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Sean Farrell

sean.farrell2@durham.ac.uk

Durham University

Katharine Anderson

University of Liverpool

Peter-John Mäntylä Noble

University of Liverpool

Noura Al-Moubayed

Durham University

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Premature mortality analysis of 53,000 deceased cats and dogs exposes socioeconomic disparities

Sean Farrell[1*], **Katharine Anderson**[2,3], **Peter-John Mäntylä Noble**[3], **and Noura Al Moubayed**[1,4]

[1]Department of Computer Science, Durham University, Durham, United Kingdom
[2]Dogs Trust, London, United Kingdom
[3]Institute of Infection, Veterinary and Ecological Sciences, University of Liverpool, Liverpool, United Kingdom
[4]Evergreen Life Ltd, Manchester, United Kingdom
[*]corresponding: sean.farrell2@durham.ac.uk

ABSTRACT

Monitoring mortality rates provides essential insights into public health, revealing the hidden impacts of diseases, enabling the identification of trends, allocating resources, and guiding effective policy decisions. Here, we explore premature mortality in dogs and cats across the United Kingdom (UK); we leverage a novel methodology that examines data from 28,562 deceased dogs and 24,460 deceased cats. We utilise an automated large language model-based ICD-11 syndromic classifier and reveal the impact of behavioural conditions on premature euthanasia in dogs, particularly as the leading cause of years of lost life in ages one to six. Examining cephalic index variations, our study highlights a 36% increase in premature mortality risk among Brachycephalic dog breeds, underscoring critical animal welfare concerns compared to their Mesaticephalic counterparts. Importantly, our study establishes a significant correlation between premature mortality and socioeconomic status, highlighting the persisting inequalities within the UK's veterinary field. Lower index of multiple deprivation (IMD) scores are significantly associated with reduced premature mortality in both cats (0.52, $p<0.001$) and dogs (0.53, $p<0.001$). This research underscores the necessity of examining the socioeconomic disparities affecting animal health outcomes. By addressing these inequities, we can better safeguard the well-being of our companion animals.

1 Introduction

Monitoring mortality rates within a population is crucial for assessing overall public health and uncovering social inequalities that influence life expectancy and quality of life[1,2]. It is well established within human medicine that there exists a link between increasing life expectancy within regions of increased economic wealth[3–5]. This relationship between economic wealth and life expe-ctancy in humans raises questions about the health and longevity of companion animals in similar affluent regions. In human medicine, many methodologies exist to assess mortality, such as the 'Disability-Adjusted Life Years (DALY)'[6], 'Quality-Adjusted Life Year (QALY)'[7] and 'Healthy Adjusted Life Expectancy (HALE)' metrics, all frequently appearing within the World Health Organisation global disease burden reports[8]. Metrics can reflect the social, economic and environmental conditions individuals live and grow in and form a basis for comparing healthcare inequality and tracking global improvements. Through tracking across different regions and groups, public health officials and researchers can monitor the impact of initiatives and goals to improve standards and identify trends, gaps, and priorities for improving population health. Nevertheless, national mortality rates for companion animals are not subject to regular monitoring.

Understanding companion animal longevity could support the identification of factors causing premature death and develop systems to mitigate this. It may also reflect the impact of associated health characteristics, such as socioeconomic conditions, environmental quality, lifestyle choices, access to health care and disease prevention. The surveillance of electronic health records (EHR) collected from primary-care veterinary practices represents a valuable means to gain insights into companion animals' current population health status. Initiatives such as the Small Animal Veterinary Surveillance Network (SAVSNET) and VetCompass have played a pivotal role in establishing accessible, real-time, first-opinion clinical EHRs on a national scale in the United Kingdom (UK)[9,10]. Despite their potential, harnessing the total utility of first-opinion veterinary EHRs on a large scale is challenging. While advantageous for researchers, implementing disease coding frameworks in clinical practice is plagued with poor compliance and impractical for everyday use. Previous studies have underscored records annotated by clinicians as part of their routine responsibilities as being particularly susceptible to inaccuracies and omissions[11,12]. Adopting an unstructured, free-text format in veterinary EHRs while affording clinicians greater linguistic flexibility presents challenges in developing automated systems[13,14]. In response to these challenges, a pressing need exists to establish fixed, tabular data

points for clinical events that do not impose additional complexity on clinicians' responsibilities whilst facilitating downstream data analysis.

The study of mortality rates in companion animals is complex, primarily due to the extensive breed variation and the diverse conditions associated with each breed. A critical factor contributing to this complexity is the cephalic index, which quantifies the ratio between the width and length of an animal's cranium. Companion animal breeds are categorised into brachycephalic ('short-headed'), mesaticephalic ('middle-headed'), and dolichocephalic ('long-headed') based on this index. Brachycephalic breeds, such as Bulldogs and Pugs, have increasingly become a welfare concern[15–17]. Prior research has highlighted the numerous conditions prevalent among brachycephalic dogs, including heightened susceptibility to respiratory issues[18–21], ocular diseases[22,23], and digestive disorders[21,24]. These health challenges significantly impact their longevity, resulting in a median life expectancy of 8.6 years for brachycephalic breeds, markedly lower than the 12.7 years observed in non-brachycephalic breeds[25]. Understanding these breed-specific health issues is essential for improving welfare standards and lifespan in companion animals, illustrating the need for continued research and targeted interventions.

In this study, we present a large language model-based approach to identifying animals that have been declared deceased. We analyse a dataset comprising 28,562 deceased dogs and 24,460 deceased cats, exploring their lifetime histories from a broader dataset of approximately 143,000 dog and 93,000 cat records. Utilising PetBERT, we reveal the leading causes of lost years of life across different age groups around the International Classification of Disease 11 (ICD-11) chapter framework[26]. Furthermore, we perform a multivariate risk factor analysis to determine the features contributing to premature death. Finally, we discuss the impact of socioeconomic factors on premature mortality among pets. Through this automated record annotation and comprehensive analysis, our study aims to provide valuable insights into the factors affecting pet longevity and the potential interventions that could mitigate premature death.

2 Results

2.1 Data Extraction

The SAVSNET dataset, encompassing a decade of veterinary consultations from March 2014 to March 2024, initially comprised 9,281,287 records from first opinion practices across the UK. During the data cleaning process, records with missing values were removed. Specifically, records lacking data on age, owner postcode, sex, and breed. Consequently, the cleaned dataset retrained 9,281,287 consultations. Importantly, the focus was maintained on canine and feline consultations, with dogs comprising 6,149,649 entries and cats 2,388,605 entries. We identified consultations containing a declaration of death occurring by the attending clinician within the clinical notes using a BERT-based language model, fine-tuned as a binary sequence classification model on a dataset of 600 professionally annotated records by a practicing clinician. This dataset was split into 400 records for training and 200 records for testing. The model achieved a precision of 0.995 and a recall of 1.000 on the test set. Applying this model to the entire SAVSNET dataset, we identified animals annotated as having died by this classifier for further study. This resulted in the identification of 28,562 dogs and 24,460 cats.

2.2 Data Exploration

Among the total number of animals identified to have died, 28,562 were dogs and 24,460 were cats. For the dogs, 14,264 (50.1%) were females and 14,298 were males, with 18,036 (63.1%) being neutered. The overall mean age for dogs at time of death was 12.55 years, with a median age of 13.05 years. For the cats, 13,231 (54.1%) were females and 11,229 were males, with 19,082 (78.0%) being neutered. The overall mean age for cats was 14.44 years, with a median age of 15.22 years. To determine the approximate proportion of animals that were euthanised versus those that died of natural causes, a regular expression search term and manual readings were conducted on the final EHR narrative. For cats, euthanasia accounted for 24,365 cases (99.6%), with 50 cases (0.2%) being identified as having either arrived deceased or deaths occurring within the consultation room, and 55 cases (0.2%) classified as indeterminable. Similarly, for dogs, euthanasia accounted for 28,449 cases (99.6%), while already deceased or deaths occurring within of the consultation room were recorded in 35 cases (0.1%), and 91 cases (0.3%) were considered indeterminable.

Table 1 and Table 2 presents the bootstrapped median life expectancies for each breed found within our dataset across dogs and cats respectively. The defined premature threshold age for each breed, calculated as 0.85 times the lower confidence interval (CI) of their respective life expectancies is also present. We additionally categorise breeds based on the Cephalic index into the brachycephalic, mesaticephalic or dolichocephalic classifications. We observe in dogs the median age is highest for the mesaticephalic breeds at 12.51 years, followed by dolichocephalic at 12.46 years and the brachycephalic at 10.95 years. In cats, the inverse was observed. Brachycephalic cats had the longest median lifespan at 14.79 years, followed by mesaticephalic at 14.55 years and dolichocephalic at 14.00 years.

