**GRAD: 7050 - M.Eng. Project and Report**

# Effect of Ballistic Vest on Canine Core Body and Skin Temperature

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## Acknowledgements

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## Chapter 1

### 1.0 Introduction

This chapter evaluates the purpose of comparing a canine's core body and skin temperature after wearing a ballistic vest and without any vest. Moreover, this chapter covers the major factors that might predispose a dog to heatstroke.

### 1.1 Background

Police and military working dogs are significant assets to society. Because the training for service dogs is lengthy (24 months and longer) (RCMP, 2022) and expensive (around 15000 USD or more) (National police dog foundation, n.d), replacing a fallen canine officer is an enormous challenge. "Canine Heatstroke" is a sensitive subject among Police and Military Dog Handlers. Scrutiny of police dog death records over the past 50 years in the USA, shows that heat exhaustion, gunfire, and automobiles were the most significant causes of death (Barberi et al.,

2019). Only 3% of deaths were reported to be due to heatstroke in the line of duty, as shown in Fig 1.1 (Officer down the memorial page. n.d); however, during the summer months of June, July, and August in the southern states of the USA, the most significant portion of police dog deaths was because of heatstroke (Barberi et al., 2019).

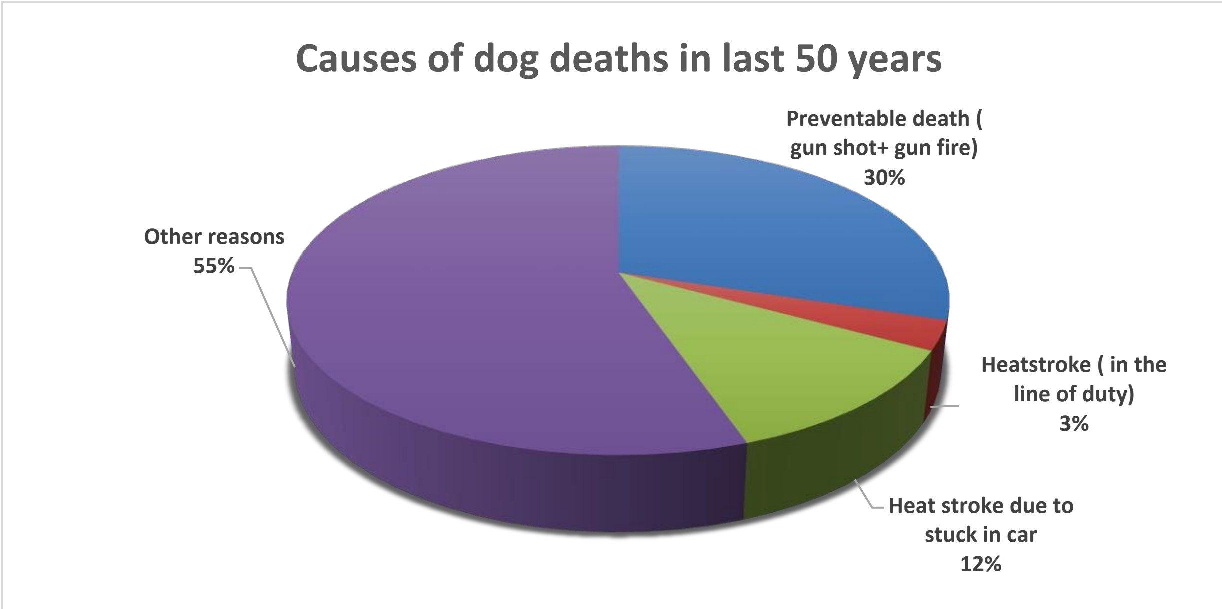


Figure 1.1 (Officer down the memorial page. n.d)

In the last 50 years, 30% of dogs died from gunshot and gunfire, which is ten times higher than the heatstroke cases (Officer down the memorial page, n.d). Police dog deaths from gunshots and gunfire could be prevented with proper ballistic gear. Many handlers have bulletproof vests for their dogs but are hesitant to use them because of the concern of heatstroke (Raschke et al., 2013). From the human standpoint, the handlers believe that the bulletproof vest may increase the core body temperature of the dog, leading to a higher risk for heatstroke. Meanwhile, a ballistic vest can save the lives of Police Service Dogs (PSD) or Military Working Dogs (MWD) during a perilous mission, as shown in Fig 1.2.


Fig 1.2: One PSD (Police Service Dog) wearing a custom fit K9 Storm Ballistic Vest during his work (K9 storm, n.d.)

**1.2 Objectives**

Raschke et al. (2013) studied the impact of a ballistic vest on a canine's core body temperature using ten male German Shepherd working dogs (average age: 4 years; average weight 37 kg). HQ Inc.'s Core Body Temperature Monitoring Systems were used to monitor the dogs' internal temperature. The course exercise consisted of a timed obstacle course (a wood fence panel jump, a window jump, a wire fence panel jump, and an A-frame, Time: 30-45 min). They also ran a tracking exercise (1.5 km tracks in 2-3 hours) followed by the obstacle exercise. The results showed that the ballistic vest did not put the dog at higher risk of heatstroke. The core temperatures remained consistent both with the vest and without the vest. Though the results were significant, the study was done on a small group of dogs covering a single breed male dog. The impact of the dog's breed, age, training history, and ambient conditions was not considered in the study. Moreover, the study lacks the effect of the ballistic vest on a dog's skin temperature.

Our research aims to determine the effect of a ballistic vest on a dog's core temperature and skin temperature irrespective of breed, age, training history, and environmental factors. This research aims to provide appropriate evidence to the Police and Military Dog Handlers regarding their most profound concern about heatstroke. We strongly believe the results of this research will undoubtedly prevent dog deaths due to gunfire and gunshots.

**1.3 Heatstroke and heat dissipation physiology of canines**

Heat stress in dogs can be severe and lead to some dire conditions or death. The clinical definition of *heatstroke* is central nervous system (CNS) dysfunction because of the core body temperature exceeding 41°C (Otto et al., 2019). Police Service Dogs (PSD) or Military Working Dogs (MWD) can generate heat during exercise, work, or under challenging conditions due to muscle activities or mental stress (Otto et al., 2019). It is crucial to diminish the surging heat during or immediately after work or exercise.

Humans depend mainly on sweat glands to dissipate their body heat. However, since dogs have a different physiology than humans, they rely mainly on panting to release their heat. Canines dissipate 70% of their heat through radiation and convection through panting, ears, nostrils, and paw pads (Bruchim et al., 2017). Excessive heat can increase salivation and lingual blood flow, which helps the canine cool down through the convection and evaporation process (Otto et al., 2019).

**1.4 Factors that predispose a dog to heatstroke**

Several heat studies have been conducted on canine core body temperature to determine the risk of heatstroke in working dogs due to physical exercise or training and other external factors such as breed, sex, coat color, diet, ambient temperature, and relative humidity.

### 1.4.1 Canine's breed

A study showed that the impact of exercise on a dog's core temperature varies with the dog's breed. During a 30 min. indoor play at a controlled temperature (25.6-27.7 °C), Labrador Dogs showed a higher mean temperature of 0.5°C (38.3°C ± 0.1°C) compared with Beagles (37.8°C ±0.1°C). Furthermore, post-exercise temperature recovery to their initial temperature (Labradors: 37.3 ± 0.1 °C, Beagles: 36.9 ± 0.1°C) in 15 min. was significant in both breeds ($p > 0.01$), though Labradors required an additional 15 minutes to return to their pre-exercise temperature compared with Beagles (Zanghi, 2016).

Ineffective evaporative ability (example: stenotic nares, elongated soft palate, and hypoplastic trachea) makes the brachycephalic breeds (English Bulldogs) prone to being affected by heatstroke, and they can quickly develop laryngeal edema (Bruchim et al., 2017).

### 1.4.2 Optimal diet protocol

Research showed regular optimal diet impacted the dog's internal temperature. A total of 17 Labrador Retrievers (11 males and 7 females, 18-24 months, trained in detection) participated in a 12-week research program. Throughout the program, the dogs who had been fed the low protein and high-fat (LP-HF) diet maintained a lower post-exercise core temperature (40.44°C) compared with the dogs fed the high protein, low-fat diet (HP-LF) (40.66°C). Their pre-exercise temperature was almost identical at 38.4°C (Ober et al., 2016); however, post-exercise recovery temperatures after 10 and 20 minutes were still high for HP-LF diet-fed dogs compared with LPHF diet (post 10 min: HP-LF: 40.39°C, LP-HF: 40°C; post 20 min: HP-LF: 39.78, LP-HF: 39.39°C). Every week, the dog's weight was measured to ensure the diet's impact on their body weight (accepted weight: ± 5% of their initial body weight).

Thornton et al. (2021) researched the impact of a supplementary fiber diet on canine core body temperature. Fourteen domestic dogs (12 Siberian Huskies and 2 Alaskan Huskies, age: 3.75 ± 2.7 years, weight: 21.54 ± 2.83 kg) participated in the research for nine weeks. Seven dogs were fed a controlled diet with an insoluble: soluble fiber ratio of 4:1 (94% dry matter, 47% crude protein, 25% fat, and 0.74% soluble fiber), while the other seven dogs were fed a treatment diet with an insoluble: soluble fiber ratio 3:1 (94% dry matter, 47% crude protein, 26% fat, 2.12% soluble fiber). Treatment diet-fed dogs showed lower working body temperature (mean: 39.4 °C) and lower post-work body temperature (mean: 39.2 °C) compared with control diet-fed dogs (mean work body temperature: 39.8 °C, mean post-work body temperature: 39.6 °C).

**1.4.3 Training history**

O'Brien et al. (2017) recorded the internal temperature of a wide range of military working dogs consisting of 8 Belgian Malinois, 3 German Shepherds, 5 German Shorthair Pointers, 6 Labrador Retrievers, 1 Flat-coated Retriever, and 1 Dutch Shepherd during different training activities, and kennel walks. The training activities included obedience, obstacle course, controlled aggression, building search, vehicle search, scouting, and gunfire. The average duration of each activity was 11.69 ± 5 mins. They found that peak temperature may occur several minutes after the work ends. Therefore, it is very crucial to monitor recovery temperature during resting time. The study suggests that an alternative period of a walk and a minimum of 15 minutes of recovery time is an effective strategy to manage heat exhaustion during training or exercise (O'Brien et al., 2017).

Moreover, there is a correlation between heatstroke and the background training history of military dogs. Most heatstroke cases happened to military working dogs during their first year of training (Bruchim et al., 2017). Bruchim et al. (2014) claimed that the combination of heat acclimatization and training exercise helped to reduce the temperature rise during physical exercise. In that study, 15 young (average age: 1.94 years) Belgian Malinois Dogs were monitored throughout their two years of the training period. The training courses included indoor treadmill exercise (between 2 and 8 km without inclination), outdoor exercise (between 3-10 km), and outdoor obstacle trails under high heat and relative humidity (temperature ranges: 22°C- 29°C, humidity ranges: 63%-69%). The result showed dog's rectal temperature rise after physical activities were reduced by 0.79°C within the six months of training (Bruchim et al., 2014).

### 1.4.4 Exercise course

Rizzo et al. (2017) studied the impact of treadmill exercise on a dog's internal temperature. The treadmill exercise consisted of 15 min. walks, 10 min. trotting, and 10 min. gallop in 20-22°C temperature and 65% R.H. Inclination was not added during treadmill exercise. They recorded skin temperature at different points: neck, shoulder, ribs, flank, back, internal thigh, and eyes. The data showed that physical exercise increased the dog's core body temperature (from 38.5°C- 40.5°C). Also, exercise significantly increased the red blood count (RBC), hemoglobin (H.B.), and hematocrit (Hct) ($p<0.05$). They found a comparatively higher temperature (on average 6-7°C ±1.82°C) in the thigh and eye area compared with the neck, shoulder, and ribs (($P < 0.0001$) (Rizzo et al., 2017).

### 1.4.5 Ambient temperature and humidity

Moon et al. (2021) studied the environmental heat exposure on rural and urban dogs. They measured only the dog's skin temperature with iButton Thermometers. The study showed that the urban dogs had a higher body temperature (36.9°C) compared with rural dogs (34.7°C) in the same geographical area (United Kingdom). The study also found that urban indoor dogs had a cooler average body temperature (25.8°C) than outdoor dogs (27.4°C). The ambient temperature showed a direct impact on the dog's body temperature. Similarly, ambient humidity significantly impacted a dog's heat releasing process. Dogs cannot dissipate heat effectively if humidity levels go above 35%. In worst cases, it has been shown that humidity over 80% could negate evaporative losses (Iowa veterinary specialties, n.d.).

**1.4.6 Canine’s gender and coat color**

Carter and Hall (2018) researched cross-country racing dogs to determine the impact of running speed, sex, coat color, and coat length on a dog's core body temperature. Data were collected from 108 dogs with an average age of 4.4 years (59 males and 49 female dogs). Statistical Package for Social Science (SPSS) 23.0 (SPSS Inc, Chicago, IL) was used to analyze the statistics. The study determined a weak correlation between race speed and post-race temperature increase of dogs ($p<0.0001$) evaluated by a general linear model. The study also observed that the male dogs had a higher post-race body temperature (5.2°C higher) than the female dogs. Similarly, dark color coated dogs had higher post-racing body temperature (average 1.5°C higher) than pale or medium-coated dogs, whereas coat length showed no impact on the dog's temperature. The average speed of the race (15.58 km/h) significantly impacted the dog's post-racing body temperature ($p= 0.006$) (Carter & Hall, 2018). To the contrary, Neander et al. (2019) found no effect of coat color and gender on a dog's body temperature ($p> 0.05$) after 15 min and 30 min walks.

**Chapter 2 Materials, Device and Methodology**

## 2.0 Introduction

This chapter contains detailed descriptions of materials and devices that were used to evaluate the effect of a ballistic vest on canine core body temperature. Methodology detail and experimental protocol are also described in the later portion of this chapter.

## 2.1 Materials

### 2.1.1 Custom-fit K9 Storm Ballistic Vests

Since 1998, K9 Storm has been a leading ballistic vest manufacturing company around the world, currently providing custom-fit ballistic vests to Police and Military Working Dogs in 37 countries. At this moment three ballistic vests are listed in their product catalogue (K9 Storm, n.d.): Aerial Insertion Vest, Patrol Swat Vest, and SAR Vest as shown in Fig 2.1.


(a) (b) (c)

Fig 2.1: Custom-fit ballistic vest manufactured by K9 Storm (a) Aerial Insertion Vest, (b) Patrol Swat Vest, and (c) SAR Vest (K9 Storm, n.d.)

The custom fit K9 Storm Patrol Swat Vests were used throughout the research experiments. The non-trained dogs used an available best possible custom-fit Patrol Swat Vest, and the trained dogs (Police Service Dogs-PSD) used their own custom fit K9 Storm Ballistic Vest. The benefit of using a custom-fit ballistic vest is that it fits perfectly based on the dog's size and shape, making the dog more comfortable and agile during their work. In Fig 2.2, K9 Officer Loki (Roanoke Police Department, Dallas, US) is wearing a custom fit K9 Storm Patrol Swat Ballistic Vest (K9 Storm, n.d.)

