
Peer reviewed version

License (if available):
CC BY-NC-ND

Link to published version (if available):
10.1016/j.applanim.2021.105507

Link to publication record in Explore Bristol Research

PDF-document

This is the accepted author manuscript (AAM). The final published version (version of record) is available online via Elsevier at https://doi.org/10.1016/j.applanim.2021.105507. Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/
Thinking outside the lab: can studies of pet rats inform pet and laboratory rat welfare?

Vikki Neville\(^1\)*, Jessica Mounty\(^1\), Livia Benato\(^{1,2}\), Kristina Hunter\(^2\), Michael Mendl\(^1\), Elizabeth S Paul\(^1\)

\(^1\)Bristol Veterinary School, University of Bristol, Bristol, BS40 5DU, UK
\(^2\)City Vets, Exeter, EX4 1QS, UK

*Corresponding author: vikki.neville@bristol.ac.uk
Abstract

Surveys provide a low-cost means to obtain large amounts of data that are ideal for conducting exploratory research, and they are becoming an increasingly valuable tool in a veterinary context. We investigated whether surveys of pet rat owners might provide useful data that could pave the way for more targeted empirical studies of pet and laboratory rat welfare. To achieve this, we used an online survey, distributed via social media, in which we asked pet rat owners questions about the housing, handling, and behaviour of their pet rats, from which we obtained 677 fully-completed surveys. We conducted both qualitative and quantitative analyses of these data, examining the reported frequency of the behaviours and using general linear models to investigate how these reported frequencies varied according to age, sex, total number of rats owned, human-interaction (a variable which summarised data relating to questions about human interaction), total number of enrichment types (a variable which summarised data relating to the provision of enrichment), and predator exposure (a variable which summarised data about the ownership of predator species). The study firstly identified well-established and intuitive findings that supported the validity of this approach, including age-dependent changes in behaviour. The study also identified behaviours that are commonly performed by pet rats, many of which are restricted by standard laboratory cages and may be restricted in poorer pet rat housing. This includes the first scientific report of ‘boggling’ in rats. Additionally, by assessing which behaviours varied according to predator exposure (which is likely to be aversive to rats), the study identified potentially novel, spontaneous behavioural indicators of rat welfare. Specifically, the reported frequency of each of the following behaviours was significantly reduced by greater exposure to predator species: digging (LRT=7.264, FDR-adjusted p-value=0.032), bounding (LRT=8.990, FDR-adjusted p-value=0.015), pinning (LRT=9.242, FDR-adjusted p-value=0.015), and bruxing (LRT=17.780, FDR-adjusted p-value<0.001). We conclude that survey data obtained from pet rat owners may provide useful and fruitful information that can inform both pet and laboratory rat welfare.
Introduction
Data collection using postal and online surveys is an established component of medical and social science research\textsuperscript{1–3}. Providing large sample sizes at relatively low cost, the survey approach offers researchers the opportunity to obtain broad-sweep information on the prevalence of, and associations among, a wide variety of participant-reported measures. Common examples include attitude and opinion polls, household economic surveys, and cross-sectional and longitudinal epidemiological studies\textsuperscript{4,5}. Although still far less common than in human-focused research, such survey methods have been increasingly used in recent years to address questions in animal health and welfare. This is especially the case in the field of companion animal studies; in the past five and a half years, a search on Web of Science (Titles “pet” + “survey”; “rat” + “survey”; Jan 2015–July 2021) identified more than thirty studies of companion animal health and welfare using survey methodologies. Veterinary issues concerning cats and dogs, such as vaccination rates and attitudes towards vaccination amongst owners\textsuperscript{6,7}, and the prevalence and prevention of parasitic infections\textsuperscript{8–10}, have demonstrated the value of survey techniques as an important first step towards improving the health and welfare of owned animals. By following owner report surveys with experimental studies and sampling (e.g. endoparasite collection by veterinarians), improvements to clinical care, as well as more fundamental research goals, can be achieved. Similarly, the frequency of occurrence and co-occurrences of a range of behaviour problems of dogs\textsuperscript{11,12} and cats\textsuperscript{13,14} have been explored using wide-scale surveys with large sample sizes.

In sum, self-report owner surveys have been used in both veterinary and behaviour-problem contexts to investigate potential predictors of clinical or behaviour-problem morbidity, as well as highlighting broader welfare concerns associated with poor husbandry practices amongst some owners. For example, a number of studies have considered owner reports of diet and behaviour management in relation to dog obesity\textsuperscript{15–17} while Oxley et al. (2019) investigated the ways in which owners (and other caregivers) reported handling their pet rabbits\textsuperscript{18}, a feature of husbandry with known importance for rabbit welfare. Pet owner surveys clearly have a role to play in informing health, husbandry and welfare improvements for domesticated species. However, while the survey approach to companion animal welfare research has grown, studies to date have been largely restricted to owners of cats and dogs.

Pet rats
Of the smaller mammals commonly owned as pets, only rabbit and guinea pig surveys have been reported\textsuperscript{18–21}. Small mammals represent an important component of the companion animal population. The Pet Food Manufacturers Association (PFMA), for example, estimates a population of approximately 3.3 million small mammals being kept as pets in the UK in 2021 (rabbits, guinea pigs, hamsters, gerbils, rats, ferrets, mice), 200,000 of which are rats\textsuperscript{22}. While these numbers are small compared to the numbers of owned dogs and cats (estimated 12.5M and 12.2M respectively), their popularity appears to be growing. And in the USA, there have been recent suggestions that pet rat popularity is also likely to grow, thanks to their interactive nature and ease of maintenance\textsuperscript{23}.