2.2.1 Causes of Mortality

To analyse the causes of death among animals, we leveraged ICD-11 chapter labels automatically assigned using PetBERT. A full description of how these were derived can be found elsewhere[26]. In some cases, the final 'death' record did not provide precise details regarding the cause of death. We extended our analysis to include consultations up to six months before the recorded death to address this. Any syndromic label present during this period was considered a potential indicator of the cause of death. For each ICD-11 chapter, we computed the total years of lost life (YLL) for each age group by summing the total YLL for animals within that group who died due to specific ICD-11 chapters and dividing this sum by the total YLL across the entire age group, yielding a proportion. The results of which can be observed in figure 1. The data highlights the distribution of life-limiting conditions across different life stages in cats and dogs, providing insights into age-specific mortality risks associated with various health conditions. For cats, *'Neoplasms'* emerge as a significant cause of YLL, particularly in older age groups, reaching a peak of 12% in years 11-12. *'Certain infectious or parasitic diseases'* are the leading cause of YLL from ages 0 to 5. As cats age, the impact of endocrine, nutritional, or metabolic diseases becomes more pronounced, with YLL increasing from less than 5% in ages 0-7 to 7% beyond that age range. *'Diseases of the genitourinary, digestive, and respiratory systems'* consistently manifest across all age groups, with respiratory diseases being notably high in the youngest and oldest cats. In dogs, *'Mental, behavioural or neurodevelopmental disorders'* are the predominant cause of YLL between years 1 and 2, accounting for 31%, and remain the leading cause until the age group of 6-7 years. *'Neoplasms'* become increasingly significant as dogs age, starting at 2-3% YLL in ages 0-3 and rising to 12% by ages 12-13. Respiratory conditions initially account for 11% YLL, stabilise at 7-8% during middle age, and increase again to 13% in dogs aged 12-13.

An additional examination of YLL data across various dog breed types—brachycephalic, mesaticephalic, and dolichocephalic —unveiled notable disparities in the primary causes of mortality among these groups. The findings can be found within the supplementary materials in figure 1. We continued the use of the ICD-11 classification to categorise the causes of YLL, with the results presented in two-year intervals due to the reduced sample sizes in the breed-specific analyses. For brachycephalic breeds, *'Developmental anomalies'* emerged as the most significant cause of YLL in the 0-2 age group, accounting for 14.0% of the YLL. This was notably higher than mesaticephalic and dolichocephalic breeds, which reported *'Developmental anomalies'* at 7.0%. Instead, *'Mental, behavioural, or neurodevelopmental disorders'* was the predominant cause of YLL in these latter breeds, with 20.0% for mesaticephalic and 19.0% for dolichocephalic breeds. Across all breeds, *'Neoplasms'* exhibited a marked increase in YLL proportion with age. The YLL due to 'Neoplasms' peaked at 12% for both brachycephalic and mesaticephalic breeds in the older age groups. In contrast, dolichocephalic breeds showed a significantly higher YLL proportion due to *'Neoplasms'*, reaching 17.0%. *'Diseases of the musculoskeletal system or connective tissue'* were present across all breed groups but were most prominent in dolichocephalic breeds. In the 4-6 age group, the YLL proportion was 18.0%, and it remained the highest among the breeds at 14.0% in the 10-12 age group. This compares to 10.0% for brachycephalic and mesaticephalic breeds in the same age group. *'Endocrine, nutritional, or metabolic diseases'* constituted a minor cause of YLL in brachycephalic and mesaticephalic breeds, each accounting for 3.0-4.0% of YLL. However, in dolichocephalic breeds, the YLL proportion for these diseases doubled, reaching 8.0%. *'Diseases of the respiratory system'* showed a higher average YLL proportion in brachycephalic breeds, averaging 9% across all age groups. This was compared to 7.6% in mesaticephalic breeds and 6.5% in dolichocephalic breeds, indicating a breed-specific predisposition.

2.3 Risk Factors for Premature Mortality

To reveal the risk factors associated with premature mortality in animals, we evaluated a dataset including only records of animals that had not yet reached their breed-specific premature mortality thresholds. Key demographic variables incorporated in our analysis encompassed the deprivation level of the owners' postcodes and whether they resided in rural or urban areas. Phenotypic features included sex, cephalic index and the set of ICD-11 disease codes from clinical history data, treated as binary outcomes in the analysis. We employed univariate mixed-effect logistic regression to examine associations using case-control status as a binary dependent variable. We categorised animals that died prematurely as cases and those whose deaths occurred beyond the breed-specific premature threshold age as controls. The results of the multivariable logistic regression for cats and dogs are detailed in Tables 3 and 4, respectively.

Our findings indicate a significant decrease in the risk of premature mortality as deprivation levels decrease (IMD 5: OR for dogs = 0.59, $p<0.001$; cats = 0.52, $p<0.001$) relative to the most deprived category (IMD 1). This trend was consistent across both species. Analysis of ICD-11 disease groups revealed substantial variations in risk. For instance, developmental anomalies, more common in younger animals, were associated with a 10.13-fold increase in premature mortality in cats and a 2.07-fold increase in dogs. Conditions originating in the perinatal period posed the highest risk, with a 59.89-fold increase in cats and a 22.25-fold increase in dogs. Moreover, *'Diseases of the blood and blood-forming organs'* exhibited particularly high odds ratios for premature mortality in both species (cats: 17.32; dogs: 17.32). Similarly, 'Diseases of the nervous system' had

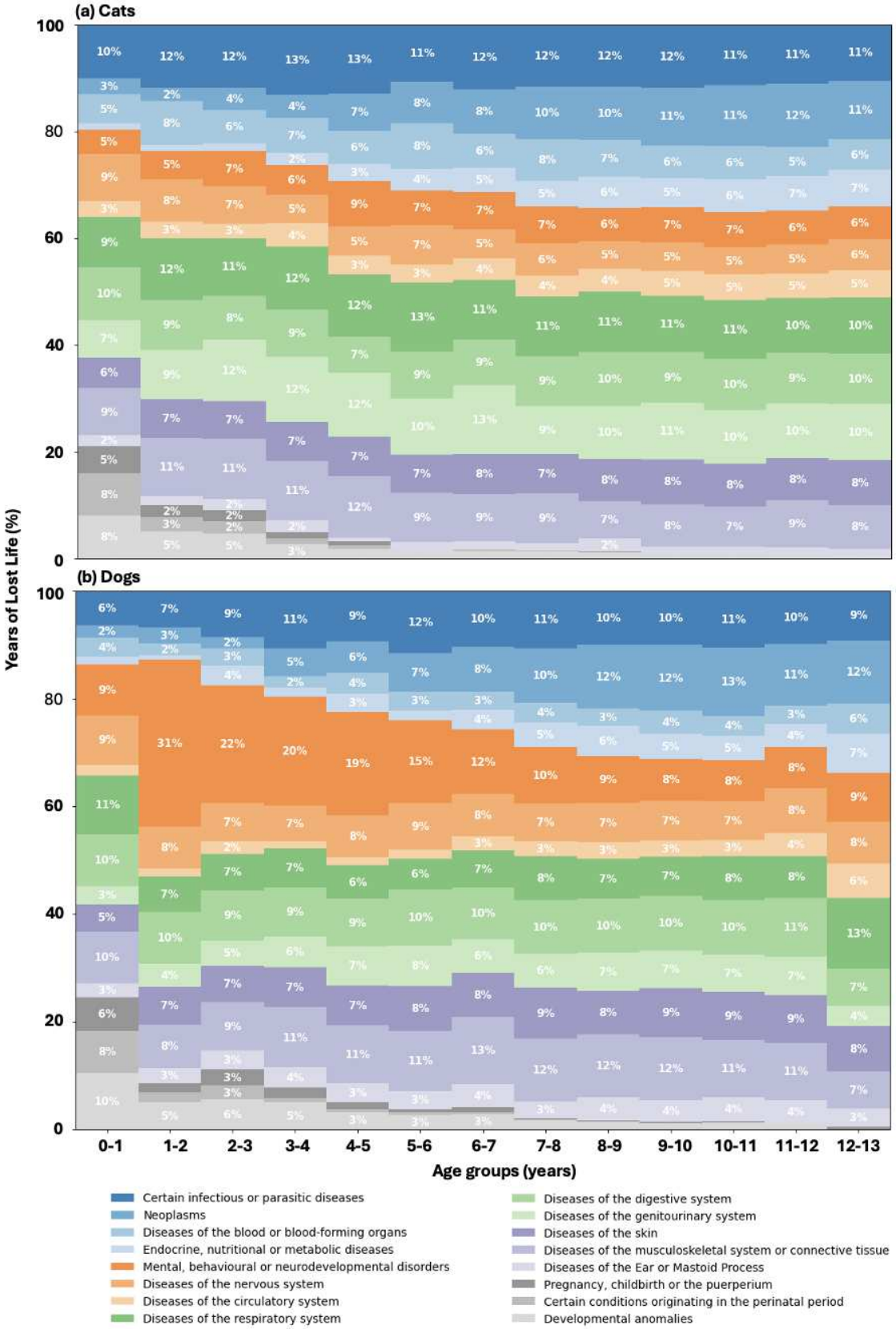


Figure 1. Proportional years of life lost (YLL) as a percentage due to assigned ICD-11 chapters at death across different age groups ranging from 0 to 13 years for (a) cats and (b) dogs

high-risk ratios (cats: 19.19; dogs: 7.02). A slight protective effect was observed for females, with odds ratios of 0.72 in cats and 0.97 in dogs. Certain conditions displayed species-specific impacts. For instance, behavioural issues, a known risk factor for euthanasia in dogs, had an odds ratio of 5.68, compared to 2.13 in cats, highlighting notable differences in the impact of behavioural factors between species.

