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Surveillance of heat-related illness in small animals presenting to veterinary practices in the UK between 2013 and 2018

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Abstract

Background: Heat-related illness (HRI) can affect all companion animals and is likely to become more common as global temperatures rise. The misconception that HRI is primarily a result of dogs being trapped in hot cars, highlights a lack of awareness of HRI risk factors within the UK companion animal population.

Aim: This project aimed to review all species of small animal presentations of HRI to UK veterinary practices participating in the Small Animal Veterinary Surveillance Network (SAVSNET), describe the inciting triggers and seasonality of HRI events, and review the clinical grade of canine patients presenting with HRI.

Methods: Electronic consultation records were submitted by volunteer veterinary practices across the UK to SAVSNET. Cases were defined as animals presented for consultation with strong evidence of current, or recent heat induced illness during the study period (2013–2018).

Results: The HRI cases included 146 dogs, 16 cats, 8 guinea pigs, 3 rabbits and 1 ferret. Of the 118 HRI cases with a recorded trigger, exercise was the primary trigger for dogs presenting (73.5%); 7 (6.9%) canine HRI events followed vehicular confinement. Environmental HRI was recorded as a trigger for the remaining dogs (19.6%), and for all cats, guinea pigs, rabbits and the ferret. Brachycephalic breeds comprised 21.2% of canine HRI cases, and all rabbits were brachycephalic breeds. Dogs with HRI were presented between April and October, with 42.5% during July, typically the UK's hottest month of the year. Cats with HRI were presented between May and September, with 75.0% during June and July. The smaller companion species—ferrets, rabbits and guinea pigs—were presented during the UK's summer months June to August.

Conclusion: This study highlights the risk of HRI to all pet animals during the UK's warmer summer months (June to August). The findings support previous claims that exercise is the most common trigger of HRI in dogs, while environmental HRI (a hot ambient temperature) accounted for all HRI events in cats, rabbits, guinea pigs, and ferrets. Both brachycephalic dogs and rabbits were overrepresented, adding further evidence that owners of these animals should be particularly vigilant for HRI during hot weather.

Keywords: Canine heatstroke, Feline heatstroke, Heat-related illness, Heatstroke, SAVSNET.

Introduction

Hyperthermia describes a body temperature elevated above the accepted normal reference range (*Miller, 2015*). Temperature elevation can be part of the body's acute-phase response to infection and inflammation, termed fever or pyrexia, brought about by pyrogens from damaged tissues triggering a raised thermoregulatory set point in the anterior hypothalamus (*Ramsey and Tasker, 2017*). In contrast, hyperthermia is not associated with changes to the thermoregulatory set point, so as body temperature rises both behavioural and physiological cooling mechanisms are initiated to try to dissipate excess heat (*Ramsey and Tasker, 2017*). Hyperthermia can occur in response to medications and toxins or due to underlying metabolic disorders such as hyperthyroidism, but most frequently arises from exposure to an elevated environmental temperature or following exercise in hot, humid environments (*Miller, 2015*; *Ramsey and Tasker, 2017*). The term heat-related illness (HRI) describes the clinical condition that results from failure of thermoregulatory mechanisms in response to environmental or exercise induced hyperthermia (*Yamamoto et al., 2018*).

All companion animals can be affected by HRI which is predicted to become more common (*Shih et al., 2019*) as global temperatures continue to rise (*World Heath Organization, 2019*). Traditionally HRI is more commonly encountered in tropical and hot climates (*Drobatz and Macintire, 1996*; *Bruchim et al., 2006*). However, increasingly frequent heat wave events and warmer weather outside the typical summer period—such as the mini heat wave of February 2019 in the United Kingdom (*Met Office, 2019*)—can pose a particular threat in temperate climates, when animals are exposed to hot conditions or exercised in warmer weather having had no heat acclimation opportunity.

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There are two main etiologies for HRI (traditionally termed "heat stroke") defined by the source of the excess body heat; exogenous heat from exposure to high environmental temperatures (environmental HRI) or endogenous heat production resulting from strenuous exercise (exertional HRI) (*Bouchama and Knochel, 2002*). In human medicine, the two aetiologies affect different demographics of the population with environmental HRI most commonly affecting the very young or elderly (*Lewis, 2007*; *Duzinski et al., 2014*) and environmental HRI typically affecting young male athletes or those working in physically demanding industries (*Armstrong et al., 2007*; *Gauer and Meyers, 2019*). This information informs public health warnings aimed at reducing the incidence of HRI during hot weather, allowing targeted educational campaigns to be delivered to the different demographics with more effective messaging (*Lowe et al., 2011*). Companion animals can also experience environmental HRI and exertional HRI (*Drobatz and Macintire, 1996*; *Bruchim et al., 2006*; *Hall et al., 2020a*), with vehicular HRI identified as a subtype of environmental HRI that frequently affects dogs left in hot cars.

