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ORIGINAL RESEARCH

Epidemiology of heat-related illness in dogs under UK emergency veterinary care in 2022

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Abstract

Background: Dogs are exposed to increasing environmental risk for developing heat-related illness (HRI), with 2022 recorded as the hottest year to date in the UK and most of Europe.

Methods: This study used VetCompass data to report the incidence risk, event fatality rate and canine risk factors for HRI in dogs presenting to Vets Now emergency care practices in the UK during 2022.

Results: From the clinical records of 167,751 dogs under care at Vets Now emergency clinics in 2022, 384 HRI events were identified. The 2022 incidence risk of HRI within the Vets Now caseload was 0.23% (95% confidence interval [CI]: 0.21%–0.25%), with an event fatality rate of 26.56% (95% CI: 21.66%–32.25%). Multivariable analysis identified breed, age and sex/neuter status as risk factors for HRI. Brachycephalic dogs had 4.21 times the odds of HRI compared to mesocephalic dogs (95% CI: 3.22–5.49, $p < 0.001$).

Limitations: The clinical data used in this study were not primarily recorded for research and had some substantial levels of missing data (especially patient bodyweight).

Conclusion: In order to protect canine welfare, improved long-term mitigation strategies are urgently needed to minimise HRI risk and associated fatality in UK dogs.

KEYWORDS
canine heat-related illness, canine heatstroke, climate action

INTRODUCTION

Heat-related illness (HRI) is an often preventable and potentially fatal condition that occurs when the core body temperature increases to the point at which the animal can no longer effectively thermoregulate unassisted back to a safe body temperature.[1] The resulting hyperthermia can lead to systemic inflammation, organ dysfunction and eventually death if not treated urgently and effectively.[1] At the time, 2022 was the hottest year on record in the UK, with the first recorded UK ambient temperature above 40.0°C.[2] The number of human heat-related deaths hits their highest recorded level in England in 2022,[3] while more than 70,000 excess deaths were reported in Europe.[4] The numbers and severity of both canine and human HRI cases are likely to increase even further over the coming years because of ongoing rising global temperatures[5,6] unless effective mitigation strategies are employed to protect both human and animal lives and welfare.

Previously, canine HRI studies have presented case series from referral populations focusing on more severe, hospitalised cases.[7–8] HRI is now recognised as a progressive condition,[1] and more recent studies have taken this into account, including studies of dogs with less severe stages of HRI in their risk factor analysis.[9,10] Previous VetCompass research on HRI reported an estimated annual incidence risk of 0.04%, with an event fatality rate of 14.18%, in dogs under primary veterinary care in the UK in 2016.[9] The significant risk factors for HRI identified in various

studies include breed, heavier bodyweight relative to the breed/sex mean and being over 2 years old.[7,9,10,11] Brachycephalic breeds and dogs over 50 kg were also at increased risk. Research within VetCompass Australia identified similar HRI risk factors and highlighted increased case numbers during heatwave years across a 20-year period (1997–2017).[10] Multiple studies have identified exertion as the most common trigger of HRI in dogs[7,11–14] and have found that brachycephalic breeds are at particularly high risk.[7,9,10,12,13]

Ownership of brachycephalic breeds has increased over the past decade in the UK, with nearly 35% of dogs aged under 1 year and 20% of the overall canine population categorised as brachycephalic in 2019.[15] During the COVID-19 pandemic, 2.5 million dogs were acquired in the UK,[16] with 'pandemic puppy' owners more likely to be first-time dog owners,[17] who consequently may have less experience and awareness of HRI and its potential triggering events. As HRI in dogs should be considered an emergency condition,[18] veterinary data from an emergency care provider could provide a rich source of clinical information and also offer proportionally higher numbers of severe HRI cases compared to primary care veterinary data. Therefore, the present study aimed to investigate the incidence risk, demographic risk factors, initial trigger events and event fatality rate of canine HRI in a novel resource of dogs presenting to emergency care veterinary practices during 2022.

The objectives of the current study were to interrogate the VetCompass database to (1) estimate the annual incidence risk of HRI in dogs under the care of an emergency care provider (Vets Now) in the UK; (2) estimate the event fatality rate for HRI in dogs under emergency veterinary care in the UK; and (3) identify HRI risk factors in dogs under emergency veterinary care in the UK. The results could assist veterinary surgeons, welfare scientists and dog owners with a stronger evidence base to support improved prevention and management of canine HRI and could contribute to a greater understanding of how climate impacts the health of all living species.

METHODS

The study used data from the VetCompass research database of de-identified electronic patient records (EPRs) from veterinary practices in the UK.[19] The study population included all dogs under Vets Now emergency veterinary care from 1 December 2021 to 1 December 2022 (this 12-month period is hereafter referred to as '2022'). Dogs under veterinary care were defined as those with at least one EPR during this period within the Vets Now dataset. Vets Now is a national network of out-of-hours companion animal emergency clinics that provide veterinary cover when member primary care practices are closed.[20] Data fields available for each dog included a unique animal identifier with breed, sex, neuter status and date of birth, alongside clinical information from free-form text clinical notes, bodyweight, treatments and deceased status with relevant dates.

The study used a cohort design with a cross-sectional analysis. The study design was aligned with previous VetCompass HRI research[9] and used the same HRI case definition and inclusion and exclusion criteria (Figure 1). An incident case was defined as an HRI event that first presented to Vets Now during 2022. Candidate cases for HRI were identified by searching the full EPR of all study dogs using the following terms: heatst*; heat exhaust*; overheat*; hri; high ambient temp*; heat stress*; collaps* + heat; heat intoleran*; cooling + heat; 'heat stroke'; cool + heat; cool*. The EPRs of all candidate dogs detected were randomly ordered and manually reviewed by a veterinary surgeon (S.B.) to identify all confirmed HRI cases that met the study case definition. For HRI classifications with uncertainty, the EPRs were reviewed by a second veterinary surgeon (E.H. or J.B.), and inclusion/exclusion was discussed until agreement was reached. For two dogs with more than one incident HRI event during the study period, only the earliest event was included in the analysis.

