Do coats improve sleep and alter activity rhythms in New Zealand farm dogs? An accelerometer-based study

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Abstract

New Zealand farm dogs are integral to the nation's agricultural industry, facing high workloads and overnight outdoor kenneling that may expose them to significant thermal stress, potentially compromising restorative sleep. While sleep is critical for the health, performance, and welfare of these working animals, the efficacy of simple management interventions to improve their rest have not been investigated. This study aimed to determine if a practical intervention, wearing a coat, could improve the sleep quality, daily activity rhythms, and nutrient digestibility of colony dogs in spring.

Using a crossover design, eight healthy dogs housed in outdoor kennels were monitored over 10 days, alternating between periods of wearing and not wearing a coat at night. Sleep and activity patterns were measured using triaxial accelerometers and analysed with a machine-learning model. Apparent nutrient digestibility was assessed in parallel using a standard AAFCO protocol.

The results showed that wearing a coat significantly increased the proportion of time spent sleep during the night particularly during the coldest hours of the night. Dogs wearing coats also exhibited a more balanced 24-hour activity rhythm, with significantly reduced nocturnal activity and increased activity during the following day (0900 to 1500 h), which may result in improved recovery and readiness for work. There was no effect ($P>0.05$) on apparent nutrient digestibility observed in the study.

This study demonstrated that providing working dogs coats is a simple, non-invasive, and effective management strategy to mitigate the disruptive effects of low ambient temperatures on sleep. By promoting longer and more stable restorative rest, this practice can directly enhance the welfare, health, and functional capacity of New Zealand's vital farm working dogs.

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Chapter 1: Literature review: sleep, energy expenditure, and the welfare of working farm dogs

1.1 Working dogs in New Zealand

Canis are primarily considered pets, but since their domestication, they have also performed working roles (Menache, 1998). These roles include assistance and service (e.g., disability support), detection (e.g., search and rescue, explosives, drugs, medical alerts), protection (e.g., military and law enforcement), and farm work (e.g., herding livestock) (Evans et al., 2007; Moore et al., 2002). A working dog is described as a dog used to perform practical tasks, as opposed to a pet or companion (Otto et al., 2019). In New Zealand, working dogs are specifically defined as disability assistance dogs, dogs used by government agencies for official duties, or those involved in herding livestock or private security (Dog Control Act, 1996). Working dogs are selectively bred for specific tasks and traits such as stock-handling skills, loyalty, resilience, and courage (Oliver & Shield, 2004).

1.2 Working farm dogs

New Zealand's temperate maritime climate, sparse population, and abundant land resources support an economy heavily reliant on agricultural exports (Rutledge et al., 2017). New Zealand agriculture employs extensive pasture-based grazing systems for cattle and sheep (Morris, 2013). As of June 30, 2024, New Zealand had 3.7 million beef cattle, 23.6 million sheep, and 5.8 million dairy cows Agricultural production (Agricultural production statistics, 2024), with 47,000 farming holdings averaging 279 hectares (Beef+Lamb New Zealand, 2024). Working farm dogs are essential for managing livestock due to the large farm sizes and extensive production systems (Cave et al., 2009). In 2008, it was estimated that there were 200,000 working dogs in New Zealand (Dalton, 2009), however, no accurate census data on working dog numbers have been collected.

1.2.1 Breeds of farm dogs

New Zealand herding dogs are typically classified into "Huntaway," "Heading," and "Handy" groups (Jerram, 2013). The two dominant breeds of herding dog are the Huntaway and Heading dog

(Cave et al., 2009), although there are also other breeds such as Handy dogs (e.g., Kelpies) or crossbreeds which make up 3% of herding dogs and are often overlooked (Isaksen et al., 2020).

The New Zealand Huntaway is believed to descend from breeds including the Border Collie, Rough Coated Collie, Labrador, Rottweiler, Harrier Hound, Gordon Setter, and Smithfield Collie (Dalton, 2010; Dogs New Zealand, 2025). The breed standard describes the Huntaway as a mid-sized dog, weighing 25-30 kg, with a more solid build than the Border Collie, a short coat, and typically black and tan coloring (Dogs New Zealand, 2025). Huntaways use vocalisation to push livestock and are commonly used in close proximity to sheep in yards and races (Cave et al., 2009; Oliver & Shield, 2004).

The Heading dog, descended from the Border Collie, lacks a formal breed standard (Dogs New Zealand, 2025). Compared to Huntaways, Heading dogs are lighter and more agile, typically weighing 15-20 kg with an average weight of 19 kg (Cave et al., 2009). They have inherited the calm, silent working style of their Border Collie ancestors, using body positioning and eye contact to gather and drive livestock without vocal commands and excel in open areas, guiding sheep toward the stockperson (Cave et al., 2009; Oliver & Shield, 2004). As compared to Huntaways, Heading dogs are more upright, stand out more, and tend to be more outgoing and eager to please. While often black and white or black, tan, and white, both breeds exhibit considerable phenotypic diversity (Dalton, 2010).

1.2.2 Role of farm dogs

Farm dogs in New Zealand perform critical tasks in herding and managing sheep and cattle, with each breed fulfilling complementary roles (Cogger & Sheard, 2017). Huntaways are vital for extensive herding operations, often used to push sheep through gates or into pens (Singh, 2013). As their name suggests, Huntaways are versatile working dogs that chase and drive livestock away from the handler. They work closely with sheep, responding quickly if an animal strays from the flock (Dalton, 2009). Their vocalisation enhances their effectiveness in controlling livestock movement, particularly in confined spaces like yards (Cave et al., 2009).

Heading dogs employ a silent herding technique, using body positioning and eye contact to maneuver livestock (Singh, 2013). They continuously move around flocks to maintain order and prevent sheep from dispersing (Dalton, 2010). Despite their high mobility, Heading dogs have been shown to cover similar distances to Huntaways, averaging 20 ± 1.3 km per day during peak periods (Singh, 2013). This mobility enables farmers to manage large groups of sheep effectively, particularly in open paddocks or mountainous terrain where visual control is challenging.

1.3 Management of farm dogs

1.3.1 Feeding

Feeding practices for working farm dogs vary, but surveys have found that most farmers (97%) provide their dogs with one meal at the end of the working day (Singh et al., 2011). The workload of the dogs fluctuates during the year from peak (maximum workload) to off-peak (minimum workload) periods. Peak periods often align with critical agricultural tasks such as calving, lambing, shearing, or other seasonal activities that require maximum effort from farmers, workers, and farm animals, while off-peak periods are times of reduced activity, lower workload, or decreased resource demands on the farm. These periods typically follow or precede peak seasons and involve maintenance tasks, rest, or planning rather than intensive labour (Beef+Lamb New Zealand, 2024). According to survey data (Singh et al., 2011), during the peak and off-peak work periods, over 25% of farmers primarily fed their working dogs homekill (livestock killed on the farm generally for animal consumption). While the quantity of food provided was higher during peak work periods, the composition of the diet remained largely unchanged between peak and off-peak (Singh et al., 2011). Importantly, the nutritional composition of these diets was not assessed, making it difficult to determine whether they met the dogs' energy and nutrient requirements. Isaksen et al. (2020) and Singh et al. (2011), however, both reported that compared to pet dogs, New Zealand working farm dogs generally had lower body condition scores (BCS). These studies suggests that a BCS of 4-5 is ideal, implying that dogs in this range are likely receiving adequate nutrition to maintain health and performance. Even a BCS of 3 might still indicate a dog is adequately fed if their lean body mass is appropriate for their skeletal size and work demands. Lower BCS likely reflects farmers' perception that lighter dogs are more agile and efficient than dogs with a higher BCS (Hand et al., 1989; Laflamme, 1997). While a low BCS in working farm dogs can raise concerns, it doesn't necessarily indicate insufficient feeding. Due to their high physical demands and energy expenditure, these dogs often have a naturally leaner body composition that doesn't compromise health. Conversely, a BCS of 1-2 is more likely to reflect energy deficiency or underlying health issues and should prompt further clinical assessment (Isaksen et al., 2020). However, the absence of detailed nutritional data limits our understanding of optimal feeding practices, underscoring the need for research into the long-term dietary requirements of these working dogs.

1.3.2 Housing

Optimising kennel conditions are essential for improving the welfare and rest of farm dogs. Kennel temperatures between 20-26°C minimise energy expenditure via thermoregulation, supporting health and promote restful sleep by the dog (Prescott et al., 2004). Extreme temperatures, either excessively hot or cold, increase the dog's energy demands, elevating overall energy requirements (Wakshlag & Shmalberg, 2014). Research has shown cold environments, in particular, raise stress hormone levels, disrupting rest, while actively heated kennels fostered more restful behaviour (Rooney et al., 2009). When maintaining ideal temperatures in a farm setting is not feasible, owners should monitor dogs for signs of thermal discomfort, such as shivering, and provide additional bedding or coats (Rooney et al., 2009). Although housing conditions significantly affect energy expenditure and welfare, low BCS in working sheepdogs showed no relationship with housing (O'Connell et al., 2019; The World Small Animal Veterinary Association, 2010).

Research on the kenneling of working dogs in New Zealand is extremely limited. To date, the only substantial investigation is the study by Isaksen et al. (2020), which was conducted in Canterbury and Otago in the South Island and therefore may not be reflective of national practices. Nonetheless, it provides valuable insight into prevailing conditions and potential welfare challenges. The study reported that approximately 99% of respondents housed their working dogs in kennels, with 68% using commercially purchased designs and 31% relying on homemade structures. Most kennels were standalone units (72%), with a small outside run, a smaller proportion (26%) were smaller with the dog chain-fixed to the kennel. These findings underscore both the widespread use of kennels and the need for further research to establish best-practice guidelines for kennel design and management across different farming systems.

1.3.3 Coat use

In the survey by Isaksen et al. (2020), 68% of farmers (333 out of 487) did not put coats on their dogs, while 32% (154 out of 487) did, and despite this relatively low number, working farm dogs show high acceptance of clothing, with only six out of 333 coatless dogs in the study rejecting coats.

There is currently no data available on the types of dog coats, but sales figures from commercial website suggest that waterproof, wool, cotton, and polyester fleece coats are the most popular (Table 1.1). For working farm dogs, the most common coat sizes are medium (57 cm), large (62 cm), and extra-large (67 cm) (Table 1.2).

Table 1.1 Common dog coats by style and material.

Brand	Picture	Materials / Styles	Website
Naturalhound		Waterproof polycotton canvas / wool	https://www.naturalhound.co.nz/collections
Horselands NZ		Polyester fleece / waterproof jacket / warm filling style	https://horselands.co.nz/collections/dog-coat?utm_source=chatgpt.com
Swanndri Classic Wool Dog Coat		Wool / fleece / cotton	https://www.nznature.co.nz/swan-dog-coat?utm_source=chatgpt.com
FurFrienz		fleece	https://www.furfrienz.nz/product-page/dog-fleece-coats?utm_source=chatgpt.com

Table 1.2 Dog coat's size guide

Extra Small	Small	Medium	Large	Extra Large
Breed example: French Bulldog, Jack Russel, Border Terrier	Breed example: Small Heading dog	Breed example: Border Collie, Dalmatian	Breed example: Huntaway, Greyhound	Breed example: Large Huntaway, German Shepherd
Length: 36cm Girth: 35cm-65cm Neck: 25cm-35cm	Length: 52cm Girth: 60cm-80cm Neck: 35cm-45cm	Length: 57cm Girth: 65cm-95cm Neck: 40cm-60cm	Length: 62cm Girth: 65cm-95cm Neck: 25cm-35cm	Length: 67cm Girth: 75cm-100cm Neck: 40cm-60cm

https://www.naturalhound.co.nz/collections

1.4 Health and welfare

Working farm dogs are indispensable to New Zealand's agricultural sector. Although some studies have examined their nutrition and health (Sheard, 2014; Singh et al., 2011), relatively little is known about their workload, dietary requirements, or overall health. A survey by the New Zealand Sheep Dog Trial Association (NZSDTA) revealed that 54% of owners described their dogs as moderately to extremely tired, with dogs rested or spelled a median of eight days in the prior month. Notably, farms with more dogs reported higher levels of perceived tiredness ($P < 0.001$), but no correlation was found between tiredness and rest days (Singh et al., 2011). Supporting this, Cave et al., (2009) and Isaksen et al., (2021) identified a higher prevalence of joint diseases, musculoskeletal issues, injuries, and skin trauma among working farm dogs, indicating high workloads on rough terrain.

Research suggests that inadequate rest may be a critical issue for these dogs. Sufficient rest and sleep are vital not only for their welfare but also for maintaining physical health (Cobb et al., 2021). Working farm dogs often endure long hours of work, are fed at day's end, and are kenneled outdoors overnight, with inconsistent provision of insulation or bedding. Isaksen et al. (2020) reported that only 44% of the dogs sampled had bedding, 32% wore coats, and 14% had insulated kennels. Ambient temperatures can increase energy expenditure, and providing bedding or coats in cold conditions could reduce this while enhancing sleep quality through greater thermal comfort. Quality sleep is essential for working dogs, supporting emotional well-being, cognitive function, immune health, performance, and recovery, all of which contribute to longevity (Cobb et al., 2021). Improving sleep conditions for New Zealand's working farm dogs could significantly enhance their health and welfare.

1.5 Energy expenditure and body condition score in working farm dogs

Working dogs, as warm-blooded mammals, rely on dietary energy to fuel essential functions, including thermoregulation, physical activity, and metabolic processes (Sheard, 2014). After digestion, absorbed energy supports vital activities such as maintaining body temperature and supporting exercise. There is no precise data on the energy requirements for working farm dogs in New Zealand despite the extreme physical demands of work (Singh et al., 2011). Cold weather can increase energy needs by 50% or more due to increased thermoregulatory demands, while their high activity levels necessitate specialised nutrition (Singh et al., 2011). Compared to pet dogs, working dogs require higher dietary protein to support enhanced protein synthesis and degradation driven by intense exercise, a need especially critical for athletic farm dogs living predominantly outdoors (Case, 2013; Isaksen et al., 2020). This underscores the challenge of meeting their nutritional needs without tailored guidelines.

1.5.1 General energy requirements in dogs

Canine energy needs vary by life stage, breed, and activity level, making adequate nutrition essential for health and well-being (Sheard, 2014). Research on dog energy requirements began in the early 20th century, with Cowgill (1928) estimating needs based on food intake and body weight under experimental conditions. Both the Association of American Feed Control Officials (AAFCO) (2025) and the European Pet Food Industry Federation (FEDIAF) (2025) provide comprehensive frameworks, though they differ in approach and emphasis.

