Predictors of bed bug-related stress in people who have experienced a recent infestation. Results from a cross-sectional survey in the city of Lyon, France

Guillaume Barbalat,[a]* [ID] Virginie Berthillot,[a] Cédric Thenoz[b] and Nicolas Franck[a]

Abstract

BACKGROUND: The number of bed bug infestations has risen dramatically in the past decades. Infestations are responsible for mental health issues such as lower quality of life, insomnia and symptoms that may resemble those of post-traumatic stress disorders. Here, we sought to investigate whether bed bug-related stress may be predicted by a range of sociodemographic, clinical and infestation-related characteristics. We collected data using a paper and online survey of 305 adults who had experienced a bed bug infestation.

RESULTS: From the 167 individuals dealing with a recent (<1 year) bed bug infestation, about two-thirds were deemed to have a high level of bed bug-related stress. The cross-validated performance of a naive Bayes algorithm in predicting bed bug-related stress was good, with an area under the receiving operating characteristics curve (AUROC) of 0.80. We calculated SHAP values to determine the explanatory power of predictors. Factors associated with bed bug-related stress were young age, female sex, childlessness, being single, social isolation, severity of infestation and treatment by insecticides (especially when health issues had not been taken into account). We also found that the likelihood of bed bug-related stress based on the severity of the infestation decreased when participants felt they were socially supported.

CONCLUSION: Although social isolation and inappropriate use of pesticides are two common behaviors, our results emphasize the importance of social support and the safest use of pesticides to mitigate bed bug-related stress.
© 2025 Society of Chemical Industry.

Supporting information may be found in the online version of this article.

Keywords: bed bugs; post-traumatic stress disorder; bed bug-related stress; pesticides; social isolation

1 INTRODUCTION

The past three decades have seen a dramatic increase in bed bug infestations (Hemiptera: Cimicidae) worldwide, particularly in crowded cities.[1,2] In France, it was shown that 11% of citizens' homes had been infested between 2017 and 2022,[3] with Paris being the most exposed.[4] According to a recent study, bed bug infestations represent on average a bit more than one consultation to the general practioner per 1000 inhabitants.[5] Treatment is very costly (c. €1249)[4] and takes time to be effective (2.5 months on average).[4] With the impending 2024 Paris Olympics, some have even raised concerns that the bed bug epidemic may spread even further as a result of the 2024 Paris Olympics.[6]

Bed bug infestations are usually described as medically benign. Medical concerns are associated with dermatological (allergic reactions) and mental health consequences. Negative mental outcomes are thought to be underestimated and not well investigated.[7] However, studies exist showing that those who are dealing with bed bug infestations may experience social isolation, lower well-being and insomnia.[8–10] Symptoms also may suggest post-traumatic stress disorders (PTSD), including nightmares, flashbacks, hypervigilance, avoidance behaviors and personal dysfunction.[7,11] Criterion A for a DSM-5 diagnosis of PTSD requires that 'The person was exposed to: death, threatened death, actual or threatened serious injury, or actual or threatened sexual violence'.[12] However, some studies have shown that upsetting nonlife-threatening accidents also may give rise to typical PTSD symptoms.[13,14] Although some individuals might experience symptoms similar to those of PTSD, it is important to note that a

---

* Correspondence to: G Barbalat, Centre ressource de réhabilitation psychosociale et de remédiation cognitive, Hôpital Le Vinatier, Pôle Centre rive gauche, UMR 5229, CNRS & Université Lyon 1, France. E-mail: guillaume.barbalat@ch-le-vinatier.fr

a Centre Ressource de Réhabilitation Psychosociale et de Remédiation Cognitive, Hôpital Le Vinatier, Pôle Centre rive gauche, Bron, France

b Société Lyonnaise de Détection Canine, Neaux, France

diagnosis of adjustment disorder may be more appropriate in many cases. This is because the stressors associated with bed bug infestations are typically less severe than those that typically lead to PTSD, and adjustment disorder does not require a latency period for diagnosis.

To the best of our knowledge, only one study has investigated factors that may be associated with mental health outcomes of bed bug infestations.[10] This study, however, focused on well-being and insomnia, not on bed bug-related stress. Other reports have mentioned that investigations of mental health effects of bed bug infestations 'remain largely anecdotal',[15] and that 'research should focus on understanding which factors are responsible for more severe and prolonged mental health impacts among those experiencing a bed bug infestation'.[16] Mental health consequences of bed bug infestations are important to take into account for another reason. Mental health challenges may compromise the preparation of an individual's unit as well as the effectiveness of pest control strategies, just like physical, financial or social issues.[17]

In the current study, we aimed at determining factors linked to bed bug-related stress in people who have experienced a recent infestation. Those are likely to be the result of complex relationships between socioeconomic and health-related factors, as well as infestation-related characteristics (e.g. severity of infestation, moving house, use of various treatment methods).[18] We used results from a paper and online cross-sectional survey, and analyzed whether a range of sociodemographic, clinical and infestation-related factors were associated with bed bug-related stress.