To establish guidelines for the best ways to house and care for pet rats, animal welfare organizations and veterinary bodies have had little information outside that provided for laboratory rodents (e.g. RPSCA\textsuperscript{24}, PDSA\textsuperscript{25}). But surveying existing rat owners may provide a feasible and potentially informative additional approach.

Laboratory rats
The welfare of rats used in scientific research has long been a focus of welfare research, given their prevalence as a laboratory species\textsuperscript{26}. Currently, it is estimated that 0.16 million rats are used in scientific research (third only to mice and fish at 1.06 million and 0.28 million each) in the United
Kingdom alone\textsuperscript{27}. The good welfare of research animals is necessary for good science\textsuperscript{28-30} - compromised welfare can alter an animal’s behaviour and (neuro)physiology, potentially reducing the reliability and repeatability of results\textsuperscript{28,29,31}. And for the public to tolerate scientific research, there is steady demand for high welfare provision amongst laboratory animals\textsuperscript{32,33}.

To date, research into laboratory rodent welfare has focused almost exclusively on experimental studies of potential housing and husbandry modifications. For example, many potential refinements to laboratory rat housing have been investigated, with much focus on the provision of enrichment\textsuperscript{31,34-38}. Other studies have emphasised the development of measures for detecting negative affective states\textsuperscript{39-41} and refining experimental and husbandry procedures\textsuperscript{42-46}. However, we suggest that there is also scope and untapped potential from survey studies of pet rodent welfare. A recent study of laboratory animal personnel has demonstrated that people involved in the day-to-day care of laboratory rodents are willing and able to engage productively with researchers conducting survey research\textsuperscript{47}. So it is not unreasonable to anticipate that surveys of pet rat owners might be able point to housing and husbandry practices of concern, and those that may be associated with high welfare. While such surveys, unlike experimental studies, are not able to pinpoint causal relationships between particular manipulations or interventions and behavioural or other welfare-related outcomes, they can identify potential issues for further investigation.

The aim of this study was to investigate the kinds of behavioural and husbandry-related information that can be successfully garnered from an online survey of pet rat owners, and to establish how this information might inform approaches to improving rat welfare. While the primary focus of this was the welfare of pet rats, a secondary aim was to consider whether the survey data collected in this way might also inform future studies of relevant to the welfare of all domesticated rats, including those used in laboratory research.

**Methods**

*Ethics statement*

This study received ethical approval from the Faculty of Science Ethics Committee at the University of Bristol (reference number: 103082). No interactions occurred between research team and animals and therefore additional ethical approval was not sought from the University of Bristol Animal Welfare and Ethics Review Body. Respondents were all over the age of 18, their participation in the study was voluntary, and they provided informed consent before completing the survey.

*Survey Contents*

The survey (see Supplementary Material 1), which was created using Google Forms, was designed to take approximately 5 to 15 minutes to complete. This survey duration balanced maximisation of data, against the risk of satisficing and abandonment\textsuperscript{48,49}. The survey comprised seven sections: 1. You and your rat(s); 2. Your rat(s); 3. Your rat’s/rats’ cage(s); 4. Interacting with your rat(s); 5. Your rat’s/rats’ behaviour 6. Your rat’s/rats’ health; and 7. Your experience as a rat owner. Some of the survey data were collected solely for the purpose of a parallel study, which investigated the current state of the pet rat population in the United Kingdom\textsuperscript{50}.

There were several types of questions: those that required the respondent to type a response (either numeric or text), those where the respondent had to select only one answer or could type an ‘other’ response where this was relevant (multiple choice), those where the respondent could select all responses that were applicable and type an ‘other’ response where this was relevant (checkbox), and those where the response was made on a visual-analogue scale, ranging from ‘Never’ through to ‘Several times per day’ (scored from 1 to 10). We opted to provide multiple choices for age instead of allowing respondents to type a response to reduce the time taken to complete the survey and to
provide cleaner data (e.g. free from errors introduced by variation in rounding) and because we considered that many owners may only have approximate information on which to base their answers (e.g. age may be an estimate if the rat had been adopted/or was unknown at the point of purchase). The options provided for questions relating to enrichment and bedding/nesting materials were chosen based on scoping discussions with a range of pet rat owners about the enrichment and bedding/nesting material they use, as well as informal observations of the enrichment and bedding/nesting materials provided in local pet stores – in all cases, an ‘other’ option was provided to allow owners to type in any item that we had not included. The behaviour section of the survey was designed to capture information about a range of types of behaviours, e.g. aggressive behaviours, social behaviours, housing/enrichment directed behaviours, and non-social activities. The specific behaviours selected were based on informal discussions with pet rat owners and laboratory personnel about the behaviours they observe, and also on published studies of laboratory rat behaviour\textsuperscript{36,51,52}. A visual analogue scale was used for owners’ reporting of behaviour frequencies (e.g. as opposed to a Likert scale, with several fixed options) because we considered owner estimations of behaviour frequency to be most readily reported as a continuous variable (given that owners would only observe their rats for a proportion of each day, and are therefore making an approximate estimate). Visual analogue scales, which only provide descriptors at each end-point, have previously been used to assess the frequency of specific behaviours or disease progression in companion animals\textsuperscript{53-55}.