Maintenance energy requirements (MER) refer to the energy needed to maintain energy balance, encompassing thermoregulation, spontaneous activity, exercise, and energy lost during digestion and metabolism. The National Research Council (NRC) (2005) estimated an average MER of 132 kcal/kg $BW^{0.75}$ per day for adult dogs in kennels with moderate exercise, but this formula was designed for young, active experimental dogs and does not fully account for the elevated needs of working dogs like New Zealand farm dogs, sled dogs, or police dogs (Singh, 2013).

1.5.2 Energy demands of working dogs

Working dogs, such as military, police, and sled dogs, have significantly higher energy needs than pets dogs due to the physical demands of their tasks (Case, 2013). The MER of working dogs often exceed those of typical pet dogs at rest by 1.5 to 3 times, depending on the type of work (Case, 2013). Sled dogs engaged in intense activities in cold weather require 8,995-13,779 kcal/day (6 to 8 times more), driven by physical exertion and thermoregulation (Gerth et al., 2010; Mullis et al., 2015). Similarly, police dogs performing search, detection, or protection tasks consume 6,132-8,118 kcal/day, which varies with work intensity (Schäfer & Hankel, 2020). To support their health and performance, working dogs require specialised low-carbohydrate, high-fat, high-protein diets, which enhance nutrient digestibility (Hill et al., 2009).

1.5.3 Specific energy requirements of New Zealand farm dogs

New Zealand working farm dogs, particularly herding dogs, have substantial energy requirements due to their intense physical workloads, comparable to those of endurance athletes (Singh, 2013). These dogs travel an average of 10 km per day during off-peak periods and up to 20 km per day during peak periods, similar to the activity levels of sled dogs (Singh, 2013). Their energy needs reach up to 202 kcal / kg $BW^{0.75}$ in peak periods and 128 kcal / kg $BW^{0.75}$ in off-peak periods, significantly exceeding the MER of 123.8 kcal/kg $BW^{0.75}$ for moderately active pet dogs during peak work (Bermingham et al., 2014; Singh, 2013). The standard formula of 132 kcal / kg $BW^{0.75}$, designed for less active dogs, may be inadequate for these working dogs (Singh et al., 2011). Unfortunately, there is a lack of studies on the energy requirements of the New Zealand Sheepdog, so it is challenging for New Zealand Sheepdog owners to feed the right diet to meet their energy needs.

1.5.4 Body condition of New Zealand farm dogs

As mentioned previously, New Zealand working farm dogs exhibit significantly lower BCS than pet dogs, reflecting nutritional challenges. Research found that 35% of these dogs had a BCS below 4 (underweight), 63% were at BCS 4 or 5 (normal weight), and only 3% exceeded BCS 5 (overweight) (Isaksen et al., 2021). Similarly, a survey of 1,115 farm dogs across 118 farms in New Zealand's North Island reported that 18.8% were underweight and only 1.9% were overweight, in stark contrast to Australian pet dogs, where 33.5% were overweight and 7.6% were obese (McGreevy et al., 2005; Sheard, 2014). Low BCS and underweight conditions indicate insufficient fat reserves, impairing thermoregulation. Unlike ectotherms, mammals like dogs rely on brown adipose tissue for heat production during cold periods, and its scarcity in emaciated dogs exacerbates heat loss (Harding et al., 2020). Studies also suggest that lower body temperatures in underweight dogs may disrupt sleep, as warmer temperatures facilitate sleep onset and reduce non-rapid eye movement (NREM) sleep duration, potentially compromising recovery and welfare (Jhaveri et al., 2007; Van Someren, 2006).

1.6 Sleep and animal health

1.6.1 Role of sleep

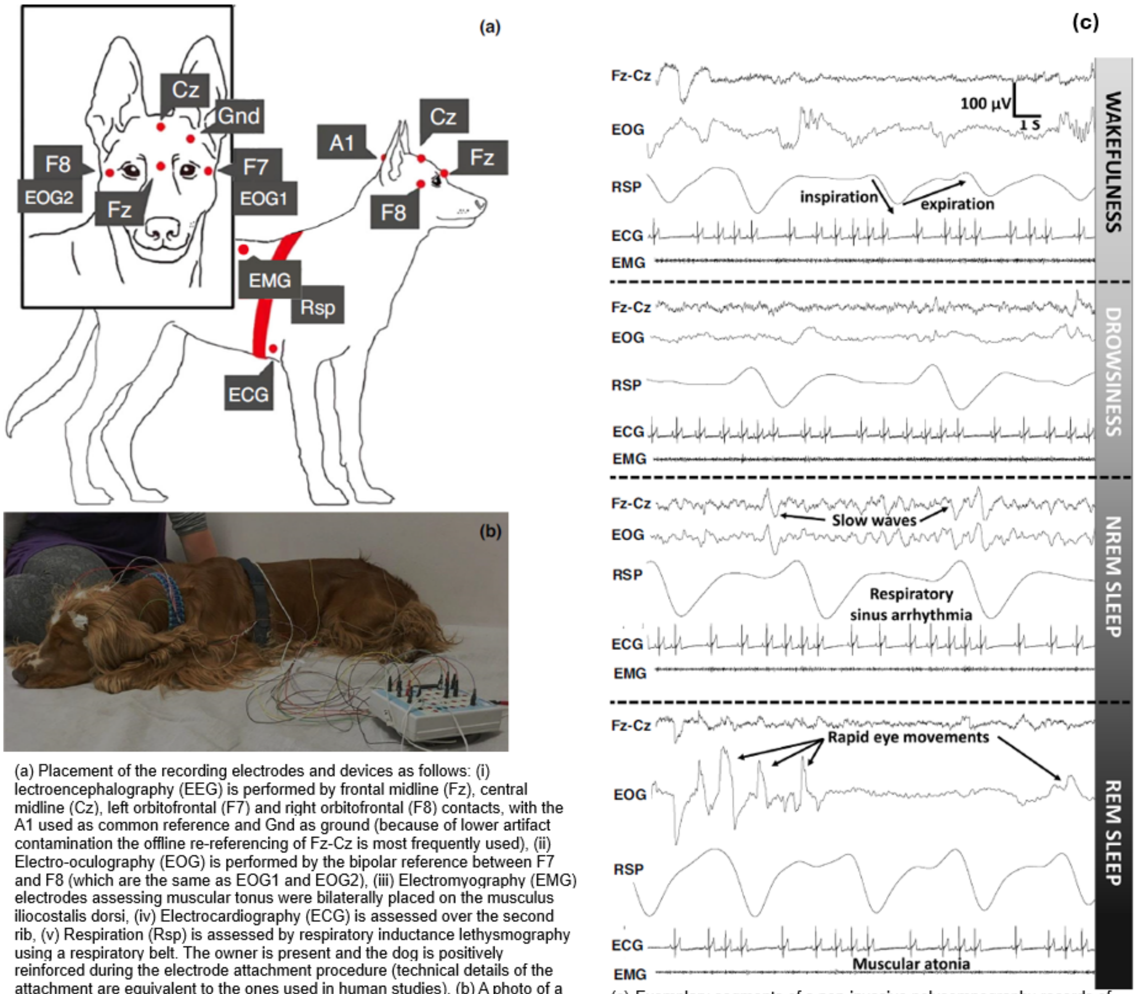
Sleep is a critical form of rest that is essential for all animals and supports energy conservation, thermoregulation, and predator avoidance in prey species (Fradin & Chamaillé-Jammes, 2023). Sleep is fundamental to health, boosting immune responses, regulating metabolism and hormone production, and promoting neural maintenance, brain development, and cognitive function (Irwin, 2019; Ramar et al., 2021). Despite its significance being recognised, comprehensive empirical research on the effects of sleep on animals only began in the mid-20th century (Moore et al., 2002). Working dogs often have high workloads and travel long distances, creating a profound need for effective recovery. Therefore, the benefits of sleep are vital for this group, as it enhances immunity, sustains energy demands, and supports cognitive performance, directly impacting their welfare and longevity.

1.6.2 Sleep pattern of dogs

The sleep of mammalian species has been broadly classified into two types: NREM sleep and rapid eye movement (REM) sleep, while in humans NREM sleep is further divided into falling asleep, light sleep, and slow wave sleep (Rechtschaffen & Anthony, 1968). The length of a sleep cycle containing both NREM and REM in mammalian species can vary greatly between different animals. For example, sleep cycles can last for as little as 10min (in *Rattus*) to 85 min (in *Pan*) (Tobler, 1995). Reports have shown that domestic dogs sleep between 7.7 to 16 hours per day with an average 12.9 hours (Savage & West, 2007)

Dogs are characterised by polyphasic sleep (alternating with active movement) which occurs predominantly at night with additional short-term episodes of sleep during the day (Fomina et al., 2023). Using non-invasive polysomnography recording, we can divide a dog's sleep state into wakefulness, drowsy state, NREM sleep (slow-wave sleep), and REM sleep (Figure 1.1). An early study of dogs in an experimental setting, revealed time budgets of 44% of alert wakefulness, 21% in the drowsy state, while slow-wave sleep occupied 23% and REM sleep 12% of the time in dogs (Bódizs et al., 2020).

Like humans, dogs' sleep characteristics are influenced by the time of day. At night, NREM sleep predominates, with a reduction in drowsiness stage. Dogs exhibit polyphasic sleep, characterized by frequent awakenings and a reduced proportion of REM sleep, which can even be absent. A key difference lies in sleep fragmentation: in humans, REM sleep is followed by the next sleep cycle, while dogs typically wake after REM sleep (Reicher et al., 2021). In dogs, the mean length of a REM sleep episode is 6 min and the mean REM sleep cycle is 20 min. The mean polycyclic sleep-wake cycle is 83 min which consists of sleep episodes which average 45 min, with mean waking episodes of 38 min (Lucas et al., 1977). Subsequently, more studies on dog sleep have provided more accurate data on dog sleep times. Most dogs' sleep occurs between 9 pm and 6 am with a period of rest during the afternoon with afternoon naps, however, night sleep has higher sleep efficiency and continuity (Bódizs et al., 2020).



(a) Placement of the recording electrodes and devices as follows: (i) lectroencephalography (EEG) is performed by frontal midline (Fz), central midline (Cz), left orbitofrontal (F7) and right orbitofrontal (F8) contacts, with the A1 used as common reference and Gnd as ground (because of lower artifact contamination the offline re-referencing of Fz-Cz is most frequently used), (ii) Electro-oculography (EOG) is performed by the bipolar reference between F7 and F8 (which are the same as EOG1 and EOG2), (iii) Electromyography (EMG) electrodes assessing muscular tonus were bilaterally placed on the musculus iliocostalis dorsi, (iv) Electrocardiography (ECG) is assessed over the second rib, (v) Respiration (Rsp) is assessed by respiratory inductance lethysmography using a respiratory belt. The owner is present and the dog is positively reinforced during the electrode attachment procedure (technical details of the attachment are equivalent to the ones used in human studies). (b) A photo of a dog with electrodes attached.

(c) Exemplary segments of a non-invasive polysomnography records of night time sleep in an adult dog.

Figure 1.1 Record method and exemplary segments of a non-invasive polysomnography records of nighttime sleep in an adult dog (Bódizs et al., 2020)

It is worth noting that the sleep time of dogs also changes with physiological state or daytime activities / environmental influences. Studies have shown that, similar to the elderly, older dogs sleep less than puppies (Zanghi, 2010), and show a marked reduction of REM sleep, fragmentation of wakefulness in the daytime and sleep disruption during the night (Zanghi, 2010). These animals also show an increase in the total amount of time spent in NREM sleep during the daytime followed by an increase of time spent in wakefulness during the night (Takeuchi & Harada, 2002). Animal behaviour studies have shown pre-sleep activity improves sleeping time, time spent in REM sleep, reduced latency to the first sleep bout, and less awakening during subsequent sleep and increasing overall sleep efficiency (Schork et al., 2022b). At the same time, environmental conditions affect sleep in dogs. A pilot study showed that nocturnal sleep decreased in response to increases in temperature and daylight duration, while no effects of sound on dogs' sleep were observed (Schork et al., 2022a). The study implied that a decrease in daily activity and increased physiological stress responses could be associated with maladaptation to the environment. Another study showed that stray dogs were nervous and slept less when they first arrived at the shelter, but after a period of adaptation, their sleep time gradually increased (Van den Berg, 2017).

In summary, while the dogs' sleep patterns are similar to those of humans, there are notable differences. Dogs tend to have longer overall sleep durations but spend a greater proportion of their sleep in the "light sleep" or "transitional state" compared to humans (Bódizs et al., 2020). Like human sleep, canine sleep is also affected by environmental factors and surrounding activities. Given that sleep quality impacts not only immune function and energy metabolism but also neurological development, mood, and behaviour, further research into the sleep patterns of dogs is crucial. These studies could have significant implications for improving working dogs' health and be able to improve overall animal welfare.

1.6.3 The effects of sleep on animal physiology

Muscular recovery

The goal of muscle recovery is to repair exercise-induced damage and, through adaptation, synthesise new proteins to strengthen the muscle (a process known as muscle protein synthesis, or MPS).

The anabolic hormonal environment created during sleep is believed to be a key facilitator of MPS. While direct measurement of MPS during sleep is technically challenging, the physiological conditions are optimised for this process (Del Gallo et al., 2014). During sleep, the body can redirect its energy resources. With physical and cognitive demands minimised, a greater proportion of the body's energy can be allocated to restorative processes, including the transport of amino acids to muscle cells and their incorporation into new proteins (Besedovsky et al., 2019). Sleep deprivation can disrupt these processes, potentially blunting the MPS response to exercise and nutritional stimuli, thereby compromising muscular adaptation and repair (Del Gallo et al., 2014).

Sleep is an active and indispensable component of physiological and muscular recovery. It exerts its restorative effects through a coordinated series of mechanisms, including the promotion of an anabolic hormonal state, the precise modulation of the immune and inflammatory systems, the facilitation of muscle protein synthesis, and the restoration of the central nervous system. As the evidence strongly indicates, neglecting sleep can severely compromise the body's capacity to heal and adapt. Therefore, prioritising sufficient, high-quality sleep should be considered as fundamental as nutrition and training in any program aimed at optimising physical performance and well-being (Ramar et al., 2021).