2 MATERIALS AND METHODS

2.1 Data

2.1.1 Database

This cross-sectional study was conducted from January 2023 to December 2023 in the city of Lyon, France. Lyon is the second biggest urban unit in France, with a population of 1.7 million inhabitants. The Auvergne-Rhône Alpes region, from which Lyon is the capital city, has been shown to be the leading region for reporting bed bug complaints to general practitioners, with *c.* 214 consultations per 100 000 inhabitants.[5]

The survey was advertised via social media platforms and flyers in town halls, outdoor markets and at social housing organizations. Upon acceptance, each participant was asked to fill in an online self-reported questionnaire via the use of a QR code or an electronic weblink. For participants who did not have an electronic device at hand, a paper version was utilized.

The very first question of the survey asked participants if they had encountered a bed bug infestation during the past year. If so, participants were asked to identify a bed bug among 20 insects. Then, further data were collected on the history of infestation (section 1), sociodemographic characteristics (section 2), place of living (section 3), and health and well-being (section 4). Note, however, that data from section 3 were not analyzed for the purpose of the current study owing to our relatively small sample size and to avoid the 'curse of multidimensionality' in our statistical analysis.

Participants were recruited by volunteer sampling. They were deemed eligible to participate if they lived in Lyon and were aged 18 or above. After accessing the link to the online survey, participants were shown a consent form which explained the details of the study. All participants provided their informed consent.

2.1.2 Outcome variable: bed bug-related stress

We used the French version of the impact of event scale-revised (IES-R) to assess bed bug-related stress in the past week.[19] The IES-R is a 22-item self-report scale used to evaluate post-traumatic stress. Each item asks respondents about distress caused by a symptom on a 5-point Likert scale (0–4 response format with equal intervals). Items are further grouped into three subscales: intrusion (e.g. flashbacks, nightmares – eight items); avoidance (e.g. staying away from reminders – eight items); and hyperarousal (e.g. irritability, hypervigilance – six items). It was found that the French version of the IES-R has satisfactory internal validity and test–retest reliability, and that the factor structure of the translated version was similar to the proposed theoretical structure of the IES-R.[19]

Rather than computing a sum of item scores, the authors of the IES-R suggest using the mean of nonmissing items,[20] which we calculated if participants had responded to ≥75% of the 22 items. The IES-R is not designed to make a categorical diagnosis of PTSD or stress-related disorder. However, a cutoff of 1.5 (equivalent to a total score of 33) has been found to provide the highest overall diagnostic power against the PTSD checklist[21] – a tool that provides a provisional diagnosis of PTSD before structured clinical interviews are used. We used such a 1.5 cutoff to differentiate participants with a high level of bed bug-related stress *versus* those with a low level.[22] In the introduction, we have noted that a diagnosis of adjustment disorder may be more appropriate than PTSD in many cases of bed bug-related stress, owing to the nature of the stressor and the absence of a required latency period. However, when interpreting our results, we will consider the broader literature on PTSD. This approach is justified because both PTSD and adjustment disorder belong to the category of stress-related disorders, sharing some common features and underlying mechanisms.

In order to check whether our set of predictors was important in predicting other aspects of mental health and not just bed bug-related stress, we also measured well-being as per the Warwick–Edinburgh Mental Well-Being Scale (WEMWBS[23]). The WEMWBS is a 14-item scale, including statements on positive effects, satisfying interpersonal relationships and positive functioning. Participants are asked to rate the frequency of how they have experienced each statement over the past week from 1 (none of the time) to 5 (all of the time). The WEMWBS has been shown to detect subtle changes in populations with both good and poor mental health.[24] WEMWBS was found to have a mean score of 51 in general population samples in the UK. The recommended cut-off point for low well-being is of 42 and that for high well-being is of 60.[23]

2.1.3 Predictors

We reasoned that both infestation history, and sociodemographic and clinical characteristics may predict bed bug-related stress. Below, we provide a list of 30 predictors that we measured in our survey.

2.1.3.1 Infestation history.
The characteristics of a bed bug infestation, its severity (spread to more than one room, treatment ineffectiveness) and social consequences (social restrictions) may impact an individual's well-being and level of stress. Likewise, treatments (e.g. treatment by heat or cold, insecticides), and their direct consequences on the individual (having to move house, destruction of materials) may be deleterious to mental health. A

detailed list of our infestation-related predictors is described as follows:

- traces of insects (yes: insects or their feces seen *versus* no);
- spread of infestation (one room *versus* two rooms or more);
- start of infestation (<3 months ago *versus* >3 months ago);
- duration of infestation (<3 months *versus* >3 months);
- preparation for treatment (no preparation *versus* preparation done by self *versus* preparation done by someone else);
- difficulties in accepting preparation (yes: preparation accomplished with a lot of difficulties or not done *versus* no: no difficulty or a bit of difficulty);
- treatment by pesticides applied by a pest control company (no pesticides *versus* pesticides used and conditions of use not explained *versus* pesticides used and conditions of use explained but health effects not taken into account *versus* pesticides used and health issues taken into account). We further defined unclear pesticide use as instances where usage conditions were not explained or when potential health effects were not considered;
- treatment by heat or cold (yes *versus* no);
- treatment by steaming (yes *versus* no);
- removal of material (yes *versus* no);
- moving house (yes *versus* no);
- treatment acceptance at the beginning of treatment (yes: done with a lot of difficulties or not done *versus* no: nil difficulty or a bit of difficulty);
- treatment acceptance at the end of treatment (yes: done with a lot of difficulties or not done *versus* no: nil difficulty or a bit of difficulty);
- treatment effectiveness (yes: bed bugs disappeared after a few weeks or less *versus* no: effectiveness after a few months or no effectiveness to date);
- financial support from the landlord (yes *versus* no);
- support from family (yes *versus* no: poor or no support);
- support from landlord (yes *versus* no: poor or no support);
- support from pest controller (yes *versus* no: poor or no support);
- fear of contaminating others (yes *versus* no);
- social restrictions (self-decision) (yes *versus* no);
- social restrictions (decision made by others) (yes *versus* no).