3 Discussion

Unlike human medicine, veterinary medicine does not have a death register, leaving the frequency and cause of companion animal death poorly quantified. Previous works have aimed to use insurance data to achieve this goal[27,28]. However, such methods are inherently biased such as towards certain breeds[29], incomplete data due to limitations imposed by the insurance companies[30], or insurance claims only being made in more severe disease cases[31]. Identifying the risk factors for premature death in companion animals from first-opinion clinical narratives offers new insights into opportunities for targeted healthcare measures. There are challenges in maximising first-opinion clinical narrative's utility; for example, their free-text nature and absence of standardised disease coding systems make extracting meaningful clinical events from the narratives difficult[32].

The ethical dimensions surrounding euthanasia are multifaceted and often revolve around assessing the quality of life for the individual patient. The loss of a companion animal can profoundly impact their owners, leading to profound emotional distress[33–36]. Navigating the decision-making process related to end-of-life discussions requires a delicate balance between owners and clinicians[37–39]. Considering the various factors involved in such decisions ensures that the animal's well-being remains the top priority. A common concern among owners is the fear of prematurely ending their animals' lives and the associated guilt, or conversely, the fear of prolonging their suffering by waiting too long[34]. Similarly, some clinicians feel that broaching the topic of end-of-life discussion may be perceived as premature and subsequently cause unnecessary distress for owners[40]. This is despite a survey reporting 67% of participants reported that discussions with veterinary practitioners about the decision to euthanise were significant in managing their grief[41]. In our study, euthanasia accounted for 24,365 cases (99.6%) in cats and 28,449 cases (99.6%) in dogs. Previous research has reported euthanasia frequencies of 91.5% in the UK[42], 85.2% in the United States[43], 91.0% in New Zealand[44], and 21.8% in Taiwan[45]. Our findings, which indicate a higher euthanasia rate of 99.6%, did not consider animals expected to succumb to their condition shortly without intervention; many were euthanised in the terminal stages, including those that collapsed on the same day. Additionally, our data exclude cases where animals died outside of veterinary care or where deaths were unreported or undocumented by veterinarians.

The observed inequalities in companion animal life longevity reveal a significant correlation between socioeconomic status and premature mortality rates. Data indicates a clear trend: as the index of multiple deprivations (IMD) scores decrease, indicating less deprivation, the probability of premature mortality also decreases for both cats (0.52, $p<0.001$) and dogs (0.53, $p<0.001$). This disparity underscores the social inequalities mirrored in human health outcomes[46,47]. Several factors likely contribute to this increased mortality in deprived areas. Pets in wealthier households often have better and more frequent access to veterinary care, which includes the ability to afford advanced treatments and diagnostics[48]. Furthermore, wealthier owners are more likely to afford comprehensive health insurance for their pets, reducing the financial barrier to accessing necessary medical care. Across the SAVSNET dataset, the highest insurance rate at 40.3% is observed in the least deprived (IMD5) steadily decreasing to 29.6% in the most deprived quintile (IMD1). A previous study has looked at the link between euthanasia and financial stress and revealed owners would be willing to increase the amount spent at a given visitation if they had pet health insurance[49]. Discussions around being unable to afford available treatment and thus opting for euthanasia instead were frequently observed. Other factors, such as the increased quality of the animal's diet brought about by a more affluent household, also likely play a role[50]. These findings point to the multi-faceted nature of the issue, suggesting that addressing these inequalities requires a holistic approach. Further research is necessary to explore these dimensions and develop strategies to mitigate the impact of socioeconomic disparities on companion animal health.

Our analysis reinforces the established understanding that brachycephalic breeds generally experience poorer health outcomes compared to their non-brachycephalic counterparts[15,17]. Specifically, we found a higher number of years of life lost (YLL) due to developmental anomalies in brachycephalic breeds during the first two years of life compared to mesaticephalic and dolichocephalic breeds. This is consistent with previous studies suggesting issues related to excess soft tissue, aberrant conchal growth, and obstruction of the nasal passage[20,51,52]. Furthermore, the average lifespan of brachycephalic breeds was reduced to 10.95 years, compared to 12.51 years for mesaticephalic breeds and 12.46 years for dolichocephalic breeds, corroborating prior research indicating shorter lifespans in this category[17,53]. Respiratory disease also contributed to a higher average YLL proportion in brachycephalic breeds, averaging 9% across all age groups, this can be described through the impacts of Brachycephalic Obstructive Airway Syndrome (BOAS) and pneumonia[19,20]. However, certain conditions, such as *'Neoplasms'*, exhibited a similar propensity across all breed types. The prevalence of *'Neoplasms'* increased from below

2-3% before age 3 to 12% by ages 11-12, mirroring trends observed across both species and supporting the notion that older mammals are generally more prone to neoplasias.

Of note within our analysis is the significant years of lost life for young dogs, namely aged 1-2 years, as a result of behavioural disorders. Behavioural disorders have previously been discussed as a leading cause of negative welfare outcomes such as euthanasia, with one study finding that behaviour was the fourth most common reason for euthanasia, accounting for 7.3% of euthanasia deaths in dogs[42]. Our results suggest a significant increased risk (OR 5.68, $p<0.001$) of premature mortality in dogs with behavioural disorders compared to dogs without, which is supported by previous literature that suggests age is a risk factor for the development of problematic behaviour, with younger dogs (particularly adolescent dogs under three years old), potentially more prone to problematic behaviours increasing their risk of euthanasia or relinquishment. Existing data from a UK-based study, also using primary-care consult data, showed that around one-third of deaths in dogs under three years are ascribed to behavioural issues, and of these deaths, 75% are from euthanasia[54]. Similarly, an Australian-based study revealed that 29.7% of dogs under primary care that died at three years of age or under had deaths attributed to at least one problematic behaviour[55]. Many studies suggest aggression, in particular, is commonly related to premature death in younger dogs and is frequently reported as the most common cause of behavioural euthanasia[54–56]. As well as euthanasia, problematic behaviour has previously been discussed as a leading cause of relinquishment of young dogs to shelters[57], as well as a factor in unsuccessful adoptions from shelters[58]. A study by Clark et al. also found that behavioural problems accounted for 65.6% of dogs euthanised in UK rehoming centres in 2009, which could suggest that many dogs may also have been relinquished due to behavioural issues prior to their euthanasia[59]. With the evidence growing around the higher prevalence of behaviour problems and subsequent relinquishment and euthanasia in younger dogs, further investigation is warranted to determine associated factors behind this and thus implement preventative measures to reduce the likelihood of problematic behaviours firstly developing and further resulting in euthanasia or relinquishment where they do occur.

The use of the ICD-11 labels provides only a general overview of the events described in the narratives. Consequently, these labels do not capture the exact reasons behind an animal's death. Additional research will be required to extract more detailed causal information. Furthermore, conditions not explicitly documented in the clinical notes were inevitably excluded from our analysis. The completeness and accuracy of the free-text consultation notes are inherently dependent on the individual attending clinicians, introducing variability in the data quality. Our previous work reveals our model's performance, such as an 83% F1 score accuracy for ICD-11 assignment. Although we made efforts to minimise false positives and false negatives in identifying deceased animals, some inaccuracies likely remain within the dataset. This omission likely under-represents the number of animals that died without euthanasia. Lastly, the SAVSNET network only partially represents veterinary consultations and the companion animal population across the UK.

In conclusion, our comprehensive study on premature mortality in dogs and cats across the UK leverages a novel large language model-methodology to identify and analyse patterns within the deceased animal population. By examining data from 28,562 deceased dogs and 24,460 deceased cats and utilising our automated ICD-11 syndromic classifier, we have unearthed critical insights into the conditions affecting years of lost life across various age groups. Notably, our analysis highlights the significant impact of behavioural conditions on premature euthanasia in dogs, particularly as the leading cause of lost years of life in the one to six age bracket. Furthermore, our investigation into premature mortality risk factors reveals a significant correlation with socioeconomic status, underscoring how the impact of social inequalities extend to companion animal health. This research identifies areas needing urgent attention and underscores the importance of continued investigation into the socioeconomic disparities affecting animal health outcomes. Our findings advocate for targeted interventions and underscore the necessity for enhanced research efforts to address and mitigate these inequities, paving the way for more equitable health prospects for companion animals across the UK.