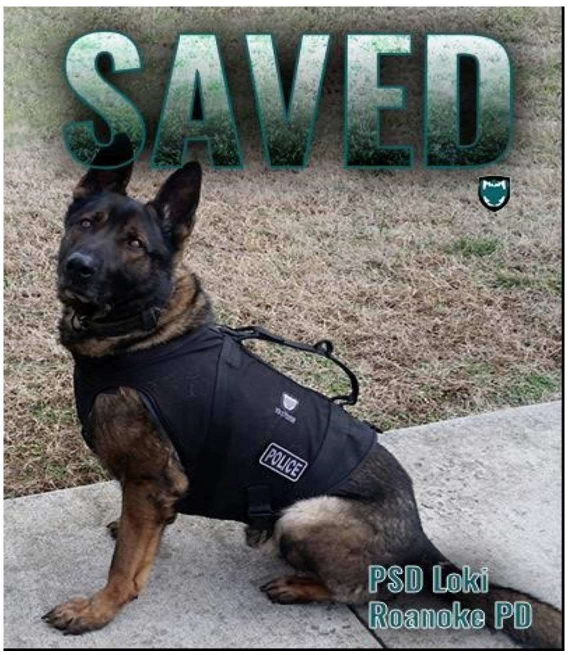


Fig 2.2: PSD Loki wearing a custom fit K9 Storm Ballistic Vest (Ref: K9 storm, n.d.)

### 2.2 Devices

The equipment for the research work was selected based on accuracy and convenience. After analysing several previous research studies in the veterinary research field and various types of vet thermometers, finally, two devices were selected to conduct the research work. Other than temperature measuring devices, a laptop, stopwatch, and first aid kit were always used throughout the research work.

### 2.2.1 Device for measuring core body temperature

CorTemp by HQ Inc, FL, USA, was used to measure the core body temperature. The device consists of a CorTemp ingestible sensor and a CorTemp data recorder. The device is widely used in space flight, sport, military, occupational safety, medicine, research, agriculture, and industrial applications (HQI wireless temperature sensing, n.d). Bongers et al. (2015) used the same ingestible temperature sensor in their study and claimed the device is a reliable and valid method to assess gastrointestinal temperature. Separate research found that core temperature was always 0.3°C-0.4°C higher than the rectal temperature with a 95% of LoA (limits of Agreement) (Osinchuk et al., 2014).

In mid-1980, the John Hopkins Applied Physics Laboratory developed a core temperature sensing technology in collaboration with Goddard Space Flight Center. Initially, the device was used only for NASA space flights, but in 1988, the manufacturer licensed this device for commercial uses (HQI wireless temperature sensing, n.d).

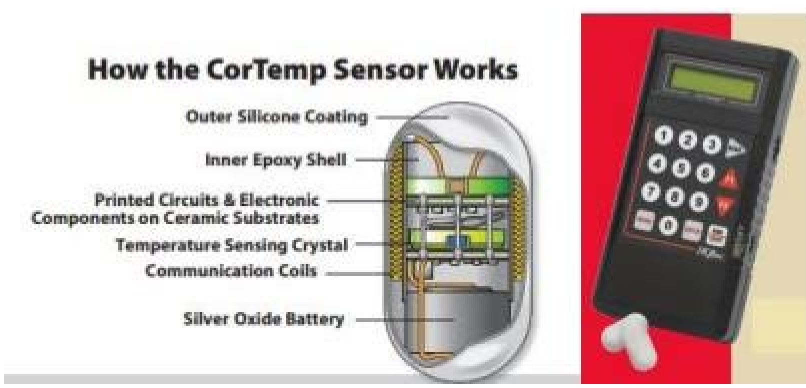


Fig 2.3**:** a) CorTemp Ingestible Sensor (left side) b) CorTemp Data Recorder with two temperature sensors (right side) (ref: HQI wireless temperature sensing, n.d)

The device has two parts, shown in Figure 2.3: CorTemp Ingestible Sensor and CorTemp Data Recorder. The temperature sensor capsule is a medical-grade epoxy capsule with silicone (Dimethyl polysilicoxane) coating, which contains a micro battery, quartz crystal, communication coil, and a circuit board. The size of a CorTemp Ingestible Sensor is 22.352mm × 10.668 mm. This ingestible sensor can measure temperatures from 30°C- 45°C with an accuracy of ± 0.1°C. The size of the data recorder is 120mm ×60mm× 25mm. The recorder can operate within the temperature range of 0 to +50°C, and can record temperatures in both degrees C and F (HQI wireless temperature sensing, n.d).

Figure 2.4 shows different units of the CorTemp device. Figure 2.5 shows the ingestible capsule. Initially, the capsule is wrapped with a sticker and a magnet. The magnet must be removed to activate the capsule.

Figure 2.4: Data recorder device with pouch and connecting cable (CorTemp, HQ- FL, USA)


(a) (b)

Figure 2.5: (a) Capsule with magnetic pin inside. (b) Serial number and calibration number on the packet

After swallowing, the crystal sensor vibrates at a frequency relative to the body's internal temperature. The sensor passes a low-frequency harmless signal to the recorder. The recorder receives the signals, displays, and stores the data, as shown in Figure 2.6 (Bongers et al., 2015). The unit can be programmed manually or via the CorTrak Software (HQI wireless temperature sensing, n.d).

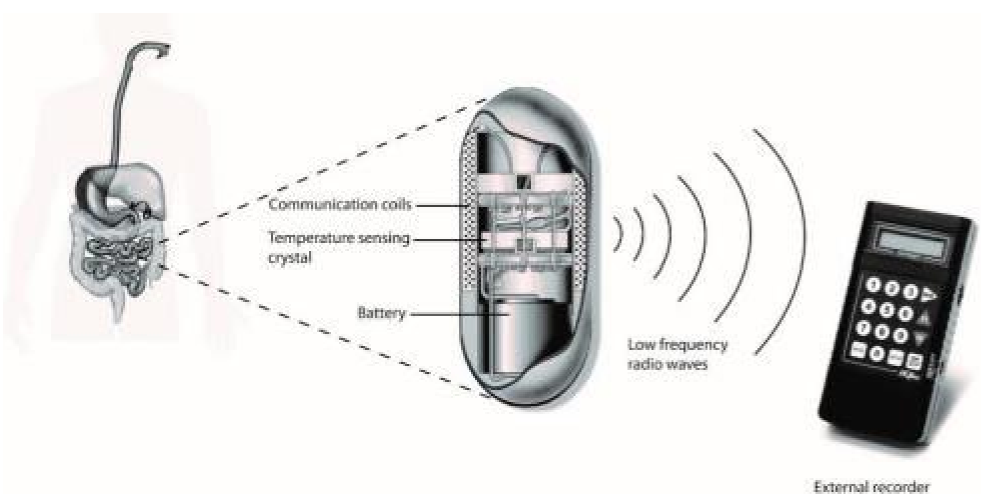


Figure 2.6: Schematic overview of gastrointestinal temperature measurement with CorTemp (Bongers et al., 2015)

### 2.2.2 Device for measuring skin temperature

To address the question, "Does a dog's skin get hot after wearing a vest?", a Thermocron Temperature Logger was used to measure the temperature on the dog's skin. In this research, high-capacity temperature loggers with 122KB Data-Log Memory (model DS1952) (Maxim integrated, California, USA), as shown in Figure 2.7 were used. IButton Thermometers contains a computer chip within a 16 mm thick steel casing, has a temperature resolution of ± 0.5°C for temperatures from −10 to 65°C, and an operating range of −40 to 85°C (Moon et al., 2021). The model DS1925 can take a total of 122K- 8-bit readings or 61K-16- bit readings within an interval ranging from 5 min. to 273 hrs. These durable stainless-steel thermometers are highly resistant to environmental hazards like dust, moisture, and shock (Maxim Integrated, n.d.).

Figure 2.7: Thermocron Temperature Sensor Device; a) Thermocron iButton b) Custom fit Velcro belt with soft iButton Holder (top), data reader and cable (middle)

IButton gives a consistent result with an accuracy of ±0.5°C. iButtons are inexpensive compared to other transmittable thermometers, and results are not manipulated by other sensors when animals are in proximity (Davidson et al., 2003). Perhaps, the major disadvantage of iButtons is their short-term data recording, and data is not accessible until it has been removed from the subject and attached to the data recorder (Davidson et al., 2003). These thermometers are widely used in temperature logging in the cold chain, food safety, bioscience, pharmaceuticals, and medical products. Recently, researchers are also using this device for veterinary or human research (Maxim integrated, n.d.). As iButton Thermometers are tiny, to make them user-friendly, we made a holder for the buttons (carbon+ nylon holder) and a Velcro belt, as shown in Figure 2.7.

### 2.2.3 Device calibration

As both devices are factory calibrated, we did not need to calibrate them. However, the data was verified several times before each experiment by cross-checking the readings. Based on the previous research, both devices are reliable in measuring the temperature.

## 2.3 Methodology

The study was designed to cover a range of ambient conditions, different dog breeds, ages, color coats, and training history. The experimental methodology was designed in collaboration with Jim Slater, President, and co-founder of K9 Storm. The research work was divided into two parts to cover both trained and untrained dogs. In the first part, the experiments were done on two untrained (NT) dogs of different breeds, and in the second part, the experiments were conducted on two highly trained Police Service Dogs (PSD). Figure 2.8 shows the basic flow chart of the process of the experiments.

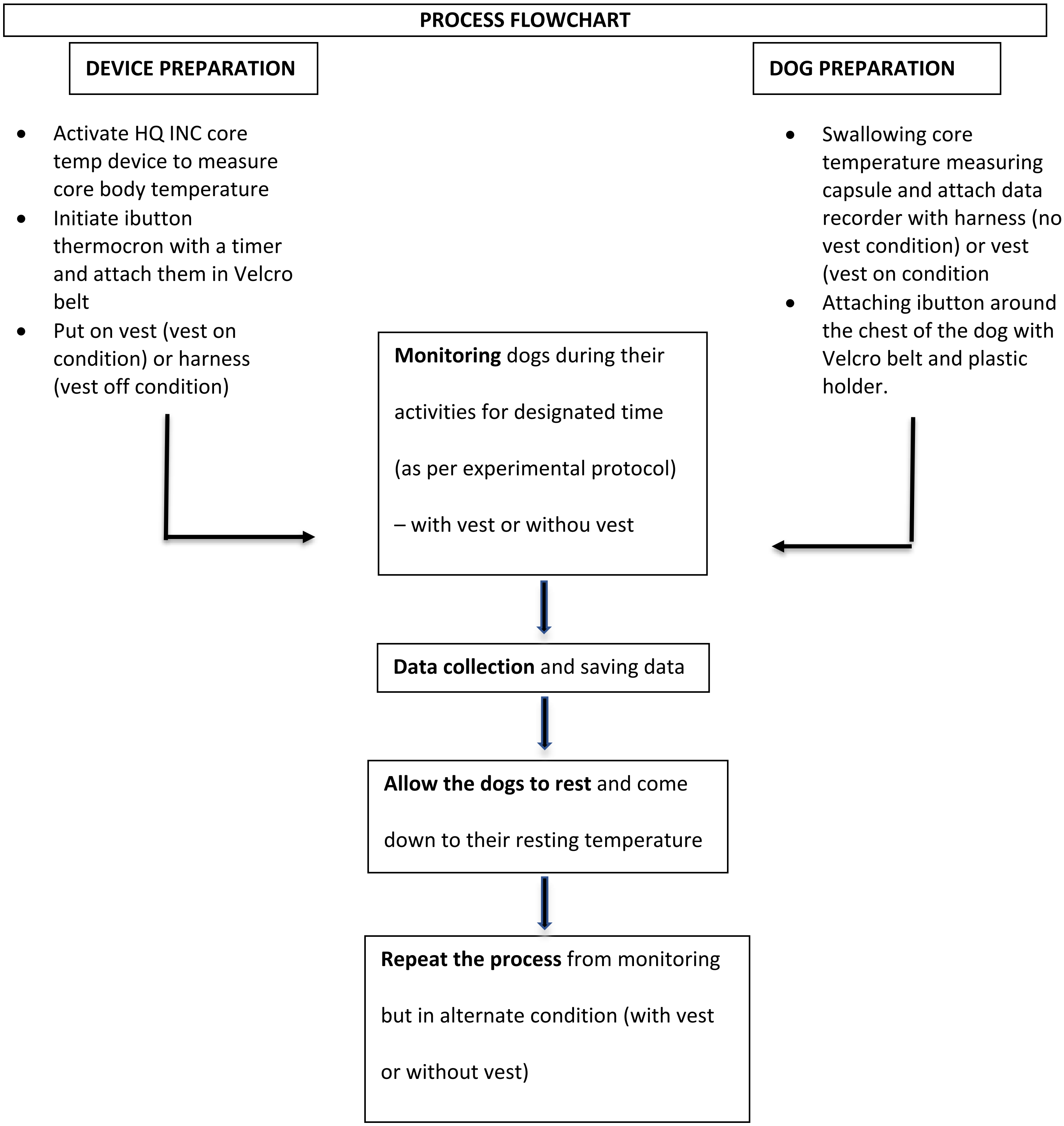


Figure 2.8: Process flow chart of the basic methodology of the experiments.

### 2.3.1 Device setup and subject preparation

#### 2.3.1.1 HQ Inc core temperature monitoring system

At the beginning of the experiment, the device was reset with the serial number and the calibration number of the capsule in the software and the data recorder. The capsule was initiated by removing the attached magnet. After initiation, the capsule was given to the dogs for swallowing.

#### 2.3.1.2 Thermocron iButton

A Thermocron iButton Thermometer was used to measure the dog's skin temperature. The Thermocron iButton Thermometers were initiated each day before starting any experiments with a timer.

#### 2.3.1.3 Ambient conditions

Ambient temperature and relative humidity were measured with Google weather update throughout the experiments.

#### 2.3.1.4 Dog's preparation

The dogs were prepared at the same time during the device preparation. Initially, the capsule was given with some other food, but chewing the capsule was risky. As a result, the capsule was given directly, deep down into the mouth. After swallowing the pills, normal waiting time was 15-20 minutes so that the pills could go deep inside the intestine and give reliable data. The dog had breakfast (homemade dog food prepared with rice and meat) in the morning. Usually, the dogs had two meals a day throughout experiments.

#### 2.3.1.5 Dog profiles

Tables 2.1 describe the details profile (breed, color, age, weight, gender, training history) of dogs used in the experiments.