2.1.3.2. Sociodemographic and clinical information. We measured the following features, which typically relate to well-being and stress:

- sex (male *versus* female);
- age (<25 years-old *versus* 25–35 *versus* 35–45 *versus* 45–55 *versus* >55 years-old);
- employment status (yes: work part-time or full-time *versus* no: does not work or student);
- relationship status (in a relationship: yes *versus* no);
- number of children living at home (0 *versus* 1 *versus* 2 or more);
- education level (pre-Baccalaureate *versus* Baccalaureate, Baccalaureate +1 year, Baccalaureate +2 year *versus* Baccalaureate +3 years (Bachelor's degree) or more);
- medical history (yes *versus* no);
- psychiatric history (none *versus* past *versus* current).

2.1.4 Missing values

A total of 548 participants responded to the survey, of which 167 had experienced a recent bed bug infestation (less than a year before they filled in the questionnaire; Fig. 1). After excluding participants with >30% missing values and participants with <75% completion of the IES-R, our final sample included a total of 138 participants. No covariate included >30% missing values. Missing values were imputed five times using the predictive mean-matching method from the R package MICE.[25]

2.2 Analysis

2.2.1 Modeling strategy

Using the R package CARET,[26] we evaluated the performance of a naive Bayes algorithm in predicting a high-level *versus* low-level of bed bug-related stress, based on the 30 predictors described above. Naive Bayes is a probabilistic classifier that relies on the Bayes' theorem, where features are assumed to be conditionally independent from one-another. We incorporated a small-sample correction called Laplace smoothing, which ensured that no probability in the training data was ever set to be exactly zero, and is seen as a way of regularizing the model.[27]

We used a $k = N$ (138)-fold cross-validation procedure, as recommended for relatively small samples.[28] For each of the N-folds, the procedure trained the algorithm on $N - 1$ observations based on 10 bootstrap samples. The model with the set of hyperparameters that maximized the area under the receiving operating characteristics curve (AU-ROC) was selected and then used to predict the outcome on the remaining observation. Repeating this procedure N times, we obtained N predicted outcomes which we compared to the corresponding observed outcomes in order to evaluate the model performance, once again based on the AU-ROC.

For our analysis on well-being, we trained a regularized regression model aiming to maximize the coefficient of determination (R^2), which reflects the fraction of variation in the WEMWBS total score captured by the model. For this analysis, we also used a $k = N$-fold cross-validation procedure where training occurred on $N - 1$ observations based on 10 bootstrap samples. We used an adaptive sampling scheme aimed at tuning hyperparameters in an efficient way.[29]

Pre-processing involved the exclusion of 'near zero-variance' predictors. Note that methods such as weighting or propensity scores were not used to adjust for the nonrepresentativeness of the sample to the French population.