Immune response

Sleep and immune responses are reciprocally and intricately linked. Lack of sleep harms the immune response, which can contribute to the dysregulation of inflammatory and antiviral responses (Irwin, 2019). Research has shown sleep generally regulates immune functions in a supportive way (Ruiz et al., 2017). Some studies have shown that insufficient sleep at night can reduce antibody levels after vaccination, while good sleep is beneficial for enhancing immunity and promoting antibody production (Lammers-van der Holst et al., 2022; Lange et al., 2003). A study that evaluated clinical protection status 6 months after healthy middle-aged adults consistently received the standard 3-dose hepatitis B vaccination showed that shorter activity-based sleep duration was associated with a lower secondary antibody response (Prather et al., 2012).

Sleep quality also affects the secretion of immune-related factors such as growth hormone, prolactin, and cortisol, and the metabolism of oxygen free radicals (Del Gallo et al., 2014). The effects of sleep on the immune system have been demonstrated primarily through sleep deprivation experiments, including both epidemiological and laboratory studies. The data show that sleep deprivation is associated with alterations of innate and adaptive immune parameters, leading to a chronic inflammatory state and an increased risk for infectious / inflammatory pathologies, including cardiometabolic, neoplastic, autoimmune, and neurodegenerative diseases (Garbarino et al., 2021). For example, a study on sleep deprivation in humans showed that after sleep deprivation, all participants showed elevated granulocyte counts (Sochal et al., 2024) while another study showed that long-term deprivation of sleep affects changes in the levels of C-reactive protein, tumor necrosis factor, and cytokine production (Savard et al., 2003).

Interestingly, sleep seems to affect the immune system in different ways (Figure 1.2). Immune system activation alters sleep, though sleep can in turn affect both the innate and adaptive arms of the immune system as well (Besedovsky et al., 2019). That means it is now well-accepted that the immune response affects sleep, and many routes of infection, including bacteria, viruses, protozoa, or fungi, are known to increase NREM sleep, inhibit REM sleep, and fragment sleep (Del Gallo et al., 2014). Although the above studies are mainly focused on humans, based on the similarities between the immune systems of mammals (e.g., dogs) and humans (Yuan et al., 2012), it is reasonable to believe that good sleep quality can help improve the immune status of working dogs.

Figure 1.2 Sleep and immunity are bidirectionally linked (Besedovsky et al., 2019)

Regulation of metabolism

Studies have also shown that lack of sleep can negatively impact glucose metabolism and increase insulin resistance (Simon et al., 1994), leading to a higher risk of diabetes and obesity (Leproult & Van Cauter, 2010). The brain is almost entirely dependent on glucose for energy and is the main site of glucose processing. Brain glucose utilisation accounts for 50% of the total body glucose processing under fasting conditions and 20-30% after meals (Leproult & Van Cauter, 2010), so brain activity has a huge impact on body metabolism.

Further studies have shown that the reason for the increase in obesity is related to the reduction in leptin secretion after sleep reduction (Spiegel et al., 2004). To suppress hunger during nighttime fasting, leptin levels increase during nighttime sleep (Leproult & Van Cauter, 2010). When sleep is lacking, leptin levels decrease, growth hormone levels also decrease (Spiegel et al., 1999), and insulin sensitivity decreases, which ultimately leads to energy conversion into fat accumulation, causing animal obesity.

However, the above studies were conducted when food was sufficient, and food intake was not restricted. In the wild, due to limited food sources, frequent sleep interruptions will increase the energy consumption of animals (Olejarz et al., 2023), and the impact of this on body weight is still unclear.

In short, sleep time and pattern affect the release of insulin, growth hormone, leptin, and ghrelin in animals, thereby regulating metabolism in animals and supporting neural maintenance and brain development.

Supporting neural maintenance

Research in brain development has mainly focused on humans. Studies have shown that in the first period of human brain development (around birth), the brain focuses on the accumulation of neuronal connections, while in the second period (from late infancy to adolescence), brain development centers more around the pruning of neuronal connections (Knoop et al., 2021). Sleep plays a vital role in both processes.

Studies on rats have shown that lack of REM sleep during early development delays the maturation of the visual cortex and impairs the maturation of the motor system (Shaffery et al., 2006). Other studies have found a critical association between sleep and glial activation following neural injury, and good sleep is conducive to the clearance of damaged neurons (Stanhope et al., 2020).

Influence on cognition and emotion

In human studies, sleep deprivation is closely linked to negative emotions (Walker, 2009). For example, sleep disturbances are frequently associated with, and can comprise, core features of anxiety disorders (Mellman, 2006), which include specific and social phobias, obsessive-compulsive disorder, generalised anxiety disorder, panic disorder, and posttraumatic stress disorder (Mellman, 2006).

In dogs, a recent study showed that both the number of awakenings as well as relative NREM duration influenced viewing patterns in a task where sad and happy human faces were simultaneously projected with sad or happy human voice playbacks (Bolló et al., 2020). This suggests there is a causal link between sleep structure and emotional processing in the dog (Bolló et al., 2020)

Another non-invasive polysomnography study also indicated increased NREM delta and REM theta, as well as decreased NREM alpha activity in post-learning when compared to baseline sleep in dogs (Kis et al., 2017). Behavioural performance significantly increased after the 3-hour-long rest / sleep compared to the pre-sleep baseline period. In contrast, the within-subject increase in performance correlated with certain aspects of the sleep EEG spectrum (REM beta and delta power).

However, compared with humans and rodents, there are still relatively few dog sleep studies (Bódizs et al., 2020). It is believed that as the animal welfare system improves, more attention will be paid to the relationship between dog sleep and its cognitive behaviour and emotions.

1.6.4 Sleep pattern and energy metabolism

The sleep patterns of animals can be altered by their energy consumption. In humans, for instance, the onset of sleep is linked to circadian-driven changes in body heat production and heat loss (Kräuchi & Deboer), a phenomenon that may be relevant for energy conservation in infants or small mammals (Zoccoli & Amici, 2020).

Sleep appears to be a physiological regulation measure evolved to allow animals to save energy (Berger & Phillips, 1995). When energy stores decline, energy is conserved through more consolidated sleep (with fewer periods of wakefulness) or by increasing the daily duration of sleep (Berger & Phillips, 1995). A recent study showed that increased human activity (termed “anthropulse”) during the COVID-19 lockdown influenced sleep quality among suburban wild boars (*Sus scrofa*) with shorter, more frequent sleep bouts and a 41% increase in energy expenditure (Olejarz et al., 2023). Sleep allows the conservation of energy by lowering the animal’s metabolic rate and reducing the need for food intake, which is particularly beneficial in environments where resources are scarce. Animals with short sleep durations, such as large herbivores, have high energy demands that typically prevent extended rest, as staying alert minimises predation risks and maximises feeding opportunities (Harbison, 2010; Lakhiani et al., 2023). Conversely, animals in safe environments or with lower energy demands, such as small mammals or those with safe sleeping spots, often engage in longer or deeper sleep, thus conserving energy more efficiently with some undergoing torpor or hibernation states to further reduce their metabolic rate (Lakhiani et al., 2023).

Sleep also plays a crucial role in metabolic health with insufficient sleep leading to metabolic imbalances and increases in hunger-related hormones resulting in higher food intake (Siegel, 2010). A study of American teenagers showed that for each hour of lost sleep per night the odds of obesity increased by 80% and daytime physical activity diminished by 3% (Gupta et al., 2002). A New Zealand survey of 1,037 babies born in Dunedin between April 1972 and March 1973 found that there was a negative correlation between childhood sleep duration and BMI at 32 years of age (Landhuis et al., 2008). Similar associations have been observed in animals, where sleep restriction has been linked to altered energy balance and increased food consumption (Harbison, 2010; Lakhiani et al., 2023). Studies in rodents have also demonstrated that chronic sleep deprivation can lead to significant weight gain and impaired glucose metabolism (Berger & Phillips, 1995).

Recent work has shown that the regularity of sleep-wake cycles, which governs our internal circadian rhythms, is more critical for metabolic regulation than the total amount of sleep (Yuan & Yadlapalli, 2024). For example, a *Drosophila* study found that disruption of light-dark cycles was enough to alter metabolic function, regardless of their total sleep duration (Duarte et al., 2024). Similarly, the importance of time within the circadian rhythm was highlighted in a rat study, which showed that performing exercise in the morning versus the evening had different impacts on adipose tissue and metabolism (Kutsenko et al., 2025). These findings collectively suggest that the consistency and timing of daily activities are fundamentally more influential on metabolic health than the sheer quantity of rest (Kutsenko, 2023).

Studies involving high-caloric diets and time-restricted feeding protocols, which show altered metabolic efficiency and energy conservation, highlight the bidirectional relationship between sleep patterns and energy metabolism (Gangitano et al., 2023; Manoogian et al., 2021). This means that sleep architecture is not only a determinant but also a consequence of the body's energy management.

1.6.5 Methods to alter animal sleep patterns

In companion animals, sleep patterns are closely linked to the animal's mood and ultimately the quality of the human-animal bond (Bremhorst & Mills, 2021). Using positive methods to improve animal sleep to enhance health and production efficiency can not only improve animal welfare but also help reduce emotional fluctuations in working dogs (Lefter et al., 2022; Sharma & Kavuru, 2010).

Strategies to modify sleep patterns include manipulation of light, controlled feeding, and optimisation of thermal conditions (Sharma & Kavuru, 2010).

Light manipulation

Adjusting light exposure can significantly influence an animal's circadian rhythm, as light is the primary cue for entraining internal biological clocks (Dibner et al., 2010). The solar day serves as a critical Zeitgeber, synchronising circadian rhythms and sleep-wake cycles, thereby restricting activity to the appropriate temporal niche (Foster & Kreitzman, 2017). Under normal conditions, organisms experience a 24-hour light/dark cycle, and most animal circadian systems rely on day-night transitions to maintain alignment with environmental time (LeGates et al., 2014).

Human studies have shown that light is a critical modulator of sleep and circadian rhythms (Cajochen et al., 2010). Light intrinsically affects photosensitive retinal ganglion cells by activating the photopigment melanopsin (Hattar et al., 2002). Signals are then transmitted through the retino-hypothalamic tract to the suprachiasmatic nucleus and other brain regions involved in sleep–wake regulation (LeGates et al., 2014). Moreover, the use of bright light has been reported to shift the phase of the human circadian temperature rhythm (Drennan et al., 1989).

For humans, an international standard defines an SI-based method to quantify how light affects photosensitive retinal neurons that express melanopsin and mediate these responses. These are supported by a detailed analysis of the sensitivity of human circadian and neuroendocrine systems, and responses to ocular light and provide a straightforward framework to inform lighting design and practice (Brown et al., 2022). Although these standards are designed for humans, they underscore the critical role of light in circadian regulation, which could inform future studies on companion animals.

Research on the effect of changes in the brightness of light before "lights-out" on sleeping behaviour in dogs has found that between 1600 h and 1730 h, there were no differences in behaviour between dogs kept at 600 lux (control), 50 lux (poorly lit), or 1600 lux (brightly lit), but dogs exposed to poorly lit conditions showed more lateral recumbency between 0500 h to 0700 h than control dogs (Fukuzawa & Nakazato, 2015). Further, dogs in the poorly and brightly lit groups showed more events with eyes closed than control dogs (Fukuzawa & Nakazato, 2015). Unfortunately, while there is a lot of research on the effects of light on sleep, there is little research on the use of light modulation to treat sleep disorders or influence sleep patterns in dogs.

Controlled feeding schedules

The timing of feeding can also influence sleep patterns. Studies in mice have shown that food intake during the biological night, akin to night shift work in humans, causes a 12-hour shift in the peripheral clock, but not the central clock based on the 24-hour pattern of light / dark (Mukherji et al., 2015). This is because the central clock, located in the brain's suprachiasmatic nucleus, is the master pacemaker synchronised by light, whereas peripheral clocks in organs like the liver regulate metabolic functions and are strongly entrained by feeding times. Another study on humans showed that shift workers experience chronic circadian misalignment due to a complete reversal of feeding-fasting and wake-sleep behavioural cycles (Pickel & Sung, 2020). A more in-depth study found that orexin neurons project throughout the central nervous system to nuclei known to be important in the control of feeding, sleep-wakefulness, neuroendocrine homeostasis, and autonomic regulation (Willie et al., 2001). Orexin mRNA expression is upregulated by fasting and insulin-induced hypoglycemia. C-fos expression in orexin neurons, an indicator of neuronal activation, is positively correlated with wakefulness and negatively correlated with REM and NREM sleep states. The study showed that the orexin neuropeptide system plays a significant role in feeding and sleep-wakefulness regulation, possibly by coordinating the complex behavioural and physiological responses of these complementary homeostatic functions.

Thermal comfort

Ambient temperature is the main factor affecting sleep length and quality (Harding et al., 2020). Research suggests that changes in skin temperature, rather than changes in core temperature, have a causal effect on sleep propensity (Van Someren, 2006). Humans and mammals exhibit thermoregulatory behaviours before sleep, such as curling up, using bedding, or nest building, creating a warm microclimate that promotes sleep and facilitates vasodilation in hands and feet (Harding et al., 2019; Van Someren, 2006). Even warm-blooded animals exhibit a daily body temperature cycle, typically fluctuating within a 1°C range (Mendt et al., 2017). In humans, the onset of deep sleep is closely linked to the period when body temperature drops most rapidly (Harding et al., 2019).

Studies in mice have shown that higher ambient temperatures (26 to 30°C) promote spontaneous slow wave sleep in association with reduced delta wave amplitude. Higher ambient temperatures also promote recuperative sleep after sleep deprivation, while lower temperatures result in reduced sleep depth (Jhaveri et al., 2007).

The relationship between sleep and body temperature in dogs has been studied since the 1960s. Cerebral arterial blood and brain sites cool together during slow were sleep, while deep body temperatures remain constant (Hayward, 1968). A more recent study of the environmental effects on the sleep of domestic dogs showed that higher ambient temperatures (exceeding an individual's thermoneutral zone) have a negative influence on sleep (Schork et al., 2022a). However, the ambient temperature during the study was relatively high (average daily temperatures above 18°C), and the study did not discuss the impact of ambient temperature below an individual's thermoneutral zone on the sleep time of dogs. Interestingly, a four-year study on experimental beagles by Miyazaki et al. (2002) showed that after dark (around 1900 h), the body temperature of the dogs rose during the sleep phase and then gradually decreased. This study used an invasive temperature collection device in the body that measured core temperature, suggesting that a rise in body temperature is a characteristic of falling asleep, followed by a slow decrease in body temperature, as the animal entered a deep sleep stage. Recent studies on the relationship between uncoupling protein-1 (UCP-1) and sleep support this phenomenon: UCP-1 is a protein that can separate the proton return in the electron transport chain from the ATP production process, thereby generating heat instead of ATP. Studies have found that UCP-1 knockout mice rebound less after sleep deprivation than wild-type mice (Szentirmai & Kapás, 2014), suggesting that animals need to activate sensory receptors in the skin through heat production to induce a homeostatic response to cool the body (lower core temperature), and thus trigger NREM (Harding et al., 2019; Harding et al., 2018)

Although there is no research on the relationship between body surface insulation and dog sleep quality, we can speculate from the above research that when the ambient temperature is lower than the individual's thermoneutral zone, it shortens sleep latency and promotes NREM sleep, thereby improving the dog's sleep quality.