All dogs not confirmed as incident HRI cases were included as non-cases in the risk factor analysis. Additional data were manually extracted for all confirmed cases, including date presenting to Vets Now with HRI, date of exposure to HRI trigger, type(s) of trigger event, event outcome (hospitalised, discharged to owner, transferred to member practice, died), date of death (if applicable) and method of death (unassisted, euthanasia, dead on arrival) (Table 1). All triggers recorded in the EPR as contributing to the HRI event were extracted, resulting in multiple triggers recorded for some dogs. The frequency of cases attributed to each trigger category (Table 1) was summarised, with the multifactorial trigger contributions illustrated using a non-proportional Euler diagram. All cases where the EPR included clinical signs were retrospectively graded using the VetCompass Clinical Grading Tool for Heat-Related Illness in Dogs[9] based on the information recorded in the EPR. Further information regarding the categorisation of HRI risk factors is shown in Table 1.

Ambient conditions

Five periods, all between June and August 2022, met the criteria defined by the UK Health Security Agency (UKHSA) as UK heat periods in 2022 that is, day(s) on which a level 3 heat health alert is issued and/or day(s) when the mean central England temperature is greater than 20°C.[23] The Office for National Statistics (ONS) added 1 day before and after the formal UKHSA periods to more fully capture clinical impacts from the initial increase in temperatures and any lag on effects from high temperatures[23] to calculate human excess mortality. The current study used the ONS dates as per the above definition.

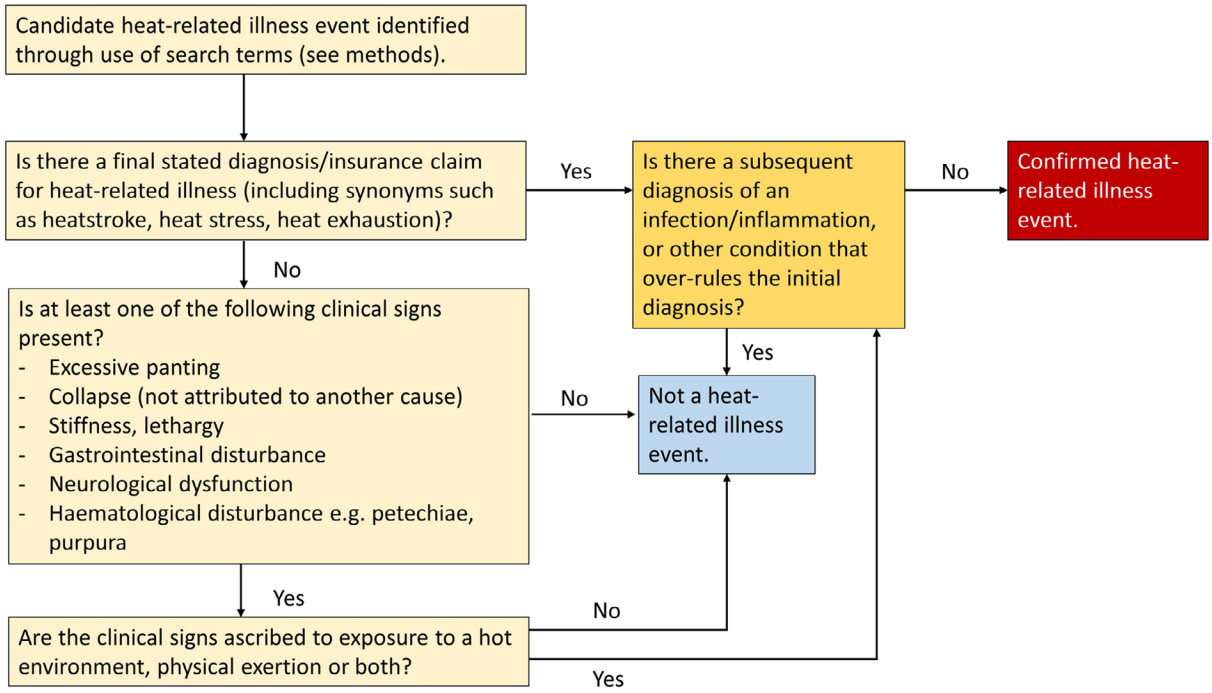

FIGURE 1 Flow chart illustrating the application of the heat-related illness case inclusion and exclusion criteria applied to candidate heat-related illness cases identified in the VetCompass database

TABLE 1 Description and categorisation of canine demographic and environmental risk factors assessed for association with UK dogs affected by heat-related illness (HRI) under Vets Now emergency veterinary care during 2022