In the UK, the predominant public educational message warning of the dangers of hot weather for companion animals is the "Dogs Die in Hot Cars" campaign (*Duggal, 2018*; *Carter et al., 2020*), reminding dog owners of the potentially fatal consequences associated with entrapment in a hot vehicle—vehicular HRI. This has resulted in a misconception amongst some dog owners that their pet can only develop HRI following vehicular confinement, meaning they fail to recognise the potential danger of exercising their dog in hot weather (Hall *et al.*, 2020a). However, recent evidence suggests that vehicular HRI is one of the least common triggers of HRI in UK dogs (Hall *et al.*, 2020a). Exertional HRI occurs when an animal's body temperature exceeds thermoregulatory limits during or following exercise, and either exceeds the critical temperature threshold of 45°C, or remains above 43°C for sufficient duration to cause multi-organ damage (*Shapiro et al., 1973*). Exertional HRI accounted for around three quarters of the dogs presenting to UK primary-care veterinary practices for HRI treatment, while environmental HRI accounted for around 13% of events (Hall *et al.*, 2020a). The same study reported canine HRI following grooming, during hospitalisation at veterinary practices, following entrapment in a hot building, and due to blanket entrapment.

The public misconception that HRI is triggered primarily as a result of dogs being trapped in hot cars, highlights a lack of awareness of HRI risk within the UK companion animal population. Hall *et al.* (2020a) suggest that some HRI events may go unrecognised due to a lack of awareness of the wider risk factors and potential triggers of canine HRI, meaning the true incidence may be much higher. These findings highlight the need for better public awareness of HRI risk to all animals, as climate change will increase the likelihood of all forms of HRI in humans and animals.

Rabbit owners are also warned of the threat of HRI to rabbits housed in outdoor runs during summer months (*RAWF, 2015*). Advice suggests hutches are moved into the shade and rabbits are provided with constant access to fresh water. Rabbits should be checked more frequently in hot weather to ensure animals can be cooled as soon as possible should HRI develop (*RAWF, 2017*). The literature relating to HRI in rabbits is mostly limited to experimental models, but young male rabbits have reportedly been found dead due to acute "heat stroke" in Spain during the spring and summer months (*Espinosa et al., 2020*). Rabbits are known to be susceptible to HRI due to having limited functional sweat glands and limited ability to disperse excess body temperature (*Elnagar, 2010*). Cats and ferrets are known to be at risk of HRI due to accidental entrapment in clothes driers (*Harris, 2015*) but could potentially be at risk from environmental HRI if restricted to a hot enclosure or trapped in a hot environment.

The Small Animal Veterinary Surveillance Network (SAVSNET) provides the opportunity to review individual consultation records for companion animals presenting to UK veterinary practices. The SAVSNET database has been used to explore a range of diseases in companion animals including the seasonality and geographical distribution of blowfly myiasis in pet rabbits (*Turner et al., 2018*), and to determine the etiological agent responsible for a national outbreak of acute gastrointestinal disease in UK dogs during 2020 (*Radford et al., 2021*). The SAVSNET database is, therefore, an ideal tool to investigate HRI in companion animals presenting to UK veterinary practices.

This project aimed to review small animal presentations of HRI to UK veterinary practices participating in the SAVSNET program, describe the inciting triggers and seasonality of HRI events for all companion animal species, and review the clinical grade of canine patients presenting with HRI.

Materials and Methods

Data extraction and inclusion criteria

Electronic consultation records were submitted by volunteer veterinary practices across the UK to SAVSNET. A full description of the data collection protocol has been described elsewhere (Sánchez-Vizcaíno *et al.*, 2017). Following owner consent to participate in the project, participating practices submitted data collected from each booked consultation. Data were collected at the end of the consultation, including consultation date, information about the animal (species, breed, sex, neuter status, age, owner's postcode), and free text clinical narratives which are anonymized to remove most personal identifiers prior to use in research (such as names of the animal or owner).

Cases were defined as animals presented for consultation with strong evidence of current, or recent (within two calendar months of presentation) heat induced illness during the study period (January 1, 2013 to December 31, 2018), in order to explore the seasonality and triggers for HRI. As HRI is not a definitive diagnosis that can be confirmed through objective diagnostic testing, the definition needed to be broad enough to include diagnosis based on the animal's recent history and the veterinary practitioner's clinical conclusions (Hall *et al.*, 2020b). The final HRI case definition included any animal with a final diagnosis of heat-related disease (including terms such as heat stroke, heat exhaustion or overheating) as recorded by the veterinary practitioner, and/or a history of clinical signs typical of HRI (see below) developing specifically after exposure to a hot environment, physical activity or both. Exclusion criteria included HRI or a synonym being listed only as one of a differential list rather than the primary diagnosis.

Clinical signs typical of HRI (*Bruchim et al., 2017a*; *Hall et al., 2021*);

- panting excessively or continuously despite removal from heat/cessation of exercise
- collapse not subsequently attributed to another cause (e.g., heart failure, Addison's)
- stiffness, lethargy or reluctance to move
- gastrointestinal disturbance including hypersalivation, vomiting or diarrhea
- neurological dysfunction including ataxia, seizures, obtunded status, coma or death
- hematological disturbances including petechiae or purpura.