Questions were only shown to respondents to whom they were relevant; if the respondent only had one rat, then they would not be asked questions that were applicable to groups of rats. Prior to distribution of the survey, a pilot version of the survey was completed by four people known to the authors, as well as the authors themselves. The survey was “live” for a three-week period from 25th August 2020 to 15th September 2020, during which it was distributed via social media – including Twitter (two posts from a research group account, each retweeted from a personal account), Reddit (one post from a research group account), and Facebook (one post from a personal account) - as well as through word of mouth. The inclusion criteria were that participants were over the age of 18 and resided in the United Kingdom.

Table 1 Summary of the survey contents relevant to this study including the survey sections, questions within those sections, response options, and the variable that they were used for.

<table>
<thead>
<tr>
<th>Section</th>
<th>Question</th>
<th>Options</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>You and your rat(s)</td>
<td>Do you have any other pets?</td>
<td>I do not have any other pets; Yes - cat(s); Yes - dog(s); Other (please specify)</td>
<td>Predator exposure: (cats, dogs, ferrets or snakes in home)</td>
</tr>
<tr>
<td></td>
<td>Do your other pets, if any, spend any time in the same room in which the rat(s) are housed? (checkbox)</td>
<td>I do not have any other pets; Yes - cat(s); Yes - dog(s); Other (please specify)</td>
<td>Predator exposure (cats, dogs, ferrets or snakes in same room)</td>
</tr>
<tr>
<td>Your rat(s)</td>
<td>What is the sex of your rat?</td>
<td>Male; Female</td>
<td>Sex</td>
</tr>
<tr>
<td></td>
<td>How many female rats do you own?</td>
<td>Sex/Total</td>
<td></td>
</tr>
<tr>
<td></td>
<td>How many male rats do you own?</td>
<td>Sex/Total</td>
<td></td>
</tr>
<tr>
<td></td>
<td>What is the age of your rat? (multiple choice)</td>
<td>0-6 months; 6-12 months; 1-1.5 years; 1.5-2 years; 2-2.5 years; 2.5-3 years; More than 3 years</td>
<td>Age</td>
</tr>
<tr>
<td></td>
<td>What is the age of your youngest rat? (multiple choice)</td>
<td>0-6 months; 6-12 months; 1-1.5 years; 1.5-2 years; 2-2.5 years; 2.5-3 years; More than 3 years</td>
<td>Age</td>
</tr>
<tr>
<td><strong>Your rat's/rats' age</strong></td>
<td><strong>What is the age of your oldest rat? (multiple choice)</strong></td>
<td><strong>0-6 months; 6-12 months; 1-1.5 years; 1.5-2 years; 2-2.5 years; 2.5-3 years; More than 3 years</strong></td>
<td><strong>Age</strong></td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Enrichment</strong></td>
<td><strong>Which of the following items are in your rat's/rats' cage? (checkbox)</strong></td>
<td><strong>Tube; Suspended area (e.g. hammock, sputnik, or hanging basket); Hideaway (e.g. cardboard box or igloo); Climbing structure (e.g. ladder or rope); Foraging toy; Other (please specify)</strong></td>
<td><strong>Enrichment</strong></td>
</tr>
<tr>
<td><strong>What type of bedding/nesting material do you use in the cage? (checkbox)</strong></td>
<td><strong>Paper pellets; Coconut husk/coir; Tissue; Fleece; Sawdust/wood shaving; Straw; Hay; Paper bedding (e.g. Carefresh); Shredded paper; Paper wool (e.g. Safebed); Fluffy bedding; Corncob bedding; None; Other (please specify)</strong></td>
<td><strong>Enrichment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interacting with your rat(s)</strong></td>
<td><strong>How often do you handle your rat(s)? (multiple choice)</strong></td>
<td><strong>Daily; Between daily and weekly; Between weekly and fortnightly; Less than fortnightly</strong></td>
<td><strong>Human interaction frequency</strong></td>
</tr>
<tr>
<td><strong>Which of the following applies to you and your rat(s)? (checkbox)</strong></td>
<td><strong>I train my rats to perform tricks; My rats have time where they can run freely outside of their cage; I have a playpen for my rats separate from their cage; My rats will climb onto my hands, arms, or shoulders; I provide activities for my rats (e.g. access to a digging tank/pea-fishing)</strong></td>
<td><strong>Human interaction/Enrichment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Your rat's/rats' behaviour</strong></td>
<td><strong>How frequently do you observe: biting another rat? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – biting conspecific frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: biting me or another person? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – biting human frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: boggling (eyes 'popping' in and out)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – boggling frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: bounding (running with leaps and hops)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – bounding frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: boxing with another rat (standing on hind legs and moving arms at each other)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – boxing frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: bruxing (grinding teeth without movement of the eyes)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – bruxing frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: caching food (moving food to a specific location)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – food hoarding frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: climbing? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – climbing frequency score</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How frequently do you observe: communal sleeping (e.g. sleeping in close proximity to each other)? (scale)</strong></td>
<td><strong>1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day)</strong></td>
<td><strong>Behaviour – communal sleeping frequency score</strong></td>
</tr>
</tbody>
</table>
How frequently do you observe: chasing each other? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – chasing frequency score
---|---|---
How frequently do you observe: digging? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – digging frequency score
How frequently do you observe: gnawing non-food item (e.g. chewing the cage bars)? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – gnawing frequency score
How frequently do you observe: grooming another rat? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – grooming frequency score
How frequently do you observe: nesting (e.g. carrying material from one area of the cage to an area in which they sleep)? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – nesting frequency score
How frequently do you observe: pinning each other (where one rat is on the floor, and another rat is holding them down)? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – pinning frequency score
How frequently do you observe: rearing (e.g. standing on hind legs)? (scale) | 1 (never), 2, 3, 4, 5, 6, 7, 8, 9, 10 (several times per day) | Behaviour – rearing frequency score