Table 2.1: Non-trained and trained dog's prolife

| Dogs Identity | Breed | Coat color | Age (years) | Weight (lbs) | Gender | Training history | Service status |
|---|---|---|---|---|---|---|---|
| NT Dog 1 | German Shephard | Dark | 7 | 85 | Male | Non-Trained | NA |
| NT Dog 2 | Bulldog | Light | 5 | 70 | Male | Non-Trained | NA |
| PSD Working Dog | Mix- Dutch Shepherd and Belgian Malinois | Dark | 3.5 | 61 | Female | 2 years in Police | Working |
| PSD Retired Dog | Belgian Malinois | Light | 11 | 62 | Female | 9 years in Police | Retired |

### 2.3.2 Experimental protocol

The experiment was done in two group of dogs, non-trained (NT dogs) and Police Service Dog (PSD) in different conditions. Conditions are stated in detail in next sections. Table 2.2 summarize the dog's breed, gender, activities during the experiments and ambient conditions for all conditions and all dogs (NT and PSD).

| Dog Profile | Dog's breed | Dog's gender | Condition | Condition ID | Temperature and R.H | Activities |
|---|---|---|---|---|---|---|
| NT dog 1 | German Shepard | Male | with vest | ID-AC-RA | Temp: 22 °C, R.H: 60% | sitting, sleeping |
| NT dog 1 | German Shepard | Male | without vest | ID-AC-RA | Temp: 22 °C, R.H: 60% | sitting, sleeping |
| NT dog 2 | Bulldog | Male | with vest | ID-AC-RA | Temp: 22 °C, R.H: 60% | sitting, sleeping |
| NT dog 2 | Bulldog | Male | without vest | ID-AC-RA | Temp: 22 °C, R.H: 60% | sitting, sleeping |
| NT dog 1 | German Shepard | Male | with vest | OD-Avg HS-RA | Temp: 17-24 °C, R.H: 39-41% | sitting, sleeping |
| NT dog 1 | German Shepard | Male | without vest | OD-Avg HS-RA | Temp: 17-24 °C, R.H: 39-41% | sitting, sleeping |
| NT dog 2 | Bulldog | Male | with vest | OD-Avg HS-RA | Temp: 17-24 °C, R.H: 39-41% | sitting, sleeping |
| NT dog 2 | Bulldog | Male | without vest | OD-Avg HS-RA | Temp: 17-24 °C, R.H: 39-41% | sitting, sleeping |
| NT dog 1 | German Shepard | Male | with vest | OD-Hot HS-LA | Temp: 27-32 °C, R.H: 45-50% | 5 Ball throwing |
| NT dog 1 | German Shepard | Male | without vest | OD-Hot HS-LA | Temp: 27-32 °C, R.H: 45-50% | 5 Ball throwing |
| NT dog 1 | German Shepard | Male | with vest | OD-Avg HS-IA | Temp: 17-20 °C, R.H: 39-41% | 15 min track |
| NT dog 1 | German Shepard | Male | without vest | OD-Avg HS-IA | Temp: 17-20 °C, R.H: 39-41% | 15 min track |
| NT dog 2 | Bulldog | Male | with vest | OD-Avg HS-IA | Temp: 17-20 °C, R.H: 39-41% | 15 min track |
| NT dog 2 | Bulldog | Male | without vest | OD-Avg HS-IA | Temp: 17-20 °C, R.H: 39-41% | 15 min track |
| Retired PSD | Belgian Malinois | Female | with vest | PSD- OD-HS-IA | Temp: 22-26 °C, R.H: 50-56% | 15 min track |
| Retired PSD | Belgian Malinois | Female | without vest | PSD- OD-HS-IA | Temp: 22-26 °C, R.H: 50-56% | 15 min track |
| Working PSD | Mix (Dutch S.-B. Malinois) | Female | with vest | PSD- OD-HS-IA | Temp: 22-26 °C, R.H: 50-56% | 15 min track |
| Working PSD | Mix (Dutch S.-B. Malinois) | Female | without vest | PSD- OD-HS-IA | Temp: 22-26 °C, R.H: 50-56% | 15 min track |

#### 2.3.2.1 Experimental protocol for non-trained (NT) dogs

The experiments to measure the core body temperature and skin temperature on non-trained dogs were done in four different conditions. They are Indoor: Air-conditioned room with regular activities (ID-AC-RA), Outdoor: On an average hot but sunny day with regular activities (ODAvg HS-RA), Outdoor: On a hot, humid sunny day with light activities (OD-Hot HS- LA), and Outdoor an average hot but sunny day with 15 min. intense activities (OD-Avg HS -IA).
Two NT dogs were involved in these experiments. NT dog 1 was involved in all four conditions: however, NT dog 2 was involved in only ID-AC-RA, OD-Avg HS-RA, and OD-Avg HS-IA conditions.
The core temperature was measured 1 minute- five minutes intervals (ID-AC-RA, OD-Avg HSRA, OD-Hot HS-LA: 5 minutes, OD-Avg HS-IA: 2 minutes, PSD-OD-HS-IA: 1 minutes).
For the skin temperature, data was measured at 5-minute intervals.

##### 2.3.2.1.1 Indoor: Air-conditioned room with regular activities (ID-AC-RA) (regular activities: sitting and sleeping)

The dog core body temperature was measured for four days consecutively in an indoor air-conditioned office space. The controlled temperature was 22°C and 60% R.H. The core body and surface temperature were measured in two states: 1) with custom fit K9 ballistic vest, and 2) without vest. See Figure 2.8.


(a) (b)

Figure 2.8: Experiments in ID-AC-RA condition (a) NT dog 1 with custom fit K9 ballistic vest (b) NT dog 2 without vest

The resting temperature of the dog was measured at the beginning of the experiments, and then the custom fit K9 ballistic vest was put on. An iButton Thermometer to measure skin temperature was attached to the dog's body with a Velcro belt and activities were monitored for 60 minutes. The dogs sat idle or slept on the couch in indoor conditions. After 60 minutes, the vest was taken off, and the core temperature was recorded. Once the internal temperature was in resting condition, the dog's core temperature was recorded continuously for another 60 minutes with the similar activities (sitting idle or sleeping). The condition (vest on and off) order was randomized and revised in the following experiments.

**2.3.2.1.2 Outdoor: On an average hot but sunny day with regular activities (OD-Avg HS-RA) (Regular activities: sitting and sleeping)**

The dog's core and surface temperatures were measured for four days in outdoor conditions of average hot, but sunny days where ambient conditions were 17-24°C and R.H:

3941%. Core body and surface temperatures were measured: 1) with custom fit K9 Storm Ballistic Vest, and 2) without vest (See Figure 2.9).


**(a)** **(b)**

Figure 2.9: Experiments were done in OD-Avg HS-RA condition with a custom-fit K9 Storm Ballistic Vest (a) NT Dog 1 (b) NT Dog 2

At the beginning of the experiment, the resting temperature of the dogs was measured, the custom fit K9 ballistic vests were put on and iButton Thermometers were attached. The dogs sat idle in the sun for 60 minutes, and then the vest was taken off and core temperatures were recorded. Once the internal temperature was in resting condition, the core temperature was recorded continuously for another 60 minutes with the similar activities.

#### 2.3.2.1.3 Outdoor: On a hot, humid sunny day with light activities (OD-Hot HS- LA) (light activities: 6 ball throwing)

The dog's core temperature was monitored for two days in outdoor hot, humid and sunny conditions of ambient temperatures 27-32°C, and R.H: 45-50%. The dog's core body and skin temperatures were measured with a custom fit K9 Storm Ballistic Vest and without a vest as described above. (See Figure 2.10)

Figure 2.10: NT Dog 1 in OD-Hot HS-LA conditions with a ballistic vest during the ball throwing activities at K9 storm premises

As previously, the resting temperature was measured, the custom fit K9 ballistic vest was put on, the iButton Thermometers were attached and the dog's activities were monitored for 60 minutes.

In this condition, the dogs were allowed to sit in the sun and had some light activities (throwing balls six times in 10 min intervals). The other experiment protocols were the same as stated in sec 2.3.2.1.1.

**2.3.2.1.4 Outdoor an average hot but sunny day with 15 min intense activities (OD-Avg HS -IA)**

The core temperature was measured in outdoor conditions of an average hot but sunny day for one day in two shifts with two different dogs. Ambient temperature was 17-20°C and R.H: 41- 39-41%. Core body temperature was measured with a custom fit K9 ballistic vest and without vest. Figure 2.11 shows NT dog 1 doing tracking exercise with Jim Slater (President, and co-founder of K9 Storm) in OD-Avg HS -IA conditions

Figure 2.11: NT dog 1 doing tracking exercise with Jim Slater (President, and co-founder of K9 Storm) at K9 Storm Premises in OD-Avg HS -IA conditions

In this condition, dogs had intense walking activities for 15 min. The goal was one lap (180 ft) in 30 sec and a total of 30 laps (5400 ft) in 15 min.: an anticipated pace of 6ft/sec. However, the dogs ended up with a pace of 6.02 ft/sec – 5.14 ft/sec. The handler was asked to continue the walk for 15 min., even if they could not maintain the expected pace. The feedback to the handler about the walking speed was given verbally throughout the course. After a 15 min. walk with a custom fit K9 Storm Vest, the dogs were allowed to take a rest, and recover their resting temperature. The same experiment was conducted again without a vest, keeping all other parameters constant. The experiments were done in this condition in both morning and afternoon, with two different dogs.

#### 2.3.2.2 Experimental Protocol for Trained dogs (Police Service Dogs- PSD)

The experiments were done with one currently working Police Service Dog and one recently retired Police Service Dog. Because of confidentiality, the identity or photo of the working K9 officer could not be revealed. The experiments with the PSDs (police service dog) were done in a single condition for one day.

##### 2.3.2.2.1 Outdoor condition on a hot sunny day with intense activities (PSD- OD- HS-IA)

Two service dogs were invited for volunteer participation in the research. The first volunteer PSD had been working in narcotics detection for over two years. On the first round of experiments, the dog's temperature was monitored while the dog walked on a track for 15 minutes without a vest. The ambient temperature was 22°C and R.H: 56%. The aim was one lap (180 ft) in 30 sec, and a total of 30 laps (5400 ft) in 15 min: a target pace of 6ft/sec. However, the dog ended up with 6.02 ft/sec – 5.63 ft/sec. While the course seemed intensive and hard for the non-trained dogs, the same course was elementary for a PSD, so they seemed very inconscient. The handler was asked to continue the walk for 15 min. even if they could not maintain the expected pace. The feedback to the handler about the walking speed was given verbally throughout the course. After 15 minutes of walking, the dog was allowed to cool down. Surprisingly, the service dog cooled down to resting temperature more quickly (only 10-15 minutes) than the non-trained dogs (about 30 min). After putting on the vest for the second round, the dog seemed excited to return to work. Immediately the temperature rose a bit, and for the next 30 minutes did not return to resting temperature. During these 30 minutes, the dog seemed very alert and sniffed all around to get the job done. Due to the time constraint, the second-round experiment with the vest needed to start with a slightly elevated resting temperature. The PSD had the second round of walks, with a vest, in the same conditions as previously (one lap in 30 sec).

The second volunteer service dog was a recently retired police dog after nine years of service with a local Police Department. As before, the dog's core temperature was monitored during a 15-minute walk activity; the ambient temperature was 24°C and R.H: 49%.
The experimental protocol was the same as stated above (2.3.2.2.1 for working PSD). Interestingly, for the retired PSD, the post exercise recovery temperature followed the same trend as the working PSD.  Fig 2.12 shows the tracking exercise of retired PSD dog 2 in a PSD- OD- HS-IA condition.

Figure: 2.12: The tracking exercise of retired PSD dog 2 in PSD- OD- HS-IA conditions with her handler at the K9 Storm Premises

### 2.3.3 Data collection

At the end of each experiment, the recorded data were collected from the core temperature monitoring device. With the help of a data cable, all measured core temperature data was collected and stored in the laptop. For condition OD-Avg HS -IA and PSD- OD- HS-IA. With the help of a reader and data cable, all measured data was collected from the iButton Thermometer and stored in the laptop.

### 2.3.4 Statistical analysis

Analysis of Variance (ANOVA) through Excel was done in each experimental condition considering initial, final, and temperature differences during the experiments. The variance was considered significant if the p-value was less than 0.05.

# CHAPTER 3: RESULTS AND DISCUSSION

## Effect of Ballistics Vest on Core and Skin Temperature

### 3.0 Introduction

This chapter contains the core body and skin temperature results of non-trained (NT) and Police Service Dogs (PSD) with and without a vest at various ambient temperatures, relative humidity, and different activities.

### 3.1 Effect of ballistic vest on core temperature

To evaluate the impact of custom fit K9 Storm Ballistic Vest on core temperature of non-trained dogs, experiments were carried out with two different dogs in 4 different conditions. To compare the effect of the ballistic vest, the same experiments were conducted without a vest, keeping the other independent variables (temperature, relative humidity, course work during experiments, diet) constant.

#### 3.1.1 Non-trained (NT) dogs

##### 3.1.1.1 Non-trained (NT) dogs - Indoor: Air-conditioned room with regular activities (ID: AC-RA)

The indoor experiments were carried out in an ambient temperature of 22°C and 60% RH. The activities are stated in sec 2.3.2.1.1**.** Table 3.1 shows average core body temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in ID-AC-RA conditions for up to 65 minutes. The temperature was taken each five minutes which gave 13, 8, 7 and 12 readings for Day 1 (Dog 1), Day 2 (Dog 2), Day 3 (Dog 1) and Day 4 (Dog 1), respectively.

Table 3.1: Average core body temperature of non-trained dogs with ballistic vest and without vest in condition ID-AC-RA (up to 65 minutes)

| Days | Dogs | Resting | Core temperature (°C) Without vest | With vest |
|---|---|---|---|---|
| Day 1 | NT Dog 1 | 38.16 | 38.51 ± 0.12 (13) | 38.51± 0.19 (13) |
| Day 2 | NT Dog 2 | 39.41 | 39.59 ±0.06 (8) | 39.60±0.07 (8) |
| Day 3 | NT Dog 1 | 38.75 | 38.75 ± 0.11 (13) | 38.81± 0.09 (13) |
| Day 4 | NT Dog 1 | 38.23 | 38.52 ± 0.21 (12) | 38.43 ± 0.25 (12) |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) core temperatures of non-trained dogs in ID-AC-RA are shown in Table 3.1. While the resting temperature was taken at the beginning, the core temperatures were shown for the 60 minutes. The core temperature for Dog 2 was slightly higher than the Dog 1 (German Shepherd), which might be because Dog 2 was a bulldog. The average core temperature for Dog 1 without vest was 38.51 to 38.75°C; with the vest, the core temperature was 38.43°C to 38.81°C. For Dog 2, no difference was noticed in core temperature with (39.60°C) or without vest (39.59°C). When the core temperatures of Dog 1 and Dog 2 were compared, it was found that as with the resting temperature, Dog 2 showed a slightly higher temperature than Dog 1 both without vest (Dog 1: 38.51-38.74°C; Dog 2: 39.59°C) and with vest (Dog 1: 38.43-38.82°C; Dog 2: 39.60°C). Table 3.2 shows the ANOVA analysis on average core body temperature with ballistic vest and without a ballistic vest in ID-AC-RA condition, where $p > 0.05$ which means variance is not statistically significant.

Table 3.2: ANOVA analysis of average core body temperature with ballistic vest and without ballistic vest in ID-AC-RA conditions for Dog 1, Day 3

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.019938 | 1 | 0.019938 | 1.891051 | 0.181786 | 4.259677 |
| Within Groups | 0.253046 | 24 | 0.010544 | | | |
| | | | | | | |
| Total | 0.272985 | 25 | | | | |

**Core temperature during the activity**

Fig 3.1 shows core body temperature data with a ballistic vest and without a vest on Day 3 experiments in ID-AC-RA conditions.

