

REVIEW

A review of the circumstances and health-seeking behaviours associated with bat exposures in high-income countries

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Abstract

Human–bat interactions are now the source of the majority of locally acquired human lyssavirus infections in many high-income countries without hematophagous or ‘vampire’ bat species. This study aims to identify the most common types and circumstances of bat exposures occurring among members of the general public in high-income countries with no hematophagous bats, and to describe the health-seeking behaviours associated with exposures in these settings. We conducted a scoping review of relevant academic and grey literature on bat exposures and confirmed bat lyssavirus infections among members of the general public in Australia, Canada, the United States and high-income European countries from 1996 to 2019. Case studies and population-based studies were included for analysis, and findings were extracted and synthesized by the literature type and geographic region. A total of 63 publications were identified, including: 47 case studies and 16 population-based studies. Overall, most exposures in Australia and Europe were intentionally initiated by humans and involved attempts to handle, touch or help a bat. In North America, however, household exposures were more common and predominantly involved a bat being found in a room or area where a person had slept. Studies also showed that a proportion of bat exposures in high-income countries go unreported in the absence of a public health investigation and are therefore unlikely to receive prompt treatment. The results of this review suggest that the most effective strategies for preventing bat exposures vary between regions and that health-seeking behaviours following bat exposures could be improved in high-income settings.

KEYWORDS

bat, health behaviour, humans, lyssavirus, public health, zoonotic transmission

1 | INTRODUCTION

Interactions between humans and bats (i.e. bat exposures) have emerged as an important health concern in many high-income countries where they now represent the primary source of locally acquired human lyssavirus infections. Interestingly, this includes countries with no indigenous hematophagous or ‘vampire’

bat species such as Australia, Canada and the United States (Fenton et al., 2020; Francis, McCall et al., 2014; Pieracci et al., 2019). Since there are currently no effective means of eliminating lyssavirus in wild bat populations, the key to averting human infection in these settings rests in public health measures aimed at preventing and appropriately managing human exposures to bats.

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Bats are known reservoirs for 15 of the 17 lyssavirus genotypes currently recognized by the International Committee on Taxonomy of Viruses, six of which have been associated with human infection (International Committee on Taxonomy of Viruses, 2019; Shipley et al., 2019). These include the following: classical rabies lyssavirus (RABV); Australian bat lyssavirus (ABLV); European bat lyssavirus type 1 (EBLV-1); European bat lyssavirus type 2 (EBLV-2); Duvenhage lyssavirus (DUVV) and Irkut lyssavirus (IRKV) (Table 1) (Shipley et al., 2019). All six of these genotypes belong to the same phylogenetic group of lyssaviruses, referred to as phylogenetic group I, and four are widely distributed in high-income countries with no hemaphagous bats (Echevarría et al., 2019; Shipley et al., 2019).

The most common route of transmission for lyssaviruses, including bat lyssaviruses, is through the bite or scratch of an infected animal (De Serres et al., 2008; WHO, 2018b). However, as bat bites and scratches may go unnoticed, any direct physical contact with a bat is considered by the World Health Organization (WHO) to be a severe or category III exposure, requiring immediate medical attention (WHO, 2018a, 2018b). Unless the animal involved is tested and found to be negative for lyssavirus, any potential exposure must be treated promptly with rabies post-exposure prophylaxis (PEP) as symptomatic infections continue to be nearly always fatal (Feder, Petersen, Robertson, & Rupprecht, 2012; WHO, 2018b). Current evidence indicates that PEP is most effective if initiated within 48–72 h (Muhamuda et al., 2007) and as a result, many countries including Canada, Australia and Belgium recommend that treatment should not be delayed beyond 48h after the encounter wherever possible (Department of Health, 2018; Government of Canada, 2015). However, national recommendations in the United States do not include explicit timeframe parameters, allowing for a more flexible testing period where the animal is available and other risk factors (e.g. severity and location of wound) permit (Manning et al., 2008).

For previously vaccinated individuals, PEP consists of only one to two follow-up rabies vaccinations (Manning et al., 2008; WHO, 2018a, 2018b). However, for most of the general public who are unvaccinated, PEP is far more complicated and resource-intensive, comprising the injection of rabies immunoglobulin (RIG) in and around the wound(s) as well as a full course of post-exposure rabies vaccinations (WHO, 2018a, 2018b). Despite their status as a critical and lifesaving resource, equine- and human-derived RIG (known as ERIG and HRIG, respectively) are both continuously in short supply worldwide, with fewer than ten countries now manufacturing either type (WHO, 2018b). Furthermore, HRIG, which is considerably more difficult and costly to produce, remains the only RIG currently approved for use in high-income countries (Jentes et al., 2013; Shelke & Rachh, 2019; Sparrow et al., 2019). As such, providing optimal post-exposure treatment to all those in need is currently fraught with logistical, economical and ethical challenges.

This scoping review aims to (1) identify the most common circumstances and types of bat exposures that occur among members of the general population in high-income countries without hemaphagous bats, and (2) determine whether these exposures were reported by the individuals to public health authorities. The findings

Impacts

- The most common circumstances and types of bat exposures in members of the general public differ between high-income countries in different regions.
- Health-seeking behaviours following bat exposures in members of the general public could still be improved in high-income countries.
- Public health interventions intended to reduce bat exposures and improve associated health-seeking behaviours should reflect local contexts and aim to consider the ecological value of bat species.

of this review will provide important insight into bat exposures in high-income settings, which could inform public health initiatives targeted at preventing and managing these events.