2.2.2 Variable importance in predicting bed bug-related stress

We then calculated artificial intelligence-based SHapley Additive exPlanations (SHAP) values to investigate variables that best accounted for the occurrence of high-level bed bug-related stress. The SHAP method is regarded as a model-agnostic explanation method with a solid theoretical foundation, and is explained in detail elsewhere.[30] SHAP values were estimated for each 'testing' observation based on the naive Bayes algorithm whose hyperparameters were selected in the training phase (see section 2.2.1). For each variable and each observation, a higher SHAP value corresponds to a higher likelihood of the target outcome (i.e. having a high level of bed bug-related stress). We first provided predictor-level SHAP absolute values aggregated at the level of the population in order to rank the predictors' overall predictive ability (aka variable importance). Second, we provided one-way dependence plots showing the association between the raw values of the 15 most important predictors and their SHAP values. Third, as mentioned above, bed bug-related stress may result from complex interactions between various types of predictors. Here, we specifically tested whether social support (e.g. from
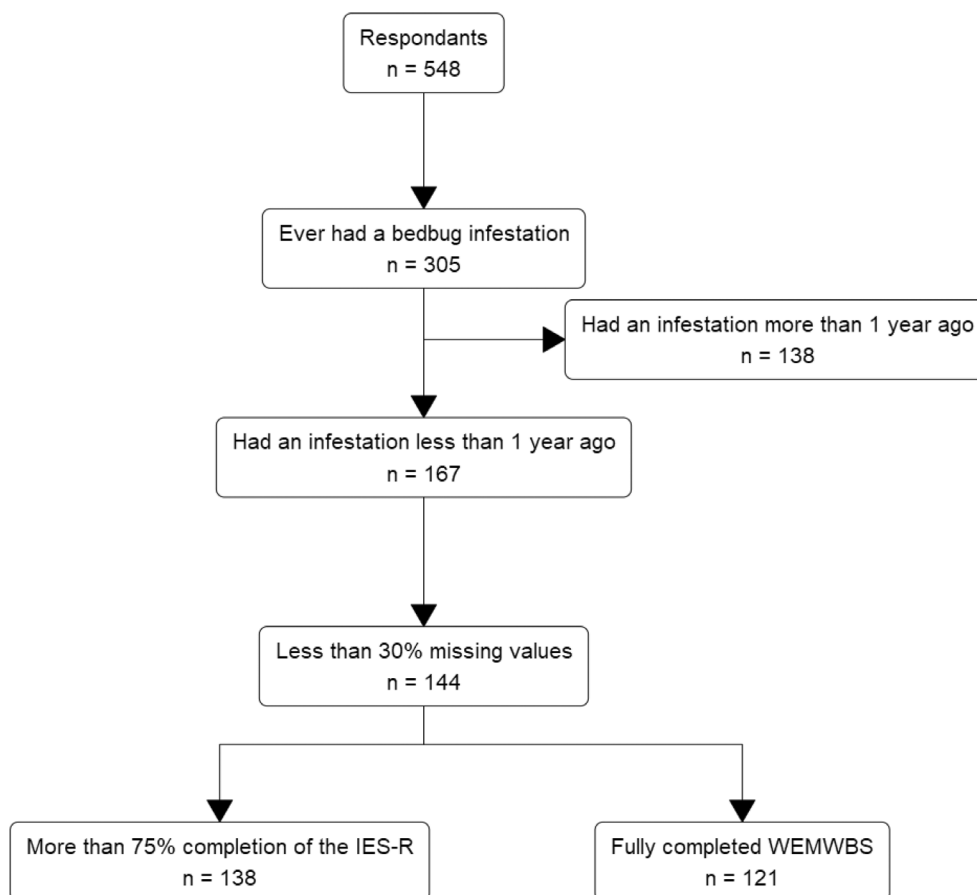
Figure 1. Flowchart of the study population. Legend. IES-R, impact of event scale, revised version. WEMWBS: Warwick–Edinburgh mental well-being scale.

family and friends) counteracted the effect of an infestation's severity (e.g. treatment ineffectiveness).

Analysis was carried out with R software and packages CARET, NAIVEBAYES, FASTSHAP and SHAPVIZ.

3 RESULTS

3.1 Observed data

Our final sample ($N = 138$) included more females than males (66.7% *versus* 24.6%; Table 1). Age categories were approximately equally represented, except for the '<25 years-old' category, which was half the size of the other categories. Most of our sample was employed (67.4% *versus* 24.6%), half was in a relationship and about half had no children living at home. Also, half of our sample reported having at least a Bachelor's degree. Additionally, 21.7% of our sample declared having a medical issue and 29.7% a current or past psychiatric issue.

Regarding the infestation characteristics, all but one of our participants either (i) had correctly identified the bed bug among a set of insects; or (ii) reported that they had seen bed bugs or their feces; or (iii) reported that their diagnosis was confirmed by a professional. A higher confidence in diagnosis, represented by professional confirmation or both correct identification and visual sighting, was achieved by 121 participants. Additionally, 45.7% of our sample had their infestation start <3 months before they responded to the survey, and 52.9% reported that their infestation had lasted >3 months. Nearly half (47.1%) of respondents

had seen bed bugs in more than one room and 53.6% reported that treatment was effective in a few weeks or less. The majority of our sample (81.9%) had used pesticides to eliminate bed bugs. An increased proportion of respondents (74.6%) said that they had restricted their social contacts and 37.7% said that they were constrained to do so.

About 65% of our sample reported an average score at the IES-R ≥1.5 [median 2.16; interquartile range (IQR) 1.05, 2.99]. The median total score at the WEMWBS was of 51 (IQR 41, 57). Further descriptions of our sample are reported in Table 1 and Supporting Information, Table S1.

Bivariate analysis demonstrated that not being in a relationship, not having children living at home, infestation spread to more than one room, treatment ineffectiveness, fear of contaminating others, social restrictions (self-decision) and unclear use of pesticides, increased the odds of having a high level of bed bug-related stress (Table S2). Likewise, being a male, having current psychiatric issues and having had difficulties in preparing one's accommodation for treatment were found to significantly decrease the total score of well-being (Table S3).

3.2 Modeling stage

Overall, our naive Bayes algorithm performed relatively well in differentiating participants with high *versus* low levels of bed bug-related stress (cross-validated AU-ROC over the 5 imputed dataset: 0.80; Fig. S1). For well-being, the performance of our

Table 1. Sociodemographic characteristics of the participants and main characteristics of the bed bug infestation