4 Methods

4.1 Dataset

Electronic health records have been collected since March 2014 by SAVSNET, the Small Animal Veterinary Surveillance Network, comprising a sentinel network of 253 volunteer veterinary practices across the United Kingdom. A full description of SAVSNET has been presented elsewhere[9]. In summary, veterinary practices with compatible practice management software with the SAVSNET data exchange are recruited based on convenience. Within these participating practices, data is collected from each booked consultation (where an appointment has been made to see a veterinary practitioner or nurse). All owners attending a participating practice are informed of the data collection process and are given the opportunity to opt out during their consultation. At this point, data is not sent to the SAVSNET data exchange and, therefore, is not utilised in any research. Pet owners are provided with informed consent that their data could be used for research purposes. Data is collected on a

consultation-by-consultation basis and includes information such as species, breed, sex, neuter status, age, owner's postcode, insurance and microchipping status and, crucially to this study, a free-text clinical narrative outlining the events that occurred within that consultation. In addition, high-level syndromic labels corresponding to the chapters of the International Classification of Diseases 11 (ICD-11) are appended to each consultation based on previous work. A detailed description of this approach is available in the original publication[?]. Sensitive information, including personal identifiers, was cleaned from the dataset prior to analysis. Additionally, all data discussed within this paper is at a population level; therefore, no specific individual will be discussed. SAVSNET has ethical approval from the University of Liverpool Research Ethics Committee (RETH000964). We hereby confirm that all experiments were conducted in strict compliance with the Research Ethics Committee.

4.2 Data Extraction

Narratives mentioning death or euthanasia were identified using a generalised Python regular expression (regex) to screen for terms such as "euthanasia", "put to sleep (PTS)", and "died". The final regex is outlined below. The generalised dataset was then randomly sampled for 250 suspected potential death/euthanasia cases. These were then manually read to verify that they met the case definition of a "declaration of death". Common false positives included discussions related to future euthanasia events or euthanasia mentioned as advisory by the attending practitioner. Unless the euthanasia event occurred in the same consultation, these records were not annotated as cases. Adapting the works of Yalniz et. al., a semi-supervised teacher-student model approach was employed, where a small subset of manually annotated records was used to train a small binary sequence classification model[60]. The resultant model from this task was then used against the entire dataset to extract animals identified as a case, a random sample of 200 records was passed to a practising clinician to verify that the performance of the extraction method was sufficient enough to continue the study.

euth|dead|died|pts|put to sleep|pento|doa|crem|burial|bury|qol|quality|ashes|scatter|casket

The cephalic index for each breed was appended accordingly. These labels were derived from a variety of sources[17,61,62]. For any breeds not covered in the literature, we consulted with a practitioner clinician to make a final determination.

4.3 Defining Premature Mortality

To define premature mortality thresholds for each breed within our dataset, we employed a bootstrapping method to estimate the median age at death for each breed. Specifically, we generated 10,000 new datasets through random sampling with replacement from the original dataset. For each new dataset, we calculated the median age at death for each breed and established a 95% confidence interval. Below 85% of the lower bound of this confidence interval served as the threshold for identifying premature mortality. To ensure robustness in our findings, we included only breeds with at least ten observations in both premature and expected death categories. Using a breed-specific 95% confidence interval, we accounted for the variances in life expectancy inherent to different breeds. An animal whose age at death was below the lower bound of its breed's confidence interval was classified as having died prematurely.

4.4 Premature Mortality and Years of Lost Life (YLL)

We determined the cause of an animal's death by utilising the produced ICD-11 chapter labels. Occasionally, the final declaration of death EHR narrative lacked precise details on the cause of death; thus, we expanded our analysis to include consultations from up to six months prior to the recorded death. Any syndromic label present during this period was considered a potential indicator of the cause of death. We calculated the YLL for each age group (ages 1 to 14) using the following equation:

$$YLL = \sum_{i=1}^{n} (L_i - A_i)$$

where L_i is the estimated premature mortality threshold produced above for a given animal for the age group and A_i is the age at death for each individual i. This computation was performed for each ICD-11 chapter to determine the YLL attributable to different causes of death. To quantify the proportions of lost life, we summed the total number of years lost for each age group due to death linked to each ICD-11 chapter and divided these by the total number of years of lost life for the same age group. This approach allowed us to understand the distributions and impacts of various causes of death across different age groups and disease classifications.

4.5 Premature Mortality Risk Factor Analysis

To prepare our dataset for analysing the risk factors associated with premature mortality in animals, we included only records of animals that had not yet reached their breed-specific premature mortality thresholds. This approach minimised survivorship bias, ensuring that our analysis focused on identifying potential risk factors that likely influence the likelihood of premature

mortality. Key demographic features included the level of deprivation associated with the available owners' postcodes and whether they lived in rural-urban conditions. The Index of multiple deprivations are expressed as quintiles with a score of 1 being the least deprived and five being the most deprived and were acquired for all participating nations. Due to differences in how the different governing bodies assign scoring, scores were re-scaled in line with England's IMD scale using a framework proposed by Abel et al., 2016[63]. Additionally, for the impact of urbanisation, records were assigned a class based on a 10-fold scale for England and Wales, a 7-fold for Scotland and Northern Ireland[64–66]. Specifically, regions A, B, and C in England and Wales, Regions 1 and 2 in Scotland, and Region A in Northern Ireland were classified as urban (populations with >10,000 people), while all other regions were classified as rural. Phenotype features included sex and the entire set of ICD-11 disease codes from the clinical history data, which were treated as binary outcomes in the analysis.

A univariate mixed-effect logistic regression was conducted using case–control status as a binary dependent variable. Animals identified as having died prematurely were categorised as cases, while controls were animals whose deaths occurred beyond the breed specific premature threshold age. Each explanatory variable was analysed individually, and the fit compared to a null model was assessed using the likelihood ratio test (LRT chi-squared test), incorporating practice as a random effect to account for potential clustering. An initial multivariable logistic regression model was constructed by including only those explanatory variables that demonstrated an LRT p-value ≤ 0.2 compared to the null model. This preliminary model was then refined through a backward selection process to achieve the best model fit characterised by the lowest possible Akaike information criterion (AIC). The final multivariable model was analysed for multicollinearity by calculating the variance inflation factor (VIF), confirming that multicollinearity was absent.

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6 Data availability

The datasets analysed during the current study are not publicly available due to issues surrounding owner confidentiality. Reasonable requests can be made to the SAVSNET Data Access and Publication Panel (savsnet@liverpool.ac.uk) for researchers who meet the criteria for access to confidential data.

7 Competing interests

All authors declare no financial or non-financial competing interests.

8 Contributions

SF conceived the study with PJ-N and NA, performed the annotations with PJ-N, wrote the code, conducted the analysis, and wrote the manuscript. KA provided guidance on the role of behavioural disorders and prematurely mortality in dogs. All authors reviewed and approved the final manuscript.

References

1. Albert-Ballestar, S. & García-Altés, A. Measuring health inequalities: a systematic review of widely used indicators and topics. *Int. J. for Equity Heal.* **20**, 1–15, DOI: 10.1186/S12939-021-01397-3/TABLES/3 (2021).

2. Holdroyd, I. *et al.* Systematic review of the effectiveness of the health inequalities strategy in England between 1999 and 2010. *BMJ Open* **12**, e063137, DOI: 10.1136/BMJOPEN-2022-063137 (2022).

3. Kawachi, I., Kennedy, B. P., Lochner, K. & Prothrow-Stith, D. Social capital, income inequality, and mortality. *https://doi.org/10.2105/AJPH.87.9.1491* **87**, 1491–1498, DOI: 10.2105/AJPH.87.9.1491 (2011).

4. Chetty, R. *et al.* The Association Between Income and Life Expectancy in the United States, 2001-2014. *JAMA* **315**, 1750–1766, DOI: 10.1001/JAMA.2016.4226 (2016).

5. Tarkiainen, L., Martikainen, P., Laaksonen, M. & Valkonen, T. Trends in life expectancy by income from 1988 to 2007: decomposition by age and cause of death. *J Epidemiol Community Heal.* **66**, 573–578, DOI: 10.1136/JECH.2010.123182 (2012).

6. Murray, C. J. & Acharya, A. K. Understanding DALYs. *J. Heal. Econ.* **16**, 703–730, DOI: 10.1016/S0167-6296(97)00004-0 (1997).

7. Torrance, G. W. & Feeny, D. Utilities and quality-adjusted life years. *Intl. J. Technol. Assess. Heal. Care* **5**, 559–575, DOI: 10.1017/S0266462300008461 (1989).

8. WHO. WHO methods and data sources for global burden of disease estimates 2000-2019. Tech. Rep., Department of Data and Analytics, Division of Data, Analytics and Delivery for Impact WHO, Geneva (2020).

9. Sánchez-Vizcaíno, F. *et al.* Small animal disease surveillance. *Vet. Rec.* **177**, 591–594, DOI: 10.1136/VR.H6174 (2015).

10. Royal Veterinary College. VetCompass: health surveillance for UK companion animals. (2019).

11. Lloyd, S. S. & Rissing, J. P. Physician and Coding Errors in Patient Records. *JAMA: The J. Am. Med. Assoc.* **254**, 1330–1336, DOI: 10.1001/JAMA.1985.03360100080018 (1985).

12. Zafirah, S. A., Nur, A. M., Puteh, S. E. W. & Aljunid, S. M. Potential loss of revenue due to errors in clinical coding during the implementation of the Malaysia diagnosis related group (MY-DRG®) Casemix system in a teaching hospital in Malaysia. *BMC Heal. Serv. Res.* **18**, 1–11, DOI: 10.1186/s12913-018-2843-1 (2018).