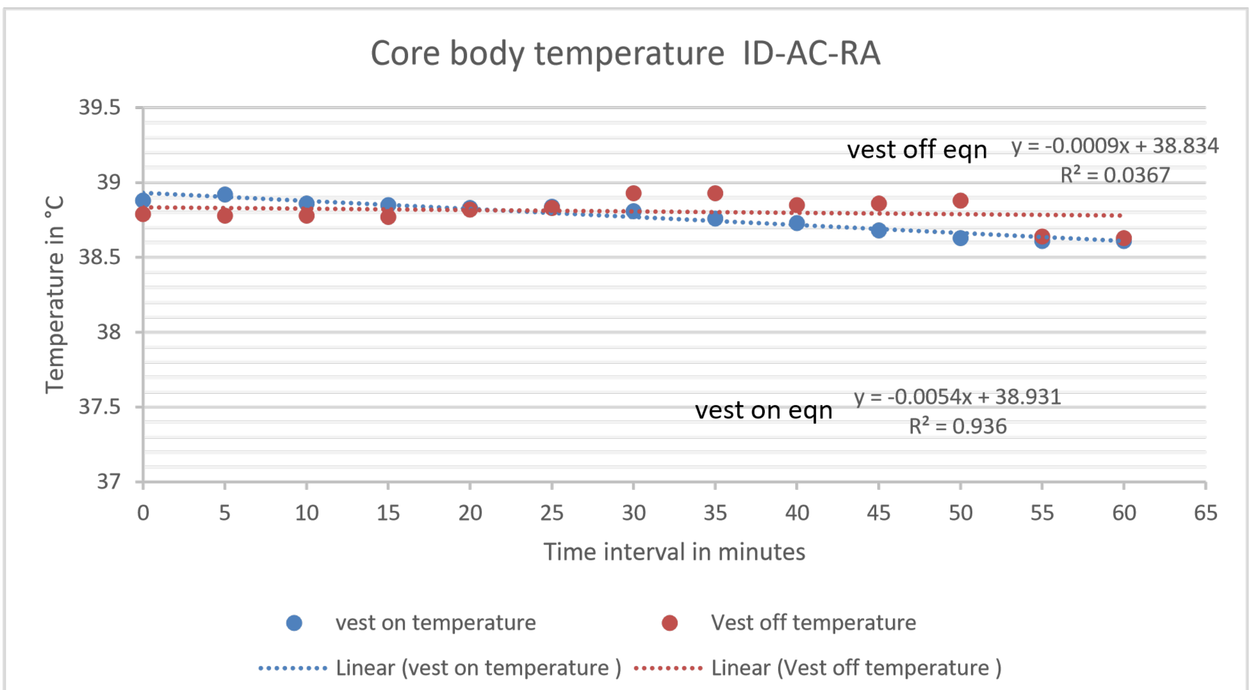


Figure 3.1: Day 3: Comparative analysis of core body temperature with vest on and vest off in ID-AC-RA conditions

In the regression analysis shown in Figure 3.1, vest on core body temperature follows a better linear trend ($y = -0.0054x + 38.931$, $R^2 = 0.936$) compared with vest off core body temperature ($y = -0.0009x + 38.834$, $R^2 = 0.0367$). Here, y represents the dependent variable which is core body temperature, and x represents independent variable for time. The slope of the linear equation is comparatively higher for vest on ( -0.0054) compared with vest off (-0.0009), which means that, with time interval, the dog's core temperature decreased more with vest on compared with vest off. Core body temperature with vest followed a more constant trend line compared with no vest condition. From t-stat analysis (Appendix iii, table: A38) to evaluate slope significancy, it is shown that p value is 0.01 (<0.05), which means the slope of the two trendline varies significantly.

#### 3.1.1.2 Outdoor: On an average hot but sunny day with regular activities (OD- Avg HS-RA)

The outdoor experiments were carried out in an ambient temperature of 17-24°C and 3941% RH with the activities outlined in sec 2.3.2.1.2**.** Table 3.3 shows average core body temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in OD-Avg HS-RA conditions for up to 35 minutes. The temperature was taken each five minutes which gave 8, 5, 6, 5 and 7 readings for Day 1 (Dog 1), Day 2 (Dog 1), Day 3 (Dog 2) and Day 4 (Dog 1), respectively.

Table 3.3: Average core body temperature of non-trained dogs with ballistic vest and without any vest in condition ID-AC-RA (up to 35 minutes) in OD-Avg HS- RA conditions

| Days | Dogs | Core temperature in °C | | | Experiment duration in minutes |
|---|---|---|---|---|---|
| | | Resting | Without vest | With vest | |
| Day 1- afternoon | NT Dog 1 | 39.3 | 40.27 ± 0.044 (8) | 39.90 ± 0.32 (8) | 35 |
| Day 2- afternoon | NT Dog 2 | 38.38 | 39.25 ± 0.25 (5) | 38.55 ± 0.18 (5) | 20 |
| Day 3-afternoon | NT Dog 1 | 38.63 | 38.75 ± 0.03 (6) | 38.68 ± 0.05 (6) | 25 |
| Day 4-morning | NT Dog 1 | 38.58 | 39.87 ± 0.24 (5) | 38.88 ± 0.23 (5) | 20 |
| Day 4- afternoon | NT Dog 1 | 38.06 | 38.54 ± 0.30 (7) | 39.61 ± 0.13 (7) | 30 |

± Standard deviation; no. of samples in parentheses resting temperature taken before first order (with vest or without vest conditions)

The resting without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) core temperatures of non-trained dogs in OD-Avg HS-RA are shown in Table 3.3. While the resting temperature was taken at the beginning, the core temperatures were shown up to 35 minutes. The average core temperature for Dog 1 without vest was between 38.54 and 40.27°C, while with the vest, the core temperature was 38.55°C to 39.90°C. For Dog 2, only a slight difference was noticed in core temperature with (38.68°C) or without vest (38.75°C). When core temperature is compared, Dog 1 shows a slightly higher temperature than Dog 2 in both without vest (Dog 1: 38.54-40.27°C; Dog 2: 38.75°C) and with vest (Dog 1: 38.55-39.90°C; Dog 2: 38.68°C).

Table 3.4 shows the ANOVA analysis of average core body temperature with ballistic vest and without ballistic vest in OD-Avg HS- RA condition for Dog 1, where $p > 0.05$ which means variance is not statistically significant.

Table 3.4: ANOVA analysis of average core body temperatures with ballistic vest and without a ballistic vest in OD-Avg HS- RA condition for Dog 1

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.142045 | 1 | 0.142045 | 0.357716 | 0.571647 | 5.987378 |
| Within Groups | 2.382527 | 6 | 0.397088 | | | |
| | | | | | | |
| Total | 2.524572 | 7 | | | | |

**Core temperature during the activity**

Fig 3.2 shows core body temperature data with the ballistic vest and without a vest on Day 3 experiment in OD-Avg HS-RA conditions.

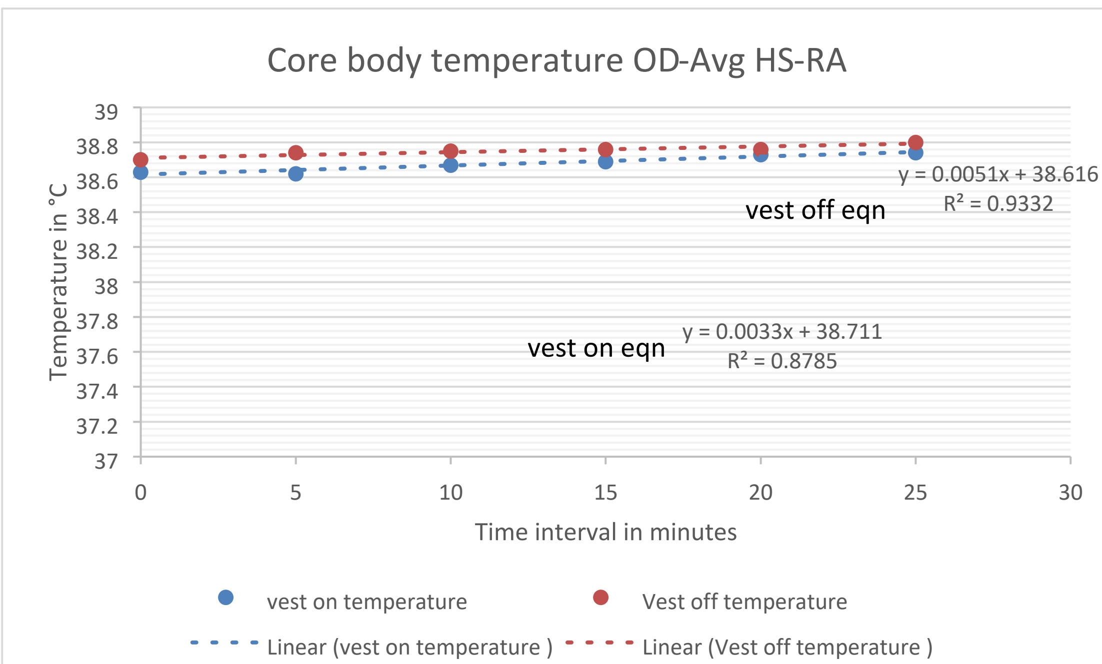


Figure 3.2: Day 3 Comparative analysis of core body temperature with vest on and vest off in OD-Avg HS-RA conditions

In the regression analysis shown in Figure 3.2, vest off core body temperature follows a better linear trend (y= 0.0051x + 38.616, $R^2 = 0.9332$) compared with vest on core body temperature (y= 0.0033x + 38.711, $R^2 = 0.8785$). Core body temperatures with vest and without vest remain almost constant throughout the 25 min. experiment. The linear equation shows the slope of vest on temperature was lower (0.0033) compared with vest off temperature (0.0051), though the difference is small. After wearing the vest, the dog's core temperature increased slightly less compared with vest off condition. From t-stat analysis (Appendix iii, table: A40) to evaluate slope significancy, it is shown that p value is 0.07 (>0.05), which means the slope of the two trendline is not significantly different.

**3.1.1.3 Outdoor: On a hot, humid sunny day with light activities (OD-Hot HS- LA)**

The outdoor experiments were carried out in an ambient temperature of 27-32°C and 4550% RH. The activities are stated in sec 2.3.2.1.3**.** Table 3.5 shows the average core body temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in OD-Hot HS-LA conditions for up to 60 minutes. The temperature was taken each five minutes (Day 5-morning) and two minutes (Day 5-afternoon and Day 6 morning) resulted in 14, 13 and 13 readings for NT Dog 1.

Table 3.5: Average core body temperature of non-trained dogs with a custom fit K9 Storm Ballistic Vest and without any vest in OD-Hot HS- LA conditions

| Days | Dogs | Core temperature °C<br>Resting | <br>Without vest | <br>With vest | Experiment duration in minutes |
|---|---|---|---|---|---|
| Day 5-Morning | NT Dog 1 | 38.42 | 39.38 ±0.63 (14) | 38.88 ± 0.28 (14) | 60 min |
| Day 5-Afternoon | NT Dog 1 | 38.4 | 38.87 ± 0.45 (13) | 38.72 ± 0.19 (13) | 25 min |
| Day 6-Morning | NT Dog 1 | 38.67 | 38.86 ± 0.11 (13) | 38.46 ± 0.23 (13) | 25 min |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting, without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) core temperatures of non-trained dogs in OD-Hot HS-LA are shown in Table 3.5. The resting temperature was taken at the beginning, and the core temperatures were shown up to 60 minutes. The average core temperature for Dog 1 without vest was between 38.86 and 39.38°C, while with vest, the core temperature was 38.46 to 38.88°C. For Dog 1 in condition OD-Hot HS-LA, the core temperature with vest was lower compared to without vest condition. Table 3.6 shows the

ANOVA analysis of average core body temperature with and without ballistic vest in OD-Hot HS- LA condition for Dog 1, where $p > 0.05$ which means variance is not statistically significant.

Table 3.6: ANOVA analysis of average core body temperature with ballistic vest and without ballistic vest in OD-Hot HS- LA condition

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.150417 | 1 | 0.150417 | 1.948823 | 0.23521 | 7.708647 |
| Within Groups | 0.308733 | 4 | 0.077183 | | | |
| | | | | | | |
| Total | 0.45915 | 5 | | | | |

Core temperature during the activity

Figure 3.3 shows core body temperature data with a ballistic vest and without any vest on Day 5- Morning experiment in OD-Hot HS- LA conditions.

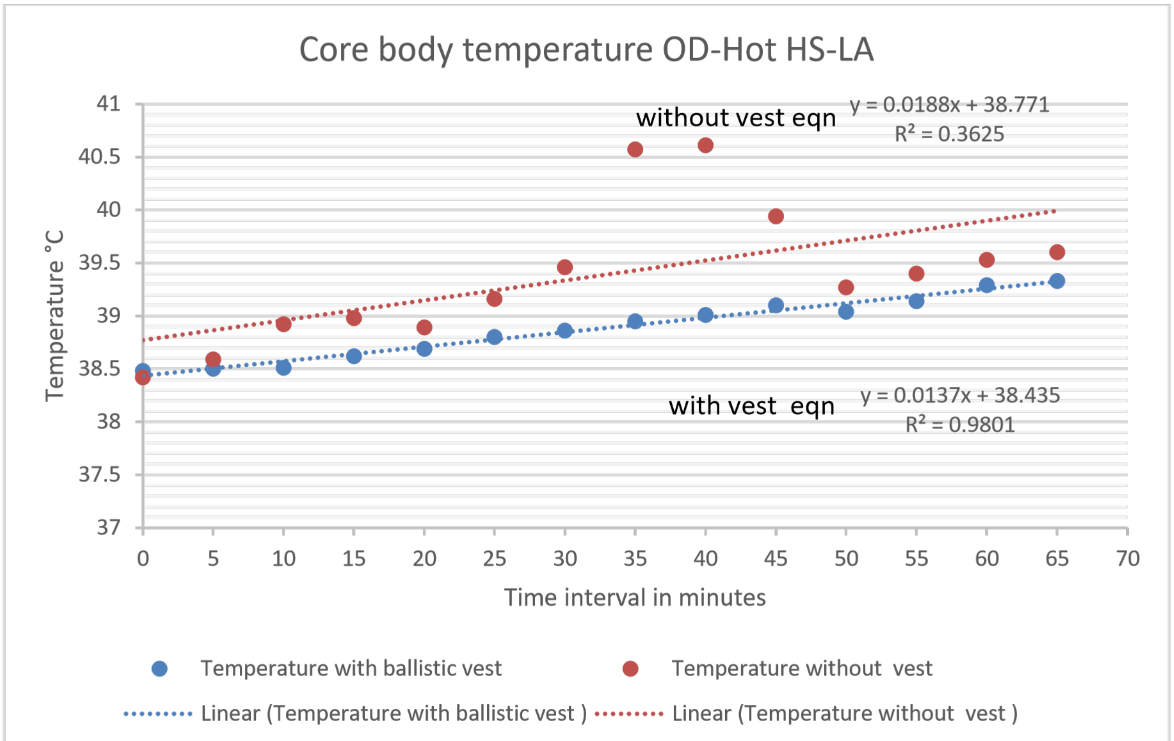


Figure 3.3: Day 5-Morning: comparative analysis of core body temperature with vest on and off in OD-Hot HS- LA conditions

The regression analysis in Figure 3.4, shows that the vest on core body temperature followed better linear trend ($y= 0.0137x + 38.435$, $R^2 = 0.9801$) compared with vest off core body temperature ($y= 0.0188x + 38.771$, $R^2 = 0.3625$). The core temperature without vest suddenly goes up from 35 minutes to 40 minutes as the dog got excited and started barking after seeing another dog passing on the street. The linear equation shows that the slope of the vest off core temperature is slightly higher (0.0188) than the vest on core temperature (0.0137), which means the core temperature after wearing the vest is slightly lower than without vest conditions. From t-stat analysis (Appendix III, table: A42) to evaluate slope significancy, it is shown that p value is 0.49 (>0.05), which means the slope of the two trendline is not significantly different.