Variables	Total sample (N = 138)
Sex	
Female	92 (66.7%)
Male	34 (24.6%)
Missing	12 (8.7%)
Age (years old)	
<25	14 (10.1%)
25–35	29 (21.0%)
35–45	27 (19.6%)
45–55	26 (18.8%)
>55	31 (22.5%)
Missing	11 (8.0%)
Employment	
No	34 (24.6%)
Yes	93 (67.4%)
Missing	11 (8.0%)
In a relationship	
No	69 (50.0%)
Yes	58 (42.0%)
Missing	11 (8.0%)
Children living at home	
0	67 (48.6%)
1	19 (13.8%)
2 or more	40 (29.0%)
Missing	12 (8.7%)
Education	
Less than Baccalaureate	29 (21.0%)
Baccalaureate, Baccalaureate +1 or 2 years	28 (20.3%)
Bachelor's degree or more	69 (50.0%)
Missing	12 (8.7%)
Medical issues	
No	91 (65.9%)
Yes	30 (21.7%)
Missing	17 (12.3%)
Psychiatric issues	
No	80 (58.0%)
Past	16 (11.6%)
Current	25 (18.1%)
Missing	17 (12.3%)
Spread of infestation	
1 room	73 (52.9%)
2+ rooms	65 (47.1%)
Start of infestation	
<3 months ago	63 (45.7%)
>3 months ago	75 (54.3%)
Total duration of infestation	
<3 months	64 (46.4%)
>3 months	73 (52.9%)
Missing	1 (0.7%)
Difficulties in accepting preparation	
No	48 (34.8%)
Yes	90 (65.2%)
Preparation for treatment	
Not done	6 (4.3%)
Done by self	118 (85.5%)
Done by someone else	14 (10.1%)

Table 1. Continued

Variables	Total sample (N = 138)
Pesticide treatment	
No	26 (18.8%)
Yes & conditions of use not explained	15 (10.9%)
Yes & conditions of use explained but health issues not taken into account	20 (14.5%)
Yes & health issues taken into account	77 (55.8%)
Heat or cold treatment	
No	80 (58.0%)
Yes	52 (37.7%)
Missing	6 (4.3%)
Steam treatment	
No	85 (61.6%)
Yes	48 (34.8%)
Missing	5 (3.6%)
Destruction of materials	
No	89 (64.5%)
Yes	43 (31.2%)
Missing	6 (4.3%)
Participant had to move	
No	119 (86.2%)
Yes	10 (7.2%)
Missing	9 (6.5%)
Treatment effectiveness	
>3 months	64 (46.4%)
<3 months	74 (53.6%)
WEMWBS total score	
Median [Q1, Q3]	51.00 [41.00, 57.00]
Missing	17 (12.3%)
IES-R average score	
Median [Q1, Q3]	2.16 [1.05, 2.99]

Legend. IES-R, impact of event scale, revised version; WEMWBS, Warwick–Edinburgh mental well-being scale; Q1, first interquartile; Q3, third quartile.

regression regularization algorithm was poor, with an average cross-validated R^2 of 0.082 (range 0.078–0.087).

In order to further investigate the explanatory power of each variable on bed bug-related stress, we carried out a SHAP analysis. For each observation, the algorithm assigns a SHAP value to each variable, which indicates the explanatory power of that variable for that observation.

Figure 2 shows the mean absolute SHAP values for the 15 most influential variables over the five imputed datasets. Variables with the highest absolute SHAP values – those that contributed the most in classifying participants in high- *versus* low-level bed bug-related stress – were: social restriction (self-decision); having children living at home; spread of infestation; treatment effectiveness; being in a relationship; fear of contaminating others; age; use of pesticides; sex; support from family and friends; education; having had difficulties with treatment preparation; social restriction (decision made by others); financial help from the landlord; and psychiatric history. The distribution of SHAP values for each of the 15 most influential predictors is reported in Fig. S2.

Figure 3 shows one-way dependence plots for the 15 most important variables over the five imputed datasets. The variables
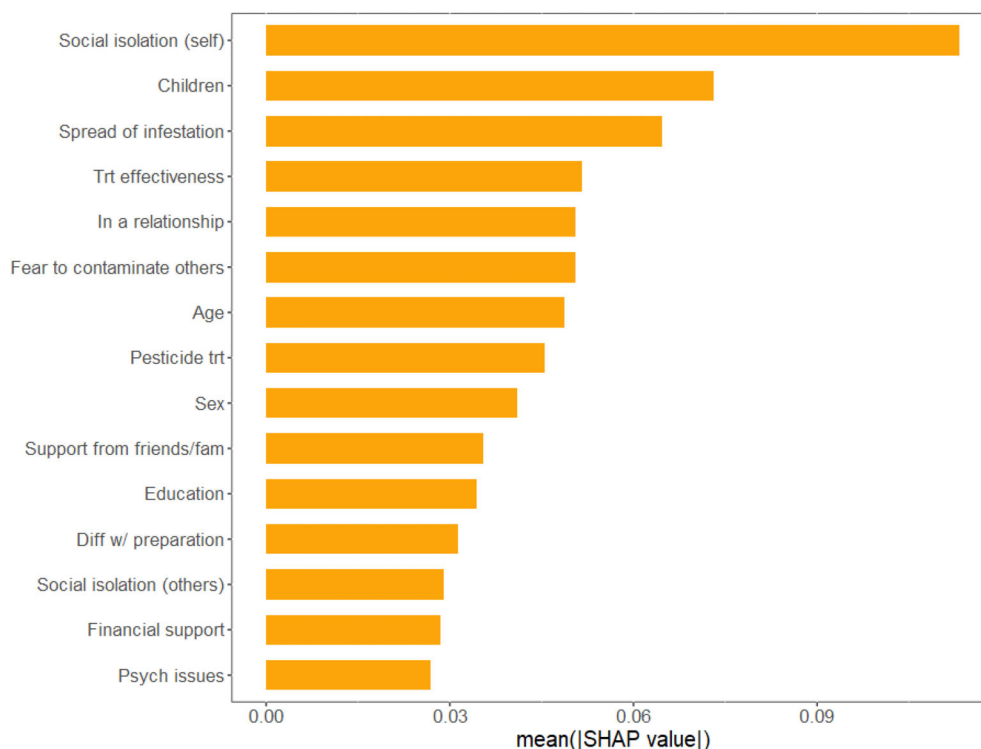
Figure 2. Variable importance plot for the 15 more influential variables. Averaged absolute SHapley Additive exPlanations (SHAP) values are calculated over the five imputed datasets and are represented on the x-axis. Predictors are represented on the y-axis. A higher averaged absolute SHAP value indicates a stronger absolute association with bed bug-related stress. Legend. Trt, treatment; Diff w/, difficulties with; Psych, psychiatric.