HRI risk factor	Definition
Breed type	Categorical variable including all named breed types (including both Kennel Club recognised purebred and non-Kennel Club recognised purebred) and designer hybrid types with contrived names (e.g., Cockapoo, Labradoodle, Lurcher) with ≥3 HRI cases and/or ≥1000 dogs in the overall study population. All remaining dogs were assigned to grouped categories of 'other purebred', 'other designer crossbreed' or 'non-designer crossbred'.
Age category	The age at the first HRI event for 2022 incident HRI cases or the age at the end of the study period (30 November 2022) for non-case dogs. Age (years) was categorised into eight groups (<2, 2 to <4, 4 to <6, 6 to <8, 8 to <10, 10 to <12, >12) with 'unrecorded' for any dogs with no date of birth recorded in the electronic patient record.
Sex/neuter status	Dogs were classified by sex and neuter status into five categories: female entire, female neutered, male entire, male neutered, with 'unrecorded' used to group dogs without recorded sex or neuter status.
Bodyweight	Bodyweight was extracted where available. Where no bodyweight was available, dogs aged over 18 months with a recorded breed type had an imputed bodyweight based on mean bodyweight for that breed and sex. Dogs under 18 months and/or crossbreeds with no recorded bodyweight were classified as unrecorded. Bodyweight (kg) was categorised into seven groups (<10, 10 to <20, 20 to <30, 30 to <40, 40 to <50, >50).
Skull shape	Purebred dogs were categorised by skull shape into three groups, 'brachycephalic', 'mesocephalic' and 'dolichocephalic'.[21] Designer crossbred dogs including a breed with a known skull shape were classified as 'brachycephalic cross', 'mesocephalic cross' or 'dolichocephalic cross' and all other dogs listed as crossbred or unrecorded breed were classified as 'skull shape unrecorded'.
Trigger events[22]	Included all HRI triggers recorded in the clinical notes. Six HRI triggers were included: • Exertion—all types of physical activity, regardless of ambient temperature. • Hot environment—the dog was reported to be indoors or outdoors in the heat. • Under care—the dog was in a veterinary clinic or with a professional groomer. • Hot vehicle—confined in a vehicle, including both stationary vehicle left unattended or travelling in a vehicle.[22] • Seizure—the dog presented following or during a seizure that was believed to be the trigger of the hyperthermia. Where no possible trigger was recorded in the electronic patient record the case was assigned to the 'unrecorded' category.

Statistical analysis

The data were exported from the VetCompass database into Microsoft Excel for cleaning. Sample size calculation using Epitools (AusVet 2019) estimated that a study population of 156,032 dogs was needed to detect a 2.1 odds ratio for HRI between brachycephalic and mesocephalic dogs, assuming 0.04% HRI incidence risk[15] and that 20% of dogs were brachycephalic,[15] with a power of 0.80 and a 95% confidence level.

The 1-year incidence risk was calculated as the proportion of all dogs that were HRI cases within the 12-month study period. The event fatality rate was

calculated as the proportion of incident HRI cases in 2022 that died with the death ascribed to HRI. The 95% confidence intervals were calculated using EpiTools (AusVet 2019).

The risk factor analysis used multivariable logistic regression modelling conducted in SPSS v29 (IMB Inc.). Model specification used information theory[24] based on previously reported risk factors associated with HRI—breed type, sex/neuter status and age—with an alternative model using skull shape and bodyweight to replace breed type.[9,10] A chi-squared test was used to compare HRI event fatality rates during and outside the UK heat periods. Statistical significance was set at a *p*-value of less than 0.05.

Labrador Retrievers were chosen as the comparator breed because the odds of HRI did not differ significantly between Labrador Retrievers and crossbred dogs, as per previous studies,[9] and the use of the Labrador Retriever as the comparator avoided the high levels of variability in skull shape, bodyweight and conformation inherent in crossbreeds. As the most common pure breed in the study, the Labrador Retriever also enabled high statistical power.

RESULTS

From a study population of 167,751 dogs under care at 60 Vets Now clinics in the UK during 2022, EPR searches identified 1090 candidate cases from which 384 HRI incident events were confirmed. The annual incidence risk for HRI in the UK emergency care dog population was 0.23% (95% confidence interval [CI]: 0.21%–0.25%). The data completeness varied across the variables, with breed recorded in the EPRs of 90.45%, sex/neuter status recorded in 85.00%, age recorded in 90.45% and bodyweight recorded in 8.28%. The completeness of bodyweight information increased to 62.35% after including imputed bodyweights (see Table 1).

In 364 of the 384 cases (94.79%), at least one clinical sign was recorded to support grading using the VetCompass clinical grading tool for HRI in dogs.[25] Among those retrospectively graded, 114 cases (31.32%) were graded mild, 113 cases (31.04%) were graded moderate and 137 cases (37.64%) were graded severe.

Overall, 309 of the 384 HRI cases (80.47%) occurred during June–August 2022, 229 of which (59.64% of all 384 cases; 74.11% of the 309 cases during during June–August) occurred during the five heat periods of 2022, as defined above[23] (Table 2). This equates to 5.73 HRI cases per day during the five heat periods, and 1.56 HRI cases per day during the non-heat periods. An unprecedented heatwave from 16 to 19 July 2022[26] accounted for 18.49% (71/384) of the total HRI events presented to Vets Now during that year. There were no HRI events recorded in December 2021, February 2022 or November 2022 (Figure 2).

Fatality and event outcome

Overall, 102 of the 384 confirmed HRI cases died while hospitalised at Vets Now or presented dead on arrival, giving an event fatality rate of 26.56% (95% CI: 21.66%–32.25%) (Table 2) in 2022 for dogs diagnosed with HRI under emergency veterinary care in the UK. Of these deaths, 64 of 102 (62.75%) were euthanased, 28 (27.45%) died unassisted at the practice and 10 (9.8%) were dead on arrival. Of the 282 surviving dogs, 188 (66.67%) were hospitalised, 81 (28.72%) received consult room care, 11 (3.90%) left the practice against veterinary advice and two (0.71%) were telemedicine consults managed at home. During the five UK heat periods, 54 of 229 cases died (23.58% fatality rate, 52.94% of total fatalities), while 48 of 155 cases (30.97% fatality rate, 47.06% of total fatalities) died outside of these UK heat periods (Table 2). The HRI event fatality rate did not differ significantly between cases that presented during the UK heat periods and those that presented from June to August outside of these periods ($\chi_{(2)} = 0.41$, $p = 0.520$).