### 3.1.1.4 Outdoor an average hot but sunny day with 15 min intense activities (OD-Avg HS IA)

The experiments were carried out with an ambient temperature 17°C -20°C and R.H. 39-41% for one day with two different non-trained dogs. The activities are stated in sec 2.3.2.1.4. Table 3.7 shows average core body temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without vest in OD-Avg HS-IA conditions for 15 minutes. The temperature was taken each two minutes (Day 6-Dog 1) and one minute (Day 6Dog 2) which gave 9 and 16 readings.

Table: 3.7: Average core body temperature of non-trained dogs with a custom fit K9 Storm Ballistic Vest and without vest in OD-Avg HS -IA conditions (15 minutes)

| Days | Dog profile | Condition | Core body temperature °C | | Temperature rise (%) during tracking |
|---|---|---|---|---|---|
| | | | Resting | During exercise | |
| Day 7 | NT Dog 1 | With vest | 38.47 | 38.76 ± 0.22 (9) | 1 |
| | NT Dog 1 | Without vest | 38.61 | 38.84 ± 0.16 (9) | 1 |
| | NT Dog 2 | With vest | 38.83 | 38.92 ± 0.1 (16) | 1 |
| | NT Dog 2 | Without vest | 38.73 | 38.93 ± 0.15 (16) | 1 |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) core temperatures of non-trained dogs in OD-Avg HS-IA are shown in Table 3.7. While the resting temperature was taken at the beginning, the core temperatures were shown up to 15 minutes. The average core temperature for Dog 1 without vest was between 38.61 and 38.84°C, while with the vest, the core temperature was 38.47°C to 38.76°C. For Dog 2, a slight difference was noticed in core temperature with a vest on (38.83 to 38.92°C) and without a vest (38.73 to 38.93°C). When the core temperature of Dog 1 and Dog 2 are compared, Dog 1 shows a slightly higher temperature than Dog 2 in both without vest (Dog 1: 38.84°C; Dog 2: 38.93°C) and vest on (Dog 1: 38.76°C; Dog 2: 38.62°C).

Table 3.7 shows the ANOVA analysis of average core body temperature for with and without ballistic vest in OD-Avg HS -IA conditions for NT dog 2, where $p > 0.05$ which means variance is not statistically significant.

Table 3.8: ANOVA analysis of average core body temperature with ballistic vest and without ballistic vest in OD-Avg HS -IA condition for NT Dog 2

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.002025 | 1 | 0.002025 | 0.240356 | 0.672456 | 18.51282 |
| Within Groups | 0.01685 | 2 | 0.008425 | | | |
| | | | | | | |
| Total | 0.018875 | 3 | | | | |

**Core temperature during the activity**

Fig 3.4 shows core body temperature of NT dog 2 with a custom fit K9 Storm Ballistic Vest and without a vest in OD-Avg HS- IA conditions.

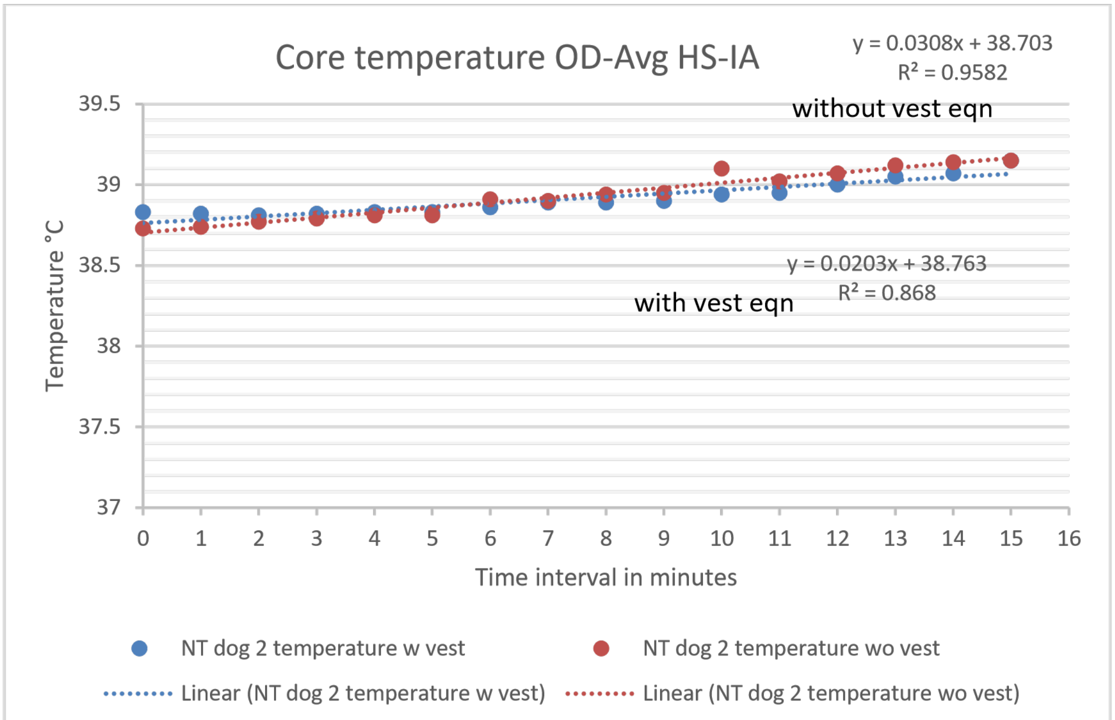


Figure 3.4: Comparative analysis of core body temperature for NT Dog 2 with vest on and vest off in OD-Avg HS- IA conditions

In the regression analysis in Figure 3.4, vest off shows that core body temperature followed a better linear trend (y= 0.0308x + 38.703, $R^2$ = 0.9582) compared with vest on core body temperature (y= 0.0203x + 38.763, $R^2$ = 0.868). The core temperature with vest remained slightly lower compared with without vest condition throughout the experiments. The linear equation shows that the slope of the vest off temperature is slightly higher (0.0308) compared to the vest on temperature (0.0203), which means that the after wearing vest, the temperature rise was slightly lower than without the vest. From t-stat analysis (appendix iii, table: A44) to evaluate slope significancy, it is shown that p value is 0.0005 (<0.05), which means the slope of the two trendline is significantly different.

### 3.1.2 Trained dogs/ Police Service Dog (PSD)

#### 3.1.2.1 Core temperature of retired and working Police Service Dog (PSD) (PSD-OD-HSIA)

The experiments were conducted with an ambient temperature 22°C -26°C and R.H. 50-56% for one day with two different (working and retired) Police Service Dogs (PSD). The activities are outlined in sec 2.3.2.2.1. Table 3.9 shows average core body temperature (± Standard Deviation) of PSD working and retired dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat), and without a vest in PSD-OD-HS-IA condition for 15 minutes. The temperature was taken each minute (Day 7- Retired PSD and working PSD).

Table 3.9: Average core body temperature of working and retired PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions (15 minutes)

| Days | Dogs Profile | Condition | Core temperature °C | | Temperature rise(%) during |
|---|---|---|---|---|---|
| | | | Resting | During exercise | tracking |
| Day 8-afternoon | Retired PSD | With ballistic vest | 38.7 | 39.22 ± 0.33 (13) | 2.8 |
| Day 8-afternoon | Retired PSD | Without vest | 38.44 | 38.98 ± 0.36 (13) | 3 |
| Day 8-morning | Working PSD | With ballistic vest | 39.19 | 39.44 ± 0.19 (13) | 1.6 |
| Day 8-morning | Working PSD | Without vest | 38.43 | 38.96 ± 0.37 (13) | 2.9 |

± Standard deviation; no. of samples in parentheses resting temperature taken before first order (with vest or without vest conditions)

The first course of this experiment was done without a vest. There was a quick rise in the internal temperature after putting on the vest because of the excitement of going to work. It was observed that the initial resting core temperature of the PSD remained higher after wearing the vest than without the vest. The results in table 3.9 show that in outdoor conditions the average core body temperature of the working PSD after 1 Day experiment with ballistic vest (39.44 °C ± 0.19 SD) was lower compared to without a vest (38.96 °C ± 0.37 SD). Similarly, the average core body temperature of the retired PSD after 1 Day experiment with ballistic vest (39.22 °C ± 0.33 SD) was lower compared to without a vest (38.98 °C ± 0.36 SD). The average temperature during exercise of the working PSD was higher (39.19°C) compared to retired PSD (38.7°C), which can be the result of the long service period of retired PSD. Table 3.10 shows the ANOVA analysis of the average core body temperature for both working and retired PSD with ballistic vest and without a ballistic vest in outdoor conditions, where $p > 0.05$ which means variance is not statistically significant.

Table 3.10: ANOVA analysis of average core body temperature for ballistic vest and without a ballistic vest in outdoor condition for retired PSD (15minutes)

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.362496 | 1 | 0.362496 | 2.783176 | 0.108255 | 4.259677 |
| Within Groups | 3.125892 | 24 | 0.130246 | | | |
| Total | 3.488388 | 25 | | | | |

### Core temperature during the activity

Figure 3.5 shows core body temperature of working and retired PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions on 15-minute track.

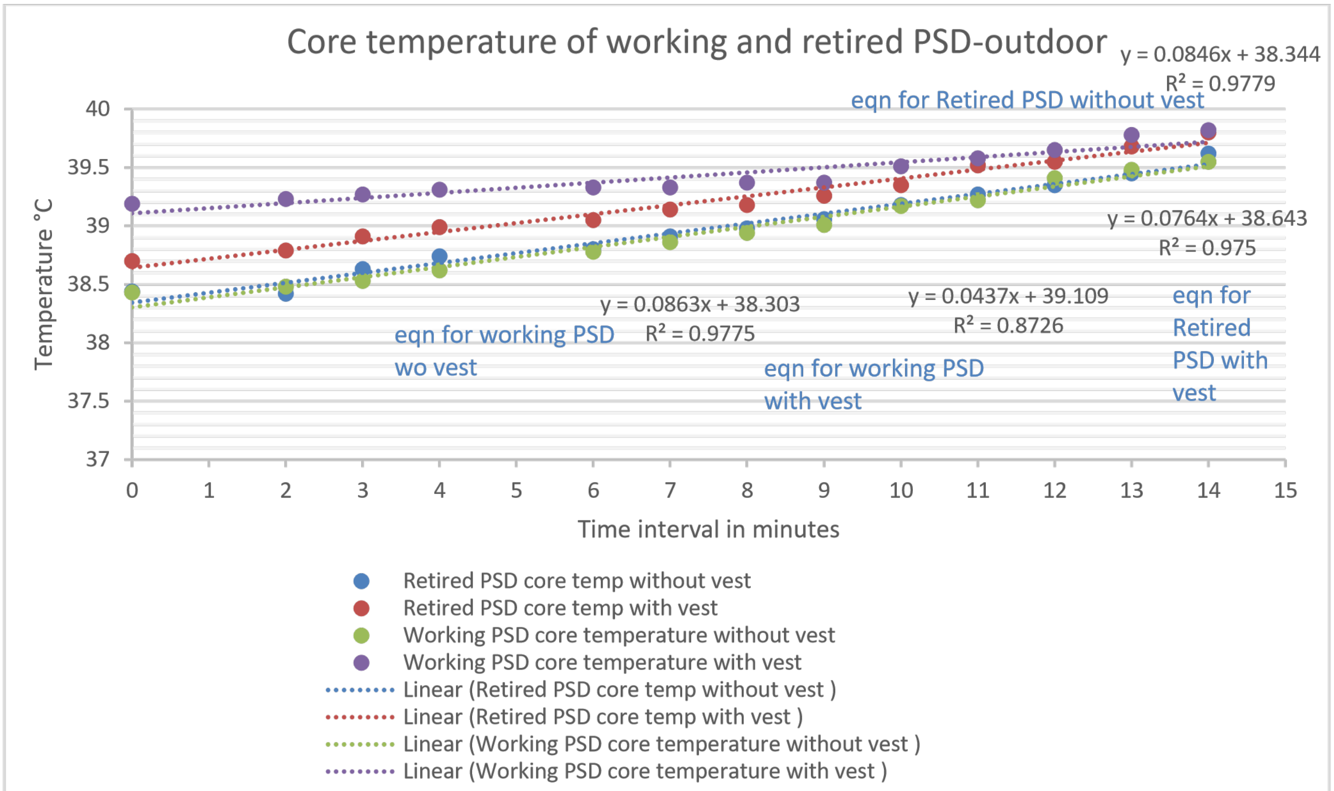


Figure 3.5: Trendline of core body temperature of working and retired PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions

The regression analysis in Figure 3.5 for working dog vest off shows that the core body temperature followed a better linear trend (y= 0.0863x + 38.303, $R^2$ = 0.9775) compared to vest on core body temperature (y= 0.0437x + 39.109 $R^2$ = 0.8726). The linear equation shows that the slope of the vest off core temperature (0.0863) is slightly higher than vest on core temperature (0.0437), which means the increase of core temperature during exercise increased less with the vest on.

On the other hand, the retired police dog vest off core body temperature followed a closely similar linearity (y= 0.0846x + 38.344, $R^2$ = 0.9779) compared with vest on core body temperature (y= 0.0764x + 38.643 $R^2$ = 0.975). The linear equation shows that the slope of vest off core temperature (0.0846) is slightly higher than the slope of the vest on core temperature

(0.0764dll), which means the increase of core temperature during exercise increased less with the vest on.

From t-stat analysis, it is shown that the slope difference between vest off and vest on of retired PSD is not significant as p value is 0.14 ($p>0.05$) (appendix iii, table: A45) On the contrary, that the slope difference between vest off and vest on of working PSD is not significant as p value is less than 0.05 (appendix iii, table: A46), which can be the impact of high resting core temperature of dogs after wearing a ballistic vest due to excitement.

Figure 3.6 shows the core temperature rise in PSD during track with a custom fit K9 Storm Ballistic Vest and without any vest. For both PSD, the temperature rise was higher without a vest than it was with a ballistic vest.

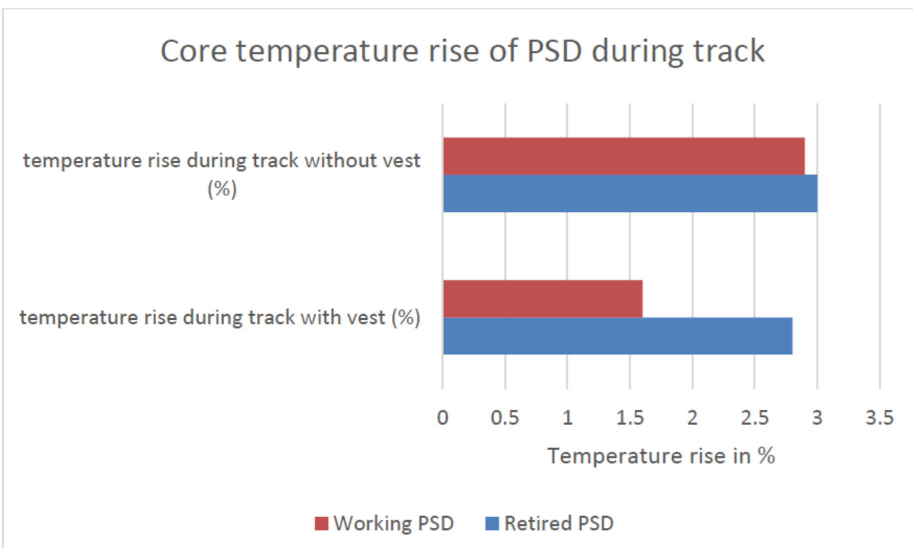


Figure 3.6: The core temperature rises for both working and retired Police service dog during tracking (with vest vs without vest)

## 3.2 Effect of ballistic vest on skin temperature

### 3.2.1. Effect of ballistic vest on skin temperature of non-trained dogs

#### 3.2.1.1 Non-trained (NT) dogs - Indoor: Air-conditioned room with regular activities (ID: AC-RA)

The experimental protocol and ambient conditions were the same (temperature: 22°C, R.H.: 60%) as stated in sec 3.1.1.1. Table 3.11 shows average skin temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in ID-AC-RA conditions up to 60 minutes. The skin temperature was taken by three different iButton Thermometers which were attached in different places of the dog's shoulder and belly. Temperature was taken each five minutes for Day 1, Day 3 and Day 4 (Dog 1), Day 2 (Dog 2) which resulted in 36, 24, 3, and 39 readings, respectively.