1.6.6 Sleep problem of New Zealand farm dogs

Resting is a crucial daily requirement for all animals for energy conservation, thermoregulation, and predator avoidance (Fradin & Chamaillé-Jammes, 2023). In fact, sleep is critical for working dogs as it is associated with emotional state and is necessary for cognitive function, immune function, optimal performance and recovery to ensure longevity in working dogs (Cobb et al., 2021; Owczarczak-Garstecka & Burman, 2016).

Unfortunately, despite their physically demanding jobs, little research has been conducted on sleep patterns in New Zealand farm dogs. even so, several factors suggest that they may experience sleep deprivation or disrupted rest periods: 1) Extended working hours: just as mentioned above, farm dogs are often required to work long shifts, which could limit their opportunity for rest, especially during peak mustering seasons; 2) Kennel environment: for example, according to Isaksen et al. (2020), many farm dogs are housed in outdoor kennels, where exposure to cold temperatures, noise, and other distractions could all reduce sleep quality.

Given the importance of sleep for working farm dogs in New Zealand, further research is needed to determine how food, the kennel environment, and potentially clothing affect their sleep. Corresponding measures should then be taken to effectively improve the sleep quality of these dogs.

1.7 Aims and objectives of this thesis

Working dogs are important components of livestock farming in New Zealand. They work long hours and are usually fed at the end of the day before being kenneled outdoors overnight. There is a high degree of variability in the insulation and bedding provided in kennels, and ambient temperatures can impact a dog's energy requirements and energy expenditure.

As mentioned above, providing dogs with bedding or coats in cold weather may influence not only their energy expenditure but also their behaviour if greater thermal comfort can result in improved sleep.

This study aims to test the impact of wearing a coat (Natural Hound NZ) on the dogs' sleep / resting patterns, when kept in kennels at the Canine Nutrition Unit (Massey University). In addition to this, I will also investigate if the wearing of coats improves nutrient uptake from a working dog diet, using a standard AAFCO (2025) apparent nutrient digestibility protocol. This research will help to understand the effects of wearing a coat on sleep and energy metabolism in dogs and hopefully improve the welfare of working dogs.

Chapter 2 The use of coats to improve the sleep of New Zealand working farm dogs

2.1 Abstract

Working dogs play a crucial role in New Zealand's agricultural industry, and their health is directly related to the quality of rest they obtain. Given the varieties in temperature between night and day in spring and autumn, maintaining body warmth may enhance sleep quality. This study investigated whether wearing a coat could improve the overnight rest of New Zealand farm working dogs during spring. The study involved eight healthy working dogs of working dog breeds housed in outdoor kennels. Sleep patterns were monitored using a triaxial accelerometers (tri-axial ActiGraph WGT3X-BT accelerometers) over 10 days, with dogs alternating between periods of wearing and not wearing a coat at night. A total of 6,912,000 seconds (~1,920 hours; ~240 hours per dog) of triaxial acceleration data were recorded, which was then analysed using a machine learning model to classify behaviours. Environmental parameters such as temperature, wind speed, and humidity were recorded concurrently. Results showed that overnight the proportion of time dogs spent asleep per hour when wearing a coat was 55.15 ± 1.15%, which was significantly ($P = 0.046$) longer than when they did not wear a coat (47.48 ± 3.28%). When wearing a coat overnight, the daily activity rhythm of the dog, measured by overall dynamic body acceleration (ODBA), showed a significant interaction with the time of day: dogs were significantly less active during the afternoon and night ($P < 0.05$) but more active the following morning (0900 to 1500 h; $P < 0.01$). The average hourly sleep time was more stable when dogs wore coats, especially during the coldest hours of the night between 0200 h and 0500 h. These results demonstrated that wearing coats can mitigate the disruptive effects of low temperatures and improve the sleep quality of farm working dogs. This non-invasive approach demonstrated that simple interventions, such as providing coats, can enhance animal welfare by promoting better sleep and potentially overall health as a result of this. These results are particularly relevant for farm management practices during colder seasons, ensuring that working dogs are well-rested and work efficiently the next day.

2.2 Introduction

Working farm dogs, primarily Huntaways and Heading dogs, are a vital component of New Zealand's agricultural industry (Singh et al., 2011). In 2009 it was estimated that there were nearly 200,000 farm dogs in New Zealand (Dalton, 2009). Today, many farms in New Zealand, especially sheep and beef units, rely heavily on farm dogs to help move and manage stock (Sheard, 2014). According to Arnott (2014), the average shepherd dog can contribute $40,000 in value over its lifetime and costs only $7,700 to feed and maintain.

New Zealand farm dogs are characterised by their high workload, travelling average distances of at least 20 ± 1.3 km per day during peak periods with working long hours (Singh, 2013). The intensity of work of New Zealand working dogs is comparable to that of sled dogs, with a mean daily energy requirement of up to 202 kcal/kg $BW^{0.75}$ during peak periods (Singh, 2013). In contrast, pet dogs have daily energy requirements of 123.8 kcal/kg $BW^{0.75}$ (Bermingham et al., 2014). To maintain their bodyweight and support their workloads New Zealand working dogs need a higher energy intake than pet dogs and tend to have lower body condition scores. Indeed, many working dogs in New Zealand have body condition scores below what is considered "ideal" weight for pets, and many farmers say they are unable to feed their dogs sufficient energy to keep their dogs in good physical condition throughout extended periods of work (Isaksen et al., 2021; Sheard, 2014).

In addition, there is limited research on the impact of the environmental conditions (e.g, temperature) on the overall health of New Zealand farm dogs. From its origin, the New Zealand Heading dog was descended from the border collie. Although the border collie is long haired dog, the New Zealand Heading dog is the result of breeding border collies with shorter-haired dogs. Farmers established a breed that was better suited to work in the hot summer conditions of the local environment (Dalton, 2009). Therefore, it is likely that the shorter coat of the New Zealand Heading dog may required a higher energy expenditure to thermoregulate during the colder winter months.

Despite substantial feed intake, some farm dogs struggle to maintain body weight under peak work. There is a need, therefore, to optimise their energy balance either by reducing energy expenditure or improving dietary nutrient uptake. One strategy to achieve this could be to minimise the energy required for thermoregulation. While energy expenditure from work cannot be readily reduced, other avenues, such as providing external insulation through the using of wearable coats, may be a method to reduce the energy requirements for thermoregulation and therefore spare more energy for recovery and allow better sleep after a day's work.

This study aimed to determine whether wearing a coat could improve the sleep and apparent nutrient digestibility of New Zealand working dogs kenneled outside.

2.3 Methods

The manipulations in this study were approved by the Massey University Animal Ethics Committee (Protocol 24/38) under the New Zealand Animal Welfare Act (1999).

2.3.1 Animal facility

The study was carried out between the 7th and 17th of October 2024, at the Massey University Canine Nutrition Unit (CNU), located in Palmerston North, New Zealand (latitude 40°23'30"S longitude 175°36'58"E). Dogs were housed from 1500 h to 0900 h the following morning in a building containing eight individual runs, each measuring 4 m × 3 m (Figure 2.1). The building had open sides, a solid concrete floor and was covered with a metal sheet roof, allowing exposure to natural light. Each run was equipped with a kennel (70 × 65 × 70 cm), water bucket, and food bowl (Figure 2.2). Blankets were placed in each kennel as bedding, and they were replaced if they got dirty or damaged. These pens were washed out daily using a high-pressure hose and fresh water was provided *ad libitum*.

During the day, from 0900 h until 1500 h, the dogs were housed in outdoor paddocks. The outdoor paddocks contained a kennel for shelter and a water bucket. All dogs were lead walked daily for 30 minutes.

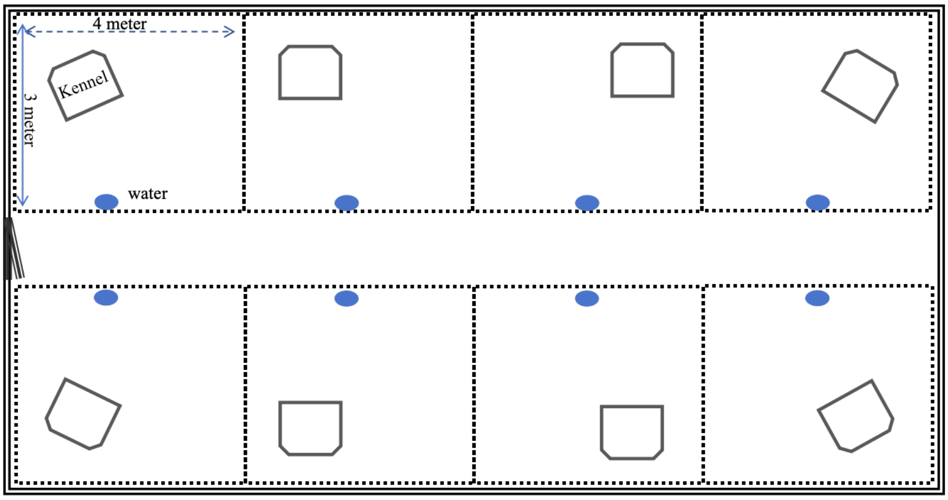


Figure 2.1 Diagram of the individual runs, showing the position of the kennels and water buckets.

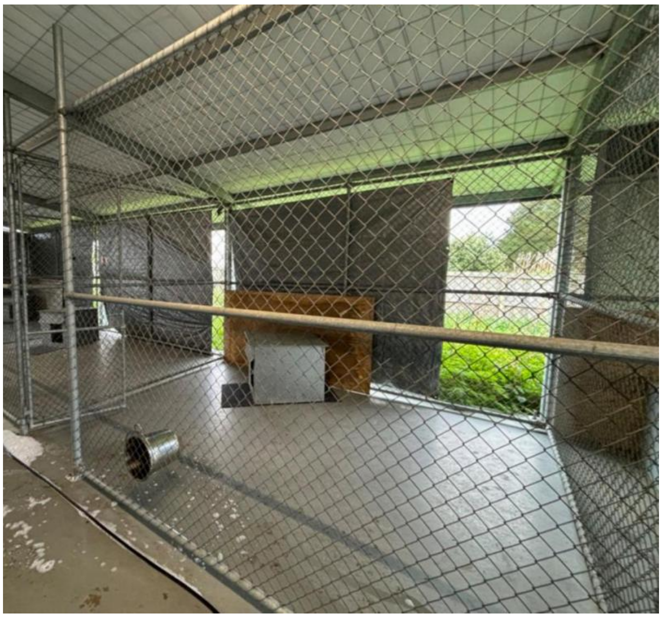


Figure 2.2 Photo of the housing for the dogs during the study showing the position of the kennel and water bucket.

2.3.2 Animal management

Eight desexed dogs of farm working dog breeds (4 males and 4 females), aged 5.75 years (± 0.81), and weighing 25.01 kg (± 1.01), were selected from dogs at Massey University's Centre for Canine Nutrition (Table 2.1). All dogs were fed a complete and balanced diet for working dogs with a metabolisable energy (ME) content of 4,090 kcal/kg (Black Hawk Working Dog, Masterpet Corporation Ltd., Lower Hutt, New Zealand). Daily feed allowances were based on weekly body weight measurements and calculated using the equation: ME Requirement = 125 × Body Weight (kg) $^{0.75}$ (Burger, 1994). Dogs were housed individually and received their daily food allowance at 1600 h each day. Water was freely available throughout the trial period.

Table 2.1 Dogs enrolled in the study including their name, study group, breed, sex, and age (years)

Name	Group	Breed	Sex	Age	Bodyweight (kg)
Buzz	1	Huntaway/Bearded Collie	Male	3	24.9
Viva	1	Harrier Hounds	Female	6	20.6
Cecco	1	Huntaway	Female	11	26.3
Ice	1	Heading Dog	Male	5	25.0
Bonnie	2	Huntaway	Female	5	24.5
Utah	2	Harrier Hounds	Male	6	30.3
Archy	2	Harrier Hounds	Male	5	26.0
Chloe	2	Harrier Hounds	Female	5	22.5

2.3.2 Experimental design

Prior to commencing the study, each dog was fitted with a collar-mounted ActiGraph (WGT3X-BT, ActiGraph, Pensacola, FL, USA) triaxial accelerometer. Data collected continuously throughout the ten-day study period. The study used cross-over block design with dogs randomly allocated into one of two groups, balanced for body weight (Table 2.1). Group 1 consisted of Buzz, Viva, Cecco and Ice and group 2 had Bonnie, Utah, Archy and Chloe. In each phase of the study the dog allocated coats (Natural Hound, Ongaonga, Hawke's Bay) had a one-day acclimatisation period to adjust to wearing the coat (Figure 2.4). In phase 1 (study day 0 to 5), dogs in Group 1 were fitted with a coat from 1500 h to 0900 h for five consecutive days, while the dogs in Group 2 served as controls (i.e., no coat). In phase 2 (study day 5 to 10), dogs in Group 2 were fitted with a coat and Group 1 served as the controls (Figure 2.3).

