20-40.50^\circ C$) (Figure 4-6).

![Histogram of Rectal Temperature](image)

**Figure 4-6** Rectal temperature of 229 greyhounds recorded on arrival at race meetings.

*Effect of ambient temperature*

No significant effect of shade (ambient) temperature on rectal temperature on arrival was detected ($P = 0.99$)
Figure 4-7 Rectal temperatures of greyhounds recorded (a) pre- and (b) post-race.

Rectal temperature before and after racing was recorded for 229 greyhounds (Figure 4-7). Mean post-race temperature was 41.0 ± 0.48°C (39.7-42.1°C). There was an increase in rectal temperature in all dogs, with a mean increase of 2.1 ± 0.4 °C (P= 0.0001) (Figure 4-8).

Figure 4-8 Increases in greyhounds’ rectal temperatures recorded post-race.
There was a small but significant relationship between shade temperature and rectal temperature ($r^2 = 0.023$, $P = 0.03$) and the increase in rectal temperature ($r^2 = 0.033$, $P = 0.007$) following racing (Figure 4-9).

Figure 4-9 Relationship between shade temperature and (a) post-race rectal temperature and (b) increase in rectal temperature.

An inverse relationship between pre-race rectal temperature and the increase in rectal temperature after racing was determined (Figure 4-10).
Effect of relative humidity.

Relative humidity (RH) ranged from 17-92% with an inverse relationship to ambient temperature which is typical of a Mediterranean climate (Fig 4-5). No association between RH and post-race rectal temperature was apparent (P = 0.5).

Effect of race distance

No association between race distances and levels of post-race rectal temperature was found (P = 0.4).

Effect of dog fitness

No association was detected between dogs' levels of fitness and levels of post-race rectal temperatures (P = 0.7).
4.3.3 Cooling jackets

An unpaired t-test with Welch’s correction of post-race rectal temperatures of greyhounds which raced in temperatures >30°C and wore (N=41) or did not wear (N=80) jackets, revealed a significant difference (P = 0.04, $r^2 = 0.04$) (Figure 4-11). Mean 41.19 ± SEM 0.06°C vs 41.01 ± SEM 0.06°C.

![Figure 4-11 Rectal temperature of greyhounds post-race ± cooling jackets showing mean ± SEM.](image)

4.3.4 Critical temperatures

As 41.5°C has been suggested as a critical body temperature for precipitating heat illness in dogs (Aroch et al. 2009; Bruchim et al. 2006; Drobatz & Macintire 1996; Flournoy 2003; Johnson, McMichael & White 2006), dogs were allocated into two groups using post-race Tre $>$41.5°C as the delimiter. The mean shade temperature at race time of dogs with post-race Tre $>$41.5°C was significantly greater (31.2°C ± 1 N=40) than the mean shade temperature
(27.3°C ± 0.5 N=189) at race time of dogs recording Tre <41.5 (unpaired t-test, t=2.9, df = 227, P = 0.004) (Table 4-2).

**Table 4-2 Relationship between ambient (shade) temperature and post-race temperature of greyhounds.**

<table>
<thead>
<tr>
<th>Ambient Temperature °C</th>
<th>Number of race starts</th>
<th>Mean post-race rectal temperature °C</th>
<th>Mean increase in post-race rectal temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 30</td>
<td>126</td>
<td>40.9 ± 0.44</td>
<td>2.12 ± 0.16</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>103</td>
<td>41.5 ± 0.49</td>
<td>2.19 ± 0.40</td>
</tr>
</tbody>
</table>

When the percentage of greyhounds with post-race Tre >41.5°C was plotted against ambient temperature, a marked increase in the % dogs with Tre>41.5° was noted when Ta exceeded 36° and when Ta reached 38°C, 39% of dogs had Tre >41.5°C (Figure 4-12).

![Figure 4-12 Relationship between ambient temperature and the percentage of greyhounds with post-race rectal temperature >41.5°C.](image)
4.3.5 Urinalysis

Fifty-seven percent (100/177) of post-race urine samples provided positive dipstick readings for haemoglobin/myoglobin (Tables 4-4, 4-5). Myoglobin levels detected in post-race urine samples ranged from 3-402ng/ml. Linear regression analysis showed no association between urinary myoglobin levels and ambient temperature ($P = 0.74$), race distance ($P = 0.29$), dogs’ level of fitness ($P = 0.37$) or post-exercise body temperature ($P = 0.93$). A marginally significant association between dog bodyweight and myoglobin levels was detected ($P = 0.05$). As variances of male and female myoglobin levels were significantly different ($P = 0.0003$) an unpaired t-test with Welch’s correction was conducted. A significant difference ($P = 0.02$) in myoglobin levels was detected (male $73.17 \pm 7.76$ ng/ml, female $128.20 \pm 20.15$ ng/ml).

Table 4-4 Results of dipstick test for blood, haemoglobin or myoglobin in post-race urine samples.

<table>
<thead>
<tr>
<th>Screened</th>
<th>Total positive haemoglobin</th>
<th>$\geq 2^6$ ng/ml haemoglobin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>104</td>
<td>70</td>
</tr>
<tr>
<td>Female</td>
<td>73</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 4-5 Myoglobin results from 87 urine samples

<table>
<thead>
<tr>
<th>Dipstick result</th>
<th>Positive Myoglobin</th>
<th>Negative Myoglobin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive blood/haemoglobin</td>
<td>77</td>
<td>73</td>
</tr>
<tr>
<td>Negative blood/haemoglobin</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Unknown blood/haemoglobin</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

4.4 Discussion

4.4.1 Environmental conditions and body temperature

The current study revealed a small but positive association between ambient temperature and post-exercise body temperature. However, no significant effect of relative humidity on rectal temperature was demonstrated. These findings are in accord with those of Bjotvedt, Weems and Foley (1984) which had indicated that greyhounds performing in temperatures above 107°F (42.0°C) were at risk of heat stroke. Although intense exercise is generally estimated to cause an increase in metabolic rate of 10 -14 times the BMR (Schutz 2005), increases in metabolic rate of up to 25 times BMR have been recorded in some canine species (Gerth et al. 2010; Gorman et al. 1998) and dissipation of the resultant heat generated may pose a particular challenge. Susceptibility to heat illness may vary between breeds of dog as ambient temperature has not been shown to affect rectal temperature in exercising Labrador retrievers (Matwichuk et al. 1999), however, that study was conducted in a temperature range of 11.0–28.0°C. In contrast, Phillips, Coppinger and Schimel (1981) found a significant correlation (r=0.821) between T₄ and Tₑ in sled dogs working in ambient temperatures -9.0 – 25.0°C.
In the current study, greyhounds competed in temperatures between 11.0-40.8°C. The mean increase in rectal temperature of 2.1°C was remarkable in view of the short duration of the periods of exercise although a similar increase in the surface temperature of the gastrocnemius muscle has also been recorded (Vainionpaa et al. 2012). However, as greyhounds expend almost as much energy in the first 7.5 secs of a race as in the subsequent 22 secs (Staaden 1984), it is not surprising that body temperature may increase markedly in a short period of time. Most of the studies on hyperthermia in human and equine athletes have focused on hyperthermia as a result of prolonged periods of exercise. However, Drobatz and Macintyre (1996) in their review of 42 clinical cases of heatstroke in dogs, remarked on the degree of morbidity after relatively short (20-30 minute) periods of exercise, which suggests a high degree of susceptibility for dogs, compared to other species. In the current study, the period of strenuous exercise was between 15-45 seconds for distances 295-730m. Additional activity was low intensity and was restricted to a total period of less than 15 minutes during which greyhounds were removed from holding kennels, approximately 10 minutes prior to scheduled race start time and walked to the starting boxes, two minutes prior to the race. Greyhounds, bred and trained for racing, may develop an increase in rectal temperature (from resting levels) due to anticipation of activity (Gillette et al. 2011). During the current study greyhounds were seen to exhibit varying levels of excitement in the pre-race period, demonstrated by fine tremors or vigorous activity such as pulling or bouncing. The muscular activity involved in such behaviour would generate heat and may have contributed to the increases in rectal temperature recorded. However, the inverse relationship between pre-race rectal temperature and increase in rectal temperature found in the current study, illustrates the effectiveness of the thermoregulatory system, even under significant challenge.
4.4.2 Critical temperature

Many authors (Aroch et al. 2009; Bruchim et al. 2006; Drobatz & Macintire 1996; Flournoy 2003; Johnson, McMichael & White 2006) consider a rectal temperature $\geq 41.5^\circ$C to be a critical level for initiation of heat illness in dogs. During the current study, 45 greyhounds recorded a post-race rectal temperature $\geq 41.5^\circ$C which if not reduced, would place them at risk of heat illness. The mean ambient temperature at the time of these races was 31.2°C which was 4°C greater than the mean ambient temperature at race time for greyhounds recording a rectal temperature $< 41.5^\circ$C. Therefore, 31°C might represent a threshold for risk estimation for heat stress in racing greyhounds. Such a threshold might be broadly accepted by participants in the greyhound racing industry, as there is a common perception amongst trainers of greyhounds that, at ambient temperatures $> 30^\circ$C, the animals show signs of thermal stress such as panting, which concurs with evidence from experimental settings (Goldberg, Langman & Taylor 1981). However, as in South Australia there are $> 80$ days in summer with maximum daily temperature $> 30^\circ$C (Australian Bureau of Meteorology) setting 31°C as a threshold for cancelling race meetings would represent major disruption to the industry. Thiele and Albers (1963) asserted that 36°C is the temperature at which thermal equilibrium can only just be maintained by dogs. In the current study, the percentage of greyhounds recording post-race $T_{re} \geq 41.5^\circ$ increased in gradual linear fashion, with increasing ambient temperature up to 36.0°C and a sharp rise when shade temperatures reached 38.0°C. As 38.0°C is within the normal range of body temperature for dogs, the sharp increase in the number of greyhounds with temperature $> 41.5^\circ$C when ambient temperatures neared 38°C, is in accord with the widely accepted view that, in environments at or above body temperature, thermoregulation is difficult.
No significant effect of relative humidity on rectal temperature was demonstrated in the current study. However, as the climate of South Australia is described as Mediterranean (Atlas of South Australia), with an inverse relationship between temperature and humidity, days with concurrent elevation of both factors are rare. In areas with a tropical climate, humidity might impose greater challenges. In exercising horses, the rate of increase in temperature of blood, measured in the pulmonary artery, is significantly higher in hot, humid conditions than in either hot or cold, dry conditions (Geor et al. 1995). Sports Medicine Australia, which is Australia’s peak advisory body on medical and health issues for active people, advises consideration of humidity levels amongst its recommendations for the management of human sporting events in hot weather (Sports Medicine Australia 2013).

4.4.3 Cooling jackets

The use of cooling jackets on greyhounds at racetracks, when temperatures exceed 30°C, has been encouraged for over four years (P. Marks, personal communication January 2014), however their use has been fairly limited. During the current study, there appeared to be reluctance by some trainers to use them, either because of a belief that they were uncomfortable for the dogs or because of a perception that the time taken to don the jackets was wasted. Results of this study revealed the unexpected finding that the mean rectal temperature of dogs wearing jackets post-race was slightly higher than those dogs which did not. However, as cooling jackets of a different type have been demonstrated to be effective in reducing the duration of post-exercise hyperthermia in military dogs (Robertson & Cooke 2012), the use of cooling jackets might be advantageous as a management option for greyhounds in the period after racing. Although pre-competition use of ice jackets has been effective in reducing the degree of body heating in human athletes (Hunter, Hopkins & Casa
post-exercise use of ice jackets has not been shown to be advantageous in hyperthermic athletes (Lopez et al. 2008). A more detailed, controlled study of cooling jackets for greyhounds is warranted.