that were associated with a high likelihood of high-level bed bug-related stress: social restrictions (self-decision); having no children living at home; spread of infestation spanning two rooms or more; ineffectiveness of treatment; being single; fear of contamination; being <35 years old; use of pesticides (especially when health issues were not taken into account); female sex; and support from family. Other variables that were associated with high-level bed bug-related stress were (Fig. 3): having less than a Bachelor's degree but more than the Baccalaureate; having had difficulties with treatment preparation; social restrictions (from others); financial help from the landlord; and having past or present psychiatric issues. One-way dependence plots for the 15 least influential predictors are reported in Fig. S3.

Figure 4 shows interaction plots of spread of infestation by four variables: support from family and friends; support from landlord; support from pest controller; and being in a relationship. Figure S4 shows interactions plots of treatment effectiveness by the same four variables. Spread of infestation to more than one room was associated with higher SHAP values, but less so if the person dealing with an infestation was supported by friends and family, landlord or pest controller (Fig. 4). By contrast, being in a relationship was associated with increased SHAP values when the infestation was spread to at least two rooms but with decreased SHAP values in case of a more localized infestation. Similar patterns of results were observed for treatment effectiveness (Fig. S4).

In order to address our skewed sex ratio, we conducted an additional analysis using inverse probability weighting for female participants. This analysis yielded similar results regarding sex as a predictor, despite adjusting for the over-representation of women (Fig. S5).

Re-analysis of the 121 participants with higher diagnostic confidence (professional confirmation or both correct identification and visual sighting) largely replicated our findings from the full sample. The naive Bayes algorithm maintained good performance in distinguishing between high and low bed bug-related stress levels (cross-validated AU-ROC across five imputed datasets: 0.78). One-way and interaction plots showed similar patterns (Figs S6 and S7).

4 DISCUSSION

4.1 Preliminary remarks

Well-being in our sample was roughly comparable to that of the general population, yet almost two-third of participants who had experienced a recent bed bug infestation reached threshold for a high level of bed bug-related stress. This figure needs to be taken with caution: as always with nonprobability samples, our sample should not be seen as a representation of the target population because of the unknown sample inclusion or participation mechanisms. We will aim to approach the true prevalence of bed bug-related stress using a probability sample from a national survey institute.