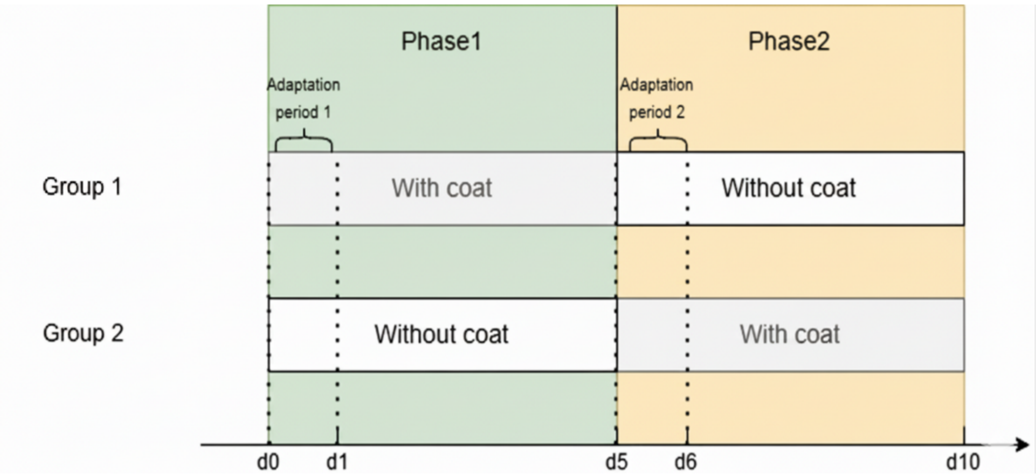


Figure 2.3 Cross-over block design showing the treatment of each group in phase 1 (Study days 0 to 5) and phase 2 (Study days 5 to 10).

Figure 2.4 The dog coat used in the study constructed from waterproof polycotton canvas outer and thick wool lining with an adjustable belly strap (Natural Hound, Ongaonga, Hawke's Bay).

2.3.3 Weather data

Hourly weather data, including temperature (°C), wind speed (m/s), and rainfall (mm), were downloaded from the National Institute of Water and Atmospheric Research (NIWA) weather station located within 2 km of Massey University (latitude 40°39'20"S longitude 175°61'00"E).

2.3.4 Accelerometry and behaviour

The ActiGraph wGT3X (Actigraph, Pensacola, FL, USA) devices weighed 19 g and measured 33 × 46 × 15 mm. The devices were fitted to the dogs' existing collar and positioned ventrally (Figure 2.5). The devices measured acceleration in three independent dimensions (lateral, craniocaudal, and dorsoventral) at 30 Hz with a dynamic range of ±8.0 m/s^2. At the end of the study, the raw acceleration data were downloaded from the devices using ActiLife 6® (ActiGraph, Pensacola, FL, USA) and exported as ‘CSV’ files. For each second, 32 features were calculated, as described by Redmond et al. (2024) (Table 2.2). These features included statistical metrics (e.g., mean, standard deviation, minimum, maximum, skewness, and kurtosis) for each of the three axes (X, Y, Z) and for the overall vector magnitude, as well as inter-axis correlations (XY, XZ, YZ) and the overall dynamic body acceleration (ODBA) (Redmond et al., 2024).

Figure 2.5 Accelerometer placement and coat fitting showing (A) Close-up view of the accelerometer wrapped in waterproof tape and fixed to a collar (B) a dog fitted with a coat and accelerometer secured to the collar.

Table 2.2 Description of features calculated (Redmond et al., 2024)

Feature	Description
Mean acceleration	Mean calculated for every second using the raw acceleration data (30 measures per second).
Sum acceleration	Sum (Axis) = Σ Axisi
Minimum (min)	Minimum value of every 30 measures per second.
Maximum (max)	Maximum value of every 30 measures per second.
Standard deviation (SD)	Quantifies the amount of variability within a dataset.
Skewness	Measures the asymmetry of the probability distribution of a dataset.
Kurtosis	Measures the weight of the tails in relation to normal distribution.
Vector magnitude (VM)	$\mathrm{VM} = \surd(X^2 + Y^2 + Z^2)$
Overall dynamic body acceleration (ODBA)	$\mathrm{ODBA} = \Sigma \lvert \mathrm{DBA}_x \rvert + \lvert \mathrm{DBA}_\gamma \rvert + \lvert \mathrm{DBAz} \rvert$
Dynamic body acceleration (DBA)	$\mathrm{DBA} = \mathrm{Sum}_{\mathrm{axi}}\mathrm{s}$ – moving average.

Dog behaviour was then classified using a Random Forests model developed by Redmond et al (2024). The algorithm was developed using 132,295 seconds of concurrent acceleration data (32 features) and observed behaviour data scored from video. The data were split into training (70%; 90,741 seconds) and test (30%; 38,874 seconds) datasets using stratified random sampling to ensure that a 70%/30% ratio for each behavioural category was maintained. Several behavioural models were trained and evaluated using Random Forests, with the optimal model being selected based on behaviour complexity and model performance (Redmond et al., 2024). The selected model used in the present study classified nine distinct behaviours: barking, defecating, drinking, locomotion, resting-asleep, resting-alert, sniffing, and standing (Table 2.3). The model had an overall accuracy of 74%, a balanced accuracy of 83%, and an F1-score of 78%, and a kappa coefficient of 0.68. Furthermore, it demonstrated the best agreement between predicted and observed behavioural frequencies, evidenced by a low average CV% of all tested models (10.2%).

Table 2.3 Ethogram of defined dog behaviours categorised as either active, inactive, or maintenance (Redmond et al., 2024)

Category	Behaviour	Model Behaviour Classification	Description
Active	**Walking**	**Locomotion**	The slowest upright gait where the body is moving forward, each paw lifting from the ground one at a time in a regular sequence (Koler-Matznick et al., 2005).
	Trotting		A rhythmic two-beat gait where diagonally opposite paws strike the ground at the same time as the subject moves forward. This gait is faster than walking (Koler-Matznick et al., 2005).
	Running		Can also be defined as a ‘canter’. This is a three-beat gait in which two legs move separately and two as a diagonal pair. This gait is faster than a walk and trot (Koler-Matznick et al., 2005).
	Barking	**Barking**	Barking is defined as the mouth being opened and closed quickly in a snapping motion, releasing a low frequency vocalisation (Walker et al., 2016).
	Sniffing	**Sniffing**	Nose directed to a point of interest and sniffs (Lee et al., 2022).
	Scratching	**Scratching**	Grooming behaviour directed towards subjects’ own body, using paw (Walker et al., 2016).
	Standing	**Standing**	All four paws planted on ground and legs extended so they are upright in stationary position (Walker et al., 2016).
Inactive	**Lying (alert)**	**Resting（alert）**	Lying on stomach with forelegs extended to the front, hind legs bent and resting close to the body on each side, or with the body twisted and both hind legs on one side. Head is held up off the ground or surface (Koler-Matznick et al., 2005).
	Sitting		Hind quarters on ground with front legs standing up straight and being used for support (Walker et al., 2016).
	Lying (asleep)	**Resting（asleep）**	Lying on stomach with forelegs extended to the front, hind legs bent and resting close to the body on each side, or with the body twisted and both hind legs on one side. Head is lowered to rest on either forelegs or the ground between them (Koler-Matznick et al., 2005).
	Lateral recumbency		Lying down flat on one side with head resting on surface in sideways position (Fukuzawa & Nakazato, 2015).
Maintenance	**Eating**	**Eating**	Subject chews and ingests food from bowl provided by human (Walker et al., 2016).
	Drinking	**Drinking**	Subject drinks from water bowl in paddock by lapping up the water with their tongue (Koler-Matznick et al., 2005; Walker et al., 2016).

2.3.5 Apparent nutrient digestibility

Faeces were collected from the kennels at 1000 h and 1530 hours each day. The total faecal output from each dog was weighed, and stored in a sealed bag at -20°C. After the completion of the study stool samples were freeze-dried for approximately one week until they reached a constant weight. Samples were then ground to an even particle size using an electric grinder. Faecal samples were pooled for each animal for each test period, and a 50 g sub-sample taken for nutrient analysis. Feed samples that were collected during each test period were ground using different electric grinder, and a 50 g sample was taken for analysis.

The feed and faecal samples were analysed in duplicate to determine their chemical composition at the Massey University Nutrition Laboratory (College of Sciences, Massey University). The samples were analysed for moisture, dry matter, crude ash, nitrogen, crude fat and crude fibre content according to AOAC International approved analytical methods (Horwitz & Latimer, 2005) and for gross energy content using bomb calorimetry. The dry matter and moisture contents were determined using a convection oven at 135°C (AOAC 930.15). Crude ash content was determined using a furnace at 600°C (AOAC 942.05). The nitrogen content was determined according to the combustion method (AOAC 992.15) using the Elementar rapid MAX N exceed (Elementar Analyesensysteme GmbH, Langenselbold, Germany). Compressed helium gas (99.99%) was used as a carrier gas and ethylenediaminetetraacetic acid (EDTA) was used as a nitrogen standard for calibration. Nitrogen content was converted to crude protein by multiplying by 6.25. The crude fat content of the diet was determined using the gravimetric (Mojonnier) method (AOAC 954.02), while the crude fat content of the faeces was determined using the Randal modification of the standard Soxhlet extraction (AOAC 2003.06). The crude fibre content was determined using the fritted glass crucible method (AOAC 978.10). The nitrogen free extract (NFE) was then calculated using the following equation.

$$Nitrogen\ Free\ Extract\ (\%) = 100 - (Ash\% + Crude\ Protein\% + Crude\ Fat\%)$$

The apparent digestibility of nutrients was calculated using the following equation:

$$Apparent\ Digestibility\ (\%) = \left(\frac{Nutrient\ Intake\ -\ Nutrient\ in\ Faeces}{Nutrient\ Intake}\right) \times 100$$

The determination of ME was based on assays of the gross energy consumed, minus the energy in the faeces and correction for energy lost in the urine as follows:

$$
\begin{aligned}
&\mathit{Metabolisable\ energy} \\
&\qquad = [(\text{GE food consumed} - \text{GE faeces collected}) - ((\text{protein consumed (g)} \\
&\qquad - \text{protein in faeces (g)}) \times \text{correction factor})]
\end{aligned}
$$

Where GE = gross energy and correction factor is for the energy lost in urine = 1.25 kcal/g for dogs.

2.4 Statistical analyses

Statistical analyses was performed using R statistical software (Redmond et al., 2024) and a significance of $P<0.05$, with a trend/tendency being defined as $P=0.05<0.10$. All values are expressed as the mean (± SEM) unless otherwise stated. A Shapiro-wilk test was used to test the normality of all data prior to statistical evaluation. To control for the significant variation in the ODBA between dogs, the daily ODBA data were converted to proportional difference from the animal's mean daily ODBA recorded during the control period. The effect of treatment (coat vs. no coat) on the proportional ODBA of dogs was evaluated using a repeated measures ANOVA. Time periods were classified as afternoon (1500 h to 2100 h), night (2100 h to 0300 h), early morning (0300 h to 0900 h) and day (0900 h to 1500 h). The impact of treatment on the amount of time the dogs spent exhibiting each behavior during each timepoint were then compared using a combination of Kruskal-Wallis test and pairwise Wilcox tests. Apparent digestibility of dry matter, crude protein, and crude fat, and metabolizable energy content were calculated using standard methods and compared between treatments using paired t-tests.

2.5 Results

2.5.1 Weather

As shown in Figure 2.6 A, temperatures during the study period (October 8th to October 17th 2024) were generally stable. The average daily temperature varied by only 4.4° C across the 10-day study. While the daily maximum temperatures were also fairly stable (range: 15 - 18° C), the daily minimum temperatures, which occurred during the early morning, varied and more widely ranged from 3° C to 13 ° C. Rainfall was recorded on three days in phase 1 and two days in phase 2. The wind speed during the study ranged between 2 and 5 m/s (Figure 2.6 B).

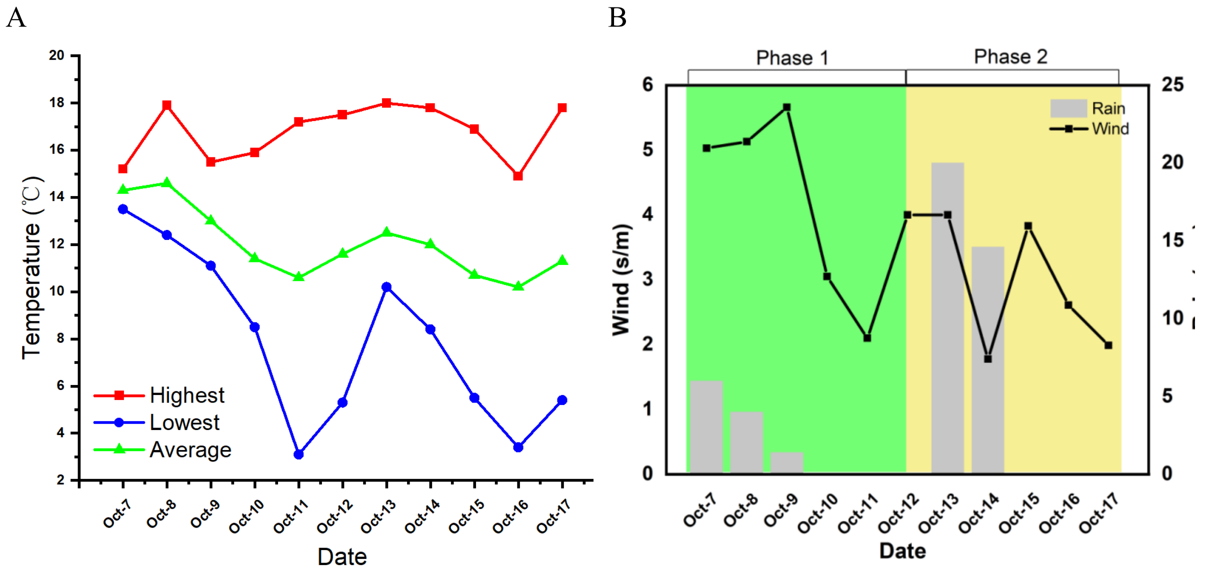


Figure 2.6 Mean daily weather conditions during the study period including temperature (°C, Panel A) and wind speed (m/s) and rainfall (mm; Panel B). Data retrieved from National Institute of Water and Atmospheric Research (NIWA) weather station (latitude 40°39'20"S longitude 175°61'00"E) (https://niwa.co.nz/).

2.5.2 Sleeping duration

Between 1500 and 0900 h the total proportion of time dogs spent sleeping was significantly longer ($P = 0.046$) when they were wearing coats (55.15 ± 1.15%) compared to those not wearing a coat (47.48 ± 3.28%; Figure 2.7). When not asleep, dogs were primarily resting but alert. The total time dogs spent resting tended ($P = 0.052$) to be less when wearing a coat compared to no coat (Figure 2.7, Table 2.4). The coat treatment had no significant effect ($P>0.05$) on the time spent exhibiting active behaviours. During the night (1500 to 0900 h) there was no significant effect ($P>0.05$) of coat treatment on the percentage of the period that dogs showed barking, sniffing, standing or locomotive behaviour (Figure 2.8).