Anonymized clinical narratives were filtered to identify consultations referencing HRI using regular expressions to detect HRI terms and their synonyms: heat stroke, heatstroke, heat-stroke, heat exhaustion, heat stress, hyperthermia, overheated. When applied to the full SAVSNET database, the search strategy identified 296 potential HRI consultations. These data were manually checked by two authors (EH and AC), identifying 175 consultations (59.1% of those extracted) that satisfied the case definition. One animal was identified with two consultations dated 2 weeks apart relating to the same HRI event; the clinical narrative confirmed the later date was a follow up appointment thus only the first consultation was retained. The final dataset therefore consisted of 174 companion animals presenting with HRI (Fig. 1).

Animal data

For each animal included in the study, the unique consultation number was used to extract the rest of the animal's information. This included: partial postcode of the owner, species, breed, sex, neuter status, date of consultation, and date of birth. The study population included dogs, cats, rabbits, guinea pigs and ferrets. Age was calculated as the difference in years between the date of consultation and the animal's date of birth. Where no date of birth was recorded the age was categorized as "unrecorded." Dogs, cats and rabbits were categorized into breed types including both named purebred and designer crossbreeds (known crossbreds with contrived names, e.g., Cockapoo, Labradoodle), "crossbred" or "unrecorded" if no breed was entered. Breed terms were also used to categorize cats, dogs and rabbits by skull shape into three groups "brachycephalic" (including all brachycephalic purebreds as defined by Hall *et al.* (2020b), "not brachycephalic" (including all non-brachycephalic purebreds) and "unknown" (all unknown crossbreds and unrecorded breeds). Animals were further classified by sex (male or female) and neuter status (entire or neutered).

Seasonality

The seasonality of HRI was evaluated by calendar month for all animals; the date of consultation was used to determine the month of the HRI event. Where animals were presented more than 24 hours after the onset of clinical signs, or for a follow up appointment the month of the event was estimated using the clinical narrative (e.g., check following heat stroke last month), or if this was not possible, categorized as "unrecorded."

HRI event data

A manual review of the clinical narrative data was undertaken to identify the inciting event leading to a HRI presentation. Where no information was recorded regarding the events leading up to the HRI presentation, the cause was recorded as "unknown." If the narrative recorded a history of physical activity (including any form of physical exertion from walking, to running or play) prior to the onset of clinical signs the cause was recorded as "exertional." Any narrative recording a history of being in a hot environment was recorded as "environmental," and the category "vehicular" recorded for any events following confinement in a vehicle or caravan.

The clinical narrative data were manually reviewed to extract the approximate delay between inciting event and presentation to the veterinary clinician for the consultation. Animals presenting as an emergency or with minimal delay after the onset of clinical signs were categorized as "same day." Those presenting between 12 and 24 hours after the onset of clinical signs were categorized as "next day." Those presenting more than 24 hours after the onset of clinical signs were categorized as "over 24 hours." Where an animal was presented for a follow up appointment to check progress after a previous HRI event this was categorized as a "follow up."

For animals presented on the same day as the HRI event, where a presenting temperature measurement was recorded, this was manually extracted and where necessary converted to °C. If no temperature was recorded this was categorized as "not recorded." Temperatures were not extracted for animals presented 24 hours or later or presenting for a "follow up"

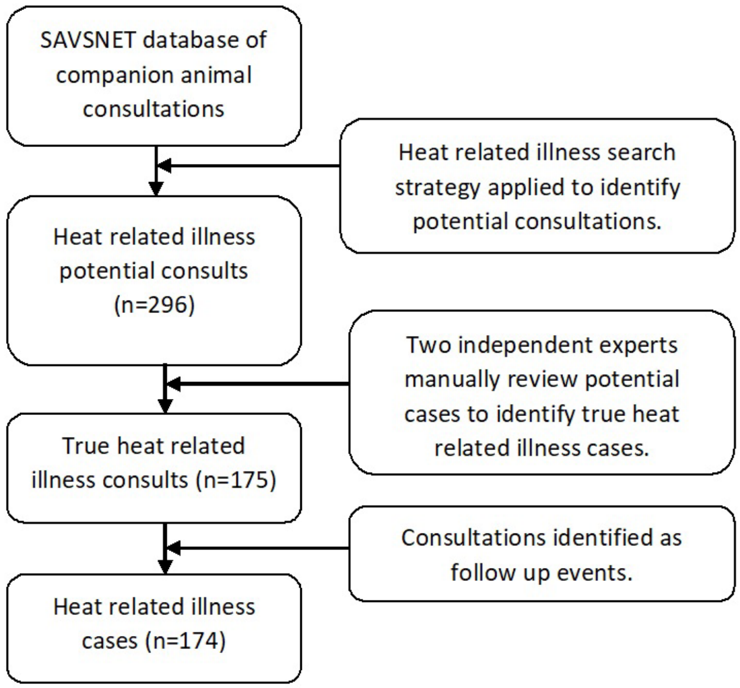

Fig. 1. Process for extraction of heat related illness consultations from the SAVSNET database.\

appointment, as this study focused on the initial presentation.

Clinical grade

The clinical signs reported to be present at the time of the HRI event were manually extracted from the clinical narrative. Where animals presented for a follow up appointment, if the narrative included historical signs from the event these were included, but not clinical signs present at the time of the follow up appointment. The presenting clinical signs were used to retrospectively apply the VetCompass Clinical Grading Tool for HRI in dogs (*Hall et al., 2021*), in order to grade the severity of HRI present in the canine patients in the study population.