However, our study's primary aim was to identify individual characteristics associated with bed bug-related stress, rather than investigating its prevalence or establishing a causal relationship between infestations and stress. Our set of sociodemographic and infestation-related variables were poor at predicting general well-being. This may be because factors related to lower well-being following a bed bug infestation may be associated with its impact on physical appearance, cost of treatment, or number and timing of bites,[10] which were not recorded in our study. By contrast, our naive Bayes model performed well at classifying high *versus* low levels of bed bug-related stress.
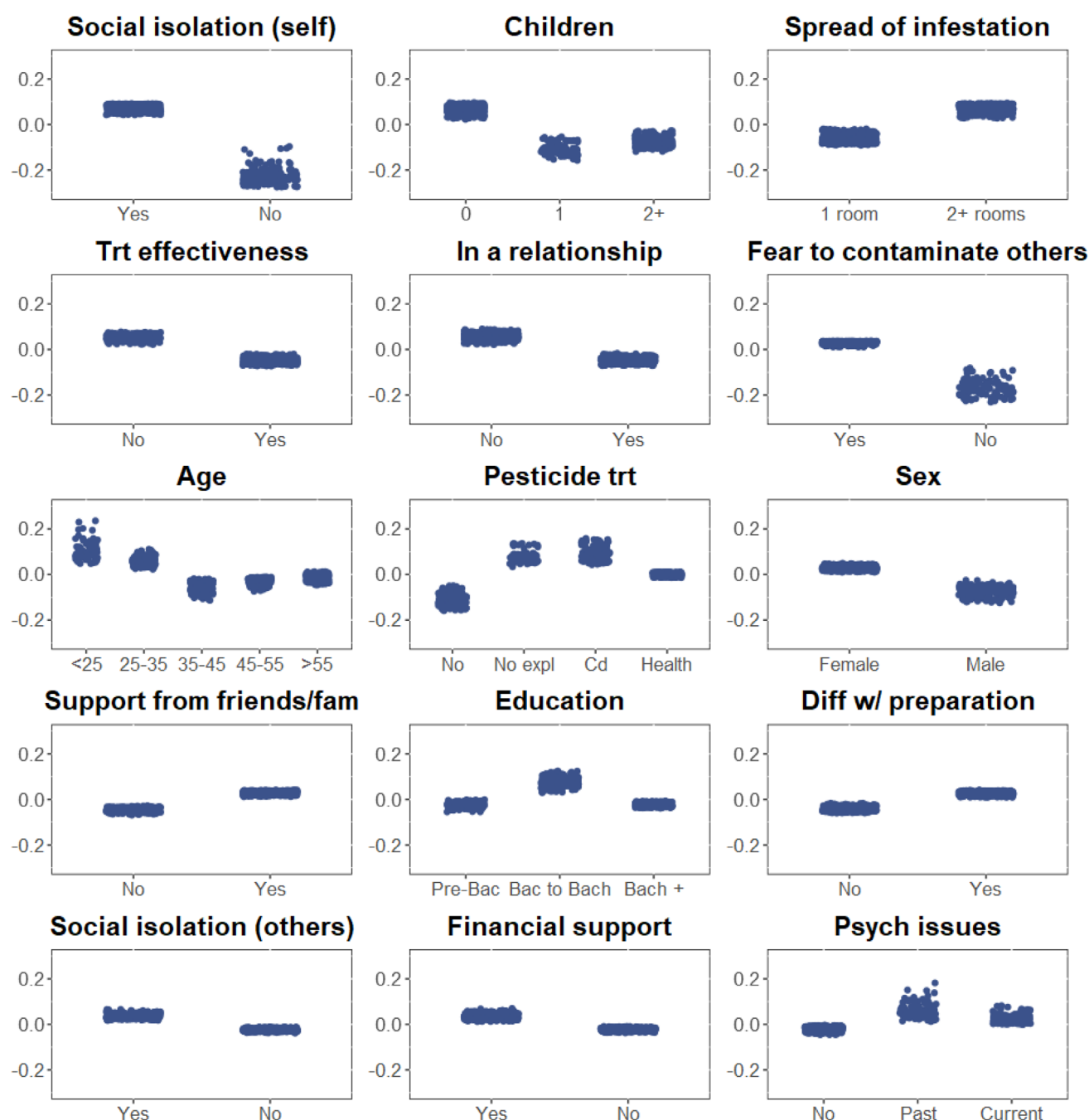
Figure 3. One-way SHapley Additive exPlanations (SHAP) dependence plot for the 15 most influential predictors. Values of the predictor are represented on the x-axis. SHAP values are represented on the y-axis. SHAP values for the five imputed datasets are displayed. A higher SHAP value indicates a higher likelihood of high-level bed bug-related stress. Legend. Trt, treatment; fam, family; Diff w/, difficulties with; Psych, psychiatric; No expl, no explanation given; Cd, only conditions of use explained; Health, Health issues taken into account; Pre-Bac, less than the Baccalaureate; Bac to Bach, Baccalaureate, Baccalaureate +1 year, Baccalaureate +2 years; Bach +, Bachelor's degree or more.

4.2 Sociodemographic and clinical features

Being a female was associated with a greater likelihood of suffering from a high level of bed bug-related stress. This is consistent with other findings from the PTSD literature showing more severe symptoms in female participants.[31–33] Female roles in handling main household tasks[34] may be responsible for the gender disparity observed in the current study.

Age was another important predictor: being <35 years old was associated with a higher likelihood of demonstrating high-level bed bug-related stress. This mirrored some findings from the PTSD literature,[33] but contradicted others showing better mental health in young *versus* older refugees.[35–37] Compared to other stressful events, it is possible that bed bug infestations result in greater mental burdens to younger individuals in terms of self-esteem, stigma and self-stigma, bonding and social contact.