13. Mcdonald, C. J. The Barriers to Electronic Medical Record Systems and How to Overcome Them. *J. Am. Med. Informatics Assoc.* **4**, 213, DOI: 10.1136/JAMIA.1997.0040213 (1997).

14. Rosenbloom, S. T. *et al.* Data from clinical notes: a perspective on the tension between structure and flexible documentation. *J. Am. Med. Informatics Assoc.* **18**, 181–186, DOI: 10.1136/jamia.2010.007237 (2011).

15. Waters, A. Brachycephalic tipping point: time to push the button? *Vet. Rec.* **180**, 288–288, DOI: 10.1136/VR.J1479 (2017).

16. Gyles, C. Brachycephalic dogs — time for action. *The Can. Vet. J.* **58**, 777 (2017).

17. O'Neill, D. G. *et al.* Unravelling the health status of brachycephalic dogs in the UK using multivariable analysis. *Sci. Reports 2020 10:1* **10**, 1–13, DOI: 10.1038/s41598-020-73088-y (2020).

18. O'Neill, D. G. *et al.* Epidemiological associations between brachycephaly and upper respiratory tract disorders in dogs attending veterinary practices in England. *Canine genetics epidemiology* **2**, DOI: 10.1186/S40575-015-0023-8 (2015).

19. Fasanella, F. J., Shivley, J. M., Wardlaw, J. L. & Givaruangsawat, S. Brachycephalic airway obstructive syndrome in dogs: 90 cases (1991-2008). *J. Am. Vet. Med. Assoc.* **237**, 1048–1051, DOI: 10.2460/JAVMA.237.9.1048 (2010).

20. Mitze, S., Barrs, V. R., Beatty, J. A., Hobi, S. & Bęczkowski, P. M. Brachycephalic obstructive airway syndrome: much more than a surgical problem. *The Vet. Q.* **42**, 213, DOI: 10.1080/01652176.2022.2145621 (2022).

21. Petchell, W. H., Noble, P. J. M., Broome, H. A. & Burrow, R. Incidence of alimentary and respiratory disease in brachycephalic dogs presenting to primary care veterinary practices participating in the SAVSNET project. *Vet. Rec.* **191**, no–no, DOI: 10.1002/VETR.1685 (2022).

22. Costa, J., Steinmetz, A. & Delgado, E. Clinical signs of brachycephalic ocular syndrome in 93 dogs. *Ir. Vet. J.* **74**, 1–8, DOI: 10.1186/S13620-021-00183-5 (2021).

23. Packer, R. M., Hendricks, A. & Burn, C. C. Impact of Facial Conformation on Canine Health: Corneal Ulceration. *PLOS ONE* **10**, e0123827, DOI: 10.1371/JOURNAL.PONE.0123827 (2015).

24. Freiche, V. & German, A. J. Digestive Diseases in Brachycephalic Dogs. *The Vet. clinics North Am. Small animal practice* **51**, 61–78, DOI: 10.1016/J.CVSM.2020.09.006 (2021).

25. O'Neill, D. G., Church, D. B., McGreevy, P. D., Thomson, P. C. & Brodbelt, D. C. Longevity and mortality of owned dogs in England. *The Vet. J.* **198**, 638–643, DOI: 10.1016/J.TVJL.2013.09.020 (2013).

26. Farrell, S., Appleton, C., Noble, P.-J. M. & Al Moubayed, N. PetBERT: automated ICD-11 syndromic disease coding for outbreak detection in first opinion veterinary electronic health records. *Sci. Reports 2023 13:1* **13**, 1–14, DOI: 10.1038/s41598-023-45155-7 (2023).

27. Bonnett, B. N., Egenvall, A., Olson, P. & Hedhammar, A. Mortality in insured Swedish dogs: rates and causes of death in various breeds. *Vet. Rec.* **141**, 40–44, DOI: 10.1136/VR.141.2.40 (1997).

28. Bonnett, B. N., Egenvall, A., Hedhammar, A. & Olson, P. Mortality in over 350,000 Insured Swedish dogs from 1995–2000: I. Breed-, Gender-, Age- and Cause-specific Rates. *Acta Vet. Scand. 2002 46:3* **46**, 1–16, DOI: 10.1186/1751-0147-46-105 (2005).

29. Egenvall, A., Hedhammar, Bonnett, B. N. & Olson, P. Survey of the Swedish Dog Population: Age, Gender, Breed, Location and Enrolment in Animal Insurance. *Acta Vet. Scand.* **40**, 231–240, DOI: 10.1186/BF03547021 (1999).

30. Bergström, A., Nødtvedt, A., Lagerstedt, A. S. & Egenvall, A. Incidence and Breed Predilection for Dystocia and Risk Factors for Cesarean Section in a Swedish Population of Insured Dogs. *Vet. Surg.* **35**, 786–791, DOI: 10.1111/J.1532-950X.2006.00223.X (2006).

31. Egenvall, A., Nødtvedt, A., Penell, J., Gunnarsson, L. & Bonnett, B. N. Insurance data for research in companion animals: benefits and limitations. *Acta veterinaria Scand.* **51**, 42, DOI: 10.1186/1751-0147-51-42 (2009).

32. Davies, H. *et al.* Text mining for disease surveillance in veterinary clinical data: part one, the language of veterinary clinical records and searching for words. *Front. Vet. Sci.* **11**, 1352239, DOI: 10.3389/fvets.2024.1352239 (2024).

33. Gosse, G. H. & Barnes, M. J. Human Grief Resulting from the Death of a Pet. *Anthrozo@UMLAUT@os* **7**, 103–112, DOI: 10.2752/089279394787001970 (2015).

34. Morris, P. Managing Pet Owners' Guilt and Grief in Veterinary Euthanasia Encounters. *J. Contemp. Ethnogr.* **41**, 337–365, DOI: 10.1177/0891241611435099 (2012).

35. Luiz Adrian, J. A., Deliramich, A. N. & Frueh, B. C. Complicated grief and posttraumatic stress disorder in humans' response to the death of pets/animals. *Bull. Menninger Clin.* **73**, 176–187, DOI: 10.1521/BUMC.2009.73.3.176 (2009).

36. Packman, W., Carmack, B. & Ronen, R. Therapeutic Implications of Continuing Bonds Expressions following the Death of a Pet. *OMEGA - J. Death Dying* **64**, 335–356, DOI: 10.2190/OM.64.4.D (2012).

37. Christiansen, S. B., Kristensen, A. T., Sandøe, P. & Lassen, J. Looking after chronically ill dogs: Impacts on the caregiver's life. *Anthrozoos* **26**, 519–533, DOI: 10.2752/175303713X13795775536174 (2013).

38. Christiansen, S. B., Kristensen, A. T., Lassen, J. & Sandøe, P. Veterinarians' role in clients' decision-making regarding seriously ill companion animal patients. *Acta Vet. Scand.* **58**, 1–14, DOI: 10.1186/S13028-016-0211-X (2016).

39. Cooney, K. A., Kogan, L. R., Brooks, S. L. & Ellis, C. A. Pet Owners' Expectations for Pet End-of-Life Support and After-Death Body Care: Exploration and Practical Applications. *Top. Companion Animal Medicine* **43**, 100503, DOI: 10.1016/J.TCAM.2020.100503 (2021).

40. Fernandez-Mehler, P., Gloor, P., Sager, E., Lewis, F. I. & Glaus, T. M. Veterinarians' role for pet owners facing pet loss. *Vet. Rec.* **172**, 555, DOI: 10.1136/VR.101154 (2013).

41. Adams, C. L., Bonnett, B. N. & Meek, A. H. Predictors of owner response to companion animal death in 177 clients from 14 practices in Ontario. *J. Am. Vet. Med. Assoc.* **217**, 1303–1309, DOI: 10.2460/JAVMA.2000.217.1303 (2000).

42. Pegram, C. *et al.* Proportion and risk factors for death by euthanasia in dogs in the UK. *Sci. Reports 2021 11:1* **11**, 1–12, DOI: 10.1038/s41598-021-88342-0 (2021).

43. Moore, G. E., Burkman, K. D., Carter, M. N. & Peterson, M. R. Causes of death or reasons for euthanasia in military working dogs: 927 cases (1993-1996). *J. Am. Vet. Med. Assoc.* **219**, 209–214, DOI: 10.2460/JAVMA.2001.219.209 (2001).

44. Gates, M. C., Hinds, H. J. & Dale, A. Preliminary description of aging cats and dogs presented to a New Zealand first-opinion veterinary clinic at end-of-life. *New Zealand Vet. J.* **65**, 313–317, DOI: 10.1080/00480169.2017.1360161 (2017).

45. Huang, W. H. *et al.* A 3-year surveillance on causes of death or reasons for euthanasia of domesticated dogs in Taiwan. *Prev. Vet. Medicine* **147**, 1–10, DOI: 10.1016/J.PREVETMED.2017.08.015 (2017).

46. Houweling, T. A. & Kunst, A. E. Socio-economic inequalities in childhood mortality in low- and middle-income countries: a review of the international evidence. *Br. Med. Bull.* **93**, 7–26, DOI: 10.1093/BMB/LDP048 (2010).

47. Mackenbach, J. P. *et al.* Socioeconomic Inequalities in Health in 22 European Countries. *New Engl. J. Medicine* **358**, 2468–2481, DOI: 10.1056/NEJMSA0707519 (2008).