HRI trigger event(s)

At least one HRI trigger was recorded in the EPR of 274 cases (71.35%), with 26 of 274 cases (9.49%) showing multiple recorded triggers (Figure 3). Among the HRI cases with at least one recorded trigger, exertion was recorded in 141 cases (51.46%), a hot environment in 85 cases (31.02%) (hot outdoors in 62 cases [22.63%], hot indoors in 23 cases [8.29%]), a hot vehicle in 34 cases (12.41%), a seizure in 31 cases (11.31%) and under care in 11 cases (4.01%) (at a veterinary practice in seven cases [2.55%] and at a grooming parlour in four cases [1.46%]).

Risk factor analysis

The final breed-focused multivariable model identified seven breeds (Chow Chow, English Bulldog, French Bulldog, Newfoundland, Pomeranian, Pug and Staffordshire Bull Terrier) with significantly higher odds of HRI compared to Labrador Retrievers (Table 3). Crossbreeds did not show significantly different odds of HRI compared to Labrador Retrievers (odds ratio [OR] = 0.85, 95% CI: 0.50–1.46, $p = 0.560$). No breed had significantly reduced odds of HRI compared to Labrador Retrievers.

Dogs aged between 4 and less than 6 years and between 8 and less than 10 years had significantly greater odds of HRI compared to dogs under 2 years old. Male entire dogs had significantly greater odds of HRI compared to female entire dogs (OR = 1.54, 95% CI: 1.15–2.05, $p = 0.003$).

After replacing breed in the final multivariable model, as described in the methods, brachycephalic breeds had 4.21 times higher odds of HRI compared

TABLE 2 Incidence risk and event fatality rate for heat-related illness (HRI) cases presented to Vets Now emergency veterinary clinics in 2022, including during each UK heat period as defined by the UK Health Security Agency with 1 day either side to fully capture mortality as per the Office for National Statistics[23] ($n = 384$).

	HRI cases, no. (% of total cases)	HRI event fatality rate, no. of deaths (% of cases that died)	95% confidence interval for fatality rate
2022 UK heat period dates			
16–19 June	21 (5.47%)	7 (33.33%)	14.59–57.00
10–25 July	151 (39.32%)	38 (25.17%)	18.47–32.87
30 July–5 August	10 (2.60%)	1 (10.00%)	2.53–44.50
8–17 August	38 (9.90%)	7 (18.42%)	7.74–34.33
3–25 August	9 (2.34%)	1 (11.11%)	2.81–48.25
All five heat periods combined (40 days)	229 (59.64%)	54 (23.58%)	18.24–29.62
All events outside of heat periods June–August (52 days)	81 (21.09%)	22 (27.38%)	0.19–0.37
Total for whole of year	384	102 (26.56%)	22.21–31.28

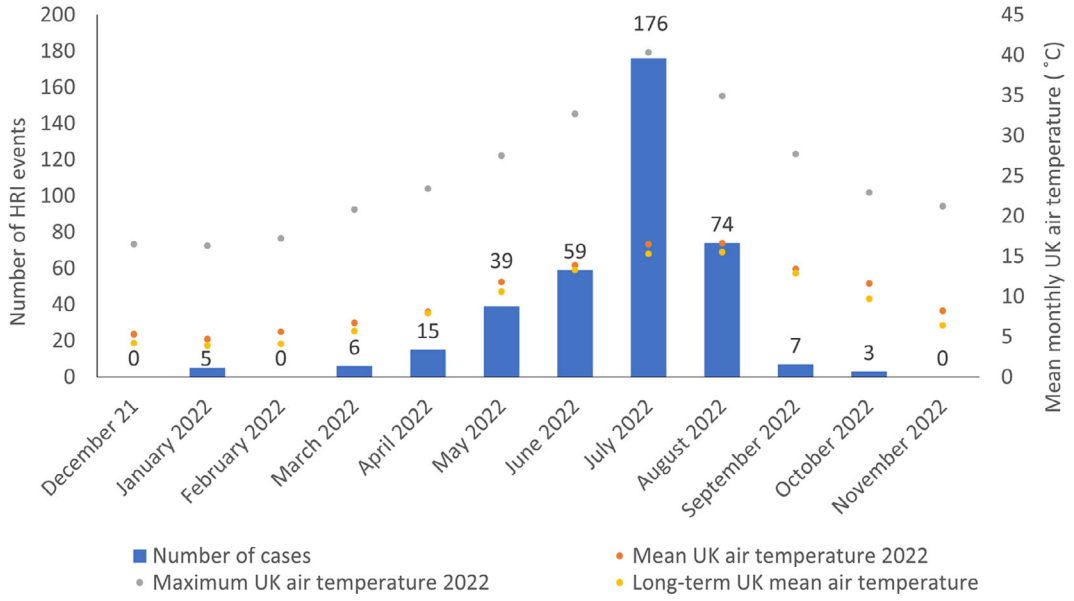

FIGURE 2 Numbers of heat-related illness (HRI) cases by month for dogs presented to Vets Now UK emergency veterinary clinics, against mean and maximum monthly air temperatures for 2022[27] and long-term UK mean (1991–2020) ($n = 384$)[28]

to mesocephalic breeds (95% CI: 3.22–5.49, $p < 0.001$). Dogs weighing between 10 and less than 20 kg, between 20 and less than 30 kg and greater than 50 kg had significantly greater odds of HRI compared to dogs weighing under 10 kg (Table 4).