2 | MATERIALS AND METHODS

2.1 | Search strategy

We conducted a search of relevant academic and grey literature on potential bat lyssavirus exposures and confirmed bat-related lyssavirus infections in the general public from Australia, Canada, the United States and European countries published between January 1996 and November 2019. The following databases were used to identify relevant publications: Pubmed, Vetmed, CINAHL, Embase and Scopus. The search strings were comprised of <country terms>AND<lyssavirus genotype terms> AND <exposure terms> AND<bat terms> AND<human and domestic pet terms>, and a mix of MeSH terms and free text were used. The complete search strings used for each database are provided in Table S1. Where MeSH terms could not be used for country terms, the expanded list of names found in the MeSH terms from Pubmed were entered into the search string. For the VetMed database, the results for specific countries of interest were independently selected from the initial search results.

To minimize publication bias, government websites and the reference lists of pertinent academic studies were hand searched for other relevant sources.

2.2 | Inclusion and exclusion criteria

For the purposes of this review, a bat exposure includes any human and bat interaction that either preceded a human lyssavirus infection or was explicitly identified in the publication as an exposure risk (i.e. resulted in the submission of the bat for testing to exclude infection or was recommended or deemed eligible for PEP by health authorities).

TABLE 1 Bat lyssaviruses known to infect humans

Bat lyssavirus genotype	Geographic distribution in bat species (Countries confirmed)	First documented human case	Sources
Australian bat lyssavirus (ABLV)	Australia	1996	Echevarria et al. 2019 Murray et al. 1996
Duvenhage lyssavirus (DUVV)	Southern and Eastern Africa (incl. Kenya, South Africa and Zimbabwe)	1970	Echevarria et al. 2019 Meredith et al. 1971
European bat lyssavirus type 1 (EBLV-1)	All 4 regions of Europe (incl. Denmark, France, Germany, Hungary, Netherlands, Poland, Russia, Spain, Slovakia and Ukraine)	1985	Botvinkin et al. 2005 Echevarria et al. 2019 Forró et al. 2021
European bat lyssavirus type 2 (EBLV-2)	Northern and Western Europe (incl. Finland, France, Germany, Luxembourg, The Netherlands, Switzerland and The United Kingdom)	1985	Echevarria et al. 2019 Lumio et al. 1986
Irkut lyssavirus (IRKV)	Eastern Europe and Northern Asia (incl. Russian Federation and China)	2007	Echevarria et al. 2019 Leonova et al. 2009
Rabies lyssavirus (RABV)	The Americas (incl. All mainland countries and territories in North, Central and South America, Cuba, Dominican Republic, Grenada, and Trinidad)	1929 ^a	Constantine 2009 Echevarria et al. 2019 Mungrue and Mahabir 2011 Seetahal et al. 2018

^aRefers to the first documented case of human rabies of suspected bat origin, which was diagnosed retrospectively. Adapted from this Table. Bat lyssaviruses in Echevarria, J. E., Banyard, A. C., McElhinney, L. M., and Fooks, A. R. 2019. 'Current Rabies Vaccines Do Not Confer Protective Immunity against Divergent Lyssaviruses Circulating in Europe', licensed under [CC BY 4.0](#).

A source was included for review if it: (1) Described the circumstances of one or more bat exposures among members of the general public in Australia, Canada, the United States or a European country designated as high-income by the World Bank in 2019; (2) Was published between January 1996 and November 2019; (3) Described exposures first reported to health authorities or researchers from January 1996 onwards or separated the information on these exposures from other historical data; and (4) Was a journal article, submitted manuscript, or government report or document. No language requirements were established. Case studies were included in addition to population-based studies, as these could provide insight into incidents with a high degree of clinical relevance, such as exposures that resulted in infections. Where year of exposure was not provided for a case study, authors were contacted for further information. If no authors could be reached but the year of publication met the inclusion criteria, the publication was deemed eligible for review.

Sources were excluded from the review for the following reasons: (1) There was no known history of a human and bat interaction identified in the publication as an exposure risk; (2) Exposure circumstances or type could not be ascertained for any exposures from the information provided; (3) All of the exposures described were occupational (i.e. exposures in veterinarians, wildlife handlers or laboratory staff); (4) Data on exposures that occurred outside of included countries could not be excluded; (5) The publication restricted the circumstances, type or setting of exposures examined (e.g. household exposures only); and (6) The publication was a newspaper article or abstract only.

Studies were screened by EW based on the relevance of the title and content in the abstract. A full-text review was then undertaken by EW to further assess the suitability of publications based on the

inclusion and exclusion criteria. Publications accepted following the full-text review were verified by SR and SA, and inconsistencies were discussed until a consensus was reached among reviewers.

2.3 | Data extraction

Publication data were extracted to describe the body of literature examined, including author; year of publication; type of literature; country; type of study; and a brief study summary. General exposure-related data were then extracted for analysis, including year of notification; number of exposures; circumstances and/or general type of exposure; and whether the exposures were reported to health authorities by the individuals involved prior to the study or a public health investigation. Where the data related to an exposure that was followed by a human infection, this was noted for further discussion.

In keeping with the aims of the study, the data extraction was limited wherever possible to: (1) Exposures in the general public not working or volunteering with animals or in laboratories; (2) Exposures reported to public health authorities or researchers in or after 1996; and (3) Exposures that met the exposure risk criteria (as described above). However, exceptions were made where data associated with any potential bat-related exposures were the best (i.e. most informative) or only data available. Notations have been made in the data tables to indicate where and how data extracted differs from the study aims.