Table 3.11: Average skin temperature of non-trained (NT) dogs with a custom fit K9 Storm Ballistic Vest and without a vest in ID: AC-RA conditions (up to 60 minutes)

| Day | Dog Profile | Skin temperature °C | | | Experiment duration in minutes |
|---|---|---|---|---|---|
| | | Resting | With vest | without vest | |
| Day 1 | NT Dog 1 | 31.33 | 34.70 ± 1.07 (36) | 32.20 ± 1.03 (36) | 60 |
| Day 2 | NT Dog 2 | 36.33 | 33.79 ± 1.05 (24) | 33.98± 0.64 (24) | 35 |
| Day 3 | NT Dog 1 | 32.5 | 36.71 ± 0.50 (39) | 35.62± 0.64 (39) | 60 |
| Day 4 | NT Dog 2 | 35.83 | 35.94 ± 0.67 (39) | 34.56 ±0.48 (39) | 60 |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) skin temperatures of non-trained dogs in ID-AC-RA are shown in Table 3.11. While the resting temperature was taken at the beginning, the skin temperatures were assessed up to 60 minutes.

The resting skin temperature for Dog 2 (bulldog) was slightly higher than the Dog 1 (German Shepherd). The average skin temperature for Dog 1 without vest was between 32.2 and 35.62°C; while with vest on, the skin temperature was 34.70°C to 36.71°C. For Dog 2, skin temperature without vest (33.98°C) was almost similar to the skin temperature with vest on (33.79°C).

In indoor conditions, the dogs were lying or sleeping most of the time. Therefore, sleeping position or lying position had a significant impact on the dog's skin temperature. If the dogs were lying with their belly on the ground, a higher skin temperature resulted.

Table 3.12 shows the ANOVA analysis of average skin temperature of Dog 1 with ballistic vest and without ballistic vest in ID: AC-RA conditions, where $p > 0.05$ which means variance is not statistically significant.

Table 3.12: ANOVA analysis of average skin temperature of Dog 1 with ballistic vest and without ballistic vest in ID: AC-RA condition

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 4.116817 | 1 | 4.116817 | 2.011458 | 0.229101 | 7.708647 |
| Within Groups | 8.186733 | 4 | 2.046683 | | | |
| | | | | | | |
| Total | 12.30355 | 5 | | | | |

**Skin temperature during the activity**

The skin temperature data of NT dog 1 with and without a ballistic vest on Day 3 experiments in ID: AC-RA conditions are shown in Figure 3.7.

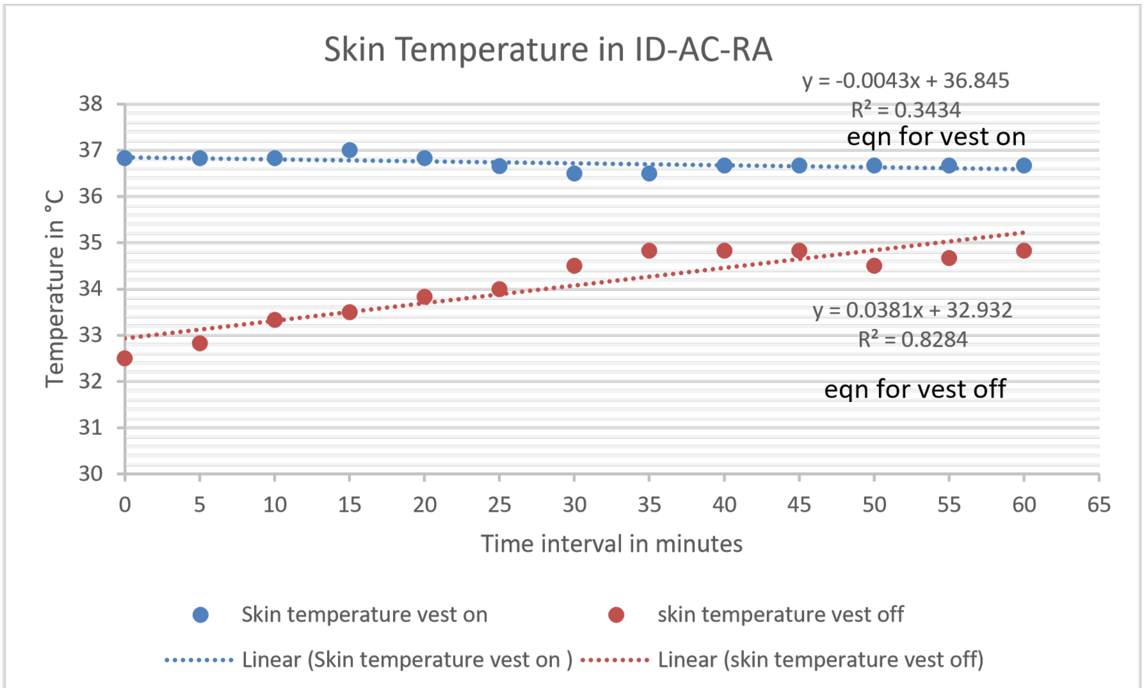


Figure 3.7: Trendline analysis of skin temperature data of NT Dog 1 with a ballistic vest and without a vest on Day 3 experiments in ID: AC-RA conditions

The regression analysis in Figure 3.7 shows that vest off skin temperature followed a better linear trend (y= 0.0381x + 32.932, $R^2$ = 0.8284) compared with the vest on skin temperature (y= 0.0043x + 36.845, $R^2$ = 0.3434). The linear equation shows that the slope of vest on skin temperature was lower (0.0043) compared with vest off skin temperature slope (0.0381), which means the rise in skin temperature after wearing the vest was lower compared with no vest. The starting skin temperature with the vest was higher compared with vest off condition, and it remained higher throughout the experiment. From t-stat analysis (Appendix 3, table: A47) to evaluate slope significancy, it is shown that p value is less than 0.05), which means the slope of the two trendline is significantly different.

### 3.2.1.2 Outdoor: On an average hot but sunny day with regular activities (OD- Avg HS-RA)

The experimental protocol and ambient conditions (Temperature: 17-24°C, R.H: 39-41%) were same as stated in sec 3.1.1.2. Table 3.13 shows average skin temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in OD-Avg HS-RA conditions up to 30 minutes. The skin temperature was taken by three different iButton Thermometers which were attached in different places of the dog's shoulder and belly.  Temperature was taken each five minutes for Day 1, Day 3 (Dog 1), Day 2 (Dog 2) which resulted in 21,15 and 18 readings, respectively.

Table 3.13: Average skin temperature of non-trained (NT) dogs with a custom fit K9 Storm Ballistic Vest and without a vest in OD- Avg HS- RA conditions (up to 30 minutes)

| | | | Skin Temperature | e °C | |
|---|---|---|---|---|---|
| Days | Dog Profile | Resting | With vest | Without vest | Experiment duration in minutes |
| Day 1 | NT Dog 1 | 29.66 | 33.28 ± 2.05 (21) | 34.55 ± 1.19 (21) | 30 |
| Day 2 | NT Dog 2 | 35.83 | 36.7 ±1.09 (15) | 36.1 ± 1.71 (15) | 20 |
| Day 3 | NT Dog 1 | 34.83 | 35.72 ± 0.62 (18) | 35.16 ± 0.44 (18) | 25 |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting without and with vest (K9 Storm Ballistic Vest, Patrol Swat type) skin temperatures of non-trained dogs in OV-Avg HS-RA are shown in Table 3.13. The resting temperature was taken at the beginning, and the skin temperatures were shown up to 30 minutes. The resting skin temperature for Dog 2 (bulldog) was found slightly higher (Dog 2: 35.83°C) than Dog 1 (German Shepherd- 29.66-34.83°C). The average skin temperature for Dog 1 with vest on was between 33.21 and 35.72°C, while with vest off the skin temperature was 34.55°C to 35.16°C.

For Dog 2, skin temperature without vest (36.1°C) was lower than skin temperature with vest on (36.7°C).

Table 3.14 shows the ANOVA analysis of average skin temperature of Dog 1 with ballistic vest and without a ballistic vest in OD-Avg HS-RA conditions, where $p > 0.05$ which means variance is not statistically significant.

Table 3.14: The ANOVA analysis of average skin temperature of Dog 1with ballistic vest and without a ballistic vest in OD- Avg HS- RA conditions (up to 30 minutes)

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.126025 | 1 | 0.126025 | 0.079691 | 0.804249 | 18.51282 |
| Within Groups | 3.16285 | 2 | 1.581425 | | | |
| | | | | | | |
| Total | 3.288875 | 3 | | | | |

**Skin temperature during the activity**

Figure 3.8 shows skin temperature data of NT Dog 1 with a ballistic vest and without a vest on Day 3 experiments in OD- Avg HS- RA conditions

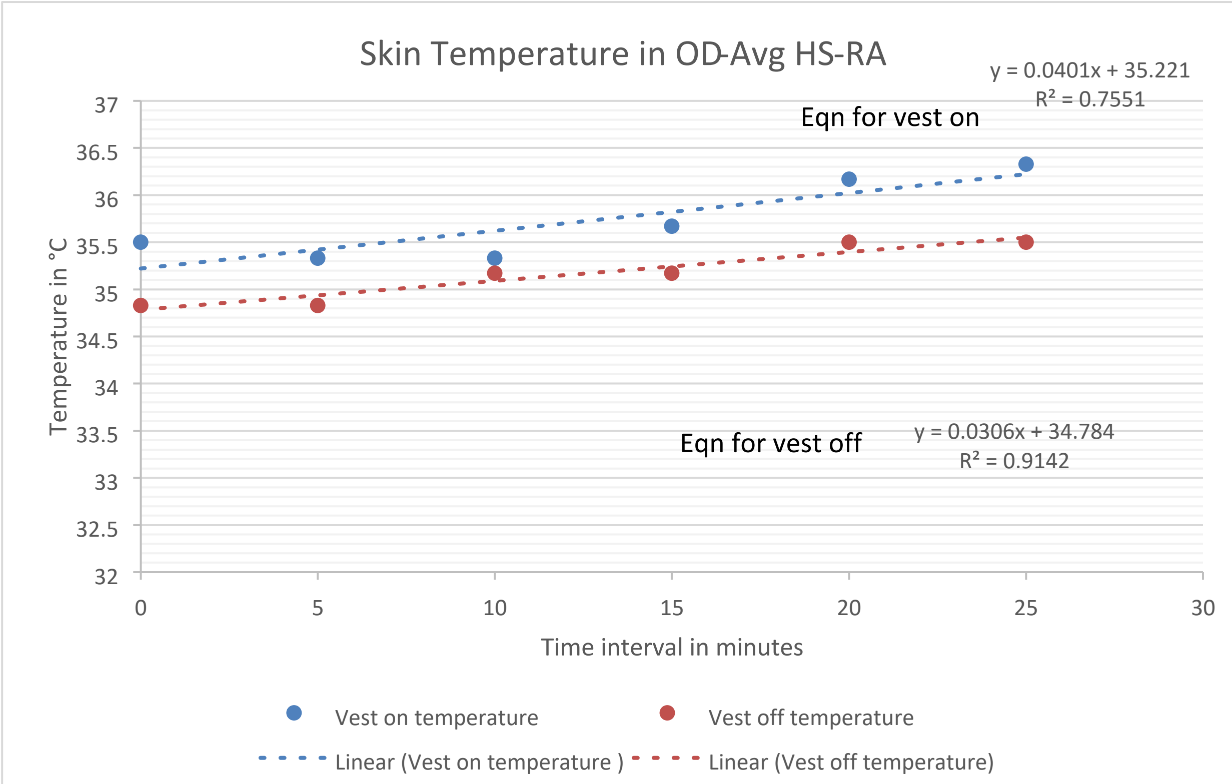


Figure 3.8: Trendline analysis of skin temperature data of NT Dog 1 with a ballistic vest and without a vest on Day 3 (NT Dog 1) experiments in OD- Avg HS- RA conditions

The regression analysis in Figure 3.8 shows that the vest off skin temperature followed better linear trend (y= 0.0306x + 34.784, $R^2$ = 0.9142) compared with the vest on skin temperature (y= 0.0401x + 35.221, $R^2$ = 0.7551). The linear equation shows that the vest on skin temperature slope is slightly higher (0.0401) compared with the vest off temperature slope (0.0306). Though the difference is minimal, still we can say, in OD-Avg HS-RA conditions, NT Dog 1 skin temperature increased slightly more in vest on conditions compared with vest off. The starting skin temperature with vest was higher compared with vest off conditions, and it remained higher throughout the experiment. From t-stat analysis (appendix iii, table: A49) to evaluate slope significancy, it is shown that p value is 0.46 (>0.05), which means the slope of the two trendline is not significantly different.

### 3.2.1.3 Outdoor: On a hot, humid sunny day with light activities (OD-Hot HS- LA)

The experimental protocol and ambient condition (Temperature: 27-32°C, R.H: 45-50%) were same as stated in sec 3.1.1.3. Table 3.9 shows average skin temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in OD-Avg HS-RA conditions up to 45 minutes. The skin temperature was taken by two iButton Thermometers, while one thermometer was attached under the vest and other one was attached on open skin. Temperature was taken each five minutes for Day 4 (morning, afternoon) and Day 5 (morning, afternoon) resulting in 10, 6, 7, and 6 readings, respectively.

Table 3.9: Average skin temperature of non-trained (NT) dog 1 with a custom fit K9 Storm Ballistic Vest and without a vest in OD- Hot HS- LA conditions

| Days | Dog Profile | Skin Temperature °C | | | Experiment duration in minutes |
|---|---|---|---|---|---|
| | | Resting | Vest on | Vest off | |
| Day 4-Morning | NT Dog 1 | 35.5 | 36.95 ± 0.91 (10) | 41.3 ± 1.58 (10) | 45 |
| Day 4-Afternoon | NT Dog 1 | 33.5 | 36.16 ± 2.01 (6) | 35.83 ± 1.80(6) | 30 |
| Day 5-Morning | NT Dog 1 | 35.5 | 36.57 ± 0.90 (7) | 37.07 ± 0.42 (7) | 30 |
| Day 5-Afternoon | NT Dog 1 | 32.5 | 33.91 ± 2.99 (6) | 33.25± 2.99 (6) | 30 |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting, without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) skin temperatures of non-trained dogs in OD-Hot HS-LA are shown in Table 3.9. The resting temperature was taken at the beginning, and the skin temperatures were recorded up to 45 minutes. The resting skin temperature for Dog 1 was (German Shepherd) 32.5-35.5°C; average skin temperature with vest on was between 33.91 and 36.95°C, while with vest off, the skin temperature was 33.25°C to 41.3°C.