DISCUSSION

This study presents the incidence risk, event fatality rate and risk factors for HRI in dogs presented to Vets Now emergency clinics across the UK during 2022, which at that point was the hottest year on record in the UK.[2] Of the 384 cases seen, 59.64% occurred during the five heat periods (spanning just 40 days), highlighting the substantial threat posed by climate change to canine health. With extreme heat events predicted to increase even further in both severity and frequency, urgent action is needed to prevent future worsening of canine suffering.

The annual incidence risk for HRI in UK dogs under emergency veterinary care in the current study was 0.23%, which is more than five times higher than the annual incidence risk of 0.04% previously reported for dogs under primary care in the UK.[9] This difference is unsurprising given that HRI is essentially an emergency condition, but this five-fold difference likely also includes contributions from the extremely high ambient temperatures during 2022,[2] as well as intrinsic differences between the caseloads included in the two studies.[29]

The HRI event fatality rate of 26.56% for the current emergency caseload was almost double the 14.18% event fatality reported previously for a primary care caseload.[9] This higher fatality likely reflects the greater severity of HRI cases under emergency veterinary care, with 35.68% of the current emergency cases graded as severe (according to the VetCompass Clinical Grading Tool for Heat-Related Illness in Dogs[25]), compared with only 13.98% of the primary care cases.[9] Many of

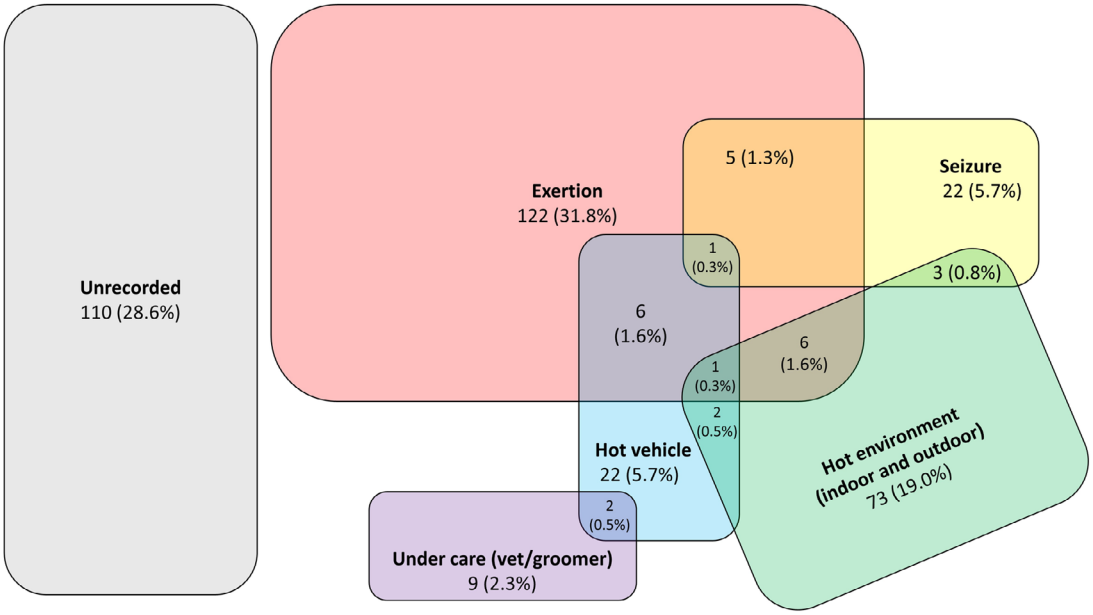

FIGURE 3 Modified Euler diagram illustrating the numbers and combinations of triggers for heat-related illness recorded in the clinical records of UK dogs under Vets Now emergency veterinary care during 2022 (% of total cases) ($n = 384$)

the mild-grade cases of canine HRI that occurred out-of-hours may have been treated at home rather than presented for emergency veterinary care to avoid the associated financial and logistical costs.[30] A primary veterinary care study in Australia reported an overall HRI event fatality rate of 23.00%, with higher rates during heatwave years.[10] Previous smaller studies from referral populations [7,11,12] reported even higher HRI fatality rates of 36%–50% but tended to include only more severe, hospitalised cases, whereas the current study included all grades of HRI presented for first-opinion emergency veterinary care. The canine HRI studies with the highest event fatality rate (50.00% or over) were based in Israel and Germany,[7,8,12,31] both of which have higher average temperatures during the summer than the UK does.

However, as the UK and global ambient temperatures continue to rise due to climate change,[2] this will put both canine and human populations under increased heat-related health pressures. Human studies have estimated the mortality of hospitalised human HRI patients to be 14%–65%.[32] The United Nations Sustainable Development Goals (SDGs) were adopted by all United Nations member states in 2015 and are an urgent call for action by all countries to work in a global partnership on 17 common goals, including climate action.[33] Gathering robust evidence on the epidemiology of HRI is crucial to support the development of climate mitigation strategies for dogs and would also contribute to the United Nations SDGs on climate action[33] to better understand human and animal HRI risk as global temperatures continue to increase.[33]

After accounting for other effects, seven breeds showed significantly higher odds of HRI compared to Labrador Retrievers. These were Newfoundland, Chow Chow, English Bulldog, French Bulldog, Pug, Pomeranian and Staffordshire Bull Terrier. These breed findings mirror previous studies reporting that extreme conformations[34] in dogs, such as brachycephaly and thick coats, increased HRI risk.[7,9,10,12] Three of the seven predisposed breeds have double coats (Chow Chow, Newfoundland and Pomeranian), aligning with an Australian study that showed that 60% of at-risk breeds had double coats.[10] Other less common double-coated breeds could be at true increased risk, but their smaller numbers may have underpowered the present study to detect these effects. While many double-coated breeds were originally bred for colder climates, there are some suggestions that double coats can also insulate from extremes of heat. A study of polar bear and koala fur suggested that mammals with highly insulating coats experience reduced heat flow from solar radiation when the wind speed is low,[35] and therefore, some double-coated dog breeds may also experience some protection from solar radiation. Uncertainty about the impact of double coats on thermoregulation in dogs has resulted in conflicting advice to dog owners about shaving double coats in efforts to protect dogs from HRI.[18] Further work is needed to provide greater certainty on this point.[10]