Where multiple bat exposures were described for a single individual in the case literature, data extraction was limited to the interaction(s) with the highest degree of physical contact (i.e. no known

contact < indirect contact < direct contact without a bite or scratch < bite or scratch).

Where the required data were not reported or were insufficient to allow for meaningful comparisons, the label 'no data' was used.

We recognize that some individuals may still have received PEP even where it was explicitly not recommended or offered by public health authorities following an exposure risk assessment. However, as this use of PEP may have been associated with other external variables (e.g. pressure to treat) as opposed to actual transmission risk, these interactions were excluded from the data extraction where possible. It is also important to note that recommendations for PEP vary between countries. For example, in the United States, PEP is recommended in circumstances where a bat is found in a room or area with a sleeping person even if there is no known contact (Manning et al., 2008). However, this is not the case in other high-income countries, including Canada where the recommendations for PEP were officially changed to exclude these exposures in the absence of other indicating factors in 2008 (Middleton et al., 2015).

2.4 | Data synthesis

To compare the general nature of bat exposures included for analysis, interactions were first grouped into overarching exposure types commonly found in the literature including intentional, unintentional, household, non-significant, and indirect or questionable. Definitions for each exposure type are provided in Table 2.

More detailed accounts of the circumstances of exposure were then summarized and grouped into categories based on the information available. Categories found in the population-based literature were often used as a starting point and adapted as required through an iterative process to facilitate comparability between publications. Every effort was made to code data in a systematic manner. However, assumptions and modifications were sometimes required given the multitude of ways in which exposure-related information was reported.

For analysis, data on exposures from included individual case studies were pooled by region because the countries share common bat hosts and environments. The process was repeated for data on individual exposure incidents (involving one or multiple people) as mass exposure events in the case literature had the potential to skew the findings. Findings from the population-based studies were also grouped by region but analysed separately to the case literature, and given the heterogeneity of the data, no meta-analysis was performed. A narrative synthesis was conducted to summarize and compare data on bat exposures in humans between regions.

3 | RESULTS

A total of 63 publications met the criteria for analysis (see Figure 1), comprising 47 case studies and 16 population-based studies (Table

S2). Of the 47 case studies, three were from Australia, nine were from various European countries, three were from Canada and 32 were from the United States. Of the 16 population-based studies, seven were from Australia, one was from France, four were from Canada and four were from the United States. Three population-based studies drew exclusively from data associated with bats submitted for laboratory testing rather than exposure incidents more broadly (Dacheux et al., 2014; Liesener et al., 2006; Mayes et al., 2013), and one of these limited its analysis to exposures involving a rabid bat (Mayes et al., 2013).

For simplicity, the remaining findings have been summarized according to geographic region: Australia, Europe and North America.

3.1 | Number of exposures

A total of 325 exposures were described for 324 people across 51 separate incidents in the case literature included for analysis (see Table S3). The majority of exposures (307) and exposure incidents (39) occurred in North America, and a total of 14 incidents involved more than one person. While incidents involving multiple people were reported in all regions, the four largest incidents occurred in North America including one that involved 200 individuals.

The number of bat exposures examined in the population-based studies ranged from eight (Craig et al., 2009) to 8316 (Eidson et al., 2011) (see Table S4). While large studies were available from both Australia and North America, the lone study from Europe (Dacheux et al., 2014) was relatively small in size, describing only 9 exposures.

3.2 | Types of exposures

Only four (50%) of the eight exposures identified in the Australian case literature had sufficient data to be categorized (see Table 3), and of these, most ($n = 3$, 75%) were defined as unintentional contacts. The findings from population-based studies, however, indicated that the vast majority (63–88%) of exposures in Australia were in fact the result of intentional contact (see Table 4), with unintentional contacts (13–37%) being far less common overall (Craig et al., 2009; Kardamanidis et al., 2013; McCall et al., 2000; Quinn et al., 2014; Si et al., 2016; Young & McCall, 2004, 2010).