Alternative methods of estimating thermal stress in racing greyhounds might include panting score such as used for sheep (Hales & Hutchinson 1971) and cattle (Gaughan et al. 2008). However, in dogs, panting is utilised, not only to maintain homeothermy (Baker & Turlejska 1989) but may occur as a result of exercise (Flandrois, Lacour & Osman 1971; Kozlowski et al. 1985), arousal (Gillette et al. 2011) or anxiety (Dreschel & Granger 2009). As this study was conducted at racetracks, all of the above factors could have influenced panting rate, so it was not practical to utilise panting rate as an indicator of heat stress.

4.4.4 Urinalysis

Rhabdomyolysis has been recorded as a result of strenuous exercise in greyhounds (Bjotvedt, Hendricks & Weems 1983; Lording 1989) and rhabdomyolysis may also result from hyperthermia (Bosch, Poch & Grau 2009). It could therefore be expected that greyhounds undertaking strenuous exercise in hot conditions would be at increased risk of developing rhabdomyolysis and myoglobinuria. Myoglobin is a small haemprotein which is released into plasma after muscle fibre rupture; plasma levels fall rapidly, as it is excreted into urine (Bosch, Poch & Grau 2009). As myoglobin is recognized as being nephrotoxic (Cervellin, Comelli & Lippi 2010) it is possible that repeated exposure to significant levels would have a cumulative effect and that such exposure might contribute to the high incidence of renal disease seen in greyhounds (D. Fegan, personal communication 2013).

The higher levels of myoglobinuria found in female subjects was unexpected, as previous studies have shown that female animals generally suffer less muscle damage than males
(Clarkson & Hubal 2002), although female horses are reported to be more frequently affected by exertional rhabdomyolysis than males (MacLeay et al. 1999; Upjohn et al. 2005). A number of studies have demonstrated that female rats are less susceptible to exercise induced muscle damage than males (Enns & Tiidus 2008; Komulainen et al. 1999). However, as the reduced susceptibility of female rats is attributed to a protective effect of oestrogen (Tiidus 2000) such an effect was unlikely to exist in the anoestrous female greyhounds in the current study (see Chapter 5). Indeed, as the use of testosterone propionate to prevent oestrous in female greyhounds, was permitted during the current study (Greyhounds Australasia 2013) it is possible that such use influenced the responses of some females to exercise. Alternatively, there may be a species related difference in response to exercise or even a breed specific response, as greyhounds exhibit other physiological and haematological variations from other breeds of dog (Campora et al. 2011; Shiel et al. 2007; Zaldivar-Lopez et al. 2011). During the current study, no data were collected on the use of testosterone or other permitted hormones nor on the natural hormonal status of the females, so further studies on the responses to exercise of male and female greyhounds are required, to adequately elucidate the topic.

4.5 Conclusions

It may be concluded that racing, or undertaking equivalent intense exercise, in hot weather carries an increased risk of greyhounds developing heat illness. The risk increases notably in ambient temperatures $\geq 38^\circ C$. 
4.6 References


Robertson, S & Cooke, K 2012, 'TURNING UP THE HEAT Effects of work on physiologic variables and body temperature in working dogs', Canine Sports Medicine Symposium, Florida, USA.


Chapter 5: Effects of phenotype on body temperature of greyhounds.

5.1 Introduction

Phenotypical factors such as breed, sex, bodyweight and coat colour may influence the response of animals, including humans, to environmental conditions. Breed differences in heat tolerance have been demonstrated in poultry (Arad & Marder 1982), cattle (Finch 1986; Gaughan et al. 2008), and sheep (McManus et al. 2009). Variations in thermal responses to climatic conditions have also been found between humans of different ethnicity (Nguyen & Tokura 2002; Wakabayashi et al. 2010).

Sex based differences in response to elevated temperatures and exercise have been demonstrated in humans over many years (Mehnert, Bröde & Griefahn 2002; Wyndham, Morrison & Williams 1965). Mehnert et al. (2002) observed highly significant differences in the sweat rates of male and female humans and proposed that such differences should be considered in the formulation of guidelines for prevention of heat illness in workers. A recent study by Druyan et al. (2012) on male and female defence force personnel, indicated that women might be less heat tolerant than men. Sex differences in the brain regions involved in thermoregulation of mice have been demonstrated by Hanada et al. (2009) and these authors suggested that sex differences might also be found in other species. Although interbreed differences in basal metabolic rate (BMR) have been demonstrated in dogs (Speakman, van Acker & Harper 2003), sex difference in thermo-tolerance does not appear to have been investigated.
There is a widely held lay opinion that black greyhounds are more stressed by high ambient temperatures than are other coloured greyhounds, a belief which might be supported by studies in other species. The white winter coats of arctic species have greater reflectivity than darker summer coats (Walsberg 1991) and in cattle, white coat colour increases heat tolerance over brown or black (Gaughan et al. 2008).

The basal metabolic rate (BMR) of mammals and resultant heat production increases with bodyweight (Hill, Wyse & Anderson 2008). With an increase in body mass there is a reduction in the ratio of body surface area to body mass and an increase in the distance from core to surface: both of these factors reduce the ability of an animal to dissipate heat and in exercising animals, may lead to greater heat accumulation (Hodgson et al. 1993).

Exertional heat illness has been reported more commonly in male than female human athletes (Kerr et al. 2013; Mueller & Colgate 2012). The population of racing greyhounds in South Australia is approximately 60% male and 40% female (T. Hayles, GRSA personal communication, June 2013). Sex limited races for greyhounds are seldom programmed so the majority of races include animals of both sexes. Greyhounds commence racing at or above 16 months of age and generally have a racing career of 18-24 months. Consequently the population of greyhounds participating in races has a relatively narrow age span of approximately two to four years of age. Five basic coat colours are recognized in greyhounds; black, blue (a dilute of black which can be pale to dark grey), brindle (dark stripes over a base colour producing black brindle, blue brindle, red brindle, dun brindle, fawn brindle, dark brindle, light brindle), fawn (dark fawn, light fawn, red fawn, blue fawn, or dun fawn) and dun which may range from a light blue fawn, through a rich red fawn, to a deep rich chocolate colour, with the dominating factor being a pink to brown coloured nose leather. Dun is extremely rare. Any
of these colours may be distributed over the body in patches over a white base and such greyhounds are described as parti-coloured (Fitzpatrick 1996).

It was hypothesized that: 1) greyhounds of greater body mass would develop higher body temperature as a result of strenuous exercise; 2) male greyhounds would develop higher temperatures than female greyhounds; and 3) greyhounds with dark hair coats would develop higher body temperatures when exposed to high environmental temperatures in sunlight.

5.2 Materials and methods

5.2.1 Pilot Study
A brief study was conducted to measure the surface temperatures of greyhounds with various coat colours.

5.2.1.1 Location
The location of the study was one kennel in the Barossa region of South Australia.

5.2.1.2 Thermometer
A hand held infra-red thermometer (ZyTemp TN408LC HsinChu, Taiwan 300).

5.2.1.3 Animals
One greyhound of each of the recognized colours (except dun), was selected (Figure 5-1). The surface temperature of the various coats was measured (a) in direct sunlight; and b) in full shade with a hand-held infra-red thermometer. Temperature was measured on the dorsal surface of each dog.
5.2.2 Racetrack study

An extended study was then conducted of a selection of racing greyhounds competing in scheduled races at racetracks in South Australia.

5.2.2.1 Locations

Locations were venues as described in Chapter 4, 4.2.1.

5.2.2.2 Environmental monitoring

Environmental monitoring was conducted as described in Chapter 4, 4.2.2.

5.2.2.3 Thermometers

Thermometers used were as described in Chapter 4, 4.2.3.

5.2.2.4 Animals

A total of 229 greyhounds were selected to participate in the study (131 male, 98 female) aged 18 months to 5 years (mean 2.6 ± 0.7 years). One greyhound was selected three times and six greyhounds were selected twice. Details of the age, sex and colour were obtained from the race programme and confirmed on inspection. Bodyweight was recorded each time a greyhound was presented for racing and a body score was assigned on a scale from 1 (lean) to 5 (obese).

In the greyhound industry, the generally accepted desirable weight range for racing dogs is 26-34 kg. For the purpose of analysis, the greyhounds were divided by bodyweight into four groups which are commonly used in the industry <26 kg, 26-30 kg, >30-34 kg, >34kg.

For the purpose of analysis in this study, any dog in with more than 50% white coat colour was classified as white, thus creating five colour groups (Figure 5-1).
5.2.2.5 Procedure
As described in Chapter 4.2.6, greyhounds’ temperatures were recorded within 5 minutes of race starts and within 3 minutes of the end of races.

5.2.2.6 Statistical analysis
Statistical analyses were conducted using SPSS version 21. A level of significance of P < 0.05 was used throughout. Data were inspected for normality in distribution using the D’Agostino-Pearson test. A mixed model which included the fixed effects of sex and colour and covariate of weight and sire as a random term was fitted to the increase in rectal temperature and the post-race rectal temperature data. There was no sire variance thus a general linear model was fitted to the data with the above fixed effects and covariate. Any significant (P<0.05) two-way interactions were retained in the model.
5.3 Results

5.3.1 Pilot study

No dun greyhounds were included in this study. In direct sunlight a difference of up to 13°C was noted between black and white coats on different dogs (45.0° and 31.9°C respectively) and a difference of 11°C was recorded between the brindle and white sections of a parti-coloured dog (43.0°C and 31.9°C respectively) (Figure 5-2). Out of direct sunlight (indoors) in an ambient temperature of 27.3°C, there was little variation between the surface temperatures of coats. (Table 5-1).

Table 5-1 Surface temperature of greyhound hair coats

<table>
<thead>
<tr>
<th>Coat Colour</th>
<th>In shade @27.3°C</th>
<th>In sunlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>30.1</td>
<td>45.0</td>
</tr>
<tr>
<td>Blue</td>
<td>31.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Brindle</td>
<td>31.2</td>
<td>43.0</td>
</tr>
<tr>
<td>Fawn</td>
<td>31.2</td>
<td>36.0</td>
</tr>
<tr>
<td>White</td>
<td>31.9</td>
<td>31.9</td>
</tr>
</tbody>
</table>
5.3.2 Race track study

Rectal temperature was recorded on arrival, pre-race (< 5 minutes prior) and post-race (<3 minutes post). Arrival temperature was recorded for 229 greyhounds, pre-race temperature was recorded for 232 greyhounds and post-race temperature was recorded for 229 greyhounds of colours as distributed in Table 5-2. The colour distribution was representative of the population racing in South Australia.
Table 5-2 Number of greyhounds of different coat colours.

<table>
<thead>
<tr>
<th></th>
<th>Black</th>
<th>Blue</th>
<th>Brindle</th>
<th>Fawn</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>115</td>
<td>23</td>
<td>28</td>
<td>26</td>
<td>37</td>
</tr>
</tbody>
</table>

5.3.2.1 Effect of coat colour

There was no significant difference in arrival or pre-race rectal temperature of the five colour groups (P = 0.5). However, mean post-race temperatures of the black, blue and brindle greyhounds were 41.06 ± 0.4 °C, 41.09 ± 0.5 °C and 41.08 ± 0.4 °C, respectively, which were significantly higher than the means of the fawn (40.86 ± 0.5 °C) and white greyhounds (40.79 ± 0.5°C; all P < 0.05) (Figure 5.3). When the dogs were grouped into two groups of dark (black, blue, brindle) and light (fawn and white) the mean increase in temperature of the dark coloured dogs (2.2±0.4°C) was significantly greater (P = 0.005) than the mean increase in temperature of the light coloured dogs (2.0±0.4°C). Post-race rectal temperatures of greyhounds racing in, (a) fully overcast /dark conditions (n = 31), or (b) sunlight (n = 131) showed no significant difference (P = 0.5).
5.3.2.2 Effect of Sex

Arrival rectal temperature was recorded for 128 males and 101 females. No significant sex related difference in arrival rectal temperature was found (P=0.897). Pre-race temperature was recorded for 132 males and 100 females. Mean male rectal temperature was 38.85°± 0.5°C and mean female rectal temperature was 38.81°± 0.3°C. Although there was a significant difference in variances of male and female pre-race temperatures, an unpaired t-test with Welch’s correction showed no significant difference between male and female pre-race rectal temperatures (P=0.456). Post-race temperature was recorded for 131 males and 98 females. A significant difference was found in post-race rectal temperature of male and female greyhounds (P = 0.004). Mean male post-race temperature was 41.08°± 0.5°C and mean female post-race temperature was 40.9°± 0.4°C (Figure 5-4).
Figure 5-4 Rectal temperatures recorded in greyhounds a) on arrival, b) pre-race and c) post-race showing median, minimum, maximum and 25th and 75th percentiles.
5.3.2.3 Effect of Bodyweight

In the greyhound industry, the generally accepted desirable weight range for racing dogs is 26-33.9 kg: 73% of the selected greyhounds were within this range (Figure 5-5). The mean bodyweight was 30.15kg ± 3.4. Mean male bodyweight was 32.50kg (median 32.00kg) and mean female bodyweight was 27.15kg (median 27.00kg). Neither sex was represented in all weight groups (Table 5-3). Three greyhounds were assigned a body score of 1.5 and 226 greyhounds were assigned a score of 2.