Overall, brachycephalic breeds had 4.21 times the odds of HRI compared with mesocephalic breeds, although no significant difference in HRI odds was detected between dolichocephalic and mesocephalic dogs. Three of the seven breeds predisposed to HRI typically show extreme brachycephaly (English Bulldog, French Bulldog and Pug).[36] Worryingly, only two breeds, the English Bulldog and French Bulldog, accounted for 36.98% of all emergency care HRI cases in the current study, supporting calls from major canine welfare stakeholders in the UK to owners to 'stop and think before buying a flat-faced dog'.[37] English Bulldog and French Bulldog comprised 16.21% of HRI cases under UK primary veterinary care practices in a previous

TABLE 3 Breed-focused multivariable logistic regression results for risk factors associated with heat-related illness in dogs under UK emergency veterinary care in 2022 ($n = 167,751$)

Independent variable	No. of cases (% of cases; $n = 384$)	No. of non-cases (% of non-cases; $n = 167,367$)	Odds ratio	95% confidence interval	p-Value
Breed type					<0.001
Labrador Retriever	20 (5.21)	12,590 (7.52)	Comparator		
Newfoundland	4 (1.04)	147 (0.09)	15.48	5.20–46.05	<0.001[a]
Chow Chow	5 (1.30)	252 (0.15)	11.46	4.25–30.88	<0.001[a]
English Bulldog	59 (15.36)	3069 (1.83)	11.09	6.63–18.54	<0.001[a]
French Bulldog	83 (21.61)	7692 (4.60)	6.03	3.67–9.90	<0.001[a]
Pug	19 (4.95)	2380 (1.42)	4.59	2.44–8.63	<0.001[a]
Pomeranian	7 (1.82)	1259 (0.75)	3.45	1.46–8.19	0.005[a]
Greyhound	5 (1.30)	1158 (0.69)	2.59	0.97–6.93	0.059
Staffordshire Bull Terrier	22 (5.73)	5429 (3.24)	2.58	1.40–4.75	0.002[a]
West Highland White Terrier	4 (1.04)	1686 (1.01)	1.63	0.55–4.81	0.377
Lhasa Apso	3 (0.78)	1231 (0.74)	1.59	0.47–5.36	0.458
American Bulldog	3 (0.78)	1199 (0.72)	1.51	0.45–5.09	0.509
Boxer	3 (0.78)	1255 (0.75)	1.49	0.44–5.01	0.523
Yorkshire Terrier	5 (1.30)	2823 (1.69)	1.14	0.43–3.04	0.797
Springer Spaniel	6 (1.56)	3391 (2.03)	1.11	0.45–2.77	0.819
Cavalier King Charles Spaniel	4 (1.04)	2326 (1.39)	1.09	0.37–3.20	0.874
Lurcher	2 (0.52)	1347 (0.80)	0.93	0.22–3.99	0.925
Border Terrier	2 (0.52)	1497 (0.89)	0.86	0.20–3.69	0.840
Crossbreed	38 (9.9)	28,288 (16.9)	0.85	0.50–1.46	0.559
Breed not recorded	25 (6.51)	15,996 (9.56)	0.79	0.43–1.44	0.439
Beagle	2 (0.52)	1669 (1.00)	0.75	0.17–3.20	0.694
Other purebred	29 (7.55)	23,985 (14.33)	0.74	0.42–1.31	0.305
Labradoodle	2 (0.52)	1920 (1.15)	0.67	0.16–2.86	0.586
Chihuahua	4 (1.04)	3703 (2.21)	0.64	0.22–1.88	0.420
Border Collie	3 (0.78)	3191 (1.91)	0.61	0.18–2.05	0.425
Cockapoo	7 (1.82)	7073 (4.23)	0.61	0.26–1.44	0.255
Whippet	1 (0.26)	1222 (0.73)	0.52	0.07–3.85	0.519
Jack Russell Terrier	4 (1.04)	5154 (3.08)	0.51	0.17–1.49	0.219
Miniature Dachshund	2 (0.52)	2206 (1.32)	0.51	0.10–2.64	0.424
Dachshund	1 (0.26)	1300 (0.78)	0.45	0.06–3.35	0.434
German Shepherd dog	2 (0.52)	2668 (1.59)	0.45	0.11–1.94	0.285
Cocker Spaniel	6 (1.56)	8633 (5.16)	0.43	0.17–1.07	0.070
Miniature Schnauzer	1 (0.26)	1746 (1.04)	0.32	0.04–2.77	0.300
Shih-tzu	1 (0.26)	3360 (2.01)	0.19	0.03–1.38	0.100
Bichon Frise	0 (0.00)	1389 (0.83)	–	–	–
Golden Retriever	0 (0.00)	2391 (1.43)	–	–	–
Other designer crossbreed	0 (0.00)	742 (0.44)	–	–	–
Age (years)					<0.001
<2	93 (24.22)	41,233 (24.64)	Comparator		
2 to <4	68 (17.71)	28,447 (17.00)	1.09	0.79–1.50	0.610
4 to <6	78 (20.31)	18,266 (10.91)	2.03	1.47–2.78	<0.001[a]
6 to <8	20 (5.21)	15,402 (9.20)	0.72	0.44–1.18	0.192
8 to <10	38 (9.90)	14,922 (8.92)	1.59	1.06–2.37	0.024[a]