Statistical analysis

Data were extracted and cleaned using Microsoft Excel (Office 365). Descriptive statistics were used to characterize key demographic variables of the animals presenting with HRI, inciting cause of HRI events, and presenting clinical signs. The SAVSNET database collects data from individual booked consultations, but not individual animal patient records. Thus, the dataset generated cannot be used to estimate incidence, as it is likely other HRI events occurred, but were not included in the dataset. As the SAVSNET demographic data includes animals on the basis of presenting for a booked consultation during the 5-year study period, there is no way of confirming which animals died within that period, and animal age is calculated using the median age if an animal presented for multiple consultations. For this reason, multivariable risk analysis was not attempted. Canine and feline HRI case distributions were compared to both the 5 year SAVSNET demographic and open access datasets from the VetCompass programme (*Royal Veterinary College, 2019*), as the VetCompass datasets represent the same population of companion animals (animals presented to a UK veterinary practice during the same time period), but include animals not presented for a booked consultation (e.g., healthy animals that have not needed veterinary treatment) so provide a reasonable estimate of population level demographics for the two species.

For canine patients, the percentage of HRI cases from the most frequent breed types and age categories were compared with the demographic data from 3,359,620 dogs recorded in the SAVSNET database between 2013 and 2018, and 905,543 dogs presenting to primary-care veterinary practices during 2016 using VetCompass data from Hall *et al.* (2020b). For feline patients, the percentage HRI cases from each age category were compared with the demographic data from 1,349,621 cats recorded in the SAVSNET database between 2013 and 2018, and 285,547 cats presenting to primary-care veterinary practices during 2013 using VetCompass data from O'Neill *et al.* (2020). The Chi-squared test was used to compare the percentage of HRI cases in each category with the percentage of the total VetCompass population in each category using Epi Info 7 (*Dean et al., 2014*). Statistical significance was set at $p < 0.05$.

Table 1. Age distribution of dogs presenting with HRI to veterinary practices participating in SAVSNET from 2013 to 2018, compared to the ages of dogs from the overall SAVSNET population demographic and dogs under primary-veterinary care in 2016 from the VetCompass programme.

Age	Number of HRI cases (*n* = 146)	Percentage of all HRI cases (%)	Percentage of SAVSNET demographic (%)	Percentage of VetCompass demographic (%)
<2 years	29	19.86	23.85	25.89
2–<4 years	28	19.18	14.33	19.68
4–<6 years	35	23.97	13.40*	15.46*
6–<8 years	19	13.01	13.19	12.52
8–<10 years	10	6.85	12.74*	10.05
10–<12 years	11	7.53	11.14	7.32
≥12 years	11	7.53	11.35	7.71
Unrecorded	3	2.05		1.37

Significant difference between HRI case population and SAVSNET or VetCompass demographic population indicated by * $p < 0.05$.

Ethical approval

Ethical approval for the SAVSNET project was awarded by University of Liverpool's independent Research Ethics Committee. This specific project was approved by the Nottingham Trent University School of Animal, Rural and Environmental Sciences Ethical Review Group (ref ARE635).

Results

A total of 174 HRI cases were identified within the SAVSNET database from primary-care veterinary consultations conducted between 2013 and 2018. The HRI cases included 146 dogs, 16 cats, 8 guinea pigs, 3 rabbits, and 1 ferret.

Case demographic

The canine patients included 75 females (43 neutered) and 71 males (39 neutered) and were aged 0.2–18.8 years old (median = 4.7 years, interquartile range (IQR) = 2.5–7.6 years). The distribution of ages is shown in Table 1, with dogs aged 4–<6 years old overrepresented compared to the overall distribution of ages within the wider UK dog population (dogs presenting to primary-care veterinary practices in 2016 from the VetCompass programme).

The 146 canine HRI patients included 111 purebred dogs from 44 different breed types, 30 crossbreed dogs, 4 designer crossbreed dogs and 1 dog with no breed recorded in the electronic consult record. The 12 breed types with the highest number of cases are presented in Table 2. The Springer Spaniel, Cavalier King Charles Spaniel, French Bulldog, English Bull Terrier, Weimaraner and British Bulldog were overrepresented compared to the VetCompass demographic population from 2016. There were 31/164 (21.2%) canine HRI cases with a brachycephalic skull shape, 84 (57.5%) with a non-brachycephalic skull shape.

The 16 feline patients with HRI included 11 females (2 entire) and 5 males (1 entire). There were 10 domestic short haired cats, 3 domestic long hair, 1 Bengal, 1 crossbreed and 1 with cat with no breed recorded. The feline HRI cases were aged 0.4–19 years old (median = 10.4 years, IQR = 4.6–14.2 years). The distribution of ages is shown in Table 3, cats aged over 15 years old were overrepresented compared to the overall distribution of ages within the wider UK cat population (cats presenting to primary-care veterinary practices in 2013 from the VetCompass programme).

The guinea pig patients were aged 1–6 years old (median = 1.5 years) and included five females and three males. The rabbits were aged 0.6–4.2 years old, included one female and two males, and were all brachycephalic breeds (two lionheads and one miniature lop). The ferret was a 9-year-old neutered male.