![Figure 5-5 Distribution of bodyweight of selected greyhounds.](image-url)
Table 5-3: Sex distribution in four weight groups of selected greyhounds.

<table>
<thead>
<tr>
<th>Bodyweight</th>
<th>&lt;26 kg</th>
<th>26-30kg</th>
<th>&gt;30-34kg</th>
<th>&gt;34kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0</td>
<td>10</td>
<td>82</td>
<td>39</td>
</tr>
<tr>
<td>Female</td>
<td>23</td>
<td>68</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Rectal temperature was recorded before and after racing for 229 greyhounds. A significant effect of bodyweight was noted on both actual rectal temperature (P=0.009) and the increase in rectal temperature (P=0.006) following racing (Figure 5-6).

![Figure 5-6](a) Relationship between bodyweight and post-race rectal temperature (P=0.009)

![Figure 5-6](b) Increase in rectal temperature (P=0.006) after racing.
5.4 Discussion

This study showed that post-exercise temperature was influenced by several phenotypic factors. A significant though weak relationship was found between bodyweight and post-exercise rectal temperature and also between bodyweight and the increase in rectal temperature. Coat colour was also found to have a significant association with post-exercise temperature, with greyhounds of dark colours developing higher rectal temperatures than light coloured greyhounds.

5.4.1 Colour

Of the sample greyhounds 50% were black; other colours represented were blue 10%, brindle 12%, fawn 11% and predominantly white 16%. The blue colour is a dilute of black and brindle consists of varying distributions of black and fawn stripes. Many greyhound trainers believe that black greyhounds are more susceptible to heat stress than other coloured dogs, as the trainers can feel temperature differences on the surface of their greyhounds. Palpable differences in the surface temperature of the greyhounds’ coats in sunlight were readily apparent to the researcher and these were confirmed by use of the infra-red thermometer which revealed up to 13°C difference in surface temperature between black and white coats. The finding that dark coloured (black, blue, brindle) greyhounds develop higher temperatures than light coloured (fawn and predominantly white) greyhounds is in keeping with findings in other species. Three naturally occurring colour morphs of antelope have differences in core temperature (Hetem et al. 2009) and McManus et al. (2009) who examined the tolerance of different breeds and colours of sheep, to heat stress in Brazil, concluded that breed, coat type (wool/hair) and coat colour were significant. A number of studies of production animals have revealed that, under heat stress, white coated animals can maintain lower body
temperatures than dark coloured conspecifics and that coat colour influences heat tolerance (Brown-Brandl, Eigenberg & Nienaber 2006; McManus et al. 2009). The differences have been attributed to the greater reflectivity of the white coats thus leading to less heat accumulation. In the current study, it was anticipated that dark coated greyhounds, racing in sunlight, might develop higher body temperatures than those racing in shaded or dark conditions, however no significant effect of sunlight was detected. It seems therefore, that direct solar radiation was not a significant contributor to the temperatures recorded. However, thermal radiation from the track surface and surroundings may have contributed to the higher temperatures recorded in dark coated dogs.

In cattle, not only does white hair have greater reflectivity than grey or red hair (Gaughan et al. 2008), differences in distribution density and structure exist between black and white hairs on Holstein cattle (Maia, da Silva & Bertipaglia 2005). Coat density and hair quality were not measured on the greyhounds included in the current study and no notable differences in the hair quality of black and white patches on parti-coloured greyhounds were apparent. However further study of coat characteristics in different body regions of greyhounds may be warranted to elucidate the topic.

As hair coat characteristics influence susceptibility to heat stress, other physiological systems, such as reproductive efficiency may also be adversely affected (Maia, da Silva & Bertipaglia 2005). In athletic humans an elevated surface temperature reduces the thermal gradient from the body core (Wakabayashi et al. 2010) and therefore leads to heat accumulation. As heat storage has been shown to be the principle limiting factor to intense exercise in cheetahs (Taylor & Rowntree 1973), it is probable that heat storage might similarly be a limiting factor to sprinting performance in greyhounds.
5.4.2 Sex

The sample of greyhounds included in this study comprised 57% male and 43% female. No significant differences were recorded between the rectal temperatures of male and female greyhounds either on arrival or pre-race. Both mean post-race rectal temperature and mean increase in rectal temperature of male greyhounds post-race was significantly higher than female greyhounds. Sex based differences in body temperature could be a result of a number of factors such as sex hormones, body proportions, or thermoregulatory mechanisms. Although sex differences (principally of sweat rates) in response to thermal and exercise challenges have been reported in humans (Mehnert, Bröde & Griefahn 2002; Wyndham, Morrison & Williams 1965) until recently, it was unclear whether such differences were due to physical characteristics, level of fitness or to the mechanisms of temperature regulation (Burse 1979; Gagnon & Kenny 2012). The principle mechanism of heat loss in humans is sweating and considerable efforts have been directed at examining gender differences in sweating and sudomotor responses (Frye & Kamon 1983; Gagnon & Kenny 2011). However, as sweating is not utilized as a heat loss mechanism in canines, it is not valid to attempt to extrapolate from such studies.

The influence of oestrogen and progesterone on core temperature during the menstrual cycle of women has long been recognized (Webb 1986). Complex interactions between norepinephrine and oestrogen have been elucidated in the brain of women whereby oestrogen raises the sweating threshold and norepinephrine narrows the thermoneutral zone by initiating heat dissipation (Freedman 2014). Hanada et al. (2009) identified receptor activator of necrosis factor kB ligand (RANKL) and its tumour necrosis factor
receptor (RANK) as key factors of central control of thermoregulation in female but not male mice and suggested that, in murine species, female thermoregulation is, in part, regulated by ovarian sex hormones.

In Australia, female greyhounds are not permitted to race whilst in oestrous or for 28 days post oestrous (Greyhounds Australasia 2013) and reduced performance in the dioestrous period of <91 days has been reported (Payne 2013). Therefore, racing female greyhounds can be assumed to be in late dioestrous or anoestrous with relatively low levels of circulating oestrogen and progesterone (Noakes et al. 2001). In the current study no record was kept of the hormonal status of participating bitches. The higher post-race temperatures recorded by males appeared to confirm the initial hypothesis that male greyhounds would develop higher temperatures than female greyhounds; however, multiple regression analysis indicated that the effect may have been partly due to the greater body weight of male greyhounds.

5.4.3 Bodyweight

Many of the studies on thermoregulation and exercise in humans have investigated the differences which might be attributable to anthropometric features such as body proportions and fat distribution (Havenith & van Middendorp 1990; Thiele & Albers 1963; van Rosendal et al. 2010). It is generally accepted that lean animals may more readily dissipate heat than obese animals, as in the latter, sub-cutaneous fat impedes heat transfer to the environment (Christopherson & Young 1981). However, Ardevol et al. (1998) found that, during exercise, both muscle temperature and core temperature increased more in lean rats than obese rats. Ninety- eight percent of the greyhounds in this study had a body condition score of 2
and as sex differences in body proportions have not been reported in greyhounds, variations in body fat or proportions were considered unlikely to affect results.

Mean bodyweight of the greyhounds in this study was 32.2kg. No male greyhounds weighed less than 26kg and no female greyhounds weighed more than 34kg. The positive relationship between bodyweight and both post-race rectal temperature ($r^2 = 0.04$, $P = 0.009$) and the increase in rectal temperature following racing ($r^2 = 0.05$, $P=0.006$) may be attributed to the amount of energy which is utilized during activity. As the energy requirements to move a body, increase with an increase in bodyweight (Leibel, Rosenbaum & Hirsch 1995), metabolic heat production also increases. In both birds and mammals, the energetic cost of exercise is related to both body mass and speed (Buresh, Berg & Noble 2005; Taylor, Schmidt-Nielsen & Raab 1970). In humans, metabolic heat production resultant from muscle contraction creates an internal heat load proportional to exercise intensity (Cheuvront & Haymes 2001; Duffield, Coutts & Quinn 2009). Although the periods of exercise of the greyhounds were limited to <45secs maximum effort, as greyhounds have a high proportion of muscle (Gunn 1978) and the rate of heat accumulation in muscle increases with intensity of work (Hodgson et al. 1993), it is apparent that greyhounds exercising at maximum effort generate a very high heat load. In a recent study, rats selected for high capacity running, exhibited high levels of energy expenditure and muscle heat dissipation (Gavini et al. 2014). The authors suggested that these effects might be due to intrinsic aerobic capacity and that similar expression of skeletal muscle proteins might be found in other species. However, greyhound muscle exhibits a high rate of anaerobic glycogenolysis (Dobson et al. 1988) so further research may be warranted in the area of greyhound muscle energetics and heat production.
5.5 Conclusion

Large, dark coloured greyhounds are at greater risk of developing high body temperature than small, light coloured greyhounds, when undertaking strenuous exercise in hot conditions. Pre- and post-exercise cooling should therefore be applied with particular care to large black, blue or brindle greyhounds to prevent development of heat strain.

5.6 References

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Chapter 6: Influence of kennel house environment

6.1 Introduction
Temperatures and humidity levels in animal housing are widely recognised as affecting the health and welfare of production animals (Banhazi et al. 2009; Christon 1988; Huynh et al. 2005; Purswell et al. 2012). A number of studies have been conducted to investigate the influence of housing and pen size on dog behaviour (Clark, Calpin & Armstrong 1991; Haverbeke et al. 2008; Hetts et al. 1992; Neamand et al. 1975). However, these studies focussed on long term effects and did not examine ambient temperature and humidity. Arousal, prior to anticipated exercise, may affect haematological values in sled dogs (Angle et al. 2009) and in greyhounds, trained to chase a lure, anticipation of chasing affects the vital signs of heart rate and respiratory rate and to a lesser extent, body temperature (Gillette et al. 2011).

It was hypothesised that: 1) ambient temperature and/or humidity in the holding kennels and kennel houses would influence the degree of increase in body temperature and level of post exercise body temperature in greyhounds and; 2) there would be considerable variation between the kennel houses and that both temperature and humidity might be considerably higher inside the individual kennels than in the traffic areas.

6.2 Background
The requirement for all greyhounds engaged in a race meeting, to be confined in kennels on the racetrack from 30 minutes prior to the start of the first race, is universal across all jurisdictions in Australia (Greyhounds Australasia 2015). The custom is driven primarily by
the need for secure supervision of the animals to maintain integrity but is also imposed for the sake of greyhound wellbeing and to permit effective employment of staff. However, kennel houses are not constructed to any defined standards and some have been erected and modified by volunteer labour over many years.