**Data analysis**
We assessed the relationship between our predictor variables and behaviour and health by fitting general linear models to the data and using a likelihood ratio test to assess the significance of each predictor variable. Visual inspection of the residuals revealed that the model assumptions of homoscedasticity were met. In many cases, the model residuals were skewed but we opted not to transform the dependent variables to remedy this as doing so would complicate interpretation of the results and because GLMs are robust to skewed residuals when analysing large datasets. Due to the large number of likelihood ratio tests conducted, increasing the possibility of obtaining a false positive result, the p-values from all GLMs were adjusted using the false discovery rate (FDR). These analyses were conducted at the household level as opposed to the rat level or cage level, given the lack of independence between rats from the same household and as much as the data were collected for groups of rats occupying the same household as a whole (e.g. a behaviour frequency score across all rats rather than for individual rats or cages). The dependent variables used were the reported frequency score for each behaviour. The predictor variables in each model were: total number of rats owned, age of the youngest/eldest rat or age of a singly owned rat (1 = 0-6 months; 2 = 6-12 months; 3= 1-1.5 years; 4 = 1.5-2 years; 5 = 2-2.5 years; 6 = 2.5-3 years; 7 = More than 3 years), sex composition of group (all female, all male, or both) or sex of singly owned rat (female, male), predator exposure (0 = no predators in same home; 1 = predators in same home with no access to same room as rats; 2 = predators in same home and have access to room in which the rats are housed), human interaction (range 0.5 - 3), and total enrichment types (range 0 - 10).
Of the predictor variables, the following were composites created using a non-weighted summary of relevant factors: total enrichment types, and human interaction (see Table 2). A non-weighted summation was used as we had no a priori reasons to weight any factor more highly than others.

**Table 2** The components of each composite variable and their possible range of values. The asterisk indicates where the component was based on the response given and our definition of nesting materials and digging substrates; we considered that rats were provided with a digging substrate if the owner provided a substrate could be easily manipulated and displaced via digging – including paper pellets, coconut husk/coir, sawdust/wood shavings, hay, paper bedding, corncob bedding, soil, hemp bedding, straw, cat litter, flax bedding, wood pellets, and were provided with nesting material if the owner provided a substrate that could unambiguously be manipulated and transported by the rat to provide insulation – including tissue, hay, paper bedding, shredded paper, paper wool, fluffy bedding, straw, and alpaca wool.

<table>
<thead>
<tr>
<th>Composite variable</th>
<th>Variable type</th>
<th>Components (possible values 0=no, 1=yes, unless otherwise indicated)</th>
<th>Possible range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total enrichment types</td>
<td>Predictor</td>
<td>Provision of nesting material* + Provision of digging substrate* + Provision of foraging device + Climbing structure + Time to run freely outside the cage + Tube + Hideaway + Suspended area + Provision of playpen + Provision of activities</td>
<td>0-10</td>
</tr>
<tr>
<td>Human interaction</td>
<td>Predictor</td>
<td>Handling frequency (0.25 = less than fortnightly, 0.5 = between weekly and fortnightly, 0.75 = between daily and weekly, 1 = daily) + Allowing rat to climb on person + Training rat to perform tricks</td>
<td>0.25-3</td>
</tr>
</tbody>
</table>

Age and sex, in addition to the interaction between age and sex, were included as predictor variables as they are known to have important effects on rat behaviour, and total number of rats owned was included to account for owners with a greater number of rats having a greater chance of observing each behaviour. The age data we collected were age of the youngest rat and age of the eldest rat; these age categories were weakly but significantly correlated (Spearman’s rho=0.321, p<0.001). To account for the possibility that different results might be obtained depending on which of these variables we used as a proxy for age, all GLMs were fitted with each of these alternate options and both sets of results are reported where the results are qualitatively different. Predator exposure, human interaction, and total enrichment types were included as we hypothesised that these variables, which provide information about the rats’ environment and its likely suitability, would impact behaviour.

**Results**

**Subjects and demographics**
A total of 677 questionnaires were completed in full, and there were 3893 rats owned across all participants. The majority of respondents (97.6%) owned more than one rat, with the respondents owning a median of four rats. Respondents more commonly reported owning only male rats (43.6%) than only female rats (36.0%), and 19.9% of respondents owned both male and female rats. The median age group for the youngest rat was 6-12 months, and for the eldest rat it was 1.5-2 years (Fig 1).
The middle horizontal line indicates the median, the upper and lower horizontal lines reflect the $75^{th}$ and $25^{th}$ percentile respectively, and the vertical line extends from the minimum value to the maximum value or from 1.5 times the interquartile range below the median to 1.5 time the interquartile range above the median, where there are values (i.e. outliers, shown as points) that exceed this range of values.

The median value of the predator exposure variable was 0; 47.7% of respondents reported owning a predator species (26.9% owned a cat; 31.8% owned a dog; 0.26% owned a ferret; 3.25% owned a snake) and 68.4% of these respondents reported that this pet had access to, or were housed in, the room in which the rats were kept.

The median value of the human interaction variable was 1; most respondents (91.6%) reported that they handled their rats daily (Fig 2) and very few reported that they allowed their rats to climb over their arms or shoulders (2.81%) or trained their rats to perform tricks (0.30%).
Figure 2 The proportion of respondents handling their rats daily, between weekly and daily, between weekly and fortnightly, and less than fortnightly.