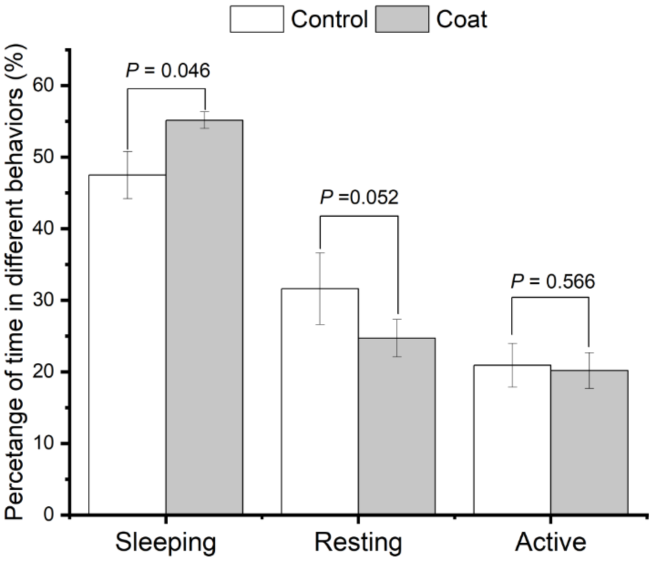


Figure 2.7 The proportion of time dogs spent sleeping, resting and active between 1500 h to 0900 h when in the control (white bar) or coat treatment (grey bars). Behaviour data were classified using the Random Forests model developed by Redmond et al. (2024).

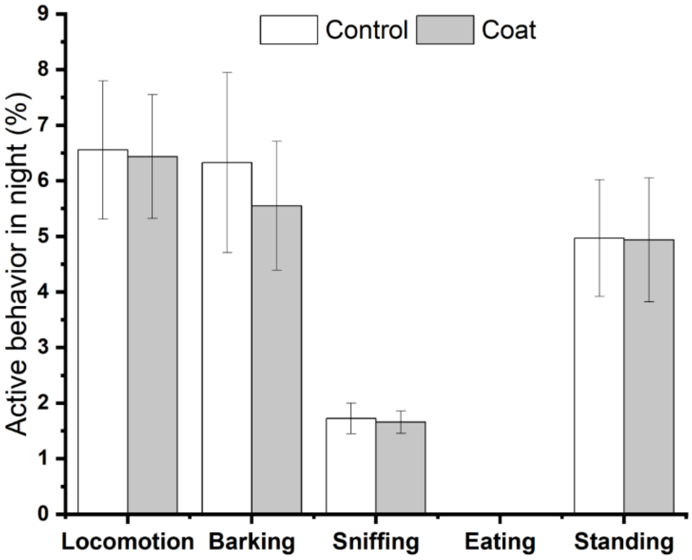


Figure 2.8 The proportion of time dogs spent on locomotion, barking, sniffing, eating and standing between 1500 h to 0900 h when in the control (white bar) or coat treatment (grey bars). Behaviour data were classified using the Random Forests model developed by Redmond et al. (2024).

Table 2.5 The effect of coat treatment (control, coat) on the proportion of time dogs spent sleeping, resting and active during the night (1500 to 0900 h) and day (0900 to 1500 h).

Dog name	Sleep (%)		Rest (%)		Active (%)	
	Coat	Control	Coat	Control	Coat	Control
Night						
Archy	80.8 ± 4.52	68.5 ± 7.84	12.9 ± 3.84	22.2 ± 6.13	6.3 ± 0.75	9.3 ± 1.84
Bonnie	82.8 ± 2.16	77.4 ± 1.84	6.7 ± 1.00	6.4 ± 0.89	10.5 ± 1.19	16.2 ± 2.05
Buzz	89.0 ± 1.29	89.5 ± 1.06	6.6 ± 1.66	4.5 ± 0.92	4.4 ± 0.39	5.9 ± 0.19
Cecco	87.6 ± 0.66	74.8 ± 3.14	7.8 ± 1.71	17.1 ± 3.74	4.7 ± 1.12	8.1 ± 1.83
Chloe	83.6 ± 1.93	50.5 ± 12.62	8.0 ± 1.71	41.3 ± 11.70	8.5 ± 0.69	8.2 ± 1.37
Ice	83.4 ± 1.45	81.2 ± 1.93	10.1 ± 1.06	7.9 ± 1.48	6.5 ± 0.53	10.8 ± 0.67
Utah	69.4 ± 3.76	55.1 ± 3.50	8.8 ± 0.48	20.3 ± 4.96	21.8 ± 3.75	24.6 ± 2.46
Viva	80.7 ± 0.81	82.1 ± 4.47	12.5 ± 1.24	10.7 ± 3.52	6.9 ± 0.74	7.1 ± 1.02
Average	**82.1 ± 2.10**	**72.4 ± 4.80***	**9.2 ± 0.87**	**16.3 ± 4.26^**	**8.7 ± 2.00**	**11.3 ± 2.20****
Day						
Archy	41.2 ± 2.15	23.6 ± 3.97	38.8 ± 2.37	53.9 ± 4.33	20.0 ± 1.28	22.4 ± 1.05
Bonnie	22.1 ± 1.85	20.4 ± 2.17	35.3 ± 0.59	37.3 ± 1.35	42.5 ± 1.84	42.3 ± 1.72
Buzz	32.0 ± 1.40	41.3 ± 2.44	28.5 ± 3.47	28.1 ± 1.82	39.5 ± 3.58	30.6 ± 3.86
Cecco	26.9 ± 2.15	13.4 ± 3.42	56.5 ± 2.42	66.7 ± 2.88	16.5 ± 0.84	19.9 ± 0.74
Chloe	26.7 ± 2.06	18.6 ± 5.27	53.8 ± 2.71	65.0 ± 5.33	19.5 ± 0.92	16.3 ± 0.37
Ice	31.6 ± 0.61	31.1 ± 2.02	17.5 ± 1.93	13.4 ± 0.93	50.8 ± 1.41	55.5 ± 2.89
Utah	46.2 ± 1.47	29.4 ± 3.36	26.7 ± 1.70	41.3 ± 3.85	27.0 ± 0.99	29.3 ± 1.17
Viva	27.5 ± 1.22	29.3 ± 3.42	46.5 ± 3.43	53.5 ± 4.02	26.0 ± 3.01	17.3 ± 0.72
Average	**31.8 ± 2.86**	**25.9 ± 3.08**	**38.0 ± 4.83**	**44.9 ± 6.52**	**30.2 ± 4.43**	**29.2 ± 4.83**

^Indicates a trend (P<0.1), * indicates a significant difference (P<0.05), ** indicates a highly, significant difference (P<0.01).

2.5.3 Hourly sleep patterns

The effect of a coat on sleep was most evident between 0300 and 0600 h (Figure 2.9 a, b, c, d and 2.10). While individual sleep patterns varied, the dogs slept more when wearing coats in this period than when they had no coat ($P < 0.05$; Figure 2.10). Generally, dog exhibited common sleep habits, such as falling asleep after dark (around 2000 h) and waking after 0400 h (Figure 2.9 a, b, c, d). There were notable individual differences between dogs, for example, Buzz, Ice, and Bonnie generally had fewer sleep disturbances, whereas Cecco and Utah showed more frequent disruptions (Figure 2.9 a, b, c, d). Chloe was more restless on nights she did not wear a coat. Observations from a two-night tracking period highlighted that the transition from wearing to not wearing a coat could induce prolonged sleeplessness in some dogs (Cecco, Ice, Chloe), with Chloe's sleeplessness being most pronounced on the coldest night of the study (Figure 2.6 A and Figure 2.9). Interestingly, Utah's sleep quality was the poorest of all the dogs at night but was highest in the day and improved further during the afternoon (1500 h - 2100 h) when he wore a coat.

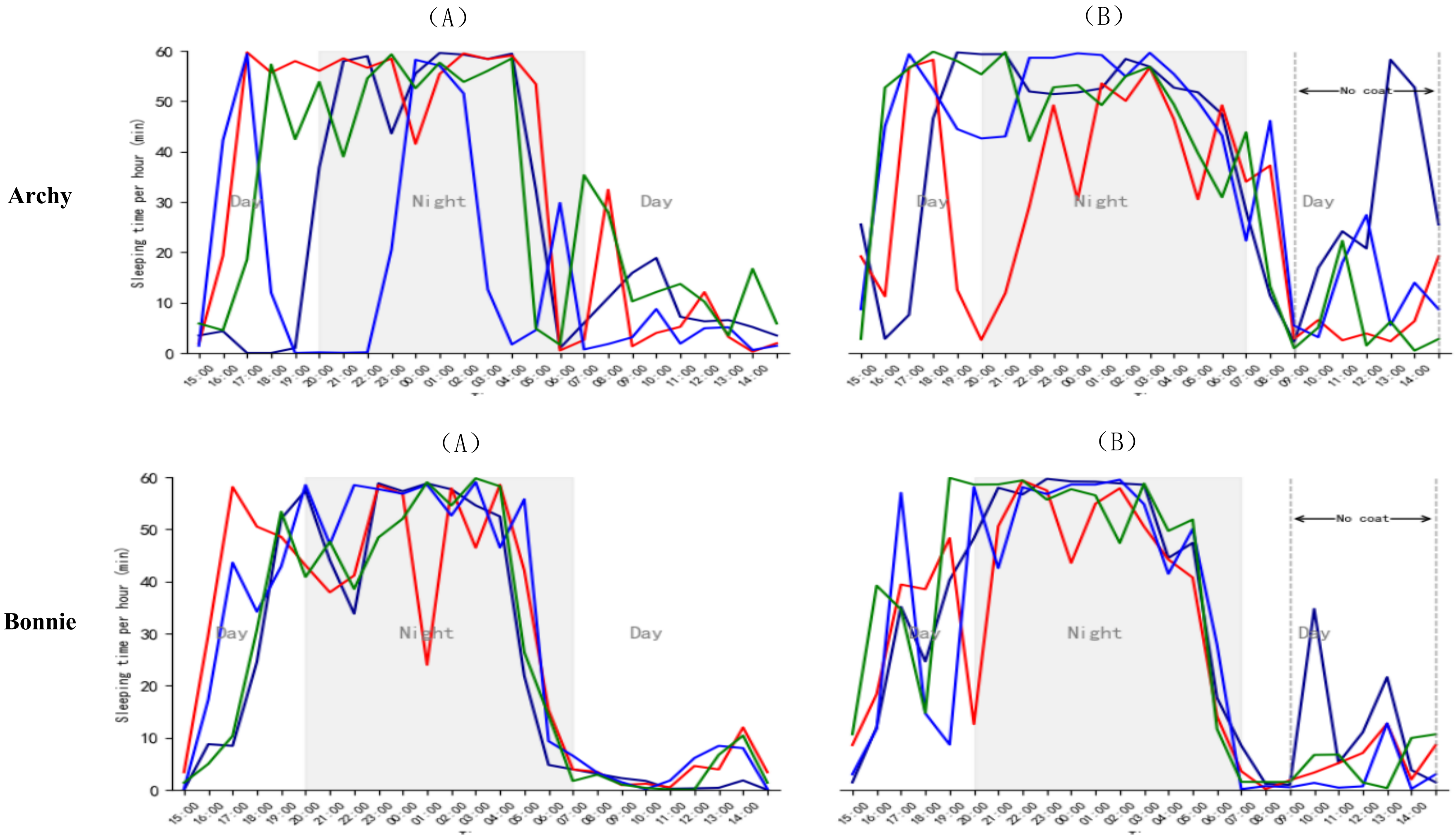


Figure 2.9 a The mean minutes per hour that Archy and Bonnie spent sleeping during the night (1500 to 0900 h) and day (0900 to 1500 h) for each of the four consecutive days (Night 1 = dark blue, night 2 = red, night 3 = blue, night 4 = green) when in the control treatment (no coat; A) and the coat treatment (B). Behaviour data were classified using the Random Forests model developed by Redmond et al. (2024). Night was defined as then 11 hours from 2000 h to 0700 h.

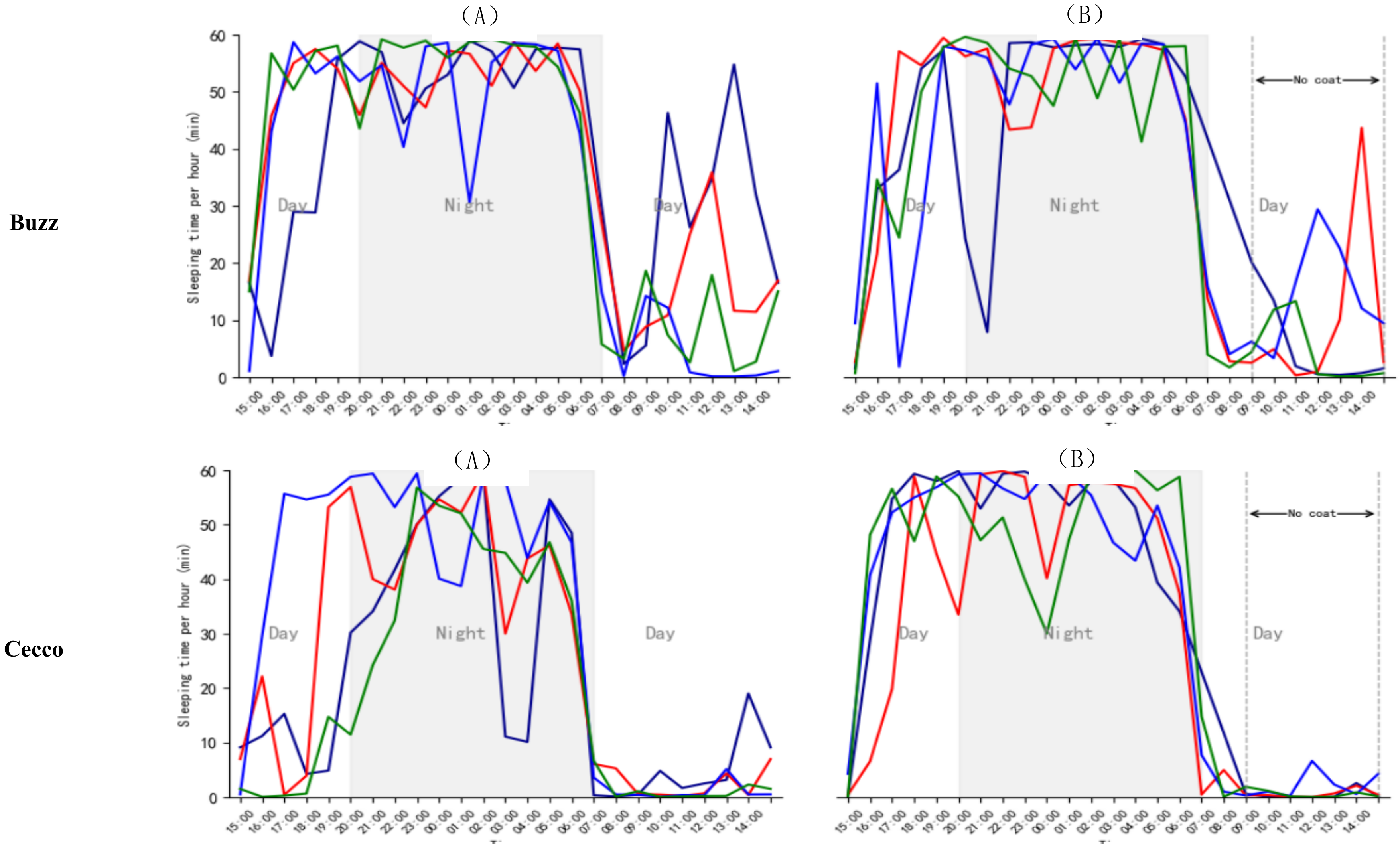


Figure 2.9 b Time spent sleeping per hour by Buzz and Cecco.