As a greyhound may have to spend up to five hours prior to its race start confined in a kennel, the conditions therein may affect its physiological state and consequently its performance. Many greyhounds exhibit signs of arousal such as barking, trembling, pawing and chewing when confined in racetrack kennels and dehydration with weight loss up to 1kg has been reported (Blythe & Hansen 1986). At the time of commencement of the current study Greyhound Racing SA lacked a formal policy on climate control in kennel houses.

6.3 Materials and methods

6.3.1 Venues

Conditions in racetrack kennel houses at six tracks as described in Table 6-1 were recorded.
<table>
<thead>
<tr>
<th>Track</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle Park</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Gawler</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strathalbyn</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barmera</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Port Pirie</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pt Augusta</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The racetrack kennel houses varied in construction. The Strathalbyn kennel facility was constructed with cavity block walls, galvanised roofing and plasterboard ceiling; Angle Park had walls and roof of galvanised sheeting with plasterboard ceiling and wall lining (Figure 6-1). The remainder had walls and roofs of galvanised sheeting without insulation. All had evaporative cooling systems installed. Banks of eight kennels were arranged to accommodate the greyhound runners in each race, with up to twelve banks in each kennel house. All kennels were at ground level to facilitate animal handling. Individual dog kennels measured 900x920x1000mm and were constructed of sheet metal walls and roofs with removable wooden floors. Doors were half mesh to permit ventilation and observation by staff (Figure 6-2).
Figure 6-1 (a) Interior kennel house Angle Park, (b) bank of eight kennels for one race Gawler kennel house.
6.3.2 Environmental monitoring

Environmental monitoring was conducted at the time of each dog race start as described in Chapter 4,

6.3.2.1 USB data loggers

On four occasions, two USB data loggers (EL-USB-2-LCD Lascar Electronics UK) were utilised to record temperature and relative humidity at 5 minute intervals, in the kennel.
area. These loggers were placed on top of dog kennels approximately 1.2m above floor level.

6.3.2.2 Ibuttons
The ibuttons (i-Wire hygrocron DS1923#F5) are temperature/humidity loggers which can be programmed to record at pre-determined intervals and the resulting data can be downloaded with a host computing device. At two race meetings (at Angle Park during March), temperature and relative humidity were recorded at 5 minute intervals with ibuttons (inserted into holes drilled into the internal frame of four kennel doors (Figure 6-3). In addition, over a period of four days, ibuttons were suspended approximately 1.2m above floor level, attached to chainmesh fences between blocks of kennels to record temperature and humidity at four hourly intervals.

![Figure 6-3 Kennel door showing location of ibutton (arrowed).](image)
6.3.2.3 Thermometers

Rectal temperature in dogs was measured with a clinical veterinary thermometer (Vicks Speed Read digital thermometer) which has a range 32.0-42.9°C and accuracy ± 0.1°C.

6.3.2.4 Animals

Greyhounds were selected as described in Chapter 4, Section 4.3.5

6.4 Results

6.4.1 Kennel house conditions

Kennel house temperatures and relative humidity were recorded on 244 separate occasions (75 at Angle Park, 16 at Barmera, 120 at Gawler, 23 at Strathalbyn and five at both Port Augusta and Port Pirie). Kennel house temperatures ranged from 13.7-32.0°C (mode 27.3°C). For 153 race starts (62%) the temperature was within the range 16-25°C which approximates the thermoneutral zone (TNZ) for greyhounds estimated by Hales & Dampney (1975). For 89 race starts (36%) the temperature exceeded 25°C (Figure 6-4).

![Figure 6-4 Frequency distribution of greyhound kennel house temperatures on race days.](image-url)
Relative humidity ranged from 38.0-83.0% with a mean of 62.5% and mode of 66.0% (Figure 6-5)

No measurements were recorded at Barmera during summer months and no measurements were recorded at Strathalbyn during winter months. There were significant differences ($P < 0.0001$) in temperatures and humidity in the four kennel houses at which 16 or more greyhound race starts were recorded (Table 6-2).

**Table 6-2 Temperature and % relative humidity recorded in greyhound kennel houses.**

<table>
<thead>
<tr>
<th>Track</th>
<th>Mean Temp °C</th>
<th>Range °C</th>
<th>Mean RH %</th>
<th>Range %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle Park</td>
<td>21.1</td>
<td>13.7-26.2</td>
<td>69.7</td>
<td>46.0-83.0</td>
</tr>
<tr>
<td>Barmera</td>
<td>20.4</td>
<td>15.0-26.0</td>
<td>58.1</td>
<td>49.0-72.0</td>
</tr>
<tr>
<td>Gawler</td>
<td>24.4</td>
<td>15.3-32.0</td>
<td>58.6</td>
<td>38.0-79.0</td>
</tr>
<tr>
<td>Strathalbyn</td>
<td>24.9</td>
<td>22.0-32.0</td>
<td>67.1</td>
<td>46.0-74.0</td>
</tr>
</tbody>
</table>
Subsequent monitoring of conditions in the Gawler kennel house by USB data-recorders revealed that on days when ambient outdoor temperature exceeded 30°C, temperatures inside the kennel house were over 25°C throughout the meetings (Figure 6-6, Figure 6-7).
Figure 6-6 Ambient conditions recorded by USB data logger in Gawler kennel house on 5th March 2013 when outside temperatures ranged from 33°C at the start of monitoring to maximum 37.5°C and 26°C at the end of monitoring.

Figure 6-7 Ambient conditions recorded by USB data logger Gawler kennel house on 12th March 2013 when outside temperatures ranged from 36.5°C at the start of monitoring to maximum 40.0°C and 30.5°C at the end of monitoring.
Ambient conditions were recorded in two locations inside the Gawler kennel house on 12/3/2013 using both the weather station and USB data logger. For security reasons, access to the banks of kennels was not permitted during the race meeting, therefore data were recorded by the USB logger. Conditions in the pre-race assembly area were recorded manually. Readings from both devices in the kennel house showed the greatest disparity at the commencement of the racing programme. At that time, temperature in the assembly area was 26.4°C vs 30.5°C in the kennel area and RH was 64% in the assembly area vs 49% in the kennel area. These differences might have been attributed to greater air movement in the assembly area during the admission process. However, as the race meeting progressed, readings from both devices showed good agreement (Figure 6-8).

Figure 6-8 Ambient conditions outdoors and in two locations in Gawler kennel house.
6.4.2 Effect of kennel houses on rectal temperatures of greyhounds

Over all kennel houses, rectal temperature on arrival and immediately before racing was recorded for 214 greyhound race starts. Mean rectal temperature on arrival was 39.15 ± 0.4°C (range 38.0-41.0°C). Mean pre-race rectal temperature was 38.8 ± 0.4°C (range 38.0-40.2°C). 48 dogs showed an increase in rectal temperature from arrival to pre-race, the mean increase was +0.4°C (range 0.1-1.3°C), 11 dogs recorded no change and in 155 dogs the rectal temperature fell between time of arrival and time of race start. The mean fall in rectal temperature was 0.3°C (range 0.1-1.9°C).

Linear regression analysis did not reveal any significant association between kennel house temperatures and pre-race rectal temperature over all kennel houses. However, a significant relationship was determined between kennel house temperature and post-race rectal temperature (P = 0.019), and the increase in post-race rectal temperature (P = 0.009) (Figure 6-9).

No significant relationship was found between kennel house RH% and rectal temperature pre-race (P = 0.62), post-race (P = 0.97) or on increases in rectal temperature (P = 0.69).
Figure 6-9 Relationship between kennel house temperatures and a) post-race rectal temperatures and b) increases in rectal temperature.

On two consecutive evenings in shade temperatures up to 40.9°C, ambient conditions in kennel houses of different construction at Strathalbyn (cavity block walls, plasterboard ceiling) and Gawler (galvanised sheeting walls, no ceiling) were monitored and pre- and post-race rectal temperatures were obtained for 16 greyhounds. A significant difference in kennel house temperatures was recorded (Strathalbyn mean 24.7± 0.4°C, Gawler mean 27.7± 2.2°C, P=0.002). For these two kennel houses linear regression analysis showed a significant association between kennel house temperatures and both pre-race rectal temperature (P=0.008) and post-race rectal temperature ($r^2=0.36$, P=0.014) (Figure 6-10)
6.4.3 Individual kennels

Ibuttons were installed in the kennels at Angle Park prior to a race meeting. The ibuttons were fitted in individual kennel doors in kennels numbered 8, 28, 64, 65 and above kennel 64 (Figure 6-11).

Figure 6-10 Relationship of temperature in two kennel houses (Gawler and Strathalbyn) to post-race rectal temperatures. Gawler mean 27.7°C SEM 0.78 and Strathalbyn mean 24.6°C SEM 0.16.
Temperature and humidity levels inside the individual kennels showed between kennel variations. Temperature in kennel 64 was consistently higher than in other kennels (mean 23.0°C vs 20.8°C) and RH readings in kennel 28 were >95.2%. However, as subsequent inspection of the channel in which the ibutton was situated (in kennel 28) revealed pooled water, these readings were discarded. RH readings in other kennels were in agreement with the RH readings from the ibutton above kennel 64 and with readings from the in-house data recorder (60-80%). Temperatures inside kennels 8, 28 and 65 were in agreement with readings from the ibutton above kennel 64 and with readings from the in-house data recorder, located adjacent to kennel 92 (18.5-21.9°C) (Figure 6-12).
Figure 6-12 Ambient conditions recorded in and around individual greyhound kennels at Angle Park kennel house.
6.5 Discussion

This study has revealed that conditions in which greyhounds are housed in the immediate pre-race period may affect the degree of hyperthermia post-exercise. These results are in keeping with studies in other species which have shown that interventions such as pre-cooling may affect both post-exercise temperature increase and performance (Epp et al. 2007; Reilly, Drust & Gregson 2006). The requirement for all greyhounds to be confined for periods up to 5 hours prior to competition entails two levels of environment; a) the kennel house; and b) the individual dog kennel. There are no recognised standards for the construction of kennel houses nor for conditions within. In the current study, design, dimensions and materials varied widely and although, in hot weather, climate control was managed with evaporative cooling systems, these were not standardised and monitoring of conditions was haphazard. During the current study, kennel staff were advised that if the forecast temperature was to exceed 25°C cooling systems should be turned on, at least an hour before kennelling commenced (P. Marks, personal communication, December 2014). Systems were set to maintain a temperature below 25°C and kennel house temperature was monitored by staff during race meetings with a variety of thermometers. Cooling systems could be adjusted if personnel considered it necessary and additional free standing fans were sometimes used. During this study, humidity levels were monitored by in-house systems, only at Angle Park where a free standing digital readout device displayed temperature and humidity. Despite attempts by GRSA to control kennel house conditions, no attempt had been made to monitor conditions inside individual dog kennels.
As the thermoneutral zone (TNZ) for greyhounds is 16-24°C (Hales & Dampney 1975), it would be appropriate for kennel houses to be maintained within this range, however, such was not the case. During the current study, kennel house temperatures ranged from 14°C - 32°C. During winter, it is customary for greyhounds to be clad in coats, except when exercising, and such garments may be worn in kennels, thus eliminating the need for heating. The use of clothing for greyhounds during the kennelling period is at the discretion of the trainers and was not monitored during the current study.

Mean rectal temperature of greyhounds on arrival was 39.15° SD 0.46 (range 38.2-40.5°C) which represents a 1°C increase over rectal temperatures measured in greyhounds in their home kennels (see Chapter 3). Such an increase could be attributed to arousal (Gillette et al. 2011) or to the conditions under which the greyhounds were transported. The absence of an effect of ambient temperature on rectal temperature on arrival was surprising, however, transport methods or duration of journey were not recorded in the current study. As it is customary for many trainers to implement some method of cooling greyhounds for transport at temperatures over 30°C it is possible that such practices influenced rectal temperatures recorded on arrival. In the majority of dogs (155/214, 72.4%) a decrease in rectal temperature occurred between time of arrival and time of race start, indicating that, most of the time, conditions in the kennel houses facilitated heat dissipation. However, in 48 dogs an increase in rectal temperature was recorded. Questioning of the handlers of these dogs revealed that the dogs customarily barked frequently during the kennelling period and such activity would cause an increase in body temperature (Gillette et al. 2011).