HRI triggers

The clinical narrative did not include details of the inciting event or trigger of the HRI event for 56/174 (32.2%) cases; 44/146 (30.1%) of dogs, 10/16 (62.5%) of cats, 1/8 (12.5%) of guinea pigs, 1/3 (33.3%) of rabbits. Of the remaining 118 HRI cases with a recorded trigger, exertional HRI was the primary trigger for dogs with 75/104 (73.5%) events triggered by exercise, whilst 7 (6.9%) followed canine confinement in a hot vehicle. Environmental HRI was recorded as a trigger for the remaining 20/104 (19.6%) dogs, and for all cats ($n = 6$), guinea pigs ($n = 7$), rabbits ($n = 2$) and the ferret ($n = 1$).

HRI seasonality

Dogs with HRI were presented between April and October, with 62/146 (42.5%) presented during July, typically the UK's hottest month. Cats with HRI were presented between May and September, with 12/16 (75.0%) presented during June and July (six presented each month). The smaller companion species—ferrets, rabbits and guinea pigs—were presented during the UK's summer months June to August (Fig. 2).

Table 2. The frequency of dog breed types presenting with HRI to veterinary practices participating in SAVSNET from 2013 to 2018, compared to the breed type percentage in dogs from the overall SAVSNET population demographic and dogs under primary-veterinary care in 2016 from the VetCompass programme.

Breed Type	Number of HRI cases (n = 146)	Percentage of all HRI cases (%)	Percentage of SAVSNET demographic (%)	Percentage of VetCompass demographic (%)
Crossbreed	30	20.55	16.21	21.42
Springer Spaniel	11	7.53	1.12	2.23*
Cavalier King Charles Spaniel	8	5.48	2.43*	1.91*
Cocker Spaniel	8	5.48	5.75	3.55
French Bulldog	7	4.79	1.27*	1.81*
Labrador Retriever	7	4.79	9.98*	6.62
Staffordshire Bull Terrier	7	4.79	3.6	5.86
Border Collie	4	2.74	3.41	2.47
English Bull Terrier	4	2.74	0.31*	0.07*
Jack Russell Terrier	4	2.74	5.44	5.35
Boxer	3	2.05	1.25	1.04
Weimaraner	3	2.05	0.34*	0.27*
British Bulldog	2	1.37	0.82	0.36*

Significant difference between HRI case population and SAVSNET or VetCompass demographic population indicated by * $p < 0.05$.

Table 3. Age distribution of cats presenting with HRI to veterinary practices participating in SAVSNET from 2013 to 2018, compared to the ages of cats from the overall SAVSNET population demographic and cats under primary-veterinary care in 2013 from the VetCompass programme.

Age	Number of HRI cases (n = 16)	Percentage of all HRI cases (%)	Percentage of SAVSNET demographic (%)	Percentage of VetCompass demographic (%)
<3 years	3	18.75	27.35	37.00
3–<6 years	2	12.5	16.5	20.97
6–<9 years	2	12.5	15.14	13.37
9–<12 years	2	12.5	13.95	9.48
12–<15 years	3	18.75	12.69	7.91
≥15 years	4	25.00	14.37	7.82*

Significant difference between HRI case population and SAVSNET or VetCompass demographic population indicated by * $p < 0.05$.

For the canine HRI events, exertional HRI occurred from April to October, environmental HRI occurred from April to September, and vehicular HRI occurred from June to September (Fig. 3).

Clinical presentation

The HRI events included 78 consultations performed on the same day as the event, 37 consultations on the next day after the event, and 30 consultations over 24 hours after the event. There were an additional 29 events recorded as repeat or follow up consultations following previous treatment for HRI. Eight electronic consultation records reported an outcome of death (three guinea pigs and five dogs), of which five were euthanased (two guinea pigs and three dogs).

No presenting clinical signs were recorded in the clinical narrative of 16/174 HRI consultations, 14 of which were follow up appointments. The remaining 158 HRI consultations had at least one clinical sign recorded. The most frequently recorded clinical signs were abnormal breathing (n = 76, 48.1%), lethargy (n = 66, 41.8%) and collapse (n = 50, 31.6%), with other clinical signs reported in Table 4.

Of the animals presented on the day of the event, 57/78 (73.1%) had a rectal temperature recorded. Reported

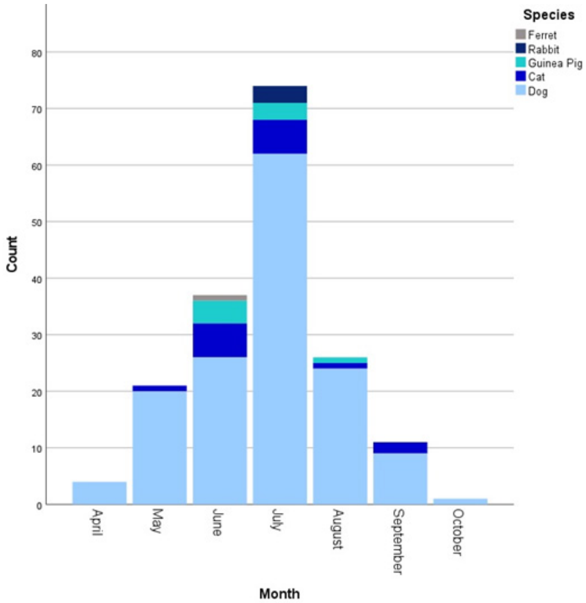

Fig. 2. Number of heat related illness (HRI) consultations recorded for companion animals presenting to primary-care veterinary practices participating in SAVSNET in the UK from 2013-2018 by species.