Table 3.10 shows the ANOVA analysis of the average skin temperature with ballistic vest and without a ballistic vest in OD- Hot HS- LA conditions for NT Dog 1, where $p > 0.05$ which means variance is not statistically significant.

Table 3.10: ANOVA analysis of average skin temperature with ballistic vest and without a ballistic vest in OD- Hot HS- LA conditions

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 1.86245 | 1 | 1.86245 | 0.283408 | 0.613604 | 5.987378 |
| Within Groups | 39.42975 | 6 | 6.571625 | | | |
| | | | | | | |
| Total | 41.2922 | 7 | | | | |

**Skin temperature during the activity**

Figure 3.9 shows skin temperature data of NT dog 1 with a ballistic vest and without a vest on Day 4- Morning experiments in OD- Hot HS- LA conditions.

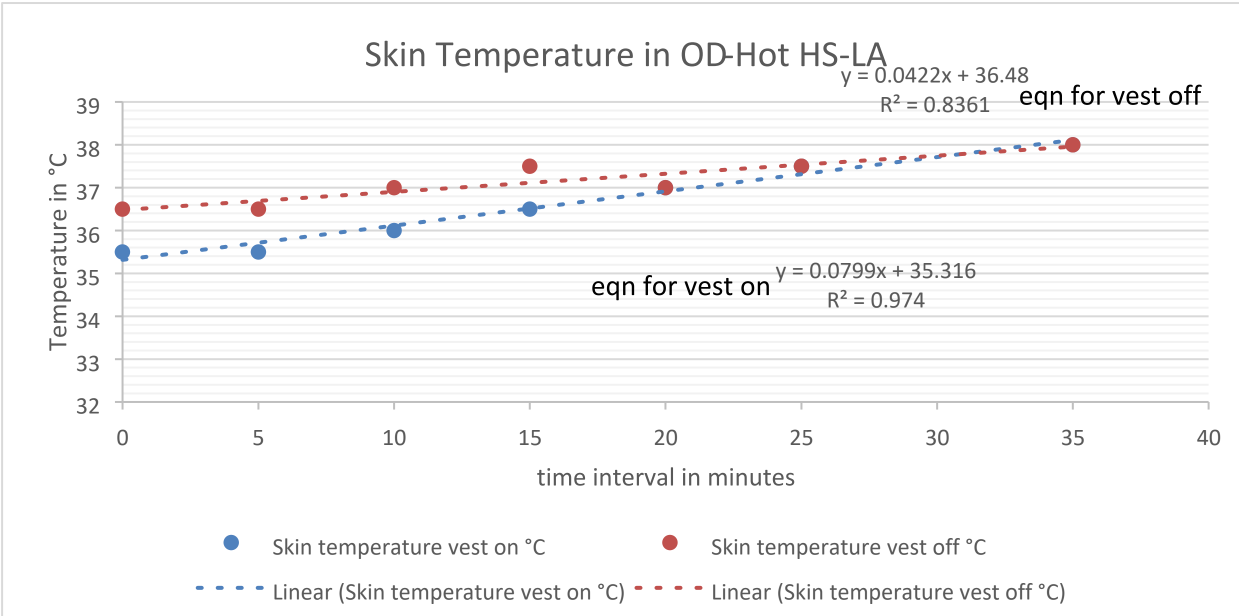


Figure 3.9: Trendline of skin temperature data for NT dog 1 with a ballistic vest and without a vest on day 5- Morning experiments in OD- Hot HS- LA conditions

The regression analysis in Figure 3.9 shows that the vest on skin temperature followed a better linear trend (y= 0.0799x + 35.316, $R^2 = 0.974$) compared with vest off skin temperature (y= 0.0422x + 36.48, $R^2 = 0.974$). The linear equation shows that the slope of the vest on skin temperature is higher (0.0799) compared with the slope of vest off skin temperature (0.0422), which means the skin temperature rise was slightly higher after wearing the vest compared with no vest. Initially, the vest off skin temperature was higher compared with vest on skin temperature; however, after 20 minutes, the skin temperature in both conditions was almost the same. From t-stat analysis (appendix III, table: A51) to evaluate slope significancy, it is shown that p value is 0.003 ($<0.05$), which means the slope of the two trendline is significantly different.

### 3.2.1.4 Outdoor an average hot but sunny day with 15 min intense activities (OD-Avg HS IA)

The experimental protocol and ambient conditions (Temperature: 17-20°C, R.H: 39-41%) were same as stated in sec 3.1.1.4. Table 3.10 shows the average skin temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in OD-Avg HS-IA conditions for 15 minutes. The skin temperature was taken by two iButton Thermometers: one thermometer was attached under the vest, and the other was attached on open skin. Temperature was taken each five minutes for Day 6 (NT Dog 1, and NT Dog 2) which resulted in 4, 4, 4, and 4 readings.

Table 3.10: Average skin temperature of non-trained (NT) dogs with a custom fit K9 Storm Ballistic Vest and without a vest in OD- Avg HS- IA conditions (15 minutes)

| Days | Dog profile | Condition | Skin Temper | | Temperature rise (%) during tracking |
|---|---|---|---|---|---|
| | | | Resting | During exercise | |
| Day 6 | NT Dog 1 | With Ballistic vest | 31 | 32.25 ± 0.90(4) | 8 |
| Day 6 | NT Dog 1 | Without vest | 33 | 36.63 ± 2.43(4) | 20 |
| Day 6 | NT Dog 2 | With Ballistic vest | 32.5 | 33.75 ± 0.90(4) | 8 |
| Day 6 | NT Dog 2 | Without vest | 32.5 | 36.25 ± 2.28 (4) | 18 |

± Standard deviation; no. of samples in parentheses, resting temperature taken before first order (with vest or without vest conditions)

The resting, without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) skin temperatures of non-trained dogs in OD-Avg HS-IA are shown in Table 3.10. The resting temperature was taken at the beginning, and the skin temperatures were taken up to 30 minutes. The resting skin temperature for Dog 2 (bulldog) was the same for both with vest and without vest conditions (32.5 °C). The resting skin temperature for Dog 1 was between 31-33 °C. The average skin temperature for Dog 1 with vest on was 32.25°C while with vest off, the skin temperature was 34.55°C to 36.63°C. For Dog 2, skin temperature with vest (33.75°C) was lower than skin temperature without vest (36.28°C). Table 3.11 shows the ANOVA analysis of average skin temperature of Dog 1 with ballistic vest and without ballistic vest in OD- Avg HS-IA conditions for both dogs, where $p < 0.05$ which means variance is statistically significant.

Table 3.11: ANOVA analysis of average skin temperature with ballistic vest and without ballistic vest in OD-Avg HS -IA condition

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 38.28125 | 1 | 38.28125 | 8.526682 | 0.02663 | 5.987378 |
| Within Groups | 26.9375 | 6 | 4.489583 | | | |
| | | | | | | |
| Total | 65.21875 | 7 | | | | |

**Skin temperature during the activity**

Figure 3.10 shows skin temperature data of NT dog 1 with a ballistic vest and without a vest in OD-Avg HS -IA conditions.

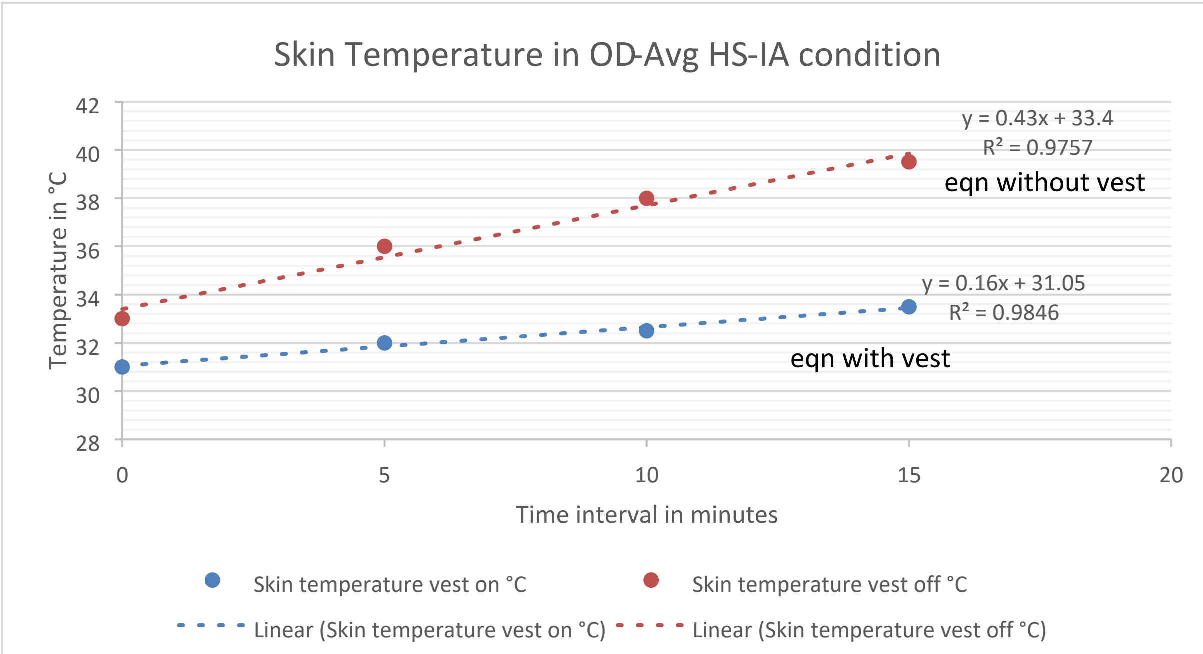


Figure 3.10: Trendline of skin temperature data of NT dog 1 with a ballistic vest and without vest in OD-Avg HS -IA conditions

The regression analysis in Figure 3.10 shows that the vest on skin temperature followed a better linear trend ($y= 0.16x + 31.05$, $R^2 = 0.9846$) compared with vest off skin temperature ($y= 0.43x + 33.4$, $R^2 = 0.9757$). The linear equation shows that the slope of the vest on skin temperature is lower (0.16) compared with vest off skin temperature slope (0.43), which means after wearing the vest, the dog's skin temperature increased less compared with no vest conditions. Initially, the vest off skin temperature was higher compared with vest on skin temperature and remained higher throughout the experiments. From t-stat analysis (appendix iii, table:A52) to evaluate slope significancy, it is shown that p value is 0.002 ($<0.05$), which means the slope of the two trendline is significantly different.

### 3.2.2 Effect of ballistic vest on skin temperature of trained dogs/ Police Service Dog (PSD)

#### 3.2.2.1 Skin temperature of retired and working Police Service Dog (PSD) (PSD-OD-HSIA)

The experimental protocol and ambient conditions (Temperature: 22-26°C, R.H: 50-56%) were the same as stated in sec 3.1.2.1. Table 3.12 shows average skin temperature (± Standard Deviation) of non-trained dogs with a custom fit K9 Storm Ballistic Vest (Patrol Swat) and without a vest in PSD OD- HS-IA conditions up to 45 minutes. The skin temperature was taken by two different iButton Thermometers, attached directly under the vest and attached directly on the skin without any cover. Temperature was taken each five minutes for Day 7 (Morning- Working PSD, Afternoon: Retired PSD) which resulted in four readings each session.

Table 3.12: Average skin temperature of retired and working Police Service Dogs with a custom fit K9

Storm Ballistic Vest and without a vest in PSD-OD- HS- IA conditions (15 minutes)

| Days | Dog profile | Condition | mperature °C | | Temperature rise (%) during exercise |
|---|---|---|---|---|---|
| | | | Resting | During exercise | |
| Day7-Afternoon | Retired PSD | With ballistic vest | 36 | 37.38 ± 0.96 (4) | 7 |
| Day7-Afternoon | Retired PSD | without vest | 38 | 41.13 ± 1.9 (4) | 13 |
| Day7-Morning | Working PSD | With ballistic vest | 35 | 36 ± 0.79 (4) | 6 |
| Day7-Morning | Working PSD | without vest | 37.5 | 37.13 ± 0.21 (4) | -1 |

± Standard deviation; no. of samples in parentheses; resting temperature taken before first order (with vest or without vest conditions)

The resting, without vest and with vest (K9 Storm Ballistic Vest, Patrol Swat type) skin temperatures of dogs in OD-Avg HS-IA are shown in Table 3.12. The resting temperature was taken at the beginning; the skin temperatures were shown for 15 minutes. The resting skin temperature of retired dog with vest was 36°C and without vest was 38°C, while the resting skin temperature of working dog with vest was 35°C and without vest was 37.5°C. The average skin temperature for retired PSD with vest was lower (37.38°C) than vest off skin temperature (41.13°C). Similarly, for working PSD, skin temperature with vest (36°C) was slightly lower than skin temperature without vest (37.5°C). Comparing the retired and working PSD, the skin temperature of retired PSD was higher (with vest: 37.38°C, without vest: 41.13°C) than that of the working PSD (with vest: 36°C, without vest: 37.13°C). Table 3.13 and 3.14 show ANOVA analysis on average skin temperature of both working and retired PSD respectively, with ballistic vest and without ballistic vest in outdoor conditions, where $p < 0.05$ which indicates that variance is statistically significant.

Table: 3.13 ANOVA analysis of average skin temperature for working PSD with ballistic vest and without ballistic vest in outdoor conditions

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 2.53125 | 1 | 2.53125 | 5.651163 | 0.054976 | 5.987378 |
| Within Groups | 2.6875 | 6 | 0.447917 | | | |
| Total | 5.21875 | 7 | | | | |

Table: 3.14 ANOVA analysis of average skin temperature for retired PSD with ballistic vest and without ballistic vest in outdoor conditions

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 28.125 | 1 | 28.125 | 8.940397 | 0.024319 | 5.987378 |
| Within Groups | 18.875 | 6 | 3.145833 | | | |
| Total | 47 | 7 | | | | |

**Skin temperature during the activity**

Figure 3.11 shows skin temperature of working PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions on a 15-minute track.