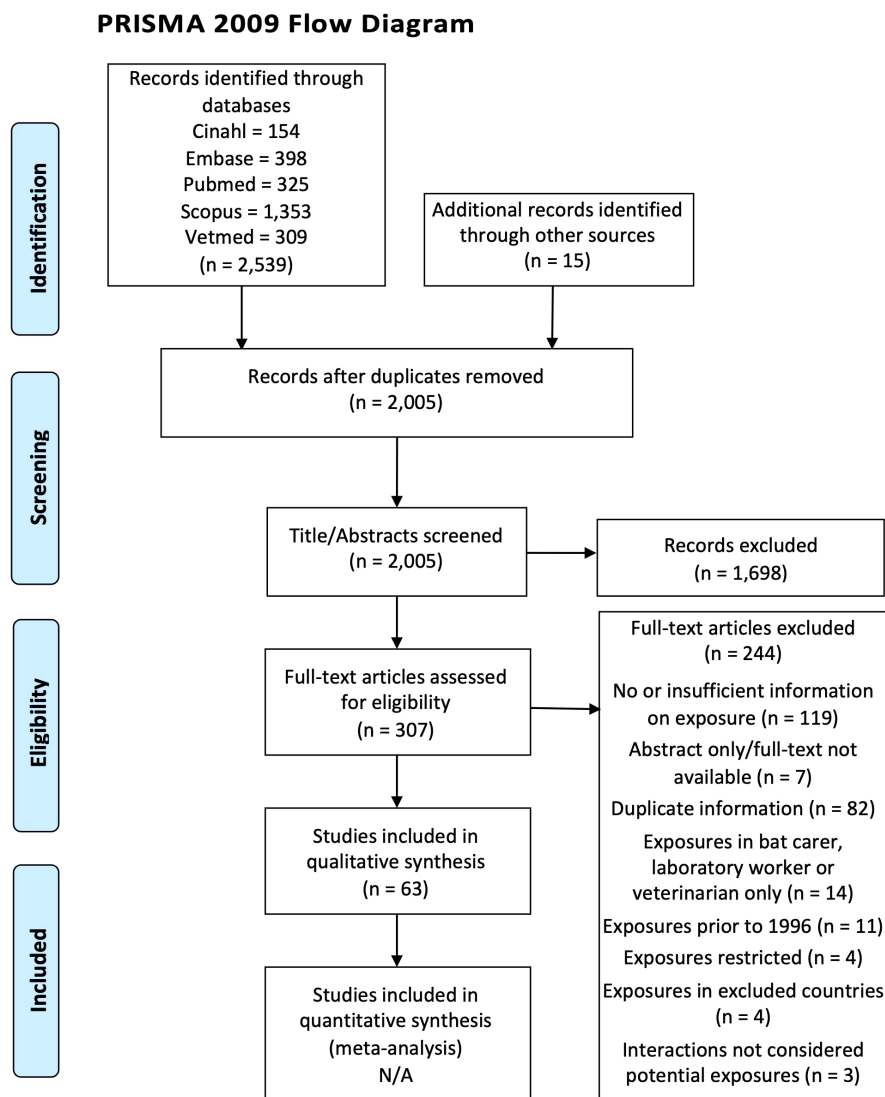
Intentional contacts were consistently the most common type of exposure described in Europe, accounting for the majority ($n = 6$, 60%) of those found in the case literature and all (100%) of those described in the lone population-based study included for analysis (Dacheux et al., 2014).

In North America, household exposures were the most common, accounting for 80% ($n = 247$) of exposures identified in the case literature and 53–94% of those reported in five of the eight population-based studies (De Serres et al., 2009; Eidson et al., 2011; Huot et al., 2008; Lankau et al., 2015; Robbins et al., 2005). While the figures for household exposures were markedly lower (24–32%)

TABLE 2 Exposure type categories, defined

Exposure type category	Definition
Household	Instances where a bat was in or near an area with a sleeping person, child or otherwise incapacitated individual who could not confirm whether direct contact took place. While generally referring to exposures indoors, outdoor interactions meeting those criteria were also included.
Intentional	Interactions where direct contact was knowingly initiated by the person involved, including attempts to touch, handle, help, remove or kill a bat.
Unintentional	Encounters involving direct contact that was unavoidable or unintentional on the part of the person involved. Includes accidental collisions between bats and humans, situations where a person has unknowingly disrupted a bat and instances where a bat has touched or landed on a person.
Indirect or questionable	Instances where the risk of transmission was unclear, or the interaction did not involve direct contact with the bat itself (e.g. contact with bat saliva or contact with a pet after it was exposed to a bat).
Non-significant	Encounters that posed no identifiable risk of lyssavirus transmission (e.g. seeing a bat flying outside).

FIGURE 1 Flow diagram for literature review on human–bat interactions resulting in lyssavirus exposures (PRISMA, Moher et al. 2009)



in the other three population-based studies (Mayes et al., 2013; Middleton et al., 2018; Middleton et al., 2015), two of these (Middleton et al., 2018; Middleton et al., 2015) drew on data from Canada following the 2008 change to PEP recommendations for such encounters.

It is worth noting that a large proportion (>95%) of household exposures in the North American case literature occurred during mass exposure events (≥ 5 people) and when individual incidents were examined separately, those that involved unintentional and intentional contacts were more common.

TABLE 3 Types of exposures, case literature

Type of exposure	Incidents	Exposures [n (100%)]
Australia		
Intentional	1	1 (13)
Unintentional	3	3 (38)
No data	1	4 (50)
Total	3	8
Europe		
Intentional	5	6 (60)
Unintentional	3	3 (30)
No data	1	1 (10)
Total	9	10
North America		
Intentional	14	18 (6)
Unintentional	17	22 (7)
Household	13	247 (80)
No data	4	20 (7)
Total	39	307

Note: Percentages may not total 100 due to rounding.

3.3 | Circumstances of exposure

All three exposure incidents described in the Australian case studies involved a bat landing on and biting or scratching (i.e. any direct contact with claws) a person (Table 5). In addition to the three individuals who had a bat land on them, a fourth person was exposed trying to protect a child when this occurred (Hanna et al., 2000). In contrast, handling, touching or trying to help a bat was the most commonly described circumstance of exposure in the population-based literature, representing between 49% and 88% of those identified (Craig et al., 2009; Kardamanidis et al., 2013; McCall et al., 2000; Quinn et al., 2014; Si et al., 2016) (see Table 6). Three studies showed this was often specifically associated with trying to free a bat from a fence, fruit tree netting, or barbed wire (see Table S4) (Kardamanidis et al., 2013; Quinn et al., 2014; Si et al., 2016).