It is widely recognised by trainers and racetrack veterinarians that some greyhounds do not cope well with confinement in racetrack kennels prior to races. Weight losses of up to 900g
between arrival and race start have been reported (C. Doyle, personal communication, February 2013). Over 90% of greyhounds experience some weight loss during the pre-race period and up to 50% of greyhounds may lose more than 1% bodyweight (Blythe & Hansen 1986). The degree of weight loss increases with the period of pre-race kennelling (Blythe & Hansen 1986; R. Ferguson, personal communication 2013). Such weight loss can be attributed to salivation and evaporation from the respiratory tract during barking, resulting in dehydration. Dehydration has been identified by many authors as a factor which may predispose to heat stroke (Epstein et al. 1999; Howe & Boden 2007; Maughan & Shirreffs 2004; Montain & Coyle 1992; Murray 1996). Reduced body fluid levels may reduce the body’s ability to transfer heat from the body core (Baker 1984). Dehydration has been proposed as a precipitating factor for heat stress in human athletes, however, that concept has effectively been challenged by Noakes (2006) and no correlation between maximal \( T_{\text{CORE}} \) and level of dehydration has been detected in footballers (Godek et al. 2006). Dehydration \( \leq 2.4\% \) has not been shown to have an adverse effect on the performance of greyhounds (Blythe & Hansen 1986) however, controlled studies on levels of dehydration and performance may be warranted.

Although no significant association was detected between kennel house temperatures and pre-race rectal temperatures, the positive association between kennel house temperature and post-race temperature indicates that even a slight elevation in surface temperature may restrict heat loss by reducing the thermal gradient from core to surface. Pre-exercise cooling of humans by immersion in water <28°C or by water misting, reduces body heat content (Marino & Booth 1998; Mitchell, McFarlin & Dugas 2003) and post-exercise cooling of hyperthermic human athletes by immersion in cold and iced water is also effective (Armstrong et al. 1996;
It could therefore be supposed that maintaining greyhounds in a cooled environment would be an effective strategy for reducing exercise-induced hyperthermia.

During the current study, individual dog kennels were relatively standardised, with similar dimensions and construction materials. Some industry participants had suggested that the limited size of the individual kennels might restrict heat loss from the enclosed dogs and that conditions inside the kennels might be substantially different from conditions in the greater air space of the building. Results from the current study using ibuttons have not shown significant differences in temperature or relative humidity between individual kennels and the building environment.

In the South Australian climate, there generally is an inverse relationship between temperature and humidity (Australian Government Bureau of Meteorology 2013) which permits effective use of evaporative cooling systems. To date, all racetrack kennels in South Australia have been cooled by evaporative cooling systems. In the current study, the RH in the kennel houses was over 50% for 203 dog race starts. On the great majority of occasions (97%) kennel house RH exceeded outdoor RH and on only eight occasions outdoor RH exceeded kennel RH. Seven of these were during winter when outdoor T was below 20°C and one occasion was in December when outdoor T was below 27.6°C. The Steadman chart (Steadman 1979) which is used to estimate heat stress for athletes, includes the combined effects of T above TNZ and high humidity. Using the Steadman chart, in kennel houses where the temperature exceeds 25°C and RH levels exceed 50%, apparent temperature may be up to 5°C higher than actual temperature recorded. In the current study, RH levels >70% were not uncommon. Although this study did not show a significant effect of kennel house humidity on post-exercise temperature, the elevated humidity might impair evaporative cooling post-exercise.
Refrigerated cooling systems might be more appropriate in future kennel house construction. Further studies on this topic are warranted.

6.6 Conclusion

Conditions in racetrack kennel houses may influence the degree of hyperthermia developed by greyhounds. From the limited data gathered in the current study it appears that there is a greater risk of greyhounds developing a rectal temperature >41.5° when the kennel house temperature exceeds 26°C.

6.7 Comments

Over the four year course of this study notable changes occurred in some kennel houses, some as a direct result of the study. Following the two consecutive meetings at Strathalbyn and Gawler where it was possible to demonstrate an effect of kennel house conditions on dog post-race temperature, GRSA immediately installed an extra evaporative cooler and fans in the Gawler kennel house. These additions improved conditions. Subsequently, a complete renovation of the Gawler kennel house, which included installation of insulation and an enhanced cooling system, was undertaken. In addition, at all racetracks when the shade temperature exceeds 30°C, baths of iced water are now provided for the dogs in the post-exercise wash down area. These baths are used by handlers for sponging down dogs and it not uncommon to see dogs voluntarily lie down in the baths on return from exercise.
6.7 References


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Chapter 7: Effects of transport and transport vehicles on greyhounds, in warm and hot conditions.

7.1 Introduction

In Australia, greyhounds are frequently transported long distances to race meetings. Road journeys of over one hour duration are common and the majority of dogs are transported in purpose built trailers. In 2011 there were 330,429 race starters (Greyhounds Australasia 2011) which would equate to 660,858 individual greyhound journeys per year for racing. In addition, greyhounds may be transported for training, breeding or other purposes. Road transport has been reported to be stressful to many livestock species (Gregory 2008; Pilcher et al. 2011; Schmidt et al. 2010; Tateo et al. 2012; von Borell 2001) and Kadim et al. (2006) showed that transport at high temperatures could cause major physiological and muscle changes in goats. Dogs transported by air exhibit behavioural and physiological indications of stress (Bergeron et al. 2002; Leadon & Mullins 1991). The Greyhound Board of Great Britain (GBGB), in its Rules of Racing, outlines specific requirements for the road transport of greyhounds, including a temperature range of 10-26°C which must be monitored (Greyhound Board of Great Britain 2011). A Model Code of Practice for land transport of dogs in Australia does not exist and although the controlling authorities of greyhound racing have policies relating to the care of greyhounds, they are not consistent between states and lack specific recommendations in relation to transport. In South Australia, greyhound racing is conducted throughout the year, and in summer, greyhounds are often transported in ambient temperatures between 25°-40°C, in vehicles without cooling systems. Commercially produced dog trailers may be fitted with evaporative or refrigerated cooling systems but no studies have
been conducted into their effectiveness in maintaining suitable conditions under both external heat load and the heat load generated by the metabolic activity of the dogs. This study aimed to compare internal temperatures and relative humidity (RH) in cooled and non-cooled dog trailers under the challenges of ambient temperatures over 25°C and full load, and to determine the influence of a refrigerated air conditioning system on dog body temperature.

7.2 Materials and methods

7.2.1 Study design

Testing was conducted in the Barossa region of South Australia during late February and early March 2012. Animal ethics approval was provided for this study by the University of Adelaide Animal Ethics Committee. Testing was conducted over seven days in ambient temperature range 27-37°C. Four sets of conditions were assessed:

1. Stationary, un-laden;
2. Moving, un-laden;
3. Moving, laden;
4. Stationary, laden (Figure 7-1).

Temperatures and relative humidity levels both inside and outside the trailers were recorded and the thermal responses of the dogs were recorded in the form of rectal temperatures and weight losses due to panting.
Figure 7-1 Study design showing trailers used for greyhound transport in both stationary and moving trials.

7.2.2 Trailers

Two four-berth, single axle dog trailers (Toledo Trailers SA) manufactured to the same specifications with overall dimensions 2500 x 1760.5 x 940mm were selected. Roofs and walls were constructed of 25mm insulated (polystyrene) sandwich panels with outer surfaces of white, lightweight, colour-bond steel and galvanized steel internal lining. Flooring was 19mm construction Formply. Each internal compartment was 1200 x 850 x 840mm with internal divisions constructed of 75 x 50mm weldmesh and each compartment was fitted with a vented door and rotating extractor vent (Figure 7-2). Air inlet vents over wheel arches measured 600mm x 600mm. One trailer was fitted with a refrigerated 240v rooftop air conditioning unit.
with cooling capacity 3.2KW and inside air delivery 140 l/s (IBIS Aircommand Australia)
powered by an externally mounted 171cm³ one cylinder, petrol engine generator (Yamaha
EF2800i). The refrigeration unit on the roof of the air conditioned trailer created an area of
shade 825 x 1040mm.

7.2.3 Environmental monitoring
External and internal temperatures and relative humidity were recorded with ibuttons (i-Wire
hygrocron DS1923#F5) at 5 minute intervals. One button was suspended in netting in the
centre of each trailer, 30 cm above floor level and one was tied in netting to the chassis under
a front compartment of each trailer, using 5mm bubble wrap to insulate the ibutton from the
chassis. Data was downloaded with eTemperature software (OnSolution

Figure 7-2 Internal compartment of dog trailer.
Ambient conditions were manually recorded using a weather station (La Crosse technology, wireless 433MHZ Weather Station).

7.2.4 Body temperature
Dog rectal temperature was recorded with a clinical, digital thermometer (Becton, Dickinson, Canada, Inc.).

7.2.5 Animals
A total of thirteen greyhounds, seven male, six female aged ten months to eleven years were used. Mean bodyweight was 31kg (range 25.9-41kg). Animal details and distribution through the trials are listed in Table 7-1.
Table 7-1 Details of dogs and allocation in trials. Wh, white; Bk, black; Bd, brindle; Be, blue; Fn, fawn; Jmy, journey; Stat, stationary; Std, standard trailer; A/C, air conditioned trailer.

<table>
<thead>
<tr>
<th>Name</th>
<th>Sex</th>
<th>Colour</th>
<th>Age</th>
<th>Weight Kg</th>
<th>Jmy 1 Std</th>
<th>Jmy 1 A/C</th>
<th>Jmy 2 Std</th>
<th>Jmy 2 A/C</th>
<th>Jmy 3 Std</th>
<th>Jmy 3 A/C</th>
<th>Stat std</th>
<th>Stat A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jac</td>
<td>M</td>
<td>Wh +Bk</td>
<td>6 yrs</td>
<td>35.0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ne</td>
<td>M</td>
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<tr>
<td>Ju</td>
<td>F</td>
<td>Wh +Bk</td>
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<tr>
<td>Spa</td>
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<td>Wh +Bd</td>
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<td></td>
</tr>
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<td>M</td>
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<tr>
<td>Li</td>
<td>F</td>
<td>Wh+Be</td>
<td>2yrs</td>
<td>27.6</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Jas</td>
<td>M</td>
<td>Bk</td>
<td>1yr</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pa</td>
<td>F</td>
<td>Wh +Bk</td>
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<td>25.9</td>
<td></td>
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</tr>
<tr>
<td>Ka</td>
<td>M</td>
<td>Wh +Bk</td>
<td>8 yrs</td>
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<tr>
<td>Bet</td>
<td>F</td>
<td>Bk +Wh</td>
<td>3yrs</td>
<td>26.9</td>
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<tr>
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<td>4yrs</td>
<td>34.0</td>
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</tbody>
</table>
7.2.6 Procedure

7.2.6.1 Trial 1 Stationary, Un-laden
In order to establish equivalence of internal conditions, both trailers were parked parallel in an open, un-shaded area in a North-South orientation and conditions were monitored continuously over three days. The air conditioner was turned on and ran for thirty minutes on the afternoon of the third day.

7.2.6.2 Trial 2 Moving, Un-laden
On one occasion, both trailers were towed simultaneously over the same route for three periods of approximately 50 minutes each, with 30-40 minute stationary intervals, while the air conditioner was operating in the test trailer. On another occasion both trailers were towed simultaneously over the same route without the air conditioner operating in the test trailer.