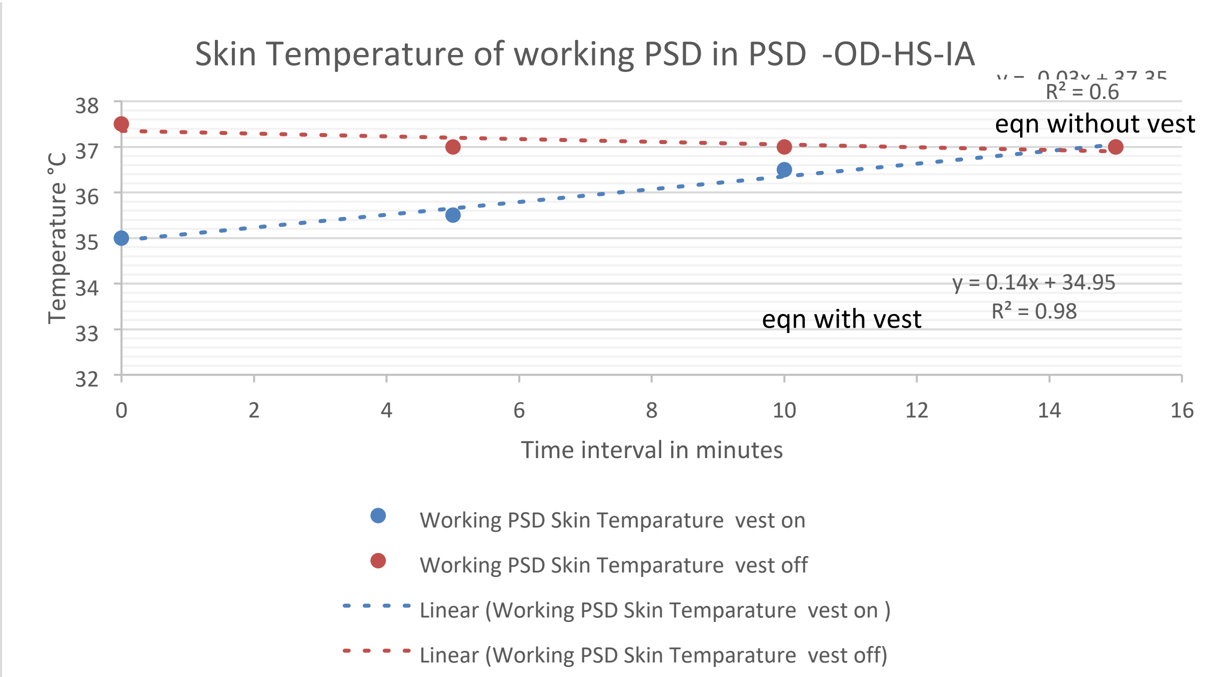


Figure 3.11: Skin temperature of Working PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions

The regression analysis in Figure 3.11 shows that vest on skin temperature follows a better linear trend (y= 0.14x + 34.95, $R^2 = 0.98$) compared with vest off skin temperature (y= 0.03x + 37.35, $R^2 = 0.6$). The linear equation shows that the slope of skin temperature is higher in vest on condition (0.14) compared with vest off condition (0.03), which means the temperature rise was higher in vest on condition compared with vest off. From t-stat analysis (appendix iii, table:44) to evaluate slope significancy, it is shown that p value is 0.0002 (<0.05), which means the slope of the two trendline is not significantly different.

Figure 3.12 shows skin temperature of retired PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions in 15-minute track

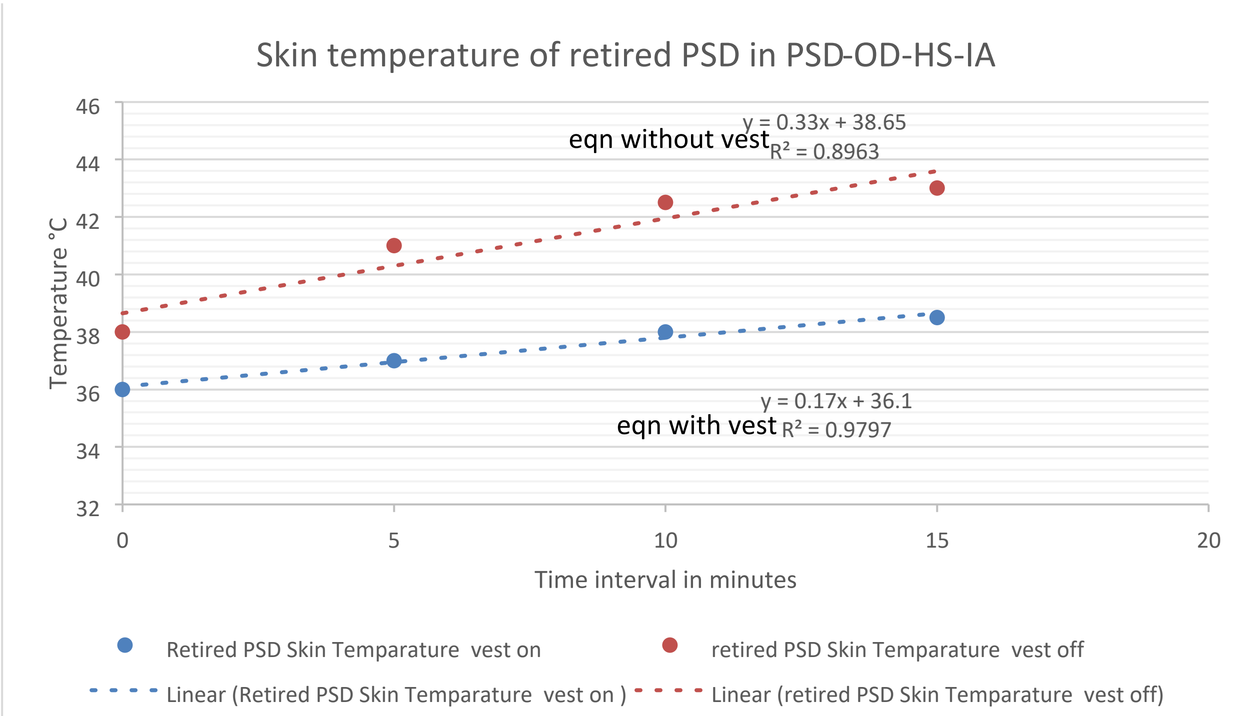


Figure 3.12: Skin temperature of retired PSD with a custom fit K9 Storm Ballistic Vest and without a vest in outdoor conditions in 15-minute track

The regression analysis in Figure 3.12 shows that the vest on skin temperature follows a better linear trend ($y = 0.17x + 36.1$, $R^2 = 0.9797$) compared with vest off skin temperature ($y = 0.33x + 38.65$, $R^2 = 0.9863$). Vest on skin temperature remained lower throughout the experiments compared with vest off skin temperature. The linear equation shows that the slope of skin temperature is higher in vest off condition (0.33) compared with vest on condition (0.17), which means the temperature rise was higher in vest off condition compared with vest on during exercise in PSD-OD-HS-IA condition. From t-stat analysis (appendix iii, table A54) to evaluate slope significancy, it is shown that p value is 0.32 (>0.05), which means the slope of the two trendline is not significantly different.

### 3.3 Discussion

The study was done using different conditions: indoor-outdoor, male-female, dog breed, ambient weather conditions, with both trained and non-trained dogs. This chapter summarizes the impact of a ballistic vest on a canine's core and skin temperature.

#### 3.3.1 Core body temperature

Core body temperature was evaluated in different conditions and tried to cover as many factors as possible as stated in Table 3.15. Table 3.16 summarizes the results of all the experiments in different conditions.

| ID | Dog Profile | Condition | Avg core temperature °C | P-value (ANOVA) | Result | P-value (slope difference) | Result |
|---|---|---|---|---|---|---|---|
| ID-AC-RA | NT dog 1 | with vest | 38.59 | 0.18 | Not significant | 0.01 | Significant |
| ID-AC-RA | NT dog 1 | without vest | 38.59 | | | | |
| ID-AC-RA | NT dog 2 | with vest | 39.6 | 0.97 | Not significant | 0.45 | Not significant |
| ID-AC-RA | NT dog 2 | without vest | 39.59 | | | | |
| OD-Avg HS-RA | NT dog 1 | with vest | 39.11 | 0.57 | Not significant | 0.07 | Significant |
| OD-Avg HS-RA | NT dog 1 | without vest | 39.38 | | | | |
| OD-Avg HS-RA | NT dog 2 | with vest | 38.68 | 0.25 | Not significant | 0.25 | Not significant |
| OD-Avg HS-RA | NT dog 2 | without vest | 38.75 | | | | |
| OD-Hot HS-LA | NT dog 1 | with vest | 38.68 | 0.23 | Not significant | 0.49 | Not significant |
| OD-Hot HS-LA | NT dog 1 | without vest | 39 | | | | |
| OD-Avg HS-IA | NT dog 1 | with vest | 38.84 | 0.39 | Not significant | 0.16 | Not significant |
| OD-Avg HS-IA | NT dog 1 | without vest | 38.76 | | | | |
| OD-Avg HS-IA | NT dog 2 | with vest | 38.92 | 0.67 | Not significant | 0.0005 | Significant |
| OD-Avg HS-IA | NT dog 2 | without vest | 38.93 | | | | |
| PSD- OD-HS-IA | Retired PSD | with vest | 39.22 | 0.11 | Not Significant | 0.14 | Not significant |
| PSD- OD-HS-IA | Retired PSD | without vest | 38.98 | | | | |
| PSD- OD-HS-IA | Working PSD | with vest | 39.44 | 0.0005 | Significant | 0.00005 | Significant |
| PSD- OD-HS-IA | Working PSD | without vest | 38.96 | | | | |

Table: 3.15: Summary of results of all experiments to evaluate core body temperature in different conditions

All the experimental results show that the ANOVA p-value is not significant, meaning that the ballistic vest has no impact on the canine's core body temperature. There is no significant statistical difference on the canine core body temperature with and without a ballistic vest except PSD-OD-HS-IA (working PSD), as already explained in sec 3.1.2.1. Due to the work excitement, the resting core temperature of the PSD was very high while tracking and while wearing a ballistic vest compared to no vest. As a result, the initial core temperature shows a significant difference in the p value by the ANOVA test.

After analyzing the p-value of slope difference, most cases found that the difference is insignificant. Only a few conditions, ID-AC-RA- Dog 1, OD-Avg HS-RA-Dog 1, OD-Avg HSIA- Dog 2, and PSD- OD- HS-IA- working PSD, showed a significant difference in slopes. In all of these cases, we found that the slope of core temperature without a vest was higher than with a vest. For these conditions, the temperature rise was higher during the experiment without vest condition than in the vest on condition.

### 3.3.2 Skin temperature

The summary data of experiments to evaluate the impact of ballistic vest on canine's skin temperature are shown in table 3.16.

| ID | Dog Profile | Condition | Avg core temperature °C | P-value (ANOVA) | Result | P-value (slope difference) | Result |
|---|---|---|---|---|---|---|---|
| ID-AC-RA | NT dog 1 | with vest | 35.78 | 0.23 | Not significant | <0.05 | Significant |
| ID-AC-RA | NT dog 1 | without vest | 34.18 | | | | |
| ID-AC-RA | NT dog 2 | with vest | 33.79 | 0.76 | Not significant | 0.03 | Significant |
| ID-AC-RA | NT dog 2 | without vest | 33.98 | | | | |
| OD-Avg HS-RA | NT dog 1 | with vest | 34.5 | 0.80 | Not significant | 0.46 | Not significant |
| OD-Avg HS-RA | NT dog 1 | without vest | 34.86 | | | | |
| OD-Avg HS-RA | NT dog 2 | with vest | 36.7 | 0.25 | Not significant | 0.86 | Not significant |
| OD-Avg HS-RA | NT dog 2 | without vest | 36.1 | | | | |
| OD-Hot HS-LA | NT dog 1 | with vest | 35.9 | 0.61 | Not significant | 0.003 | Significant |
| OD-Hot HS-LA | NT dog 1 | without vest | 36.86 | | | | |
| OD-Avg HS-IA | NT dog 1 | with vest | 32.25 | 0.03 | Significant | 0.002 | Significant |
| OD-Avg HS-IA | NT dog 1 | without vest | 36.63 | | | | |
| OD-Avg HS-IA | NT dog 2 | with vest | 33.75 | 0.13 | Not significant | 0.08 | Not significant |
| OD-Avg HS-IA | NT dog 2 | without vest | 36.25 | | | | |
| PSD- OD-HS-IA | Retired PSD | with vest | 37.38 | 0.02 | Significant | 0.32 | Not significant |
| PSD- OD-HS-IA | Retired PSD | without vest | 41.13 | | | | |
| PSD- OD-HS-IA | Working PSD | with vest | 36 | 0.05 | Significant | 0.0002 | Significant |
| PSD- OD-HS-IA | Working PSD | without vest | 37.13 | | | | |

Table: 3.16: Summary results of all experiments to evaluate skin temperature in different conditions

Through ANOVA analysis, p value for ID: PSD- OD- HS-IA, retired PSD and working PSD, and OD-Avg-HS-IA shows a significance, reflecting that on a sunny day, a ballistic vest can protect the dog from direct heat and keep their skin temperature lower compared with uncovered skin.   All the other experimental results show that the p-value is insignificant, meaning the ballistic vest has no impact on the canine skin temperature. There is no significant statistical difference on the canine's skin temperature with and without a ballistic vest for those conditions.

After analyzing the p-value of slope difference, some cases found that the difference is insignificant. However, some conditions like ID-AC-RA- Dog 1-Dog 2, OD-Hot HS-LA-Dog 1, OD-Avg HS-IA- Dog 1, and PSD- OD- HS-IA- working PSD showed a significant difference in slopes. Condition ID-AC-RA dog 1, dog 2, OD-Avg HS-IA-dog 1 showed the slope of core temperature without a vest was higher than with a vest. For these conditions, the temperature rise was higher during the experiment without vest condition than in the vest condition. However, conditions OD-Hot-LA-dog 1 and PSD-OD-HS-IA working PSD showed the slope of core temperature with a vest was higher than without a vest, contrary to the other conditions' results. In the case of PSD-OD-HS-IA working PSD, we found the skin temperature measuring thermometer was loose after the experiment. This could affect data.

# Chapter: 4

## Conclusion and future work

Police and military K9s are precious assets to their respective forces as they can perform many versatile tasks that a human cannot do. K9s can detect narcotics, explosive devices, and weapons, track fugitives, missing persons, and dead bodies. They often encounter dangerous situations which can be life threatening. A supreme quality ballistic vest can be the only solution for the preventable death of police and military dogs due to gunshots and gunfire during a deadly mission. However, police and military handlers are concerned about the heat stress that can be triggered while wearing a ballistic vest.

The current study investigated the impact of a ballistic vest on a canine's core body and skin temperature. The impact of a ballistic vest on both core body temperature and skin temperature are investigated, and the results are summarized in Tables 3.15 (Core body temperature) and 3.16 (Skin temperature).

The results of the experiments investigating the impact on core body temperature indicate that there is no significant impact of ballistic vests on the canine's core body temperature in any condition, except that shown is PSD- OD- HS-IA where the work excitement affected the canine's core body temperature. The results of experimented conditions do not indicate any significant risk of getting heat stroke after wearing a ballistic vest.

In addition, the investigation shows that there is no significant impact of the ballistic vest on skin temperature for six out of nine experimental conditions. Three experimental conditions showed a significant impact on skin temperature with a vest versus without a vest. The canine's skin temperature was lower after wearing a ballistic vest compared with no vest in three conditions (PSD- OD- HS-IA, retired PSD and working PSD, and OD-Avg-HS-IA). All these conditions were on a hot, humid, sunny day, which indicates that a custom fit K9 Storm Ballistic Vest protected the K9's skin or fur from direct sun heat and kept the dog cooler.

There was no significant difference in the result of experiments with non-trained (NT) dogs and Police Service Dogs (PSD) for both core and skin temperature. However, following the experiments, the post exercise recovery time for PSDs was much quicker (10-15 minutes) compared with NT dogs (30-45 minutes). This could be the impact of professional training and regular exercises. For the PSD, there was a quick rise in core temperature immediately after putting on a vest due to the work excitement, while the NT dog core temperature was indifferent even after wearing a ballistic vest. The 15 min tracking exercise (protocol is stated in sec 3.1.4) appeared to be intensive for the NT dog, while it was very elementary for a PSD.

Suggested future work is to collect more experimental data from working dogs to validate the temperature increase due to work excitement. Moreover, the current study did not cover the temperature recovery trend of canines with a ballistic vest and without a ballistic vest. This post-exercise recovery time after wearing a ballistic vest and without a vest can be investigated in future work. The impact of increasing temperature on heart rate and the risk of heart attack related with heat stroke could also be investigated.

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