A person handling, touching or trying to help a bat accounted for the largest proportion of exposure circumstances in the European case literature (40%), followed by a person separating a bat from a domestic pet (20%) and a bat landing on and biting or scratching a person (20%). Analysis of the exposures described in the population-based study yielded highly comparable findings, with 78% involving a person that tried to handle, touch or help a bat, and 22% involving a person that tried to separate a bat from a domestic pet (Dacheux et al., 2014).

The most common circumstances of exposures described in the case literature from North America involved a bat in a room or area with a sleeping person (69%), followed by a bat in a room with an unattended child (7%), and a bat in a house or building with possible access to a sleeping person or child (5%). The case study findings were supported by the data extracted from the population-based literature, which showed that the two most common circumstances

of exposure were bat in a room or area with a sleeping person or unattended child (17–53%) (De Serres et al., 2009; Eidson et al., 2011; Huot et al., 2008; Liesener et al., 2006; Middleton et al., 2018) and bat in an area with access to a sleeping person or unattended child (42–51%) (De Serres et al., 2009; Huot et al., 2008).

3.4 | Exposure reporting

The majority of exposures described in the case studies from Australia ($n = 6$, 75%) were not reported by individuals prior to a public health investigation. Two of the eight case study exposures ultimately resulted in human infection: one that was reported to a medical professional but did not receive PEP (Hanna et al., 2000), and one that remained unreported prior to the development of symptoms (Francis, Nourse, et al., 2014). While one of these exposures was categorized as intentional and the other unintentional, both incidents involved an unprovoked bat landing on a person (see Table S3).

Unlike Australia, most of the case study exposures from Europe resulted (80%) were reported by individuals to public health authorities prior to an investigation. The two (20%) exposures that could not be categorized as 'reported' or 'unreported' occurred during the same incident and involved the intentional handling of a grounded bat. Importantly, both were ultimately offered a full course of PEP as the bat in question tested positive for EBLV-2 after being submitted by a rehabilitator (Fooks et al., 2006). None of the European case study exposures were associated with a human case of lyssavirus (Table 6).

Similar to Australia, the majority ($n = 268$, 87%) of exposures in the case literature from North America were unreported. Of these, 27 were eventually associated with a confirmed or suspected human infection: six (22%) that involved household exposures, 10 (37%) that involved unintentional contact with a bat and 11 (41%) that involved intentional contact (see Table S3).

A household survey from North America was the only population-based study included in our analysis to describe exposures that were reported and unreported prior to the research being conducted. According to the study findings, only two (3%) of the exposures that were eligible for PEP had been reported to health authorities at the time of the survey, both of which were household encounters with no known contact (De Serres et al., 2009). The study also found that none of the five exposures that involved direct contact with a bat had been reported (De Serres et al., 2009).

4 | DISCUSSION

Our findings show that human-initiated attempts to touch, handle or help a bat account for the majority of exposures among the general public in Australia and Europe, while the most common exposure scenario in North America involves a bat being found near where a person has slept. The results also suggest that a proportion of all bat exposures occurring in these settings, including those that involve

TABLE 4 Type of exposure, population-based literature

Type of exposure	Source	Exposures [n (%)]	
Australia			
Intentional	Craig et al. 2009	7 of 8 (88)	
	Kardamanis et al. 2013	202 of 314 (64)	
	McCall et al. 2000	63 of 72 (88)	
	Si et al. 2016	853 of 1349 (63)	
	Quinn et al. 2014	12 of 16 (75)	
	Young and McCall 2004	61 of 78 (78)	
	Young and McCall 2010	57 of 73 (78)	
	Unintentional	Quinn et al. 2014	4 of 16 (25)
		Si et al. 2016	496 of 1349 (37)
		McCall et al. 2000	9 of 72 (13)
Young and McCall 2004		17 of 78 (22)	
Young and McCall 2010	16 of 73 (22)		
Europe			
Intentional	Dacheux et al. 2014	9 of 9 (100)	
North America			
Household	De Serres et al. 2008	75 of 80 (94)	
	Eidson et al. 2011	4407 of 8316 (53)	
	Huot et al. 2008	1367 of 1875 ^a (73)	
	Liesener et al. 2006	87 of 168 ^b (52)	
	Mayes et al. 2013	227 of 702 (32)	
	Middleton et al. 2015	845 of 3542 ^a (24)	
	Middleton et al. 2018	50 of 166 (30)	
	O'Shea et al. 2011	46 of 71 ^a (65)	
	Indirect or questionable	Mayes et al. 2013	9 of 702 (1)
	Intentional	De Serres et al. 2008	1 of 80 (1)
Huot et al. 2008		110 of 1875 ^a (6)	
Liesener et al. 2006		37 of 168 ^b (22)	
Mayes et al. 2013		289 of 702 (41)	
Middleton et al. 2018		22 of 166 ^c (13)	
O'Shea et al. 2011		20 of 71 ^a (28)	
Non-significant	Huot et al. 2008	246 of 1875 ^a (13)	
Unintentional	Huot et al. 2008	152 of 1875 ^a (8)	
	O'Shea et al. 2011	5 of 71 ^a (7)	

^aIncludes or may include exposures not associated with bat submissions or deemed eligible for PEP by public health authorities.

^bIncludes or may include a small number of occupational exposures (e.g. veterinarians and wildlife handlers).

^cIncludes or may include human-initiated bat disruptions, which would otherwise have been considered unintentional.

direct contact, are not readily reported to health authorities by the individuals involved.