7.2.6.3 Trial 3 Moving, Laden
Both trailers were parked in an open un-shaded area and the air conditioner ran for 30 minutes prior to loading. Four dogs (mean total mass 124kg) were loaded into each trailer and both trailers were towed simultaneously for a period of approximately 50 minutes (approximately 60km). All dogs were then unloaded and confined in kennels held at 25°C, with ad lib water, for 30-40 minutes. A fifty-minute journey of approximately 60km over a different route was then repeated twice with both trailers being towed simultaneously. Journey 1 was from the home kennel to a rest station and journeys 2 and 3 were round trips from the rest station. Dogs were allocated alternately to the cooled and non-cooled trailers. All dogs’ rectal temperatures were taken before and after each journey. Scales were not available prior to journey 1 but all dogs were weighed after journeys 1 and 3.
7.2.6.4 Trial 4 Stationary, Laden

Both trailers were parked parallel in an open un-shaded area and the air conditioner was run for 30 minutes prior to loading. Eight dogs (four of which also participated in trial 3) were housed in kennels in a room held at 20-23°C for one hour prior to loading. Four dogs (two male, two female) were then loaded into each trailer. Because of concern for the animals' welfare, the dogs were viewed at ten minute intervals by opening the rear shutter. All dogs' rectal temperatures were taken before loading and after unloading.

7.2.7 Statistical analysis

Analysis was performed using GraphPad Prism version 5.00 for Windows, GraphPad Software, San Diego California USA, www.graphpad.com. Unpaired $t$ tests were used to compare temperature and humidity between trailers, between internal and external conditions of each trailer and between stationary and in motion conditions. Paired $t$ tests were used to compare dog rectal temperature before and after trailer confinement. Differences were considered significant at the level $P <0.05$. Data were assessed for normality using the D'Agostino and Pearson omnibus normality test.

7.3 Results

7.3.1 Trial 1 Stationary, Un-laden

Temperature and RH in both trailers showed comparable levels over three 24 hour periods (Table 7-2). On day three (18/02/2012, 16.30-17.00hrs) the air conditioning unit reduced the internal temperature of the cooled trailer by 8°C (38.02°C -30.1°C) within 25 minutes at ambient temperature of 34°C. Estimated insolation for the nearest capital city, Adelaide =17 MJ/m2/day, 5.75 kW/h/m2/day (Australian Government Bureau of Meteorology).
Table 7-2 Temperature and relative humidity in stationary un-laden trailers 16-18th February, 2012.

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>Air conditioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum temperature °C</td>
<td>14.4</td>
<td>14.5</td>
</tr>
<tr>
<td>Maximum temperature °C</td>
<td>38.9</td>
<td>38.5</td>
</tr>
<tr>
<td>Mean temperature ± SD</td>
<td>25.9 ± 7.0</td>
<td>25.6 ± 6.7</td>
</tr>
<tr>
<td>Minimum RH%</td>
<td>16.1</td>
<td>18.7</td>
</tr>
<tr>
<td>Maximum RH%</td>
<td>82.4</td>
<td>80.7</td>
</tr>
<tr>
<td>Mean RH ± SD</td>
<td>43.7 ± 19</td>
<td>43.9 ± 18</td>
</tr>
</tbody>
</table>

7.3.2 Trial 2 Moving, Un-laden

When moving un-laden, without air conditioning, in ambient temperatures between 26-27°C and RH 26-31% there was no significant difference in temperature (P = 0.9) nor relative humidity (P = 0.3) between trailers. However, with the air conditioner operating, in ambient temperatures 34-35°C, the mean temperature in the air conditioned trailer was significantly lower (P = 0.0001) than the mean temperature in the standard trailer(Figure 7-3). In transit, external temperatures measured on the chassis below floor level of both trailers were 2-4°C higher than shade temperature at the parking point. When stationary between journeys 1 and 2, the internal temperature of the standard trailer increased 4.5°C (from 32.5 to 37°C) then fell to 34.0°C in transit. When stationary between journeys 2 and 3 internal temperature again increased 4.5 to 38° but fell to 35°C in transit. In contrast, the internal temperature of the air conditioned trailer decreased 1.0°C when stationary between journeys 1 and 2, and also
between journeys 2 and 3 but increased 2.0°C (from 25.4 to 27.4°C) during journey 2 and 1°C (from 26.9 to 27.9°C) during journey 3 (Figure 7-3).

In ambient RH 13-21% mean RH in the air conditioned trailer was significantly higher than the in the standard trailer (P = 0.0001) (Figure 7-4).
Figure 7-3 Temperature recorded inside un-laden, standard (Std) and air conditioned (AC) trailers over three journeys and two rest periods.
Figure 7-4 Relative humidity % recorded in un-laden, standard (Std) and air conditioned (AC) trailers over three journeys and two rest periods.
7.3.3 Trial 3 Moving, Laden

When moving and laden, in ambient temperatures 30.0-40.5°C, the air conditioned trailer maintained a mean internal temperature 31.0 ± 0.6°C which was significantly lower (P =0.0001) than the mean internal temperature of 37.0 ± 0.4°C in the standard trailer (Figure 7-5). The internal temperatures of both trailers were also significantly lower (P =0.0001) than the mean external chassis temperatures which were respectively 39.0 ± 0.6°C (A/C trailer) and 40.0 ± 0.8 °C (Std.trailer).

Mean RH inside the air conditioned trailer was significantly higher 31% ±3.0 than in the standard trailer RH 26% ± 3 (P= 0.0002) and outdoors RH 20% ± 3 (P= 0.002) ((Figure 7-6).
Figure 7-5 Temperature recorded inside laden standard (Std) and air conditioned (AC) trailers over three journeys and two rest periods.

* Ambient temp 38.5°C @13.55hh
Figure 7-6 Relative humidity (RH) % recorded in laden, standard (Std) and air conditioned (AC) trailers over three journeys and two rest periods.
No significant difference in dogs’ rectal temperatures was recorded prior to loading into the standard or air conditioned trailers ($P = 0.3$). No significant increase in mean dog rectal temperature was recorded after journeys in the air conditioned trailer but a mean increase $0.5 ^\circ C \pm 0.2 (P = 0.02)$ in dog rectal temperature was recorded after journeys in the standard trailer (Figure 7-7). All dogs lost weight between the end of journey 1 and end of journey 3, mean loss $0.34 kg$ (range $0.2-0.5 kg$), (Table 7-3). No loss of solid waste (faeces) or urine was noted.

Figure 7-7 Dog rectal temperature pre-and post-journey (means and SEM) in moving laden trailers.
Table 7-3 Bodyweight (kg) of greyhounds after journeys 1 and 3.

<table>
<thead>
<tr>
<th>Dog</th>
<th>Post Journey 1</th>
<th>Post Journey 3</th>
<th>Net loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jac</td>
<td>35.0</td>
<td>34.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Ne</td>
<td>28.2</td>
<td>28.0</td>
<td>0.20</td>
</tr>
<tr>
<td>Ju</td>
<td>27.0</td>
<td>26.6</td>
<td>0.40</td>
</tr>
<tr>
<td>Sp</td>
<td>30.0</td>
<td>26.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Co</td>
<td>30.9</td>
<td>30.5</td>
<td>0.40</td>
</tr>
<tr>
<td>Li</td>
<td>27.6</td>
<td>27.3</td>
<td>0.30</td>
</tr>
<tr>
<td>Jas</td>
<td>32.3</td>
<td>32.0</td>
<td>0.30</td>
</tr>
<tr>
<td>Pa</td>
<td>25.9</td>
<td>25.6</td>
<td>0.30</td>
</tr>
<tr>
<td>Ka</td>
<td>33.0</td>
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<td>0.50</td>
</tr>
<tr>
<td>Mean loss</td>
<td></td>
<td></td>
<td>0.38</td>
</tr>
</tbody>
</table>

7.3.4 Trial 4 Stationary, Laden

In ambient temperatures 26-27°C, when stationary and laden, the air conditioned trailer maintained a mean temperature 22.0 ± 0.2°C which was significantly lower (P = 0.0001) than the standard trailer temperature of 29.0 ± 0.2°C. Mean RH% in the air conditioned trailer was 45 ± 2% which was significantly higher than levels in the standard trailer 31 ± 1 % and mean outdoor RH% of 28 ±1% (P=0.0001) (Figure 7-8). However these results may have been affected by the decision to briefly open vents in the standard trailer after 20 minutes because of concern for the welfare of the dogs. The vents in the air conditioned trailer remained closed.
There was no significant change in dog rectal temperature after the period of confinement in either trailer.
Figure 7-8 Temperature (Temp) and relative humidity (RH %) in stationary, laden standard (Std) and air conditioned (A/C) trailers.
7.4 Discussion

It is acknowledged that major limitations of this study, as in other transport studies, were the variations in conditions due to changes in locations and time points. In ambient temperatures up to 34°C, the air conditioning system, when operated in the un-laden trailer, maintained a temperature below the limit of 27°C suggested by Hammel, Wyndham and Hardy (1958) and the Greyhound Board of Great Britain (2011). However, when laden, the cooling system was unable to maintain the temperature at or below this level once the external temperature exceeded 32°C. However, despite the internal temperature exceeding 27°C, the dogs’ rectal temperature did not increase after journeys of 50 minutes duration in the air conditioned trailer, whereas, after journeys in the standard trailer for the same period, a mean increase of 0.5°C in dog rectal temperature occurred.

Although air flow was not measured, the trailers are manufactured to maximize air inflow through the side vents and outflow through roof mounted, rotating vents. It was considered that, under hot conditions, this design might counteract the effect of the cooling system, when the trailer was in motion. However, no significant temperature difference was detected between stationary or moving states of the un-laden, air conditioned trailer with the air conditioner operating. In contrast, when un-laden, the ventilation system of the standard (non air-conditioned) trailer slightly reduced the temperature, when in motion. In the current study, obtaining accurate measurement of the external temperature of the immediate environment of the trailer presented a challenge. Although, in the stationary studies, the temperature immediately below the floor of the trailer corresponded with shade temperature, when the trailers were towed over bitumised surfaces there was an increase of approximately 2°C which could be attributed to heat radiation from the road surface.

Although Iampietro et al. (1966) found that dogs tolerated an ambient temperature of 37.8°C with only small changes in blood pH and partial pressure of carbon dioxide (p CO₂),
their studies were performed in conditions of wind speed of three miles per hour, which may have permitted heat dissipation by convection. In the current study, when transported in the standard trailer, in ambient temperatures between 35-38°C and RH<37%, dogs were unable to maintain body temperature at pre-load levels and demonstrated a mean increase of 0.5°C. These results indicate that although the ventilation system of the standard trailer permits adequate air flow in the un-laden state, it is insufficient in a fully laden trailer under hot conditions. Moreover, the small changes in blood pH and CO₂ noted by Iampietro et al. (1966) might become significant if added to the alterations of pH and CO₂ which occur following strenuous exercise (Dobson et al. 1988; Ilkiw 1989; Staaden 1984).

A rectal temperature of 41.5°C in dogs has been identified as the temperature above which heat illness or heat stroke may occur (Bruchim et al. 2006; Drobatz & Macintire 1996; Flournoy, Wohl & Macintire 2003). As described in Chapter 4, the mean post-exercise temperature of greyhounds was 41°C: therefore, if dogs are loaded into trailers immediately following strenuous exercise, further increases in body temperature may occur, which may lead to heat illness.

Although dogs may lose 70% body heat by convection and radiation, when environmental temperatures approach body temperature, evaporation from the respiratory tract through panting, becomes more important (Bruchim et al. 2006). High levels of RH may impede evaporative cooling (Brotherhood 2008). In the current trials, in ambient environmental RH <37%, the air conditioning caused an increase in RH inside the AC trailer, relative to both general environment and the standard trailer. In climates with higher RH, such an increase might represent a hazard to dogs in transit, as it might impede heat dissipation by panting.