The median number of enrichment types was 7; the majority of respondents provided their rats with a substrate that could unambiguously provide an opportunity for digging (e.g. sawdust), a substrate that could unambiguously be used to build nests (e.g. shredded paper), a suspended area, a climbing structure, a hideaway, a tube, a foraging device (i.e. a device that makes rats work to obtain food), and activities (Fig 3). Few respondents allowed their rat time to run freely outside of their cage or had a separate playpen for their rats (Fig 3).
Figure 3 The proportion of respondents that provide their rat with each different type of enrichment.

Predictor variables

There were no strong or very strong correlations, defined as Spearman’s Rho > 0.7, between the continuous predictor variables (Table 3) Age of eldest rat and number of rats were moderately positively correlated while age of the youngest rat was weakly negatively correlated with number of rats owned; owning more rats was associated with a wider age range of the rats owned (Table 3). Age of the eldest rat and age of the youngest rat were weakly positively correlated. The remaining correlations were negligible (Table 3).

Table 3. Correlation matrix showing the Spearman’s Rho value for correlations between each of the predictor variables. The colour of each cell indicates the strength of the correlation.
**Behaviour - general levels of occurrence**

Climbing and communal sleeping were observed on a daily basis by most owners and allogrooming was very frequently observed, while biting (either a human or another rat) were infrequently observed (Table 4 and Fig 4). There was considerable variation in the frequency at which the remaining behaviours were observed (Table 4 and Fig 4), but behaviour patterns that were commonly seen included bounding, bruxing, chasing another rat, digging, rearing, pinning and boggling. Less common behaviours included gnawing and boxing (Table 4 and Fig 4). There were a few behaviours that were moderately correlated (i.e. Rho>0.4 and Rho<0.69, Supplementary Table 1): those involving the same muscle (i.e. masseter muscle) movement - bruxing and boggling (rho=0.446), see Supplementary Material 2 for bruxing and boggling example; those that form part of a suite of (play)fighting behaviours – boxing and chasing (Rho=0.431), boxing and pinning (Rho=0.545), pinning and chasing (Rho=0.514) and nesting and food hoarding (rho=0.476). The remaining behaviours were weakly or negligibly correlated (see Supplementary Table 1).

**Table 4** The mean and mode of the behaviour frequency scores.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Median</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climbing</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Communal sleeping</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Allogrooming</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Bounding</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Bruxing</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Chasing</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Food hoarding</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Nesting</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Digging</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Rearing</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Boggling</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Pinning</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Boxing</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Gnawing</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Biting conspecific</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Biting human</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 4 Boxplots of the frequency scores for each of the behaviours reported by owners; the possible scores range from 1 (Never) to 10 (Several times per day). Boxplots of the age categories for both the youngest and eldest rat across respondents; the middle horizontal line indicates the median, the upper and lower horizontal lines reflect the 75th and 25th percentile respectively, and the vertical line extends from the minimum value to the maximum value or from 1.5 times the interquartile range below the median to 1.5 time the interquartile range above the median, where there are values (i.e. outliers, shown as points) that exceed this range of values.

**Behaviour – statistical analyses**

*How is reported behaviour associated with human interaction?*

Owners that reported greater interaction with their rats less frequently observed climbing and nesting, reported significantly less frequent biting of both humans and conspecifics, and more frequently observed allogroming (Table 5; Supplementary Table 2). Human interaction was a significant predictor of digging, but only when age of the eldest rat, instead of age of the youngest rat, was used as a co-variate in the GLMs (Table 5; Supplementary Table 2). However, with the exception of climbing behaviour, these results were no longer significant following adjustment for multiple comparisons (Table 5; Supplementary Table 2).