There are likely several interrelated contextual factors influencing common bat exposure circumstances and the likelihood of seeking medical care in different countries, including: public awareness

of bat lyssaviruses; general risk perception of bats; history of human deaths; national PEP guidelines; and the characteristics of local bat species. Most importantly, the patterns described in relevant studies help to highlight key intervention points for preventing bat exposures and lyssavirus infections in different high-income settings.

Compared to North America and Europe, Australia has the greatest diversity of bat species, with several types of large 'fruit bats' or flying foxes (Megachiroptera) and smaller microbats (Microchiroptera) present (Churchill, 2008). While ABLV has been detected in members of both subspecies, the majority of exposures reported to health units involve a flying fox, with the most common circumstances comprising a member of the public trying to help or handle a bat in distress outdoors (Craig et al., 2009; Kardamanidis et al., 2013; McCall et al., 2000; Quinn et al., 2014; Si et al., 2016). This has important public health implications as flying fox species have sharp teeth capable of penetrating through most types of gloves and other materials readily accessible to the public and are relatively difficult for untrained individuals to control because of their long wingspans (Quinn et al., 2014; Sánchez & Baker, 2016). Furthermore, bats that are injured, grounded, sick or orphaned have been found to have higher rates of lyssavirus (Barrett, 2004; Ewald & Durrheim, 2008). Given these considerations and the varying accessibility to laboratory testing across Australia (Iglesias et al., 2021), members of the public are advised never to touch or attempt to handle a live bat to avoid confusion (Francis, McCall, et al., 2014; Healthdirect, 2021).

Willingness to handle a bat in Australia has been linked with knowledge of health concerns, risk perception and support for conservation (Crockford et al., 2018; Paterson et al., 2014; Quinn et al., 2014). This has prompted suggestions that public health messaging should more aptly convey the risks of handling for the bat (which may need to be euthanised) and human involved, while also detailing safer courses of action such as contacting a reputable wildlife rescue for advice (Crockford et al., 2018; Paterson et al., 2014; Quinn et al., 2014). Recent examples of posters and slogans adopted by organizations employing these strategies include the phrases 'Help me by NOT touching me!' and 'NO TOUCH, NO RISK' overlaid over images of bats with a contact number for reporting animals in distress (Bat Conservation & Rescue QLD, 2019; Metro North Health, 2020). Evidence from a study by Eidson et al. (2004) in the United States suggests that educational stickers for young children and magnets for adults may serve as effective platforms for transmitting such messages to members of the public. Finally, as many of the bats being handled in Australia are entangled in fruit tree netting or barbed wire, the promotion of more wildlife-friendly alternatives has also been identified as means of reducing human-initiated exposures with the added benefit of being less harmful to native animals (Iglesias et al., 2021; Si et al., 2016).

With the exception of Cyprus and Turkey, microbats account for all indigenous bat species in Europe (del Vaglio et al., 2011; Voigt & Kingston, 2016). It is perhaps therefore surprising that like Australia, most exposures in Europe were also intentional and often involved attempts to assist a bat. While it is conceivable that, as in Australia,

TABLE 5 Circumstances of exposure, case literature

Circumstances	Incidents	Exposures [n (%)]
Australia		
Bat landed on and bit or scratched a person (unprovoked)	3	3 (38)
Person protected a child from a bat	1	1 (13)
No data	1	4 (50)
Total	3	8
Europe		
Person handled, touched or tried to help a bat	3	4 (40)
Person separated a bat from a domestic pet	2	2 (20)
Bat landed on and bit or scratched a person (unprovoked)	2	2 (20)
Bat found biting a child's hand	1	1 (10)
Bat came into contact with a person in their home	1	1 (10)
Total	9	10
North America		
Bat in room or area with sleeping person	6	213 (69)
Bat in room or area with unattended child	2	20 (7)
Bat in house or building with possible access to a sleeping person or unattended child	5	14 (5)
Bat landed on and bit or scratched a person (unprovoked)	10	10 (3)
Disturbed a roosting bat	2	2 (1)
Human-bat collision	3	6 (2)
Person handled, touched or tried to help a bat	9	12 (4)
Person removed, relocated or contained a bat	6	6 (2)
Undefined contact, no data	4	20 (7)
Other	3	4 (1)
Total	39	307

Note: Percentages may not total 100 due to rounding.

risk perception, awareness of disease and support for bat conservation efforts may play a role, no European research into these factors could be identified. The dearth of European data available when this review was conducted significantly limited our findings for this region. However, a recently published study on bat exposures in France lends some credibility to the patterns we detected. Parize et al. (2020) found that compared to bat bites, scratches and licks, bat handling accounted for the largest proportion of exposures described by individuals submitting a bat in metropolitan France between 2003 and 2016. Furthermore, similar to both our case and population-based study findings, 22.3% of submitters reported contact between the bat and a pet, most often a cat (Parize et al., 2020). The study's findings prompted the authors to call for information campaigns, of which there were reportedly none, aimed at discouraging members of the public and particularly pet owners from touching bats regardless of their condition (Parize et al., 2020). Other European literature has emphasized the importance of advising members of the public to contact a bat conservation or rehabilitation organization upon finding a sick, injured or grounded bat, and to use an aerated container and thick gloves in the event that relocating, confining or handling a bat is necessary (Bat Conservation Trust, 2020; Racey et al., 2013).