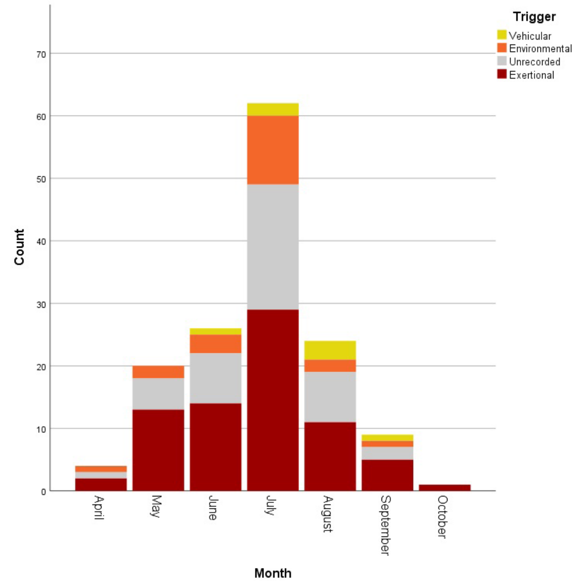

Fig. 3. Histogram of canine HRI cases presented to UK veterinary practices in the SAVSNET database from 2013 to 2018 by trigger.

canine rectal temperatures ranged from 35.7°C to >43.0°C (mean 39.6°C, SD 1.5°C). Using the normal reference range of 37.2°C–39.2°C (*Konietschke et al., 2014*), 2/52 (3.8%) were hypothermic on presentation and 28/52 (53.8%) dogs were hyperthermic, of which eight dogs had temperatures ≥41°C and two ≥43°C.

Canine clinical HRI grade

The VetCompass Clinical Grading Tool for HRI in Dogs was retrospectively applied to the canine HRI cases from the SAVSNET database presenting on the same day as the HRI event. Overall, 43/134 (32.1%) of the classified HRI events were graded mild, 72/134 (53.7%) were graded moderate, and 19/134 (14.2%) were graded severe. Of the five canine HRI cases with a fatal outcome recorded, four were graded as severe HRI. One dog was euthanased with only moderate clinical signs recorded, but was presented several days after the HRI event and was aged 18.8 years old.

Discussion

This is the first study to report surveillance of HRI in all companion mammal species presenting to UK veterinary practices. Dogs accounted for 83.9% of the HRI cases in the SAVSNET database from 2013 to 2018, followed by cats (9.2%), guinea pigs (4.6%), rabbits (1.7%) and one ferret. In line with a previous study reporting the incidence and seasonality of HRI in UK dogs from 2016 (Hall *et al.*, 2020b), the month with the highest number of HRI events was July (42.5% of all events).

Reflecting the findings of Hall *et al.* (2020a), exertional HRI was the most common trigger of HRI in dogs accounting for 73.5% of events, followed by environmental HRI (19.6% of events), then vehicular HRI (6.9% of events). Exertional HRI occurred between April and October, whilst environmental occurred between April and September and vehicular HRI from June to September. Only environmental HRI triggers were reported for all other species, although 62.5% of cats had no reported trigger, likely reflecting the free roaming indoor-outdoor lifestyle typical of the majority of UK cats (Foreman-Worsley *et al.*, 2021). Cats frequently seek warm areas to sleep and can become trapped in greenhouses and sheds in warm weather which could account for some of the unknown HRI triggers; there are also rare reports of exertional HRI in cats following hunting in hot environments (*Waddell and Boller, 2013*). Cats were presented with HRI from May to September, whilst the smaller mammals were only presented during the UK's summer months June to August. More guinea pigs than rabbits were present in this study, despite the UK rabbit population estimated at twice the UK guinea pig population (*PFMA, 2021*). Guinea pigs are known to be highly susceptible to heat stress and ambient temperatures over 28°C can be fatal; HRI is thought to be one of the most common causes of "sudden death" in outdoor housed pet guinea pigs (*Fawcett, 2011*). Caged pets such as rabbits, guinea pigs and ferrets are at risk of environmental HRI due to entrapment, if their housing provides limited access to shade or cooler temperatures.

Although HRI is typically categorized by trigger (environmental versus exertional HRI) in the wider literature and in this study, it should be noted that this practice oversimplifies the true etiology of this complex condition. For example, two animals exposed to the

Table 4. Frequency of reported presenting clinical signs for companion animals presenting to veterinary practices with HRI from 2013 to 2018.