48. Bir, C. *et al.* Familiarity and Use of Veterinary Services by US Resident Dog and Cat Owners. *Animals* **10**, 483, DOI: 10.3390/ANI10030483 (2020).

49. Williams, A., Williams, B., Hansen, C. R. & Coble, K. H. The Impact of Pet Health Insurance on Dog Owners' Spending for Veterinary Services. *Animals : an Open Access J. from MDPI* **10**, 1162, DOI: 10.3390/ANI10071162 (2020).

50. Thomson, R. M., Hammond, J., Ternent, H. E. & Yam, P. S. Feeding practices and the use of supplements for dogs kept by owners in different socioeconomic groups. *Vet. Rec.* **163**, 621–624, DOI: 10.1136/VR.163.21.621 (2008).

51. Fox, M. W. Developmental Abnormalities of the Canine Skull. *Can. journal comparative medicine veterinary science* **27**, 219–222 (1963).

52. Oechtering, T. H., Oechtering, G. U. & Nöller, C. Structural characteristics of the nose in brachycephalic dog breeds analysed by computed tomography. *Tierarztliche Praxis. Ausgabe K, Kleintiere/heimtiere* **35**, 177–187, DOI: 10.1055/S-0038-1622615 (2007).

53. Reich, L., Hartnack, S., Fitzi-Rathgen, J. & Reichler, I. M. [Life expectancy of mesocephalic, dolichocephalic and brachycephalic dog breeds in Switzerland]. *Schweizer Arch. fur Tierheilkunde* **165**, 235–249, DOI: 10.17236/SAT00390 (2023).

54. Boyd, C. *et al.* Mortality resulting from undesirable behaviours in dogs aged under three years attending primary-care veterinary practices in England. *Animal Welf.* **27**, 251–262, DOI: 10.7120/09627286.27.3.251 (2018).

55. Yu, Y., Wilson, B., Masters, S., van Rooy, D. & McGreevy, P. D. Mortality Resulting from Undesirable Behaviours in Dogs Aged Three Years and under Attending Primary-Care Veterinary Practices in Australia. *Animals 2021, Vol. 11, Page 493* **11**, 493, DOI: 10.3390/ANI11020493 (2021).

56. Hitchcock, M., Workman, M. K., Guthrie, A. P., Ruple, A. & Feuerbacher, E. N. Factors associated with behavioral euthanasia in pet dogs. *Front. Vet. Sci.* **11**, 1387076, DOI: 10.3389/FVETS.2024.1387076 (2024).

57. Diesel, G., Brodbelt, D. & Pfeiffer, D. U. Characteristics of Relinquished Dogs and Their Owners at 14 Rehoming Centers in the United Kingdom. *J. Appl. Animal Welf. Sci.* **13**, 15–30, DOI: 10.1080/10888700903369255 (2010).

58. Diesel, G., Pfeiffer, D. U. & Brodbelt, D. Factors affecting the success of rehoming dogs in the UK during 2005. *Prev. Vet. Medicine* **84**, 228–241, DOI: 10.1016/J.PREVETMED.2007.12.004 (2008).

59. Clark, C. C., Gruffydd-Jones, T. & Murray, J. K. Number of cats and dogs in UK welfare organisations. *Vet. Rec.* **170**, 493–493, DOI: 10.1136/VR.100524 (2012).

60. Zeki, I. *et al.* Billion-scale semi-supervised learning for image classification. *arXiv preprint* DOI: 10.48550/arXiv.1905.00546 (2019).

61. Bognár, Z., Szabó, D., Deés, A. & Kubinyi, E. Shorter headed dogs, visually cooperative breeds, younger and playful dogs form eye contact faster with an unfamiliar human. *Sci. Reports* **11**, 9293, DOI: 10.1038/S41598-021-88702-W (2021).

62. Alpak, H., Mutuş, R. & Onar, V. Correlation analysis of the skull and long bone measurements of the dog. *Annals Anat. - Anat. Anzeiger* **186**, 323–330, DOI: 10.1016/S0940-9602(04)80050-5 (2004).

63. Abel, G. A., Barclay, M. E. & Payne, R. A. Adjusted indices of multiple deprivation to enable comparisons within and between constituent countries of the UK including an illustration using mortality rates. *BMJ Open* **6**, e012750, DOI: 10.1136/BMJOPEN-2016-012750 (2016).

64. Scottish Government. Scottish Government Urban Rural Classification 2020. Tech. Rep., Scottish Government (2020).

65. Department for Environment Food & Rural Affairs, U. G. Rural Urban Classification - GOV.UK. Tech. Rep., UK Government (2016).

66. Northern Ireland Statistics and Research Agency. Urban - Rural Classification. Tech. Rep., NI Government (2015).

Table 1. Summary of Median Age at Death, Premature Threshold, Total Count (N), and Cephalic Index for Dog Breeds within the dataset. The 'Premature Threshold' is defined as 85% of the lower 95% confidence interval of the median age.