It is clear from the literature that household exposures to bats represent a significant challenge for public health agencies in

North America, particularly as several people may be exposed at once. Similar to most of Europe, all indigenous bats in Canada and the mainland United States are microbats, and for species that would ordinarily roost in tree hollows, caves and natural crevices, buildings can offer warm and protected environments (Voigt & Kingston, 2016). Bats may also be brought indoors by a pet (Griffin et al., 2009) or enter inadvertently through an open door or window (Geyer et al., 1997). Despite indoor encounters having been reported in the Australian and European literature, North America is the only region included in our analysis that has had several human cases linked to household exposures, with eight reported as of 2019 (De Serres et al., 2008; Pratt et al., 2016; Rupprecht et al., 2013). This, in conjunction with more than a dozen cases for which no previous bat encounter could be confirmed (Dato et al., 2016; De Serres et al., 2008), has increased concerns around undetected contact when a bat is found near a child or sleeping person (Fenton et al., 2020; Huot et al., 2008; Manning et al., 2008). These contextual factors are critical to understanding why household exposures account for such a large proportion of exposures in the North American data while being seemingly non-existent elsewhere.

Research also suggests that a large number of household exposures occur in North America every year. De Serres et al. (2009) found that 0.21% of people surveyed in Québec in 2006 were

TABLE 6 Common circumstances of exposures, population-based literature

Circumstances	Source	Exposures [n (%)]
Australia		
Accidental contact with a bat in the home	Si et al. 2016	142 of 1349 (11)
Human-bat collision outdoors (e.g. cycling, walking, driving)	Si et al. 2016	128 of 1349 (9)
Person handled, touched or tried to help a bat	Craig et al. 2009	7 of 8 (88)
	Kardamanis et al. 2013	170 of 314 (54)
	McCall et al. 2000	63 of 72 (88)
	Quinn et al. 2014	12 of 16 (57)
	Si et al. 2016	661 of 1349 (49)
Person removed, relocated or contained a bat	Si et al. 2016	192 of 1349 (14)
Person separated a bat from domestic pet	Si et al. 2016	62 of 1349 (5)
Europe		
Person handled, touched or tried to help a bat	Dacheux et al. 2014	7 of 9 (78)
Person separated a bat from a domestic pet	Dacheux et al. 2014	2 of 9 (22)
North America		
Bat in house or building	Huot et al. 2008	149 of 1875 ^a (8)
	Middleton et al. 2018	9 of 166 (5)
Bat in room or area with a sleeping person or unattended child	De Serres et al. 2008	34 of 80 (43)
	Eidson et al. 2011	4407 of 8316 (53)
	Huot et al. 2008	436 of 1875 ^a (23)
	Liesener et al. 2006	87 of 168 ^b (52)
	Middleton et al. 2018	29 of 166 (17)
Bat in area with possible access to a sleeping person or unattended child	De Serres et al. 2008	41 of 80 (51)
	Huot et al. 2008	782 of 1875 ^a (42)
Bat in bed	O'Shea et al. 2011	2 of 71 ^a (3)
Bat landed on or collided with a person	O'Shea et al., 2011	3 of 71 ^a (4)
Bat touched, bit or scratched a person (unprovoked)	Huot et al., 2008	152 of 1875 ^a (8)
Person approached or disturbed a bat	Middleton et al., 2018	22 of 166 (13)
Person handled, touched or tried to help a bat	De Serres et al., 2008	1 of 80 (1)
	Huot et al., 2008	110 of 1875 ^a (6)
	Mayes et al., 2013	289 of 702 (41)
	Liesener et al., 2006	8 of 168 ^b (5)
	O'Shea et al., 2011	9 of 71 ^a (13)
Person tried to remove, relocate or contain a bat	Liesener et al., 2006	29 of 168 ^b (17)
	O'Shea et al., 2011	11 of 71 ^a (15)

^aIncludes or may include exposures not associated with bat submissions or deemed eligible for PEP by health authorities.

^bIncludes or may include a small number of occupational exposures.

exposed to a bat in their bedroom or an area with access to their bedroom in the past 12 months. Applied to the province's entire population, this would mean several thousands of people exposed under these circumstances per year (De Serres et al., 2009). Another survey conducted in South Carolina found that 3.5% of people surveyed had encountered a bat in their home between January 2010 and June to September 2012, while 2.8% reported household roosting (Lankau et al., 2015). As most respondents were not aware of how to keep bats out of their home and attempts to do so were often unsuccessful, the authors highlighted better education around safe and humane extrication and exclusion techniques as

a potential intervention point (Lankau et al., 2015). The Centre for Disease Control and Prevention (CDC) recommends that individuals use a container with a lid or piece of cardboard and leather or other work gloves where bat handling becomes necessary (e.g. for testing or removal purposes) (CDC, 2022; CDC, n.d.). As natural habitats continue to be cleared, other interventions such as the installation of high-quality bat houses or artificial roosts, may not only help to reduce household roosting, but also benefit conservation efforts (Arias et al., 2020; Voigt & Kingston, 2016).