Dog bodyweight loss during transport has been widely reported by greyhound trainers (C. Doyle, personal communication, January 2014). Weigh scales were not available prior to
loading for these trials, therefore total weight loss over three journeys could not be measured; however, over two rest periods and two journeys the mean weight loss was 0.38kg. Greyhounds have also been reported to lose weight during the pre-race period of kennelling at race meetings, with the loss increasing relative to the period of kennelling (Blythe & Hansen 1986; R. Ferguson, personal communication 2013; also see Chapter 6, 6.5). Although Blythe & Hansen (1986) did not find that race performance was adversely affected by weight losses up to 1.4kg, dehydration has been implicated as a factor contributing to heat strain in human athletes (Coris, Ramirez & Van Durme 2004; Howe & Boden 2007; van Rosendal et al. 2010) and the combined fluid loss from periods of transport and pre-race kennelling may increase the risk of racing greyhounds developing heat strain.

The Greyhound Board of Great Britain (GBGB), in its Rules of Racing, outlines specific requirements for the road transport of greyhounds, including a temperature range of 10-26°C which must be monitored (Greyhound Board of Great Britain 2011). The International Air Transport Association (IATA) has specifications for transport containers for dogs (International Airline Transport Association 2015) and IATA also specifies an acceptable temperature range for domestic dogs of 10°-27°C with an even more limited range for dogs described as ‘snub nose dogs’ of 10°-19°C (M.Voelkl, personal communication June 2015).

### 7.5 Conclusion

Transporting dogs in standard trailers in ambient temperatures >33°C may challenge dogs’ homeothermy and transporting dogs at such temperatures, before or after strenuous exercise may pose a significant risk of initiating heat illness. As a Model Code of Practice for the land transport of dogs in Australia does not exist and the controlling authorities of
greyhound racing do not provide specific recommendations in relation to transport, results of the current study indicate the need for the greyhound industry to develop guidelines for the transport of greyhounds. In addition, further studies on cooling methods during transport and before and after exercise, should be conducted.

7.6 References


Greyhound Board of Great Britain 2011, 'Guidelines for transportation of greyhounds', Regulation, in GBG Britain (ed.), Rules of Racing Appendix II, no. 73, Greyhound Board of Great Britain Limited, pp. 73-76.


Chapter 8 Discussion

The world’s climate has changed and extreme heat waves are becoming more frequent (Australian Government Bureau of Meteorology and CSIRO 2010; Menzies et al. 2015). Climate change has been identified as an emerging threat to human and animal health (Bouchama 2006; Luber & McGeehin 2008; Poumadere et al. 2005; Solymosi et al. 2010; Summers 2009). Over the past century average temperatures in Australia have increased by almost 1.0°C (Australian Government Bureau of Meteorology and CSIRO 2014) and the number of very hot days has increased and is predicted to increase further (Hanna et al. 2011). Menzies et al. (2015) have identified climate change and associated extremes of weather as factors which threaten the continuance of many human sports and the organisations responsible for the management of human sporting events have come under scrutiny and attracted criticism from investigators in the field (Hanna 2014).

The current study examined a broad range of factors which might influence the risk of racing greyhounds suffering from heat stress. Environmental factors of outdoor temperature and relative humidity (RH), environmental conditions in holding areas, distance of races, conditions in transport vehicles and animal qualities were all assessed for their potential to affect body temperature of greyhounds. A limitation of the current study was a failure to measure wind speed at racing venues. Wind speed has been identified as a factor influencing thermal load (Shimazaki, Yoshida & Yamamoto 2015). However, during the current study the periods of exposure of subject dogs to wind was very limited and was therefore not considered likely to be of significance.

Although Moran and Mendal (2002) described the use of rectal thermometry as the gold standard for assessing heat illness in human athletes, there have been advances in
technology since that period. Methods such as ingestible sensors (Duffield, Coutts & Quinn 2009) and thermography (Costello et al. 2013) have been utilised to measure body temperature changes associated with exercise. However, the results of Chapter 3 confirmed that the use of a rectal thermometer was an acceptable, convenient and effective means of recording body temperature in canine athletes in a racetrack environment. As anticipated, proposed use of a rectal thermometer encountered some resistance from some trainers in the initial stages of the study. However, as those concerned observed the absence of adverse reactions and no effect on race performance of subject greyhounds, use of the device was widely accepted. Indeed, over the course of the study, as trainers became more conscious of heat stress, some greyhounds were voluntarily presented for temperature measurement.

Alternative methods of temperature measurement, particularly non-contact methods would be advantageous in a racetrack environment (to save time and minimise animal handling) and an ideal method would be a device permanently in place. Since 2011, all racing greyhounds in Australia have been identified by implanted microchips which are scanned prior to racing (Greyhounds Australasia 2014). Long life microchip transponders which can record body temperature have been used in other species (Chen & White 2006; Quimby, Olea-Popelka & Lappin 2009) and might therefore be suitable for use in the greyhound industry. However as Chen and White (2006) found a failure rate of 8.7% in the devices, it would be necessary for a pilot study to be conducted on greyhounds before their use could be recommended to the greyhound industry.

The positive association between environmental temperature and post-exercise rectal temperature of greyhounds was an expected outcome, and was in keeping with studies in humans (Armstrong et al. 2007; Hargreaves 2008; Hargreaves & Febbraio 1998) and horses (Geor et al. 1995; Lindinger 1999). Although rises of up to 2°C following exercise
have been recorded in humans (Duffield, Coutts & Quinn 2009; Kenefick, Cheuvront & Sawka 2007) and horses (Geor et al. 2000; Marlin, DJ et al. 1999), such rises were recorded after extended periods of exercise. The rapid rises in temperature recorded by the greyhounds in the current study (Chapter 4) illustrate the intensity of exercise and metabolic work involved. Pre-cooling of dogs might therefore be a very effective strategy to reduce post-exercise body temperature and an investigation into appropriate methods is warranted. Current racetrack management confines greyhounds in housing which is cooled by evaporative cooling systems in hot weather. However, as shown in Chapter 7, levels of humidity frequently exceed 60%. High humidity impedes dissipation of heat and may increase the risk of heat illness (Coris, Ramirez & Van Durme 2004; Jeffcott, L.B., Leung & Riggs 2009) and animal welfare might be improved by installation of refrigerated cooling systems in racetrack kennel houses. Some greyhounds in the current study, developed increases in temperature while kennelled prior to racing, and such animals might benefit by pre-cooling. A number of methods of pre- and post-exercise cooling have been applied to human athletes in attempts to limit body temperature increases or to accelerate cooling (Hunter, Hopkins & Casa 2006; Lopez et al. 2008; Marino & Booth 1998). Pre-race wearing of an ice vest reduced body temperature increases in female runners, participating in competitive outdoor events (Hunter, Hopkins & Casa 2006), however, post-exercise use of a cooling vest was not effective in accelerating cooling in hypohydrated, hyperthermic male athletes in a laboratory setting (Lopez et al. 2008). It must however be noted, that as the fore mentioned studies were conducted in different environments (outdoor competition vs laboratory) and on different subject types (female vs male) the results may not be directly comparable. A meta-analysis of pre-cooling and percooling (cooling during exercise) by Bongers et al. (2014), indicated both methods could achieve a significant reduction in post-exercise body temperature and use of cold water immersion or ingestion of cold slurries are
practical effective methods (Jones et al. 2012). Whole body immersion in cold water is effective in post-exercise cooling of hyperthermic athletes (Proulx, Ducharme & Kenny 2005) and immersion in iced water is not significantly more effective than immersion in cold water (Clements et al. 2002). Whole body immersion in cold water should therefore be considered as an effective means of post-race cooling of greyhounds.

Researchers in the field of human heat exposure regard temperatures $\geq 35^\circ\text{C}$ as ‘very hot’ (Hanna et al. 2011). As the focus of the current study was to examine the effects of hot weather on racing greyhounds, an effort was made to collect data on days when the maximum temperature was $\geq 30^\circ\text{C}$ and in particular $\geq 35^\circ\text{C}$. In the Adelaide region of South Australia, there are 25 to 35 days per annum, when maximum temperature $\geq 35^\circ\text{C}$ (Australian Government Bureau of Meteorology 2013). Nevertheless, sufficient data were collected to demonstrate a positive, albeit weak, relationship between environmental temperatures and the body temperatures of greyhounds post-race. Furthermore, 17% (41/239) greyhounds recorded a post-race rectal temperature $\geq 41.5^\circ\text{C}$. This level of body temperature has been associated with a high mortality rate for heat stroke in dogs (Bruchim et al. 2006). It is therefore clear that racing in hot weather represents a risk to greyhound welfare and careful management of animals is required.

Current South Australian management of greyhounds racing in temperatures $\geq 30^\circ\text{C}$ endeavours to minimize exposure to the outdoor environment and over the course of this study the Hot Weather Policy of GRSA was revised. The current policy sets an environmental forecast temperature threshold of 37°C at which level, trainers may elect to withdraw greyhounds from races. During the current study, an environmental temperature of 38°C was identified as a temperature at which the percentage of greyhounds recording post-race rectal temperature $\geq 41.5^\circ\text{C}$ increases markedly.
It is of interest that Cycling Australia, which is the national body responsible for administration of competitive cycling, outlines the temperature ranges of < 30°C, 31-37°C, 38-40°C and >40°C as representing distinct ranges of risk to competitors and officials. Both Cycling South Australia and the South Australian Cricket Association specify a forecast temperature of 37°C to be a trigger for postponement or cancelation of events (Menzies 2015). At temperatures ≥38°C extreme caution is advised for cyclists, which recommendation supports the concept that at 38°C strenuous exercise becomes hazardous to both human and canine athletes.

The only other species of which major athletic demands are made in hot conditions is equine and heat stress received wide spread attention following the 1992 Barcelona Olympic games (Marlin 2009). Subsequently a number of studies endeavoured to establish thresholds for heat and RH for horses engaged in strenuous activities, such as three phase events (Jeffcott, L. B. & Kohn 1999; McCutcheon & Geor 1997; Schroter & Marlin 1995; Schroter, Marlin & Jeffcott 1996). In anticipation of heat stress at the 1996 Atlanta Olympic Games, the FEI launched a research programme ‘The Atlanta Project’. A major outcome of this research programme was the Wet Bulb Globe Temperature Index (Schroter & Marlin 1995; Schroter, Marlin & Jeffcott 1996). Application of the research has been credited for the safe management of the equestrian events in Atlanta in 1996 (Marlin 2009) and in Hong Kong in 2008 (Jeffcott, L, Leung & Riggs 2009). In Australia, Equestrian Australia uses the WBGT index (based on data derived from the Australian Bureau of Meteorology) to assess the risk for heat stress for horses competing at events (Equestrian Australia 2012). A WBGT index greater than 33 (which reflects temperature >32°C and % relative humidity > 60) is considered to represent a high risk environment for horses (Equestrian Australia 2012).
Livestock industries utilise a number of indices to estimate risks of heat stress. The Temperature-Humidity index (THI) has been used in the cattle industry for decades and in 2008 Gaughan et al. (2008), proposed a new heat load index (HLI) which incorporated solar radiation and wind speed in addition to temperature and humidity. Recognising a variation in heat tolerance between cattle of different genotypes and phenotypes, the authors then developed thresholds for the different types; this work clearly illustrated the influence which breed type and coat colour may have on susceptibility to heat strain. Results described in Chapter 5 are the first clarification of the influence of coat colour and bodyweight on heat gain in exercising dogs. Although no association between sex and levels of pre- or post-exercise temperatures was found in the current study, higher post exercise levels of myoglobinuria were detected in females (Chapter 5). As rhabdomyolysis and consequent myoglobinuria may occur as a result of both strenuous exercise (Moghtader, Brady & Bonadio 1997; Sinert et al. 1994) and exertional hyperthermia (Nichols 2014) the results may indicate that although rectal temperature did not increase more in females, some other factor may be influencing female greyhound muscles (Fortes et al. 2013). These findings warrant further study.