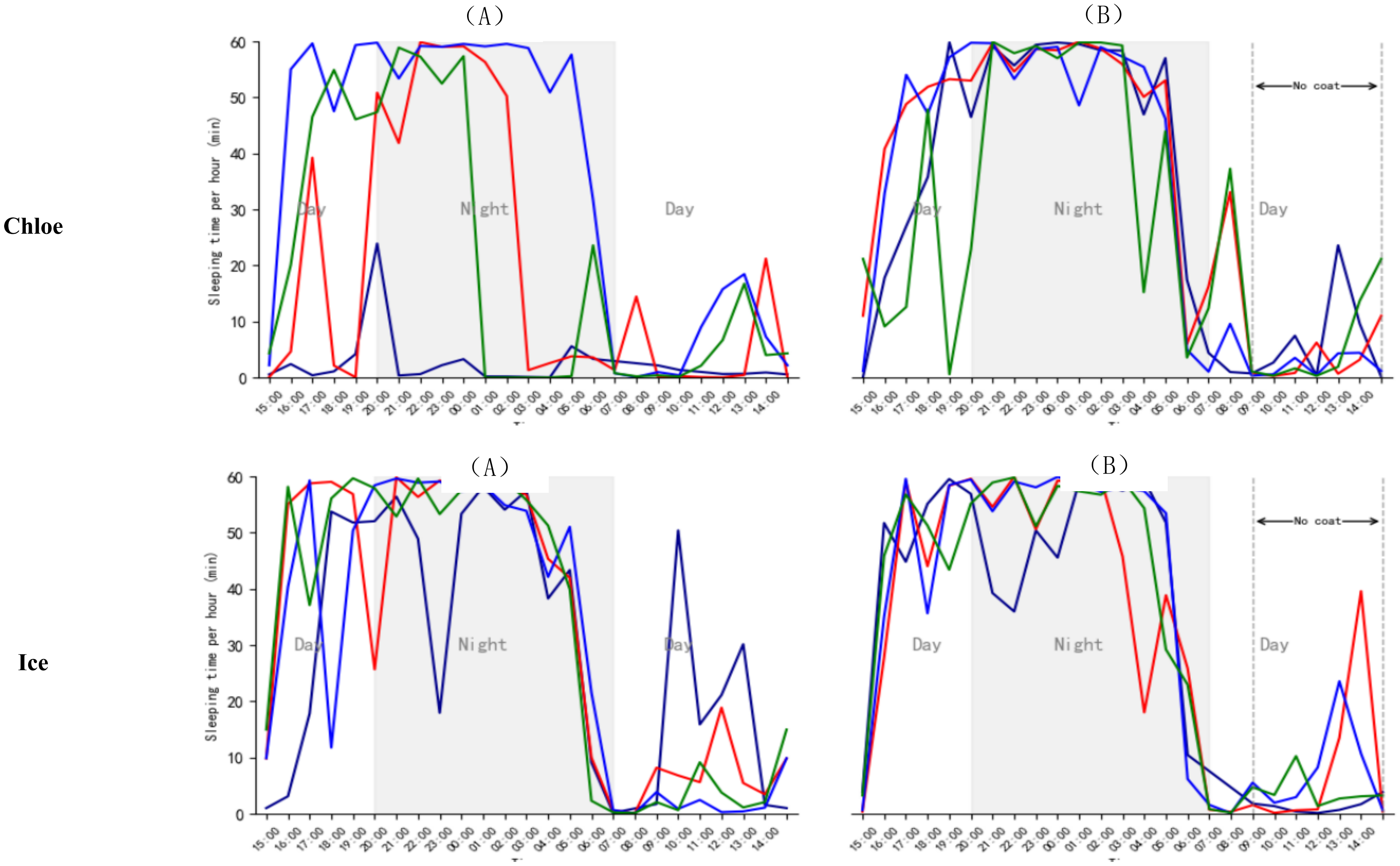


Figure 2.9 c Time spent sleeping per hour by Chloe and Ice.

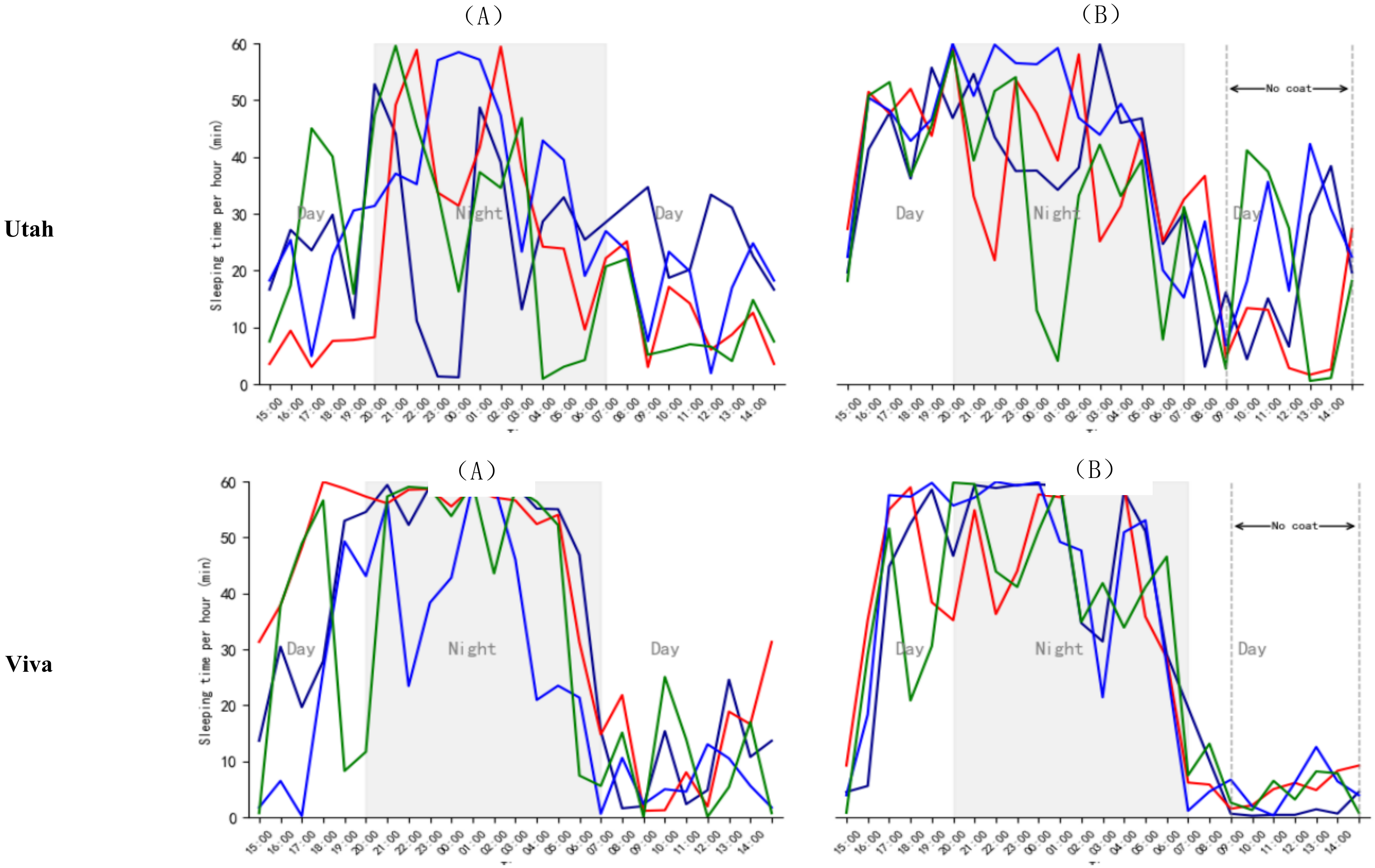


Figure 2.9 d Time spent sleeping per hour by Utah and Viva.

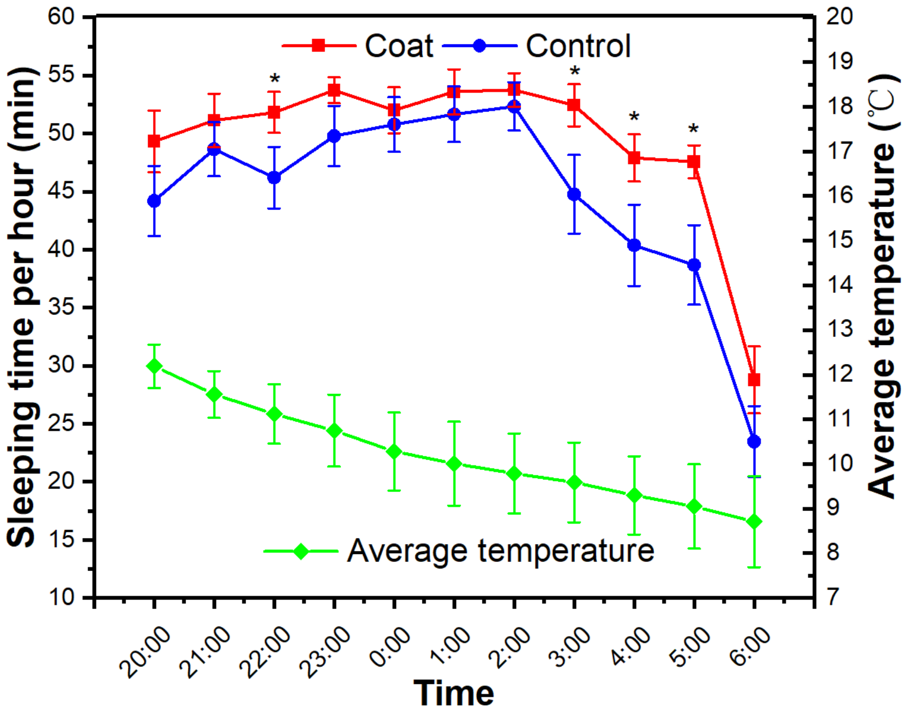


Figure 2.10 Mean (± SEM) hourly time dogs spent sleeping during the control (blue line) and coat treatment periods (red line) and temperature (green line) during the night (2000 to 0700 h). *Indicates a significant difference ($P < 0.05$).

2.5.4 Daily activity (ODBA)

The ODBA data showed a distinct 24-hour rhythm in activity (Figure 2.11) treatment group was significantly reduced nocturnal activity and increased activity during the following day (0900 to 1500 h) than the control group.

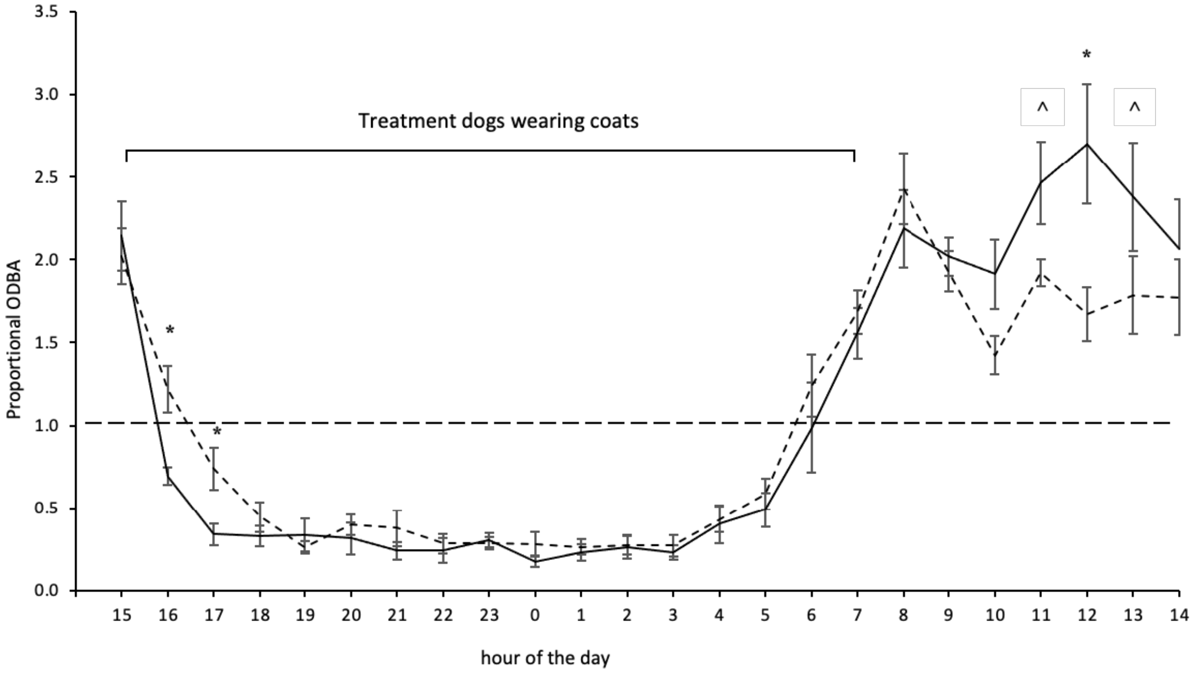


Figure 2.11 Mean ± SEM of the proportional ODBA by hour of the day (beginning at 1500 h when coats were fitted to the dogs in the treatment period) for the control (dashed line) and treatment groups (solid line). The grey longer dashed line indicates the average ODBA of each dog over the baseline period. ^Indicates a trend (0.05<P< 0.10); *Indicates a significant difference (P < 0.05).