Recent data on exposure notifications in Australia suggest that the median time to exposure reporting has improved dramatically since

the late 1990s and may now be as low as 1 day (McCall et al., 2000; Si et al., 2016; Young & McCall, 2004, 2010). Despite these improvements, a considerable proportion (14%) of all exposures (occupational and non-occupational) treated by public health units are still only reported after more than 7 days, with some remaining unreported for weeks and even years (Si et al., 2016). A dramatic increase in the number of exposures reported to public health units was noted following media attention on each of the three human cases in Australia (McCall et al., 2000; Si et al., 2016), suggesting that underreporting is typical under ordinary circumstances. Other research also suggests that a proportion of bat exposures are never reported. Paterson et al. (2014) determined that none of the 15.5% of survey respondents in New South Wales who recalled having previously handled a bat had sought medical care, including two people who reported a bite or scratch. According to survey analyses published by Crockford et al. (2018), low risk perception and citing national parks as an information source could be associated with a decreased likelihood of seeking care following exposure, sparking interest in the role of more broad (i.e. not bat or animal welfare-focussed) conservation organizations in transmitting public health messages.

While the evidence from case studies in Europe indicates high levels of exposure reporting, other data from the region appear to challenge this finding. For example, similar to Australia, notable increases in PEP administration for bat exposures have been documented in France following publicity on human and animal lyssavirus cases, suggesting that underreporting is common (Debelleix et al., 2009; Gautret et al., 2011). The typical time from bat exposure to reporting also appears to vary widely across Europe, with data from the United Kingdom (UK) and France showing median delays of two (Goodwin et al., 2019) and 5 days (Debelleix et al., 2009), respectively. If representative, these findings suggest that most exposures in the United Kingdom are reported fairly promptly, while most in France are not.

Given the constraints around bat testing in Australia and Europe, health-seeking messages in these regions should primarily focus on describing what specifically constitutes a potential bat exposure, immediate wound management guidelines, and where, when and why to access appropriate medical care (Metro North Health, 2020; Public Health England, 2019; Quinn et al., 2014). Moreover, since exposure reporting in these areas appears to vary considerably with changes in media attention (Debelleix et al., 2009; Gautret et al., 2011; McCall et al., 2000; Si et al., 2016), repeated or ongoing messaging strategies (such as the aforementioned educational magnets) could help to reduce reporting gaps and delays.

Only one study from North America describing time to reporting or PEP for bat exposures was identified. According to Huot et al. (2008), public health authorities in Québec were notified of a person's bat exposure within 24 h in 70% of cases, indicating that the majority of people sought or received care quite promptly. However, our broader findings suggest that most bat exposures that would be eligible for PEP in North America simply go unreported. Additional research also supports this conclusion. A survey conducted in Oregon in 1997 found that none of the respondents who had reported a possible household exposure to a bat in the past 12 months had sought

medical care following the encounter (Cieslak et al., 1998). Similarly, Lankau et al. (2015) found that while awareness of bat rabies and intention to seek care following a bat bite were high (>91%) among survey respondents in South Carolina, none reported having sought care for a possible exposure (household or otherwise) or having submitted bats caught in their homes. Given the accessibility and low cost of animal testing relative to PEP, public health messaging in North America should aim to include information about safe capture techniques and how to submit a bat for testing to prevent unnecessary treatment where possible (Eidson et al., 2004).

Finally, bat species play key roles in maintaining ecosystem health and there is growing recognition of the need for public health efforts around the world to balance the risks bats present to humans with the value of promoting bat conservation (Crockford et al., 2018; Fenton et al., 2020; Hang et al., 2017; Racey et al., 2013). There is particular concern regarding messaging that may trigger excessive fear or panic, which could inadvertently place even greater strain on public health services and increase hostility towards bats (Crockford et al., 2018; Fenton et al., 2020; Racey et al., 2013). As such, interventions that improve health-seeking where appropriate, reduce exposures and benefit bats should be widely encouraged wherever possible.

4.1 | Limitations and future research

This review has several limitations. The amount of data from European countries was very limited, with only nine case studies and one small population-based study having met the inclusion criteria. As such, the results presented for this region may be subject to bias and should be interpreted with caution. A small number of case studies on bat-associated human lyssavirus infections in North America were also excluded because no known human and bat interaction could be identified. While it is conceivable that at least some of these involved household exposures, other scenarios such as indirect exposures or poor recall have not been conclusively dismissed (Gibbons, 2002). Nevertheless, excluding these studies may have biased the results in favour of interactions that were more perceptible, noteworthy or recent.

All but one of the population-based studies included for review used only data from interactions that were either reported to or investigated by public health authorities prior to data collection, and as such, may not be representative of all exposures that occur in the general population. Other differences in the types of data used may have further biased findings. For example, studies based exclusively on bat submissions or lyssavirus-positive bats may have inherently favoured specific types of interactions when compared to data on exposures more broadly.

Information on the circumstances of exposure was not consistently reported across the literature and in some cases, a considerable proportion of encounters could not be characterized for analysis. It is also possible that some of the population-based studies included occupational exposures that were not identified as such, in which case the results would not exclusively reflect exposures in the general public. There was also the possibility for some overlap

between studies from the same country (see Tables S2 and S4), however the implications of this type of data duplication were considered to be negligible for the purposes of this review.

Finally, the findings of this review are only representative of exposures in high-income countries without widespread hematophagous bat populations and are therefore not applicable to other settings where bat exposures may still be an important public health concern. Future reviews should consider examining exposure circumstances and health-seeking behaviours in other regions.

5 | CONCLUSION

The patterns identified in this review provide valuable insight into the types of interventions that could be most effective for preventing bat exposures in different high-income countries around the world. The findings also indicate that health-seeking behaviours following bat exposures could still be improved in these regions. However, it is important that the value of protecting bat species also be considered in the development of bat lyssavirus-related public health strategies.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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