Presenting clinical sign	Cat *n* = 14	Dog *n* = 134	Ferret *n* = 1	Guinea pig *n* = 7	Rabbit *n* = 2	Total
Abnormal breathing	6	72		2	1	80
Lethargy	10	55	1			66
Collapsed		46		2	2	50
Vomit	3	33				36
Diarrhoea	1	16				17
Hypersalivation	1	13				14
Ataxia	1	11				12
A single seizure		7		1		8
Obtunded mentation		4		4		8
Haemorrhagic diarrhoea	1	5				6
Multiple seizures		2				2
Petechiae/purpura		2				2

same ambient temperatures may respond differently depending on their individual physiology and underlying health. If one animal is obese, brachycephalic, elderly, or has an underlying heart or respiratory disease, they will likely have impaired thermoregulatory capacity compared to a young, mesocephalic, fit and healthy animal, and will therefore be at greater risk of developing HRI despite being exposed to the same environmental conditions. Likewise, most of the dogs presented to veterinary practices with exertional HRI in a previous study had participated in relatively low-intensity activity, namely walking (Hall *et al.*, 2020a). It is therefore likely that the combined effect of the physical activity alongside the ambient temperature generates the excess body heat that ultimately results in HRI developing, rather than just the effect of the exercise. Ultimately, HRI most commonly results from human action or inaction; animals develop HRI following exposure to a hot environment or exercise with or without a hot environment (Hall *et al.*, 2020a). Humans typically control their companion animal's environment, and with the possible exception of cats, also typically control their animal's activity levels. The continued practice of defining HRI by the trigger can therefore help to improve the public's understanding of the different underlying etiologies that can lead to HRI, a crucial step in promoting strategies to prevent HRI or mitigate HRI risk during heat wave events and increasingly hot summer periods.

The present study found that dogs aged 4–<6 years old were overrepresented compared to both the overall SAVSNET canine demographic and the 2016 canine demographic presenting to primary-care veterinary practices from the VetCompass programme, and dogs aged 8–<10 years old were underrepresented compared to overall SAVSNET canine demographic. This finding differs slightly to the findings of a study reporting the incidence and risk factors for canine HRI in UK dogs during 2016, which reported that dogs aged over 12 years had the greatest odds of HRI (Hall *et al.*, 2020b). However, the same authors reported that younger dogs (under 8 years old) were more likely to develop exertional HRI (Hall *et al.*, 2020a), and used a much larger HRI study population. This could reflect the differences in the two demographics; as 5 years of patient presentations are included in the SAVSNET demographic including only animals booked for a consultation, this demographic is likely to have a higher percentage of elderly animals compared to the single year cohort from the VetCompass database which includes healthy animals that required no veterinary treatment.

Cats aged over 15 years old comprised 25% of the HRI cases, and the majority of events did not indicate the inciting trigger. Cats are not commonly exercised by their owners, and as previously mentioned, the majority of UK cats enjoy a free roaming indoor/outdoor lifestyle meaning they have greater control over their environment than most pet dogs and typically have more control over their activity levels. It is possible that older cats are at greater risk of HRI due to age related changes to thermoregulation (*Balmain et al., 2018*), and increased prevalence of underlying cardiac, respiratory and renal disorders (O'Neill *et al.*, 2015) which could impair thermoregulation through mechanisms such as respiratory function and increased likelihood of dehydration.

Several dog breeds have previously been identified as having greater odds of HRI within the UK dog population: the Chow Chow, British Bulldog, French Bulldog, Dogue de Bordeaux, Greyhound, Cavalier King Charles Spaniel, Pug, English Springer Spaniel, and Golden Retriever (Hall *et al.*, 2020b). In the present study, the Springer Spaniel, Cavalier King Charles Spaniel, French Bulldog and British Bulldog were found to be overrepresented in the HRI case population, alongside the English Bull Terrier and the Weimaraner when compared to the VetCompass demographic. When compared to the SAVSNET demographic the British Bulldog was not significantly overrepresented, and the Labrador retriever was significantly underrepresented. With only 146 canine HRI events in the present study, limited confidence can be placed in the significance of these findings, especially for the less common breed types such as the British Bulldog, Weimaraner and English Bull Terrier. It must be remembered that only animals with booked consultations are included in the SAVSNET demographic meaning emergency presentations that present without a prior booking may not contribute to the dataset. It is also probable that for emergency presentations, such as HRI, triage of the presenting patient would be prioritised over entering a detailed consultation history into the database, therefore the true number of HRI events is likely to be higher than reported here.

Brachycephalic dogs are known to be at increased risk of HRI (*Drobatz and Macintire, 1996*; *Bruchim et al., 2006*; *Hall et al., 2020b*). The popularity of brachycephalic dogs has risen dramatically in the UK over the past decade, with the French Bulldog overtaking the Labrador Retriever to become the most commonly registered UK Kennel Club breed during 2018 (*The Kennel Club, 2018*). A previous study reported that brachycephalic dogs comprised 6.1% of a population of 104,233 UK dogs under veterinary care during 2013 (O'Neill *et al.*, 2017). A later study reported that the popularity of brachycephalic dogs had increased to account for 18.4% of a population of 905,543 dogs under primary veterinary care during 2016 (Hall *et al.*, 2020b). In the present study, 21.2% of the dogs presenting with HRI between 2013 and 2018 had a brachycephalic skull shape, suggesting that brachycephalic breeds were overrepresented in the HRI case population. This is in line with previous reports from both primary-care (Hall *et al.*, 2020b) and referral hospital populations (*Drobatz and Macintire, 1996*; *Bruchim et al., 2006, 2017b*).