**Table 5** Results of the statistical analyses of behaviour with human interaction, predator exposure, total enrichment types, age, sex, total number of rats owned, and the interaction between age and sex as predictor variables. The likelihood ratio test (LRT) value and FDR-adjusted p-value are given in all instances and the direction of the effect is given where significant: ‘+’ indicates a positive correlation or that the group specified has a higher value compared to other groups, and ‘-’ indicates
A negative correlation or that the group specified has a lower value compared to other groups. The results are from the GLMs that include age of the eldest rat as a predictor variable. Where results differ qualitatively when age of the youngest rat is instead included as a predictor variable, both results are presented with brackets indicating that the result is from the GLM with age of the youngest rat as a predictor variable. Significant results are emboldened and asterisks indicate level of significance: MNS=marginally non-significant, *=<0.05, **=<0.01, ***=<0.001.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Human interaction</th>
<th>Predator exposure</th>
<th>Total enrichment types</th>
<th>Age</th>
<th>Sex</th>
<th>Total N of rats owned</th>
<th>Sex*Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biting conspecific</td>
<td>LRT=5.468, p=0.081MNS</td>
<td>LRT=3.517, p=0.168</td>
<td>LRT=1.282, p=0.483</td>
<td>LRT=2.158, p=0.308</td>
<td>LRT=0.533, p=0.943</td>
<td>LRT=0.193, p=0.833</td>
<td>LRT=4.585, p=0.394</td>
</tr>
<tr>
<td>Biting human</td>
<td>LRT=4.565, p=0.116</td>
<td>LRT=5.361, p=0.085MNS</td>
<td>LRT=0.082, p=0.873</td>
<td>LRT=0.001, p=0.998</td>
<td>LRT=5.689, p=0.290</td>
<td>LRT=1.111, p=0.523</td>
<td>LRT=2.074, p=0.740</td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boxing</td>
<td>LRT=0.457, p=0.725</td>
<td>LRT=0.072, p=0.873</td>
<td>LRT=0.021, p=0.921</td>
<td>LRT=2.712 (10.335), p=0.0248 (0.009**)</td>
<td>LRT=7.961, p=0.134</td>
<td>LRT=1.145, p=0.516</td>
<td>LRT=1.058, p=0.873</td>
</tr>
<tr>
<td>Chasing</td>
<td>LRT=1.023, p=0.548</td>
<td>LRT=2.540, p=0.266</td>
<td>LRT=0.668, p=0.631</td>
<td>LRT=33.946, p=&lt;0.001***</td>
<td>LRT=5.962, p=0.266</td>
<td>LRT=1.465, p=0.430</td>
<td>LRT=3.370, p=0.560</td>
</tr>
<tr>
<td>Communal sleeping</td>
<td>LRT=0.827, p=0.572</td>
<td>LRT=0.409, p=0.735</td>
<td>LRT=1.958, p=0.333</td>
<td>LRT=0.154, p=0.848</td>
<td>LRT=16.119, p=0.001***</td>
<td>Females +, LRT=11.688, p=0.041*</td>
<td>LRT=5.739, p=0.083MNS</td>
</tr>
<tr>
<td>Grooming conspecific</td>
<td>LRT=4.908, p=0.101</td>
<td>LRT=2.261, p=0.293</td>
<td>LRT=1.184, p=0.508</td>
<td>LRT=16.119, p=0.001***</td>
<td>LRT=5.889, p=0.269</td>
<td>LRT=0.973, p=0.552</td>
<td>LRT=0.739, p=0.911</td>
</tr>
<tr>
<td>Pinning</td>
<td>LRT=0.060, p=0.884</td>
<td>LRT=9.242, p=0.015*</td>
<td>LRT=0.265, p=0.779</td>
<td>LRT=8.904, p=0.018*</td>
<td>LRT=2.207, p=0.735</td>
<td>LRT=0.150, p=0.848</td>
<td>LRT=11.814 (4.961), p=0.001* (0.326)</td>
</tr>
<tr>
<td>Non-social behaviours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boggling</td>
<td>LRT=0.095, p=0.873</td>
<td>LRT=1.898, p=0.340</td>
<td>LRT=3.427 (6.590), p=0.173 (0.048*)</td>
<td>LRT=63.360, p=0.001***</td>
<td>LRT=0.034, p=0.998</td>
<td>LRT=0.295 (10.863), p=0.773 (0.009**)</td>
<td>LRT=1.380, p=0.854</td>
</tr>
<tr>
<td>Bounding</td>
<td>LRT=0.285, p=0.775</td>
<td>LRT=8.990, p=0.018*</td>
<td>LRT=2.655, p=0.252</td>
<td>LRT=4.351, p=0.124</td>
<td>LRT=2.633, p=0.663</td>
<td>LRT=8.666 (0.180), p=0.018* (0.355)</td>
<td>LRT=1.074, p=0.873</td>
</tr>
<tr>
<td>Bruxing</td>
<td>LRT=1.018, p=0.548</td>
<td>LRT=17.780, p=0.001***</td>
<td>LRT=0.357, p=0.737</td>
<td>LRT=17.846, p=0.001***</td>
<td>LRT=1.525, p=0.833</td>
<td>LRT=2.106 (7.068), p=0.314 (0.041*)</td>
<td>LRT=2.178, p=0.735</td>
</tr>
<tr>
<td>Climbing</td>
<td>LRT=18.465, p=0.001***</td>
<td>LRT=7.443, p=0.036*</td>
<td>LRT=12.558, p=0.001***</td>
<td>LRT=6.634, p=0.218</td>
<td>Females +ve, LRT=19.408, p=0.015* (0.873)</td>
<td>LRT=3.874 (11.598), p=0.508 (0.044*)</td>
<td>LRT=0.106, 0.998</td>
</tr>
<tr>
<td>Digging</td>
<td>LRT=4.361, p=0.124</td>
<td>LRT=7.264, p=0.040*</td>
<td>LRT=26.880, p=0.001***</td>
<td>LRT=0.413 (13.384), p=0.735 (&lt;0.001***</td>
<td>Females +ve, LRT=13.799, p=0.018*</td>
<td>LRT=19.408, p=0.001***</td>
<td>LRT=0.106, 0.998</td>
</tr>
</tbody>
</table>
How is reported behaviour associated with predator exposure?

Owners whose rats had greater exposure to predators were reported to more frequently bite humans, and their owners less frequently observed bruxing, bounding, digging, gnawing, and pinning (Table 6). Following adjustment for multiple comparisons, only the bounding, bruxing, digging, and pinning frequency scores were significantly predicted by predator exposure (Table 5; Supplementary Table 2).

To assess the extent to which these results may be due to the extent of predator exposure, as opposed to ownership of a predator species or ownership of any species, we fitted otherwise identical GLMs that included either ownership of other pet (‘yes’/‘no’) or ownership of predator species (‘yes’/‘no’) instead of predator exposure as predictor variables. We then compared these alternate models using a BIC score to investigate which model provided the best explanation of the data. For pinning, the most parsimonious model included ownership of predator species (difference in BIC to next best model, dBIC=0.866) instead of predator exposure or ownership of other pet. For bruxing (dBIC=0.764), bounding (dBIC=1.606), and digging (dBIC=0.485), the most parsimonious model included predator exposure as opposed to ownership of predator species or ownership of other pet.