The findings as described in Chapter 7 illustrate that even in purpose built, well ventilated vehicles, dogs are challenged to maintain homeothermy during transport in hot conditions. In Australia, no greyhounds are maintained at racetrack venues, all greyhounds must be transported by road. Currently there are no regulations pertaining to road transport for dogs although the International Airline Transport Association (IATA) has Live Animal Regulations (LAR) which list requirements for animal containers and the organisation provides training for staff to implement the guidelines (International Airline Transport Association 2015). As the Greyhound Board of Great Britain (GBGB) has seen the need to outline specific requirements for the road transport of greyhounds (including a temperature range of 10-
26°C), the results of the current study illustrate the need for both industry and the wider community to introduce standards for the transportation of racing greyhounds.

Despite the considerable use of dogs in the past century for research into the mechanisms and pathogenesis of heat stroke and extensive studies into management and avoidance of heat stress in both human and equine athletes, there appears to have been remarkably little research into the effects of heat stress on dogs engaged in strenuous exercise. With the development of energetic dog sports such as canine agility, flyball, tracking and lure coursing, in a climate with increasing temperatures, the number of dogs at risk from heat stress is likely to be greatly increased. The results of the current study may assist in highlighting risks and in formulating policies to minimise such risks.

8.1 Conclusion

To the author’s knowledge, this study was the first attempt to examine the interactions between environmental conditions and body temperature of racing greyhounds in Australia. The author acknowledges the limitations of working in a commercial environment where conditions could not be controlled. However, the study has highlighted a number of factors which may increase the risk of greyhounds developing hyperthermia and indicates areas where further research should be conducted.

In the Mediterranean-type climate of South Australia, it is apparent that at temperatures >31°C, greyhounds undertaking strenuous exercise are challenged to maintain homeothermy and at temperatures ≥38°C there is a significant risk of greyhounds developing hyperthermia. Large, dark coloured greyhounds are at greater risk of post-exercise hyperthermia than small, light coloured greyhounds.

Environmental conditions within racetrack kennel houses may influence greyhounds’ responses to exercise and results of the current study are in accord with the findings of
Hales and Dampney (1975) who estimated that the TNZ for greyhounds is 16°- 24°C; consequently kennel houses should be maintained within this range. Further research is required to examine the responses of greyhounds to exercise in hot, humid climates. Although the results of the current study indicate that greyhounds are able to maintain homeothermy when transported in an air-conditioned vehicle, the study did not examine responses of greyhounds to the combined effects of strenuous exercise and pre- or post-exercise transport. More detailed controlled studies are warranted in order to estimate risks and recommend standards for the land transport of greyhounds.

As the climatic conditions in the current study seldom included concurrent elevation of temperature and humidity, it was not possible to develop a heat stress index based on such variables. Further studies would be necessary to develop such an index, which would be specific to the sport of greyhound racing.

8.2 References


Bouchama, A 2006, 'Heatstroke: Facing the threat', Critical Care Medicine, vol. 34, no. 4, pp. 1272-1273.


**Appendix 1 Owner consent**

**Animal Owner Informed Consent**

**Use of animals for research**

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**INFORMATION SHEET**

As the owner or duly authorized agent for the owner you have been asked to have your animal participate in a research study. Your informed consent is required prior to this use.

Please read this document and accompanying Consent Form carefully and feel free to ask any questions you might have.

<table>
<thead>
<tr>
<th>Animal Project Title:</th>
<th>Heat Stress in Canine Athletes</th>
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<tbody>
<tr>
<td>AEC Approval No:</td>
<td>S-O59 2008 Approval Period Dates: 10/10/2008 to 31/12/2011</td>
</tr>
<tr>
<td>Chief Investigator Name:</td>
<td>Jane McNicholl</td>
</tr>
<tr>
<td>Faculty/School:</td>
<td>School of Agriculture Food and Wine</td>
</tr>
<tr>
<td>Contact Details</td>
<td>Roseworthy Campus, University of Adelaide, SA 5371 Phone 08-83037638 mobile 0427-246308</td>
</tr>
<tr>
<td>Person Responsible for the animal(s) during the Research Study:</td>
<td>Jane McNicholl</td>
</tr>
<tr>
<td>Contact Details</td>
<td>Roseworthy Campus, University of Adelaide, SA 5371 Phone 08-83037638 mobile 0427-246308</td>
</tr>
<tr>
<td>Location where animal participation/research study occurs</td>
<td>Greyhound tracks at, Port Augusta, Virginia, Gawler, Two Wells, Angle Park, Strathalbyn, Mount Gambier, Barmera and home kennels.</td>
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### Aims and Benefits of the Research Study:

- Determination of the body temperature of greyhounds undergoing maximum exertion under conditions of high environmental temperature.
- Documentation of the percentage of greyhounds exhibiting symptoms of heat stress during or following maximum exertion in high environmental temperature.
- Identification of an effective method of assessing the risk of heat stress in greyhounds under racetrack conditions.

### Duration of animal participation

Animals will be monitored for changes in body temperature for periods of between one and twenty four hours.

### Description of animal procedures to be carried out

<table>
<thead>
<tr>
<th>PROCEDURE</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement of rectal temperature using clinical digital readout thermometer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of aural (ear) temperature using clinical digital readout thermometer</td>
<td></td>
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<tr>
<td>Measurement of surface temperature using hand held infrared thermometer</td>
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<tr>
<td>Collection of urine sample</td>
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<tr>
<td>Wearing harness, data recorder and heart rate monitor</td>
<td></td>
<td></td>
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<tr>
<td>Ingestion of telemetry pill</td>
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</table>

### Possible discomfort, risks and complications and steps taken to minimise risks.

There is a very small risk of minor discomfort from insertion of rectal and aural thermometers. Rectal thermometers will be lubricated and the aural thermometer will be fitted with a disposable probe cover for each measurement. A harness will be adjusted to fit each dog and dogs will also be fitted with a lycra racing rug to minimise slippage. Dogs will be fitted with a plastic muzzle whilst wearing the harness and data recorder to prevent chewing and possible ingestion of material.

### Possible benefits to the animal

Accurate monitoring of body temperature will reveal the extent of temperature rise resulting from a range of activities and may identify dogs which are at risk of heat strain. Management of such dogs could then be adjusted to minimise the risk of heat exhaustion.

### Animal to be returned

| Yes | Instructions: Dogs which are fitted with a harness and data recorder and ingest a telemetry pill should also wear a plastic muzzle. Dogs’ faeces should be collected for 24 hours post ingestion of telemetry pill and placed in a plastic bag with time of collection recorded on bags. |

### Voluntary Participation:

The participation of your animal is voluntary, and you may withdraw your animal(s) for any reason at any time. If you do not wish to participate you do not have to provide any reason for your decision. Refusal to participate or withdrawal will in no way affect the care to which animal participants are otherwise entitled. If you withdraw, any data collected about your animal will be retained for analysis.

### Unforseen Risks:
Unforeseen risks might arise at any time during the research study. The research investigators will promptly inform owners of all animals participating in the study of any new information that may affect their willingness to participate.

Termination of Participation by Chief Investigator:

The research investigators have the right to terminate the research study for any and all participants at any time and for any reason.

Financial Implications:

There will be no cost to you for the participation of your animal in the research study. You will not be charged for any of the procedures performed solely for the study's purposes. You will receive no reimbursement for the participation of your animal in the research study. The University of Adelaide does not provide compensation or therapy for any injuries or losses that may occur as a result of participation. If the animal is insured you are advised to notify the insurer of involvement in a research project.

Knowledge Transfer/Publication of Research Findings:

This study is supported by Greyhound RacingSA and the Australian Greyhound Veterinary Association. Research findings will be made available to both organizations. Results of the research will be published in industry publications.

Privacy: Personal information collected by the research investigators will be used in accordance with the South Australian Information Privacy Principles. If you wish to enquire about the handling of your personal information, please contact the University Privacy Compliance Officer on (08) 830 35033

Confidentiality:

Owner and patient confidentiality will be maintained. No identification of individuals will be made when reporting or publishing the data arising from this study.

Questions:

1. If you have any questions or concerns relating to the practical aspects of the research study please feel free to ask at any point. You are free to contact the research personnel – Chief Investigator and the Responsible Person - using the contact details provided above.
2. This research study has been approved by the University of Adelaide Animal Ethics Committee. If you wish to discuss other matters or concerns relating to this project you may contact either of the following: (names deleted)

CONSENT FORM - FOR ANIMAL PARTICIPATION IN RESEARCH

Name & Identification of animal(s)

<table>
<thead>
<tr>
<th>Name:</th>
<th>Ear Brand/Chip</th>
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<tbody>
<tr>
<td>Breed:</td>
<td>Age:</td>
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<tr>
<td>Sex:</td>
<td>Colour:</td>
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1. I, ................................................................................................................. (please print name) certify that I am at least 18 years of age and am the owner (or duly authorised representative of the owner) of the above animal(s) and that the animal(s) are free of any lien or claim by any other person or persons.

2. I acknowledge that I have read the attached Information sheet for the research project entitled:

   Heat Stress in Canine Athletes

   and have had the participation of my animal(s) in the research study fully explained to me by the research investigator: Jane McNicholl

3. My consent is freely given. I have had the opportunity to ask questions and discuss any aspects of the participation with the research investigator. I understand that some risk always exists when animal handling and animal procedures are performed. I understand that the participation of my animal(s) is
voluntary, and I may withdraw my animal(s) for any reason at any time. I understand that this research participation may involve permitting researchers from the University of Adelaide to handle greyhounds in my care and to measure their body temperature with a range of devices which have been shown to me.

4. I understand that the research investigator(s) will inform me of any new risks that may be identified or any material changes in the way the study will be conducted.

I am aware that this project has current approval by the University of Adelaide Animal Ethics Committee.

I understand that all private data pertaining to me and my animal(s) will be treated in strict confidence.

I am aware that I should retain a copy of this Consent Form and attached Information sheet.

Consenting owner/authorised agent name: ……………………………………………..…………………
Signature:………………………………………………………Date:  ………………………………………
Proof of ownership shown: ………………………………
Owner/Agent Contact details: Telephone:……………………………………………………………………….
Address: …………………………………………………………………………………..…………………
Witness Declaration: I have described to the animal owner/authorised agent the nature of the animal(s) participation in the research study. In my opinion he/she understood the explanation.
Witness’s name: ……………………………………………………………………………..……………..
Signature:…………………………………………………..…Date:  ………………………………………
Role in Research Study: ……………………………………………………………………………………..

Original of consent form to be retained by the Chief Investigator
Copy to be given to the consenting owner/agent
# Appendix 2 Individual greyhound record

**INDIVIDUAL SHEET GREYHOUND**

<table>
<thead>
<tr>
<th>DATE</th>
<th>NAME</th>
<th>ID</th>
<th>COLOUR</th>
<th>SEX</th>
<th>AGE</th>
<th>WEIGHT</th>
<th>SENSOR</th>
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<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>TIME</th>
<th>RECTAL T</th>
<th>AURAL T</th>
<th>CORE T</th>
<th>NOTES</th>
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## Appendix 3 Racetrack record sheet for greyhound

**Date** | **Location** | **Start** | **Finish** | **Shade T** | **Kennel T** | **Cloud** | **Rel Hum** | **Distance** | **Time**
---|---|---|---|---|---|---|---|---|---

**Name** | **ID num** | **Colour** | **Sex** | **Wght** | **Age** | **Sire** | **Dam** | **Body Scr** | **Fitness** | **Notes**
---|---|---|---|---|---|---|---|---|---|---

**Before exercise** | **After exercise** | **After 10 mins** | **20 mins** | **Urinalysis** | **Notes**
---|---|---|---|---|---
**Arr** | **Pre** | **After** | **Before** | **Pre ex** | **Post ex**
**Aural T** | | | | Glu | 
**Rectal T** | | | | Bil | 
**Fem Art T** | | | | Ket | 
**Core T** | | | | Sp Gr | 
**Heart Rate** | | | | Blood | 

<table>
<thead>
<tr>
<th><strong>Body Scr</strong></th>
<th><strong>Fitness</strong></th>
<th><strong>Notes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre ex</td>
<td>Post ex</td>
<td></td>
</tr>
</tbody>
</table>