Only brachycephalic rabbit breeds were present in the SAVSNET HRI case population, highlighting the need for further research into the potential health implications of brachycephalism in other companion animal species.

Mirroring the findings of a previous UK canine HRI study (*Hall et al., 2021*), abnormal breathing and lethargy were the most frequently reported clinical signs from HRI cases for all species. All of the guinea pigs, and all but one of the dogs that died as a result of HRI presented with neurological dysfunction (ataxia, seizures, obtunded status, or coma), reflecting previous findings that neurological damage is associated with more severe HRI (*Bruchim et al., 2009*) and increased risk of death (*Hall et al., 2021*). None of the cats presented had collapse or obtunded mentation recorded in their clinical notes, and none of the electronic consultation records reported death as an outcome (however this could have occurred after the consultation). If the cats developed HRI outside, away from the home, they would have had to recover sufficiently to return home in order to be presented, thus some cats that are lost or found dead could potentially be severe HRI cases if their condition was too severe to recover from.

The canine patients were retrospectively graded using the recently proposed VetCompass Clinical Grading Tool (*Hall et al., 2021*). The distribution of cases by clinical HRI grade closely reflects those reported by Hall *et al.* (2021), with more moderate HRI cases than mild, and around 14% severe HRI cases. All bar one of the cases with a fatal outcome reported were graded severe, lending further support to the use of this clinical grading tool for assisting the recognition and management of HRI in dogs.

Limitations

As previously noted, the SAVSNET database only gathers data from individual consultations rather than all consultations in an animal's electronic consultation record. The data used in this study only relate to single consultation events, meaning any follow up consultations (such as euthanasia or worsening of clinical signs) or preceding consultations were not used in the analysis unless also found by the search term used. It is therefore not possible to report HRI fatality rates from this study, nor is it prudent to attempt incidence estimation. It is also not possible to conduct a comprehensive retrospective cohort risk analysis, due to the lack of a complete demographic population. Only animals with a recorded consultation are included in the SAVSNET database, and as their full clinical record is not accessible, date of death cannot be determined in order to establish which animals were still alive in subsequent years.

This study is also limited to animals presenting for a booked veterinary consultation. Some owners may elect to manage a mild HRI case at home and only phone for advice, these cases would by definition not be included in such databases. Likewise, owners of small animals may find a deceased animal and simply bury the pet at home, meaning there would be no record of the animal's death and no diagnosis made. As previously noted, any cats developing severe HRI away from the home, may collapse and be unable to return meaning unless they are found by someone and presented to a veterinary practice, their deaths would also go unrecorded and undiagnosed. Additionally, owners may not wish to disclose the true cause of their pet's condition, particularly if the animal was left to die in a hot environment such as a car, due to feelings of guilt or fear of repercussions over failure to protect the animal's welfare (Hall *et al.*, 2020b). There is also the potential for animals to be exposed to further environmental heat stress during car journeys to the veterinary practice for treatment, meaning the contribution of vehicular confinement to HRI morbidity may be greater than it appears. It is therefore likely that the number of HRI events reported in this study does not reflect the true scale of HRI in the UK's companion animal population, and the true proportion of HRI events triggered by vehicular confinement may be higher. As previously noted, the lack of a definitive test for HRI and reliance upon clinician reported diagnosis or presumptive diagnosis for case identification could have resulted in misidentification for some animals (Hall *et al.*, 2020b).

The study is also limited by the issues and potential sources of bias inherently associated with using primary-care electronic patient record data, namely a lack of data completeness, potential for reporting bias from the veterinary professional entering the data, potential for incomplete information stemming from owner willingness or ability to disclose details relating to the events, and access to only those veterinary clinics actively participating in such research databases (*Sánchez-Vizcaíno et al., 2017*; *Hall et al., 2020a*). Therefore, the findings of this study can suggest associations, but require further exploration to determine true causation. Additionally, data relating to animal bodyweight, overweight status, coat type and coat colour were not accessible using the SAVSNET database, further studies are needed to explore the relative contribution of these factors to HRI risk.

Conclusion

This descriptive study included the UK's most popular companion mammal pets, highlighting the risk of HRI to all pet animals during the warmer summer months of June to August in the studied population. The findings support previous claims that exercise is the most common trigger of HRI in dogs, accounting for almost three quarters of all cases, while environmental HRI (a hot ambient temperature) accounted for all HRI events in cats, rabbits, guinea pigs and ferrets. Both brachycephalic dogs and rabbits appear to be overrepresented in the HRI case population, highlighting the importance of HRI awareness and prevention education for owners of these flat-faced animals, and adding further weight to the argument that breeders should consider health before aesthetics in all companion animal species.

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Conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

EJH was responsible for the conception and design of the study, EJH, AJC, and ADR were responsible for acquisition and extraction of the data. EJH carried out the analysis and drafted the manuscript. EJH, AJC, and ADR were involved in interpreting the results, revising the manuscript, and gave final approval of the version to be published. EJH, AJC, and ADR agree to be accountable for all aspects of the accuracy or integrity of the work.

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