How is reported behaviour associated with total enrichment types?

Owners whose rats had a greater number of enrichment types more frequently observed climbing, digging, and nesting; all of which remained significant following adjustment for multiple comparisons (Table 5; Supplementary Table 2). When age category of the youngest rat was used as a covariate in the GLMs instead of the eldest rat, total enrichment types was a significant predictor of boggling (both prior to and following adjustment) and food hoarding (solely prior to adjustment) (Table 5; Supplementary Table 2).

How is reported behaviour associated with age, sex, and total number of rats owned?

Owners with older rats more frequently observed boggling, bruxing, allogrooming, nesting and less frequently observed bounding, chasing, climbing, pinning and rearing. Of these, the following behaviours remained significantly predicted by age following adjustment for multiple comparisons: boggling, bruxing, chasing, climbing, grooming conspecific, nesting, pinning, and rearing (Table 5; Supplementary Table 2). Digging and boxing were significantly predicted by age both prior to and
following adjustment for multiple comparisons, but only when age of the youngest rat was used as a predictor variable, and similarly, food hoarding (prior to adjustment for multiple comparisons only) was significantly predicted by age, but only when age of the eldest rat was used a predictor variable (Table 5; Supplementary Table 2).

Owners with female rats more frequently observed communal sleeping, digging, food hoarding, gnawing, and nesting, and less frequently observed boxing (Table 5; Supplementary Table 2). Following adjustment for multiple comparisons, sex remained a significant predictor of communal sleeping, digging, food hoarding, nesting (Table 5; Supplementary Table 2). When the age of the youngest rat was used as a covariate instead of age of the eldest rat, chasing, climbing and allogrooming were significant, although only prior to adjustment for multiple comparisons (Table 5; Supplementary Table 2).

The interaction between age and sex was a significant predictor of climbing (using age of the youngest rat only), food hoarding (using the age of the eldest rat and prior to adjustment for multiple comparisons only), and pinning (using the age of the eldest rat only) (Table 5; Supplementary Table 2); climbing and hoarding decrease most sharply with age in groups of male rats, and food hoarding increases most sharply with age in female rats.

Owners with a greater number of rats more frequently observed communal sleeping and digging, only digging remained significant following adjustment for multiple comparisons (Table 5; Supplementary Table 2). When age of the youngest rat was used as a covariate, owning more rats was associated with more frequent observations of boggling (both prior to and following adjustment for multiple comparisons) and allogrooming (only prior to adjustment for multiple comparisons), while when age of the eldest rat was used as a covariate, owning more rats was associated with more frequent observations of bounding, bruxing, climbing (all both prior to and following adjustment for multiple comparisons) and food hoarding (only prior to adjustment for multiple comparisons) (Table 5; Supplementary Table 2).

Discussion
The aims of this study were to assess whether data provided by pet owners could inform rat welfare, and to ask whether the survey data obtained could provide useful information about the relationship between variables that potentially influence welfare and putative welfare indicators (i.e., whether they can point to possible links between rat husbandry and welfare, and rat behaviour and welfare). Our survey data provide support for the utility of pet rat populations in this endeavour. Firstly, we achieved a large sample population with high heterogeneity; with data from 677 respondents reporting on rats of different ages and sexes, each in different households with varying levels of exposure to other species, different types of enrichment, and with varying levels of human interaction. Secondly, the study identified a number of previously identified and intuitive findings that support the validity of this approach, such as a greater frequency of play (e.g. chasing and pinning; core components of the rat play sequence61,64–66) and greater climbing and rearing in younger animals36, as well as sex-differences in food hoarding60. To our knowledge, this study also provides the first scientific description and analysis of boggling in rats. Although the results of the statistical analyses in this study are correlational, meaning that we cannot be certain of cause-and-effect relationships, they may nonetheless allow a more targeted approach to empirical investigations of rat welfare by highlighting potential areas that warrant further investigation. For example, methodologies for studying reward responsiveness in rats owned by the public have been developed, paving the way for empirical studies of a phenomenon that may give an insight into rat affective state and welfare68,69.
The rats in this study were reported to frequently perform a wide range of behaviours by their owners. Importantly, a large number of these common behaviours, such as climbing, food hoarding, bounding, nesting, digging and rearing, could potentially be restricted in pet rats (e.g. where owners do not provide a suitably large cage or suitable bedding/nesting substrate) and are highly restricted by standard laboratory housing. Moreover, pet rats that were provided with greater opportunities to engage in natural behaviours, through provision of a greater number of enrichment types, were observed by their owners to more frequently climb, dig, and nest. Clearly, when given the resources and opportunity, domestic rats will demonstrate an extensive behavioural repertoire. This is also consistent with a study by Makowska and Weary (2016) that found that female laboratory rats will frequently climb and dig when given an opportunity to do so. Additionally, there is evidence that providing rats with space to rear reduces anxiety-like behaviour and cages allowing sufficient room to rear and provision of foraging opportunities are recommended to enhance rat welfare. While further research should be conducted to elucidate the full extent to which allowing rats to perform these common behaviours could be beneficial to welfare, the available evidence supports the use of large cages that allow rats to rear, climb, and bound, with both nesting material and a digging substrate provided for both pet and laboratory rats.