(Continues)

TABLE 3 (Continued)

Independent variable	No. of cases (% of cases; *n* = 384)	No. of non-cases (% of non-cases; *n* = 167,367)	Odds ratio	95% confidence interval	*p*-Value
10 to <12	17 (4.43)	15,515 (9.27)	0.76	0.45–1.31	0.326
12+	33 (8.59)	25,245 (15.08)	0.98	0.63–1.51	0.919
Unrecorded	37 (9.64)	8337 (4.98)	2.19	1.46–3.29	<0.001[a]
Sex/neuter status					0.009
Female entire	74 (19.27)	34,448 (20.58)	Comparator		
Female neutered	67 (17.45)	36,619 (21.88)	1.14	0.81–1.62	0.454
Male entire	131 (34.11)	42,056 (25.13)	1.54	1.15–2.05	0.003[a]
Male neutered	64 (16.67)	38,949 (23.27)	1.00	0.71–1.42	0.988
Unrecorded	48 (12.50)	15,295 (9.14)	1.49	1.02–2.18	0.041[a]

[a]Categories with significantly increased odds ratios.

TABLE 4 Multivariable logistic regression results for risk factors used to replace breed in the final breed-focused model for association with heat-related illness in dogs under UK emergency veterinary care in 2022 ($n = 167,751$)

Independent variable	No. of cases (% of cases; *n* = 384)	No. of non-cases (% of non-cases; *n* = 167,367)	Odds ratio	95% confidence interval	*p*-Value
Skull shape					<0.001
Mesocephalic	103 (26.82)	68,245 (40.78)	Comparator		
Brachycephalic	187 (48.70)	28,443 (16.99)	4.21	3.22–5.49	<0.001[a]
Brachycephalic-cross	0 (0.00)	108 (0.06)	–	–	–
Dolichocephalic	20 (5.21)	15,313 (9.15)	0.93	0.57–1.51	0.766
Dolichocephalic-cross	2 (0.52)	1348 (0.81)	0.67	0.16–2.76	0.581
Mesocephalic-cross	9 (2.34)	9626 (5.75)	0.50	0.25–0.99	0.048[a]
Unidentified	63 (16.41)	44,284 (26.46)	0.54	0.35–0.83	0.005[a]
Bodyweight (kg)					<0.001
<10	61 (15.89)	32,414 (19.37)	Comparator		
10 to <20	102 (26.56)	33,626 (20.09)	1.91	1.38–2.65	<0.001[a]
20 to <30	52 (13.54)	20,932 (12.51)	2.56	1.72–3.81	<0.001[a]
30 to <40	15 (3.91)	14,648 (8.75)	0.88	0.49–1.57	0.657
40 to <50	1 (0.26)	1868 (1.12)	0.26	0.04–1.91	0.187
>50	6 (1.56)	1015 (0.61)	2.74	1.17–6.41	0.020[a]
Unrecorded	147 (38.28)	62,864 (37.56)	2.88	1.94–4.27	<0.001[a]

[a]Categories with significantly increased odds ratios.

study, suggesting greater severity and more rapid worsening of HRI in these two breeds compared to non-extreme breeds where progression to seeking veterinary care was less likely.[9] Overall, brachycephalic dogs accounted for 48.70% of the HRI cases in the present emergency care study, compared to 33.16% of cases in the primary care HRI study.[9] Emergency care practices are likely to see more severe cases across the clinical spectrum for any disorder; therefore, the higher proportion of brachycephalic cases in emergency care suggests that HRI is likely to progress faster and reach more severe grades in brachycephalic dogs than in non-brachycephalic dogs.[13] Interestingly, designer breeds that included one progenitor brachycephalic breed (brachycephalic crossbreeds) did not show an increased risk of HRI compared to mesocephalic breeds, mirroring previous findings by VetCompass.[9] This finding suggested that outcrossing between brachycephalic and non-brachycephalic breeds may aid in improving respiratory function and heat tolerance in the outcrossed progeny while still potentially meeting public desires to own brachycephalic dogs.

Exertion was the most common HRI trigger recorded in the current study, accounting for 51.46% of all cases with at least one trigger recorded. This finding aligns with previous studies[20] and underlines the importance of public awareness campaigns to practice caution when exercising dogs in hot weather.[38] Dogs in a hot environment, whether inside or outside, accounted for 31.02% of cases in the current study. This suggests that owners should consider actively cooling their dogs as a standard preventative measure against HRI during periods of high ambient temperature, particularly for dogs that are brachycephalic and/or double coated. However, the current study also

highlights the aetiopathogenetic complexity of HRI, with Figure 3 illustrating the contribution of multiple triggers to canine HRI events. Notably, exposure to a hot vehicle could potentially exacerbate HRI in a dog on route to a veterinary clinic for management of a pre-existing exertion-related HRI event. When recommending that owners should transport their dog to the clinic for HRI or any other clinical care, veterinary professionals should also advise vehicle cooling and air movement over the dog during travel wherever possible. While the number of HRI cases triggered by attendance at veterinary practices or grooming parlours was relatively small, iatrogenic HRI is something that veterinary professionals and groomers need to consider, given their legal and ethical responsibility for the welfare of dogs under their care.[39–41]