Breed	Premature Threshold (Years)	Median Age (Years)	n	Cephalic Index
Airedale Terrier	9.80	11.73 (11.53-11.93)	24	Dolichocephalic
Akita	8.26	10.00 (9.72-10.28)	25	Mesaticephalic
Alaskan Malamute	9.34	11.11 (10.98-11.24)	45	Mesaticephalic
American Bulldog	8.27	9.95 (9.73-10.17)	52	Brachycephalic
Basset Hound	10.19	12.17 (11.99-12.35)	80	Dolichocephalic
Beagle	10.01	11.95 (11.78-12.12)	108	Mesaticephalic
Bearded Collie	11.41	13.62 (13.43-13.81)	40	Mesaticephalic
Bedlington Terrier	10.46	12.53 (12.31-12.75)	46	Dolichocephalic
Belgian Shepherd	10.03	11.98 (11.80-12.16)	17	Mesaticephalic
Bernese Mountain	6.92	8.30 (8.14-8.46)	18	Mesaticephalic
Bichon Frise	10.90	13.01 (12.82-13.20)	215	Mesaticephalic
Border Collie	11.18	13.34 (13.15-13.53)	1179	Mesaticephalic
Border Terrier	11.88	14.12 (13.98-14.26)	459	Mesaticephalic
Boston Terrier	9.16	10.95 (10.78-11.12)	23	Brachycephalic
Boxer	9.14	10.88 (10.75-11.01)	318	Brachycephalic
Bull Terrier	9.71	11.61 (11.43-11.79)	111	Mesaticephalic
Bulldog	7.11	8.57 (8.36-8.78)	120	Brachycephalic
Cairn Terrier	11.49	13.66 (13.52-13.8)	134	Mesaticephalic
Cavalier King Charles Spaniel	9.77	11.64 (11.50-11.79)	575	Brachycephalic
Chihuahua	10.08	12.09 (11.85-12.33)	238	Brachycephalic
Chinese Crested	11.03	13.17 (12.97-13.37)	31	Mesaticephalic
Cockapoo	9.29	11.24 (10.93-11.55)	48	Mesaticephalic
Collie (Generic)	11.30	13.51 (13.30-13.72)	157	Dolichocephalic
Crossbreed	11.24	13.43 (13.23-13.62)	5524	Other
Dachshund	9.97	12.02 (11.74-12.30)	79	Dolichocephalic
Dachshund (Miniature)	10.89	13.08 (12.81-13.35)	98	Dolichocephalic
Dalmatian	10.86	12.93 (12.77-13.08)	105	Mesaticephalic
Dobermann	8.91	10.67 (10.48-10.86)	71	Mesaticephalic
Dogue De Bordeaux	5.26	6.39 (6.19-6.59)	32	Brachycephalic
English Setter	10.16	12.09 (11.95-12.23)	19	Mesaticephalic
Fox Terrier	10.47	12.50 (12.32-12.68)	23	Dolichocephalic
French Bulldog	5.94	7.23 (6.98-7.48)	154	Brachycephalic
German Pointer	9.87	11.83 (11.61-12.05)	61	Mesaticephalic
German Shepherd (Alsatian)	9.23	11.04 (10.86-11.22)	669	Mesaticephalic
Great Dane	6.88	8.31 (8.10-8.52)	28	Dolichocephalic
Greyhound	9.91	11.81 (11.66-11.96)	270	Dolichocephalic
Hungarian Vizsla	10.00	11.96 (11.77-12.15)	50	Mesaticephalic
Husky (generic)	10.09	12.10 (11.87-12.33)	40	Mesaticephalic
Irish Setter	10.46	12.47 (12.30-12.64)	40	Mesaticephalic
Irish Terrier	10.75	12.84 (12.64-13.04)	15	Dolichocephalic
Italian Spinone	8.50	10.15 (10.00-10.30)	14	Mesaticephalic
Jack Russell Terrier	12.15	14.48 (14.29-14.67)	1906	Mesaticephalic
Japanese Akita Inu	9.97	11.94 (11.73-12.15)	38	Mesaticephalic
King Charles Spaniel	9.76	11.66 (11.48-11.84)	39	Brachycephalic
Labradoodle	10.16	12.13 (11.95-12.31)	111	Mesaticephalic
Lakeland Terrier	12.54	14.93 (14.75-15.11)	70	Mesaticephalic
Leonberger	7.53	9.00 (8.86-9.14)	12	Mesaticephalic
Lhasa Apso	11.90	14.18 (14.00-14.36)	303	Brachycephalic
Lurcher	10.90	13.04 (12.82-13.26)	290	Dolichocephalic
Maltese	10.25	12.33 (12.06-12.61)	30	Mesaticephalic
Mastiff	7.66	9.20 (9.01-9.39)	36	Brachycephalic
Miniature Schnauzer	10.74	12.77 (12.63-12.91)	182	Mesaticephalic
Newfoundland	8.66	10.38 (10.19-10.57)	28	Brachycephalic
Norfolk Terrier	11.43	13.61 (13.44-13.78)	24	Mesaticephalic
Old English Sheepdog	10.05	12.00 (11.82-12.18)	24	Mesaticephalic
Papillon	12.12	14.46 (14.26-14.67)	29	Brachycephalic
Parson Russell Terrier	11.78	14.08 (13.86-14.30)	46	Dolichocephalic
Patterdale Terrier	11.55	13.81 (13.59-14.03)	168	Mesaticephalic
Pekingese	11.15	13.29 (13.12-13.47)	27	Brachycephalic
Pointer	10.17	12.16 (11.96-12.36)	41	Mesaticephalic
Pomeranian	10.28	12.33 (12.1-12.56)	33	Mesaticephalic
Poodle (generic)	11.35	13.53 (13.35-13.71)	72	Dolichocephalic
Poodle (Miniature)	11.76	14.02 (13.84-14.20)	69	Mesaticephalic
Poodle (Toy)	12.45	14.93 (14.65-15.21)	57	Mesaticephalic
Pug	8.92	10.73 (10.49-10.97)	122	Brachycephalic
Retriever (Flat Coated)	9.12	10.94 (10.73-11.15)	37	Mesaticephalic
Retriever (Generic)	11.02	13.10 (12.96-13.24)	72	Mesaticephalic
Retriever (Golden)	10.93	13.01 (12.85-13.17)	393	Mesaticephalic
Retriever (Labrador)	10.83	12.88 (12.74-13.02)	2342	Mesaticephalic
Rhodesian Ridgeback	10.04	11.97 (11.81-12.13)	44	Mesaticephalic
Rottweiler	8.10	9.69 (9.53-9.85)	220	Mesaticephalic
Saluki	10.12	12.20 (11.91-12.49)	13	Dolichocephalic
Samoyed	9.50	11.35 (11.18-11.52)	13	Mesaticephalic
Schnauzer	10.26	12.21 (12.07-12.35)	35	Dolichocephalic
Scottish Terrier	10.13	12.06 (11.92-12.20)	54	Dolichocephalic
Shar-Pei	8.13	9.77 (9.56-9.98)	64	Brachycephalic
Shetland Sheepdog	10.42	12.42 (12.26-12.58)	66	Dolichocephalic
Shih Tzu	11.12	13.30 (13.08-13.51)	533	Brachycephalic
Siberian Husky	10.37	12.41 (12.21-12.61)	88	Mesaticephalic
Spaniel (American Cocker)	10.54	12.57 (12.40-12.74)	19	Mesaticephalic
Spaniel (Cocker)	10.86	12.94 (12.78-13.10)	1103	Mesaticephalic
Spaniel (English Springer)	11.18	13.31 (13.16-13.45)	150	Mesaticephalic
Spaniel (Field)	11.24	13.41 (13.23-13.59)	13	Mesaticephalic
Spaniel (Generic)	10.98	13.16 (12.92-13.40)	31	Mesaticephalic
Spaniel (Springer)	11.09	13.20 (13.05-13.35)	814	Mesaticephalic
Spaniel (Welsh Springer)	11.79	14.00 (13.88-14.12)	25	Mesaticephalic
St. Bernard	7.16	8.59 (8.43-8.75)	12	Mesaticephalic
Staffordshire Bull Terrier	11.06	13.19 (13.01-13.37)	1558	Brachycephalic
Terrier (Generic)	12.37	14.78 (14.55-15.01)	151	Mesaticephalic
Tibetan Spaniel	12.28	14.66 (14.45-14.87)	11	Brachycephalic
Tibetan Terrier	11.46	13.67 (13.48-13.86)	71	Mesaticephalic
Weimaraner	10.50	12.51 (12.35-12.67)	85	Mesaticephalic
Welsh Terrier	11.50	13.70 (13.53-13.87)	16	Dolichocephalic
West Highland White Terrier	11.40	13.56 (13.41-13.71)	856	Mesaticephalic
Whippet	10.44	12.46 (12.28-12.64)	168	Dolichocephalic
Yorkshire Terrier	11.89	14.17 (13.98-14.36)	741	Mesaticephalic

Table 2. Summary of Median Age at Death, Premature Threshold, Total Count (N), and Cephalic Index for Cat Breeds within the dataset. The 'Premature Threshold' is defined as 85% of the lower 95% confidence interval of the median age.

Breed	Premature Threshold (Years)	Median Age (Years)	n	Cephalic Index
Abyssinian	12.69	13.25 (13.01 - 13.49)	15	Mesaticephalic
Bengal	10.93	15.52 (15.25 - 15.79)	100	Other
Birman	13.74	14.66 (14.43 - 14.89)	126	Mesaticephalic
Brazilian Shorthair	12.26	16.45 (16.13 - 16.77)	42	Mesaticephalic
British Shorthair	12.31	16.50 (16.24 - 16.77)	476	Brachycephalic
Burmese	13.80	9.84 (9.58 - 10.10)	132	Brachycephalic
Crossbreed	12.22	13.17 (12.86 - 13.48)	518	Dolichocephalic
Devon Rex	13.71	13.55 (13.30 - 13.80)	16	Brachycephalic
Domestic Long Hair	12.93	16.37 (16.17 - 16.57)	1944	Mesaticephalic
Domestic Medium Hair	11.72	15.47 (15.21 - 15.72)	504	Mesaticephalic
Domestic Short Hair	12.96	15.13 (14.93 - 15.33)	15957	Mesaticephalic
Maine Coon	10.87	14.11 (13.79 - 14.42)	166	Mesaticephalic
Norwegian Forest Cat	11.06	14.00 (13.74 - 14.26)	23	Mesaticephalic
Oriental Shorthair	8.14	14.01 (13.67 - 14.33)	14	Mesaticephalic
Persian	12.54	14.79 (14.48 - 15.09)	264	Mesaticephalic
Ragdoll	11.62	15.02 (14.76 - 15.28)	107	Dolichocephalic
Russian Blue	11.30	14.99 (14.77 - 15.21)	21	Dolichocephalic
Siamese	11.68	14.66 (14.37 - 14.95)	236	Mesaticephalic
Tonkinese	12.55	13.08 (12.79 - 13.37)	32	Mesaticephalic

Table 3. Multivariable Logistic Regression analysis for cats that died prematurely (case) and death occurring at or beyond the expected life expectancy (control). (OR = Odds Ratio, CI = Lower and Upper 95% Confidence interval, SE = Standard Error)