Predator exposure is likely to induce an aversive, stress-like response in rats, although there is conflicting evidence as to whether rats habituate to predator odours across time. Nevertheless, it is conceivable that behaviours associated with our measure of predator exposure (no predators in home / predators in home / predators in same room as rats) could represent indicators of stress in rats. Our study revealed several behaviours that were less frequently observed by owners when predator exposure was greater: bounding, bruxing, digging, and pinning. It is plausible that the predator exposure variable simply reflects the extent to which owners spend time observing their rats; with owners spending less time observing their rats because they have multiple pets that require attention. However, we consider this to be unlikely. Firstly, our results demonstrate that the relationship between predator exposure and bruxing, bounding, and digging was best explained by the degree of predator exposure experienced by the rats, and pinning was best explained by whether or not a predator species was owned, as opposed to simply ownership of another pet. Importantly, a predator score of ‘2’ is likely to indicate less divided attention than a predator score of ‘1’ – given that it would indicate that rats were not kept separate from the predator species (i.e. both species could be observed at the same time with a score of ‘2’ but not ‘1’). Moreover, if predator exposure did encode the extent to which owners spent time observing their rats or interacted with their rats then we would have anticipated a stronger correlation between predator exposure and human interaction, and would have anticipated that predator exposure would have exerted a more uniform effect across behaviours with similar levels of occurrence and variability. Similarly, if the predator exposure variable reflected the extent to which an owner has time to dedicate to providing enrichment activities or designing an appropriately enriched cage for their rats, this would most likely have been captured by the total enrichment types variable; which was negligibly correlated with predator exposure.

Additionally, our interpretation that these behaviours may be putative welfare indicators would be consistent with how some of them are currently interpreted. For example, bounding has been suggested to reflect a joy-like state, associated with play, in rats and other species, such as piglets and wolves. Likewise, pinning is a core component of play behaviour in rats, and presence of play has been proposed as an indicator of good welfare. Although bruxism has been associated with pain in rats and other species, the pet rat community have also interpreted bruxing and boggling to indicate a contentment-like state in rats. This apparent contradiction in the interpretation of behaviour is also seen in other species; although rabbits will brux when in pain, bruxing has also been associated with more positive ‘contentment-like’ states. Likewise, purring in cats is associated
with both contentment-like states and with pain\textsuperscript{91,92}. If further research confirms an association between bruxing and positive affective states, this behaviour (and possibly also the closely related boggling behaviour) could provide a valuable cage-side measure of welfare in both pet and laboratory rodents, even within smaller cages which may limit many behaviours. Indeed, with the rise of automated measures for monitoring of animals within a cage\textsuperscript{93-95} it may be possible to obtain this data with minimal time expenditure.

There was evidence that behaviours putatively associated with welfare (i.e. those influenced by predator exposure) were modulated by the sex and age of the rats; males were less likely to be observed digging, younger rats were less likely to be observed bruxing, and older rats were less likely to be observed pinning or bounding. This indicates that, many factors may need to be taken into account when attempting to use behaviour to compare welfare between individual rats or groups. Consequently, use of behaviour to measure welfare may be more appropriate to assess potential changes to the welfare of an individual over time. It is also clear that a one-size-fits all approach to measuring and improving welfare in rats may not be appropriate. We are unaware of any attempts to assess age- or sex- dependent differences in the suitability of potential refinements to rat housing. However, given the sex and age differences observed in pet rat behaviour, we speculate that female rats might benefit more from burrowing opportunities than male rats or a lack of such opportunities may be more detrimental to females than males, while young rats may benefit more from additional space, or may be more greatly impacted by smaller spaces, than older rats. Further studies with pet and laboratory rats may help to better understand how best to measure welfare or tailor welfare improvements to different rat demographics.

Owners who spent more time interacting with their rats also observed climbing behaviours less frequently. There are several potential explanations for this finding; it may be that owners that spend more time interacting with their rats are more strongly associated with rewarding treats and hence rats engage in approach or attention-seeking behaviours such as climbing to elicit treat-giving when they sense the presence of their owners, it may be that owners that spend more time interacting with their rats more frequently or solely observe their rat outside of a cage setting where there are fewer climbing opportunities, or it may be a spurious finding. There was no reliable evidence that human interaction was associated with the frequency of any of the other behaviours assessed.

Conclusions

The interpretation of survey data is naturally limited by many assumptions about how the respondents have completed the survey and assumptions about how to interpret data, such as whether the owners’ observations are a true reflection the housing conditions and behaviours performed, and whether there any inconsistencies in how owners have interpreted and responded to the questions. There are also clear trade-offs when using surveys; more detailed information may be obtained which could help to provide a more detailed understanding of the data, but only at the expense of completion rats and accuracy. Such issues are an inevitable part of this approach. Nonetheless, survey data is valuable, as evidenced by previous psychology and veterinary survey studies. Importantly, by surveying rat owners, we obtained data from a large and highly heterogenous population of rats – much larger and more heterogenous than could be achieved in an empirical study, and rats were not bred for the purpose of this study. This provided us with sufficient data to take an exploratory approach to investigating rat welfare, and allowed us to do so in a way that reduces the number of animals used in research.

This study provides much food for thought with regards to pet and laboratory rat welfare. It highlights the likely importance of providing pet rats opportunities to engage in a wide range of behaviours, and
it also identifies potential novel spontaneous behavioural indicators of welfare in pet rats such as digging, bounding, and boggling and bruxing. It is possible that these findings will also extend to laboratory rat populations, and hence our results point to potential welfare enhancements and potential welfare measures that warrant investigation. It will be important to further investigate the impact of such enhancements and to investigate the validity of these potential welfare measures.

Acknowledgements
Authors Neville, Mendl, and Paul are currently funded by a grant from the Biotechnology and Biological Sciences Research Council, reference BB/T002654/1.

References