Most HRI events in the current study (80.47%, 309/384) were recorded across 92 days between June and August 2022. The summer months of June, July and August usually represent the highest monthly mean ambient temperatures in the UK[27] and likely account for the seasonal nature of HRI. Additionally, 74.11% (229/309) of cases recorded between June and August occurred during the five major UK heat periods of 2022. The ONS and the UKHSA jointly reported 3271 (6.2%) excess human deaths above the 5-year average during the five heat periods in 2022.[23] Conversely, the summer event fatality rate of canine HRI cases was not significantly different outside of the UK heat periods (27.38%) compared to within these periods (23.58%). This may be due to several factors: owners seeking veterinary attention more quickly during a heat period; veterinary surgeons recognising the signs of HRI more quickly during a heat period and therefore (1) diagnosing more mild cases of HRI than outside of the heat periods and/or (2) treating the HRI cases more quickly than outside of the heat periods; or a combination of all the above. The unprecedented heatwave between 16 and 19 July 2022 triggered the first red warning for extreme heat issued by the Met Office since the impact-based warning service was introduced in 2011 and the first level 4 alert since the heat health alert system was introduced for England in 2004, resulting in a national emergency being declared by the government.[26] The canine HRI cases recorded in the present study during this 4-day period alone accounted for 71 cases (18.59% of the entire 2022 HRI caseload). Climate change and extreme heat periods are putting canine and human populations at progressively increasing risk of HRI. Key stakeholders such as governments, dog welfare bodies and dog owners need to urgently consider and implement long-term mitigation strategies to protect both human and canine health and wellbeing.[33]

Limitations

The current study had some limitations. There is no definitive diagnostic test for HRI so the current study relied on extracting and interpreting information and diagnoses from the EPR, which may vary in quality and quantity based on factors such as workload, experience and knowledge of HRI (e.g., awareness of triggers). Previous studies have shown that the body condition score of healthy dogs is positively associated with body temperature (independent of breed),[42] and dogs weighing above the mean bodyweight for their breed/sex are at increased risk of HRI and of HRI fatality.[7,9] However, the low levels of recorded bodyweight available for the current emergency clinic dataset precluded robust analysis of bodyweight in the present study. In mitigation, the bodyweight variable used in the present study was largely comprised of imputed values based on UK breed/sex mean bodyweights, but this reduced confidence in the bodyweight results at an individual dog level.

The emergency care population of dogs in the current study differed from the primary care population for several reasons. Substantially higher financial costs for veterinary care during emergency hours may dissuade some owners from using emergency services, instead opting to wait until their primary care practice re-opens.[30,43] The need to pay more for an emergency consultation and potentially travel further to reach the emergency clinic may have introduced selection bias towards more severe and complex cases and for animals with pet insurance. Vets Now clinics tend to be located in more urban locations and close to major road networks, leaving some regions of the UK (central Wales and East Anglia) under-represented.[20] Except for the 24-hour Vets Now hospitals in Glasgow, Manchester and Newport, most other Vets Now clinics generally open overnight on weekdays, and for full-day care from midday Saturday to Monday morning on weekends as well as on bank holidays. Therefore, HRI events occurring outside of these times would more likely be presented to a primary care practice, although some severe cases may be transferred to Vets Now for overnight care.

The clinical records for 28.65% of HRI cases did not record an HRI trigger, with these limited clinical histories possibly reflecting various effects, including the urgent nature of emergency care, limited history from transferring primary care practices or reluctance by owners to admit to perceived errors. This study was conducted as a cross-sectional analysis of data extracted for 12 months and, therefore, did not aim to explore changing HRI incidence over longer periods. The overall mean central England temperature was used to define heat periods, but the actual heat periods will have varied by region.

CONCLUSION

As a largely preventable disease, the risk factors identified in the current study could help support human behaviour change to reduce both the number and severity of HRI cases in dogs in the UK. Extreme caution in relation to HRI should be employed by all

dog owners during UKHSA heat periods and known HRI triggers should be avoided during those periods to prevent HRI. As climate change leads to further increased global temperatures, the current results support growing welfare calls for the public to 'stop and think before buying a flat-faced dog'[37] and to move away from breeding or acquiring dogs with extreme conformation such as brachycephaly that are strongly predisposed to HRI.

AUTHOR CONTRIBUTIONS

Conceptualisation: Sian Beard, Emily J. Hall, Anne J. Carter, Sophie Gilbert and Dan G. O'Neill. *Methodology*: Emily J. Hall, Anne J. Carter, Jude Bradbury, Sian Beard, Sophie Gilbert and Dan G. O'Neill. *Software*: Dan G. O'Neill. *Formal analysis*: Sian Beard, Emily J. Hall and Jude Bradbury. *Investigation*: Sian Beard, Emily J. Hall, Anne J. Carter, Jude Bradbury, Sophie Gilbert and Dan G. O'Neill. *Resources*: Sophie Gilbert and Dan G. O'Neill. *Data curation*: Sian Beard, Emily J. Hall, Jude Bradbury and Dan G. O'Neill. *Writing—original draft preparation*: Sian Beard and Emily J. Hall. *Writing—review and editing*: Sian Beard, Emily J. Hall, Anne J. Carter, Jude Bradbury, Sophie Gilbert and Dan G. O'Neill. *Supervision*: Dan G. O'Neill, Emily J. Hall, Anne J. Carter and Sophie Gilbert. *Project administration*: Sian Beard, Emily J. Hall, Sophie Gilbert and Dan G. O'Neill. *Funding acquisition*: Emily J. Hall, Anne J. Carter, Sophie Gilbert and Dan G. O'Neill. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

D.G.O. is an unpaid member of the Dogs Die in Hot Cars Campaign advisory board; however, this campaign had no input or involvement in the research. S.B. and S.G. are employed by companies providing veterinary care to dogs in the UK; however, neither company had any input or involvement in this research. The remaining authors declare they have no conflicts of interest.

ETHICS STATEMENT

Ethics approval was granted by the Royal Veterinary College Ethics and Welfare Committee (reference number SR2018-1652).

DATA AVAILABILITY STATEMENT

Supporting data are available via this link: https://doi.org/10.6084/m9.figshare.24999317.

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