2.5.5 Behaviour

A comparison of active maintenance, resting alert and sleeping behaviours across periods of the day can be found in Figure 2.12. There was a significant interaction between treatment and time of day whereby when dogs wore coats overnight, they slept for a longer duration the following afternoon (P < 0.01) and tended to sleep more in the early morning but showed no differences in either the night or morning (P>0.05) when they did not wear a coat. While a numerical difference in the duration of sleep was observed at night, the difference was not statistically significant (P>0.05).

There was a significant decrease in time spent active during the early morning afternoon, night, and after the dogs had worn the coat compared to the period when they did not wear a coat ($P < 0.05$). In contrast, the following morning after wearing the coat the treatment group was significantly more active than the control group ($P < 0.01$). There were no significant differences in duration spent showing maintenance behaviours between the control and coat treatments for any of the periods.

2.5.1 Nutrient digestibility

The apparent nutrient digestibility of the dogs did not differ between treatments ($P>0.05$, Figure 2.13). Similarly, there was no difference in the amount of metabolisable energy the dogs were able to obtain from the diet, it was numerically higher during the periods that the dogs wore a coat compared to the control (Figure 2.13).

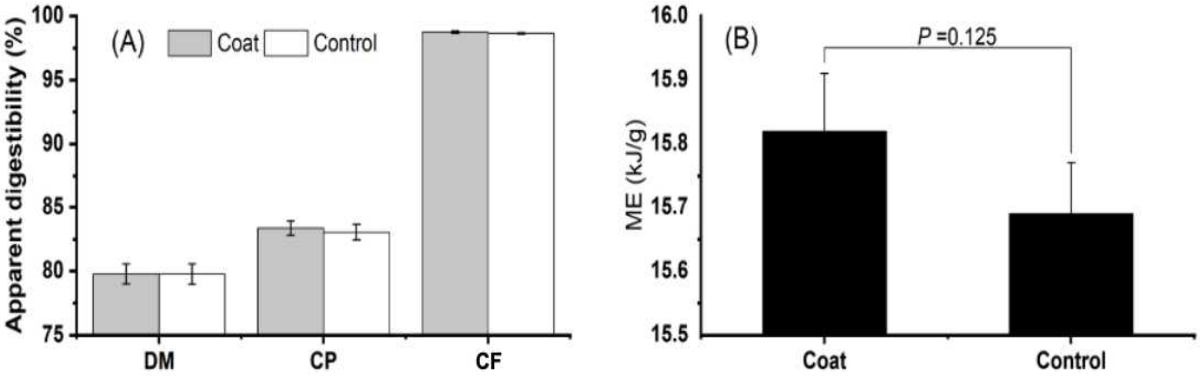


Figure 2.13 Apparent dry matter (DM), crude protein (CP) and crude fat digestibility (A) and metabolisable energy obtained from the diet (B) of dogs (n=8) during control period or when dogs wore coats at night.

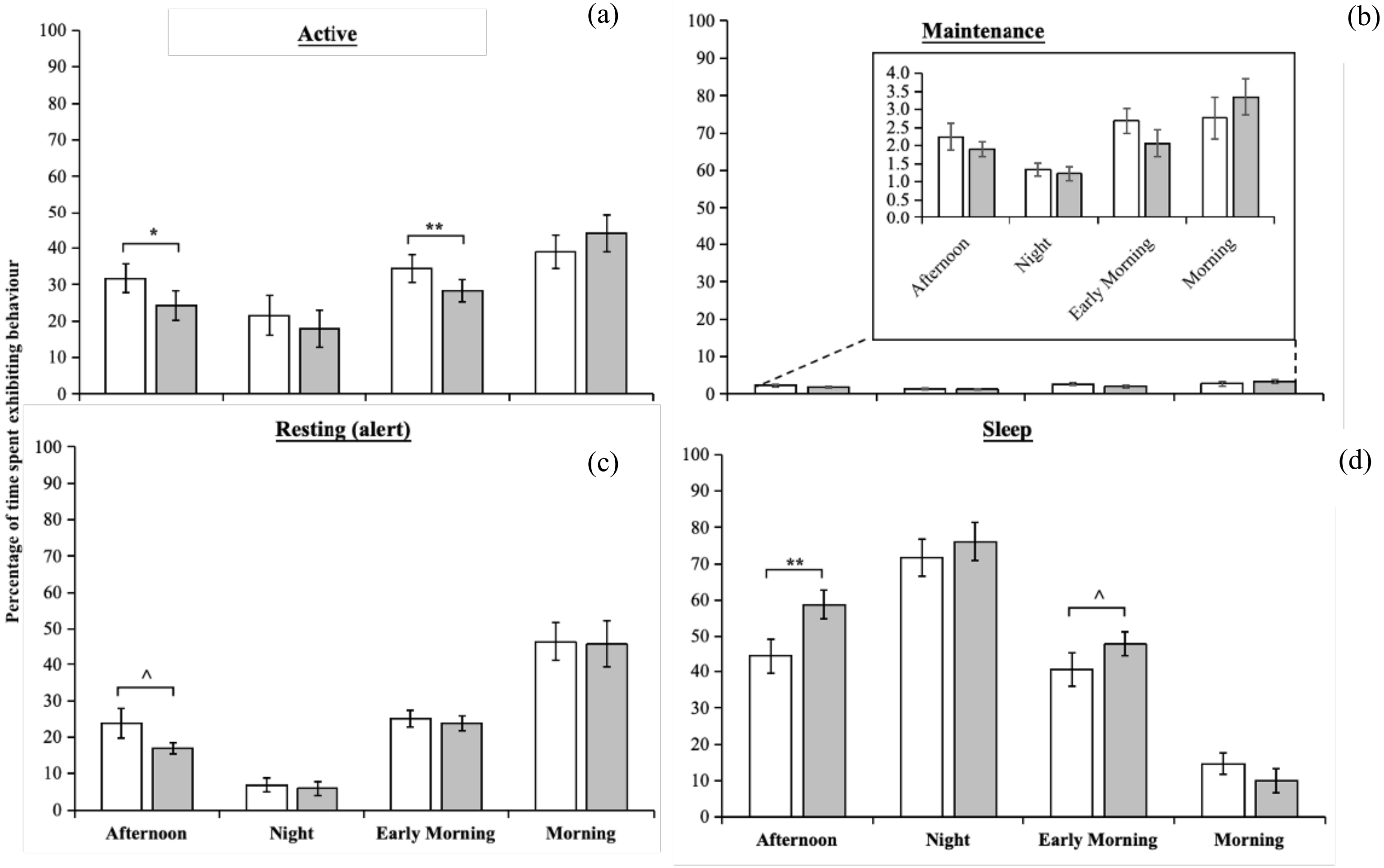


Figure 2.12 Percentage (± SEM) of time spent by dogs when in the control (without coat; white bars) and the coat treatment (grey bars) on active, maintenance, resting and sleeping behaviours across the afternoon (1500 h – 2000 h), night (2000 h – 0300 h), early morning (0300 h – 0900 h), and morning (0900 h – 1500 h). ^ Indicates a tendency (0.05<P< 0.10); *indicates a significant difference (P < 0.05); **indicates a highly significant difference (P < 0.01)

2.6 Discussion

This study aimed to evaluate the effects of coats on the behaviour, activity and nutrient digestibility of New Zealand working farm dogs. While the wearing of coats did not impact apparent nutrient digestibility of the dogs, there was an 8% increase in nocturnal sleep duration when wearing coats compared to the control period. This difference in sleep behaviour was most evident during the early morning (0200 h to 0500 h), when the ambient temperatures were at their coolest.

The increase in sleeping duration in the coldest part of the night was likely due to the additional insulation provided by the coat. This insulation can create a thermoneutral microenvironment that reduces the energy required to maintain core body temperature. Low ambient temperatures have been reported to elevate stress hormone levels and disrupt rest (Rooney et al., 2009). Wearing coats may therefore allow dogs to redirect metabolic resources toward restorative processes, with sleep as a primary outcome. In the absence of coats, dogs may have engaged in subtle, energy-intensive activities to maintain warmth, such as shivering or increasing metabolic rate (Rooney et al., 2009). This continuous low-level physiological exertion can interfere with sleep.

The impacts of low temperatures may have impacted some dogs more than others. Chloe, Cecco, and Archy showed the greatest responses to wearing coats, exhibiting marked increases in sleep duration compared to the control period. Chloe when wearing a coat showed fewer periods of wakefulness and more periods of sleep. Chloe may have had heightened sensitivity to cold due to her smaller body size, resulting in a higher surface-area-to-volume ratio and susceptibility to heat loss compared to larger dogs (Russel et al., 2025).

There was a range of responses to wearing the coat with Buzz, Ice, and Bonnie showing few disturbances during the night during the control period. Differences in sleeping disturbances could be due to a range of factors from the dog's pelage to individuel sleeping patterns. Dogs with short or thin pelage are more likely to be impacted by cooler ambient temperatures than those with longer / thicker pelages (Harding et al., 2020). There is also natural variation in sleep behaviour of dogs that is independent of ambient temperature (Harding et al., 2019). Despite this variation, it was clear that overall sleep duration was improved by wearing coats.

The average sleep time of the working dogs in this study was 507.7 minutes (8 hours 27.7 minutes). While this is shorter than the reported 12.9 hours average for domestic dogs (Wauquier et al., 1979), it is within the normal range reported by Campbell and Tobler (1984). This difference in sleep duration may be related to housing conditions, as pet dogs kept indoors tend to sleep more than colony-housed animals because they are not exposed to ambient temperatures and may therefore be more comfortable. The dogs in the current study were likely exposed to greater range of environmental conditions, such as the presence of other dogs and staff, which may have encouraged more active behaviour. Night time sleep alone does not indicate total daily sleep as it did not include daytime rest (Fomina et al., 2023). Compared with winter, the seasonal conditions in spring and autumn may contribute to slightly reduced sleep duration in working dogs.

Wearing coats overnight appeared to impact the dogs' 24-hour pattern of behaviour. When wearing coats, the dogs were less active in the afternoon and night but showed increased activity in the morning. The increase in sleep duration, especially if coupled with improved sleep quality, may have meant that the dogs were more rested after wearing a coat and had more energy for active behaviours. Although sleep quality was not evaluated in the present study. Previous research has found that improved sleep can enhance health, productivity, welfare, and emotional stability in working dogs (Lefter et al., 2022). Opposite effects such as sleep disorder have been observed in animals following sleep restriction (Harbison, 2010; Lakhiani et al., 2023). In humans, it was found that among American adolescents each hour of sleep disturbance was associated with a 3% decrease in the likelihood of engaging in daytime physical activity, and for every hour less sleep, the chance of getting obese increases by 80% (Gupta et al., 2002). Taken together, these findings suggest that for New Zealand farm dogs, which face high physical demands, thermoregulatory support may help maintain both welfare and functional capacity. Furthermore, the wearing of coats may reduce energy used for thermoregulation in New Zealand working dogs and potentially help them maintain body condition better during the colder winter months, though more research is needed to confirm this.

Rest has been reported to be closely associated with digestion (Mukherji et al., 2015), although in the current study there were no differences in nutrient digestibility observed between the control and coat treatments. These findings were likely influenced by the study's relatively mild environmental conditions, which may not have been cold enough to trigger a marked metabolic stress response. In cold conditions, the insulating effect of a coat may be more apparent due to the conservation of metabolic resources that might be diverted from processes such as digestion and nutrient absorption (Spiegel et al., 1999). The lack of an effect of coats on digestibility in the current study aligns with previous research that demonstrated that sleep was linked to metabolic health (Spiegel et al., 1999). In humans, insufficient sleep has been linked to metabolic imbalances and elevated hunger-related hormones that increase food intake (Siegel, 2010). In the current study, although there was a small numerical increase in apparent nutrient digestibility and metabolisable energy extracted from the diet observed when dogs wore coats, a larger sample size may have been required to detect a significant effect. Future work should examine these effects under colder conditions.

The current study employed triaxial accelerometers which are a low intrusive technique that can capture animals' natural activity–rest patterns while minimising experimental stress and promoting welfare (Schork et al., 2023). Using a previously validated machine-learning model with Random Forest analysis, an accuracy of 0.94 in classifying sleep behaviour was achieved (Redmond et al., 2024), providing a reliable reflection of real behavioural characteristics. Despite these advantages, accelerometry remains limited because it monitors movement rather than brain activity and therefore cannot distinguish true sleep from quiet rest or identify REM and non-REM sleep stages (Straube-Koegler et al., 2025). Therefore, sleep quality could not be assessed using this method. However, given that dogs typically wake after REM sleep, advances in machine-learning models may provide accurate analyse of canine sleep–wake cycles using this technology.

Conducting the experiment in the dogs' natural living environment enhanced ecological validity but introduced potential confounders. Variations in wind speed, precipitation, and human activity could have influenced behaviour and perceived temperature, complicating isolation of the coat's specific effects. Future research in a semi-controlled field setting could manipulate temperature, wind, and humidity to measure their independent and combined effects on sleep and thermoregulation. Controlled designs could also integrate core-body-temperature or heart rate monitoring for a more direct assessment of thermal stress.

2.7 Conclusion

This study demonstrated that providing coats to New Zealand farm working dogs significantly improved nocturnal sleep duration and stability, particularly during the coldest hours of the night. Dogs wearing coats displayed a more balanced 24-hour activity rhythm, with reduced evening activity and increased morning activity, potentially indicating a compensatory effect of improved rest. Although a small numerical increase in nutrient digestibility and metabolizable energy intake was observed, no statistically significant difference was detected, likely due to the mild environmental temperatures during the study and relatively small group size. These findings highlight that simple thermoregulatory support, such as the use of protective coats, has the potential to enhance welfare and functional capacity in working dogs facing high physical demands and outdoor housing. Future research under colder and more variable climatic conditions, including physiological measures such as core body temperature and heart rate, could help clarify the mechanisms by which thermal comfort influences sleep and metabolism. Overall, providing coats offers a practical, low-cost strategy to promote restorative sleep, conserve energy, and support the health and productivity of New Zealand's farm working dogs.

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