Variable	Level	Case (%)	Control (%)	OR (95% CI)	beta	SE	P
	(Intercept)	-	-	0.26 (0.23-0.29)	-1.362	0.057	<0.001
Sex	Male	3582 (53%)	9738 (57%)	-	-	-	-
	Female	3226 (47%)	7460 (43%)	0.72 (0.67-0.78)	-0.327	0.037	<0.001
Index of Multiple Deprivation (IMD)	1	1128 (17%)	1845 (11%)	-	-	-	-
	2	1288 (19%)	2778 (16%)	0.78 (0.69-0.89)	-0.247	0.066	<0.001
	3	1505 (22%)	3768 (22%)	0.68 (0.60-0.77)	-0.383	0.064	<0.001
	4	1534 (23%)	4160 (24%)	0.65 (0.57-0.73)	-0.438	0.064	<0.001
	5	1353 (20%)	4647 (27%)	0.52 (0.46-0.59)	-0.654	0.066	<0.001
Cephalic Index	Mesaticephalic	1353 (20%)	4647 (27%)	-	-	-	
	Brachycephalic	5837 (86%)	14994 (87%)	1.02 (0.84-1.24)	0.02	0.1	0.862
	Dolichocephalic	251 (4%)	602 (4%)	1.26 (0.91-1.72)	0.23	0.16	0.16
	Other	82 (1%)	210 (1%)	1.17 (1.03-1.33)	0.16	0.07	0.017
Certain infectious or parasitic diseases	No	5400 (79%)	16390 (95%)	-	-	-	-
	Yes	1408 (21%)	808 (5%)	2.10 (1.84-2.40)	0.743	0.067	<0.001
Neoplasms	No	5914 (87%)	17074 (99%)	-	-	-	-
	Yes	894 (13%)	124 (1%)	15.54 (12.62-19.13)	2.743	0.106	<0.001
Diseases of the blood or blood forming organs	No	6286 (92%)	17170 (99%)	-	-	-	-
	Yes	522 (8%)	28 (1%)	17.32 (11.47-26.16)	2.852	0.21	<0.001
Diseases of the Immune system	No	6597 (97%)	17021 (99%)	-	-	-	-
	Yes	211 (3%)	177 (1%)	1.06 (0.81-1.40)	0.062	0.142	0.663
Endocrine nutritional or metabolic diseases	No	6301 (93%)	16870 (98%)	-	-	-	-
	Yes	507 (7%)	328 (2%)	1.97 (1.64-2.37)	0.678	0.094	<0.001
Mental behavioural or neurodevelopmental disorders	No	6165 (91%)	16862 (98%)	-	-	-	-
	Yes	643 (9%)	336 (2%)	2.13 (1.79-2.52)	0.754	0.088	<0.001
Diseases of the nervous system	No	6265 (92%)	17159 (99%)	-	-	-	-
	Yes	543 (8%)	39 (1%)	19.19 (13.48-27.31)	2.954	0.18	<0.001
Diseases of the visual system	No	6061 (89%)	16976 (99%)	-	-	-	-
	Yes	747 (89%)	222 (1%)	3.06 (2.53-3.69)	1.117	0.097	<0.001
Diseases of the ear or mastoid process	No	6655 (98%)	17116 (99%)	-	-	-	-
	Yes	153 (2%)	82 (1%)	1.98 (1.41-2.77)	0.682	0.172	<0.001
Diseases of the circulatory system	No	6367 (94%)	17040 (99%)	-	-	-	-
	Yes	441 (6%)	158 (1%)	3.26 (2.58-4.11)	1.182	0.119	<0.001
Diseases of the respiratory system	No	5719 (84%)	17020 (99%)	-	-	-	-
	Yes	1089 (16%)	178 (1%)	9.49 (7.92-11.37)	2.25	0.092	<0.001
Diseases of the digestive system	No	5888 (86%)	16909 (98%)	-	-	-	-
	Yes	920 (14%)	289 (2%)	4.69 (3.98-5.53)	1.546	0.084	<0.001
Diseases of the skin	No	5929 (87%)	16729 (97%)	-	-	-	-
	Yes	879 (13%)	469 (3%)	2.01 (1.68-2.41)	0.7	0.091	<0.001
Diseases of the musculoskeletal system or connective tissue	No	5971 (88%)	17001 (99%)	-	-	-	-
	Yes	837 (12%)	197 (1%)	4.77 (3.89-5.85)	1.563	0.104	<0.001
Diseases of the genitourinary system	No	5771 (85%)	16979 (99%)	-	-	-	-
	Yes	1037 (15%)	219 (1%)	7.70 (6.49-9.14)	2.042	0.087	<0.001
Pregnancy childbirth or the puerperium	No	6759 (99%)	17197 (99%)	-	-	-	-
	Yes	49 (1%)	1 (1%)	11.26 (1.25-101.62)	2.422	1.122	0.031
Certain conditions originating in the perinatal period	No	6735 (99%)	17197 (99%)	-	-	-	-
	Yes	73 (1%)	1 (1%)	59.89 (7.83-458.03)	4.092	1.038	<0.001
Developmental anomalies	No	6665 (99%)	17188 (99%)	-	-	-	-
	Yes	143 (1%)	10 (1%)	10.13 (4.86-21.09)	2.315	0.374	<0.001
Injury poisoning or certain other consequences of external causes	No	6185 (91%)	16888 (98%)	-	-	-	-
	Yes	623 (9%)	310 (2%)	2.39 (1.99-2.88)	0.872	0.094	<0.001

Table 4. Multivariable Logistic Regression analysis for dogs that died prematurely (case) and death occurring at or beyond the expected life expectancy (control).

Variable	Level	Case (%)	Control (%)	OR (95% CI)	beta	SE	P
	(Intercept)	-	-	0.16 (0.15-0.18)	-1.362	0.057	<0.001
Sex	Male	3115 (51%)	10985 (50%)	-	-	-	-
	Female	2939 (49%)	11120 (50%)	0.97 (0.91-1.03)	-0.327	0.037	0.314
Index of Multiple Deprivation (IMD)	1	1118 (18%)	3247 (15%)	-	-	-	-
	2	1235 (20%)	4042 (18%)	0.88 (0.79-0.98)	-0.247	0.066	0.017
	3	1424 (24%)	5028 (23%)	0.83 (0.74-0.92)	-0.383	0.064	<0.001
	4	1274 (21%)	5198 (24%)	0.74 (0.67-0.83)	-0.438	0.064	<0.001
	5	1003 (17%)	4590 (21%)	0.59 (0.53-0.66)	-0.654	0.066	<0.001
Cephalic Index	Mesocephalic	2970 (49%)	11985 (54%)	-	-	-	-
	Brachycephalic	1226 (20%)	3602 (16%)	1.36 (1.26-1.47)	0.251	0.046	<0.001
	Dolichocephalic	369 (6%)	1325 (6%)	1.12 (0.99-1.27)	0.271	0.071	<0.001
	Other	1489 (25%)	5193 (23%)	1.15 (1.07-1.23)	0.209	0.041	<0.001
Certain infectious or parasitic diseases	No	5173 (85%)	20955 (95%)	-	-	-	-
	Yes	881 (15%)	1150 (5%)	1.35 (1.19-1.53)	0.743	0.067	<0.001
Neoplasms	No	5142 (85%)	21096 (95%)	-	-	-	-
	Yes	912 (15%)	1009 (5%)	2.48 (2.22-2.79)	2.743	0.106	<0.001
Diseases of the blood or blood forming organs	No	5856 (97%)	22087 (100%)	-	-	-	-
	Yes	198 (3%)	18 (0%)	21.59 (12.93-36.04)	2.852	0.21	<0.001
Diseases of the Immune system	No	5822 (96%)	21751 (98%)	-	-	-	-
	Yes	232 (4%)	354 (2%)	1.58 (1.28-1.96)	0.062	0.142	<0.001
Endocrine nutritional or metabolic diseases	No	5749 (95%)	21676 (98%)	-	-	-	-
	Yes	305 (5%)	429 (2%)	1.53 (1.28-1.83)	0.678	0.094	<0.001
Mental behavioural or neurodevelopmental disorders	No	5172 (85%)	21529 (97%)	-	-	-	-
	Yes	882 (15%)	576 (3%)	5.68 (5.03-6.42)	0.754	0.088	<0.001
Diseases of the nervous system	No	5511 (91%)	21922 (99%)	-	-	-	-
	Yes	543 (9%)	183 (1%)	7.02 (5.80-8.50)	2.954	0.18	<0.001
Diseases of the visual system	No	5502 (91%)	21485 (97%)	-	-	-	-
	Yes	552 (9%)	620 (3%)	1.42 (1.23-1.65)	1.117	0.097	<0.001
Diseases of the ear or mastoid process	No	5697 (94%)	21555 (98%)	-	-	-	-
	Yes	357 (6%)	550 (2%)	1.39 (1.17-1.64)	0.682	0.172	<0.001
Diseases of the circulatory system	No	5807 (96%)	21892 (99%)	-	-	-	-
	Yes	247 (4%)	213 (1%)	2.20 (1.77-2.75)	1.182	0.119	<0.001
Diseases of the respiratory system	No	5497 (91%)	21838 (99%)	-	-	-	-
	Yes	557 (9%)	267 (1%)	5.64 (4.76-6.67)	2.25	0.092	<0.001
Diseases of the digestive system	No	5337 (88%)	21623 (98%)	-	-	-	-
	Yes	717 (12%)	482 (2%)	4.38 (3.81-5.03)	1.546	0.084	<0.001
Diseases of the skin	No	5240 (87%)	20977 (95%)	-	-	-	-
	Yes	814 (13%)	1128 (5%)	1.59 (1.39-1.82)	0.70	0.091	<0.001
Diseases of the musculoskeletal system or connective tissue	No	5047 (83%)	21171 (96%)	-	-	-	-
	Yes	1007 (17%)	934 (4%)	2.36 (2.08-2.69)	1.563	0.104	<0.001
Diseases of the genitourinary system	No	5591 (92%)	21844 (99%)	-	-	-	-
	Yes	463 (8%)	261 (1%)	4.34 (3.63-5.18)	2.042	0.087	<0.001
Pregnancy childbirth or the puerperium	No	5991 (99%)	22091 (99%)	-	-	-	
	Yes	63 (1%)	14 (1%)	6.01 (3.02-11.95)	2.422	1.122	<0.001
Certain conditions originating in the perinatal period	No	6005 (99%)	22102 (100%)	-	-	-	-
	Yes	49 (1%)	3 (0%)	22.25 (6.43-76.95)	4.092	1.038	<0.001
Developmental anomalies	No	5890 (97%)	22025 (99%)	-	-	-	-
	Yes	164 (3%)	80 (1%)	2.07 (1.50-2.86)	2.315	0.374	<0.001
Injury poisoning or certain other consequences of external causes	No	5403 (89%)	21308 (96%)	-	-	-	-
	Yes	651 (11%)	797 (4%)	1.85 (1.6-2.14)	0.872	0.094	<0.001

Supplementary Files

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- MortalityPapersupp.pdf