Not having a Bachelor's degree was associated with a higher likelihood of a high level of bed bug-related stress, consistent with findings showing that lower education is associated with severe
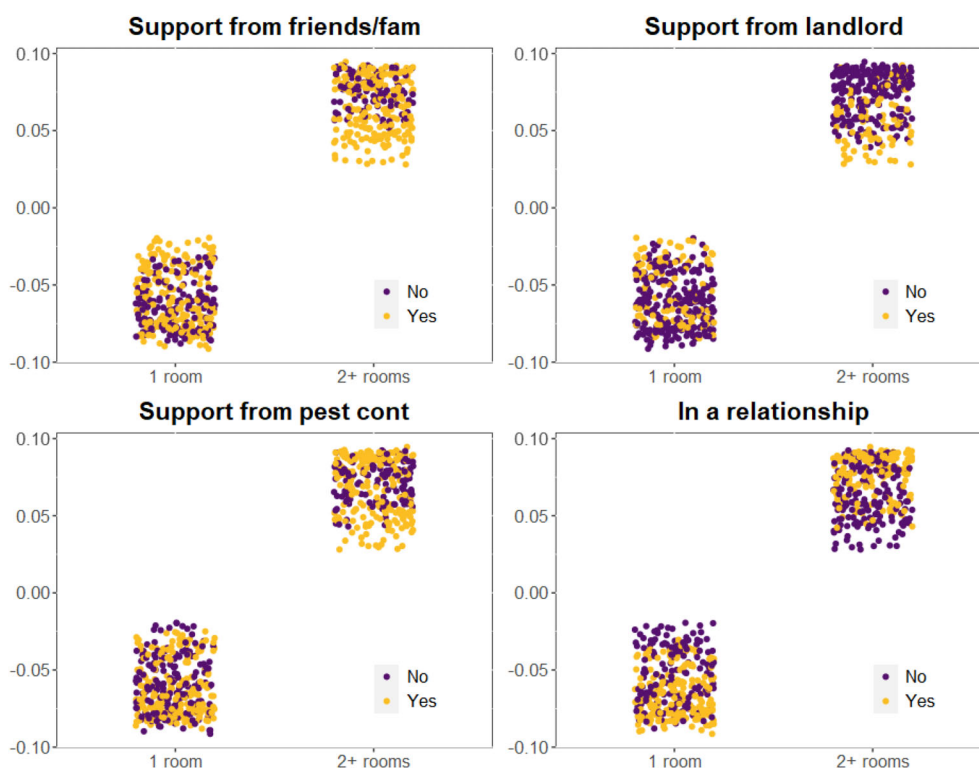
Figure 4. SHAP interaction plots of spread of infestation by social support. Values for spread of infestation are represented on the x-axis. Values for each interaction variable are represented in different colors (orange and purple). SHAP values are represented on the y-axis. SHAP values for the five imputed datasets are displayed. A higher SHAP value indicates a higher likelihood of high-level bed bug-related stress. SHAP values are higher when two rooms or more (*versus* only one room) are infested (all panels). In case of a disseminated infestation, SHAP values tend to decrease when participants are supported by friends/family (top left panel), landlord (top right) or pest controller (bottom left). In case of a disseminated infestation, SHAP values tend to decrease when participants are not in a relationship (bottom right). Legend. fam, family; cont, controller; 2+ rooms, two rooms or more.

PTSD symptoms.[31,38] In our study, however, participants with a lower educational background (i.e. those that did not have their Baccalaureate) showed a risk for bed bug-related stress that was roughly similar to those with at least a Bachelor's degree. We speculate that this may be explained by the fact that vulnerable individuals are those prioritized by the French state for social and welfare protection.

As expected, having current or past psychiatric issues was related to an increased risk of having a high level of bed bug-related stress.[38] Having a psychiatric history may directly result in heightened vulnerability for bed bug-related stress. Another possibility is that the relationship between psychiatric issues and bed bug-related stress is in fact mediated by typical vulnerability factors for PTSD, such as childhood adversities.[38]

4.3 Infestation- and treatment-related factors

It should not be seen as surprising that features that are directly related to the severity of a bed bug infestation – infestation spread to at least two rooms and treatment ineffectiveness – were associated with a higher likelihood of bed bug-related stress. This finding mirrors those from the PTSD literature where symptoms severity was directly linked with the severity of the trauma or its direct consequences.[32,33,38,39]

Difficulties in preparing for treatment were related to a greater likelihood of a high level of bed bug-related stress. Preparation for bed bug treatment is an extensive process that can be quite demanding, involving washing of all bedding, clothing, curtains and other fabric items in hot water (>60 °C) and drying on a high heat (>60 °C); removing all clutter, boxes and unnecessary items; emptying closets, dressers and nightstands; moving away furniture; thoroughly vacuuming all surfaces, including furniture, mattresses, floors and crevices, and isolating clean items; standing mattresses, removing flip drawers; and disposing of heavily infested items. From the point of view of the person dealing with an infestation, preparation is expensive, time-consuming and tiring.[40] In that sense, an extensive preparation may be associated with an additional mental burden. Additionally, preparation is regarded as paramount by most pest controllers, with some professionals refusing treatment in accommodation that is not fully prepared. Difficulties with preparation would then result in a lower likelihood of treatment success, and by extension in a greater risk of bed bug-related stress.

The unclear use of pesticides was related to a high level of bed bug-related stress. Potential mediators for this relationship may be fear of contamination by pesticides or misapplications and related symptoms (such as vomiting, sweating, pinpoint pupils, nausea, headache, weakness and dizziness).[41] According to a US study, 34% of professional treatments by pesticides and 44% of nonprofessional treatments were characterized by unintended exposure and adverse outcomes.[42] In France, 39% of individuals dealing with an infestation complain of a lack of information related to treatment conditions and processes.[4] However, our data suggest that, when all precautions are being taken, the use of pesticides is not associated with any negative effect on bed bug-related stress. We therefore add our voice to others who plead for a reinforcement of education of both pest controllers and people experiencing infestations for the safest use of pesticides.[43,44]

4.4 Social isolation

Having sufficient social contacts post-trauma is an important predictor of PTSD.[31,39,45] In our study, features related to social isolation, such as being single or restricting social contacts (e.g. owing to fear of contaminating others), were associated with a high level of bed bug-related stress. Further research is needed to understand the mediators of social restrictions faced by individuals dealing with bed bug infestations. Shame associated with the infestation and fear of contamination may significantly influence these restrictions. Likewise, having no children at home may be interpreted as a lack of social support and also resulted in a higher likelihood of bed bug-related stress. Others had shown that childlessness was in fact a protective factor for a series of mental health problems, including PTSD, in recently arrived refugees.[31] Yet in this context, having children may be seen as an additional burden, where one needs to rapidly adjust to a changing environment and find necessary resources.

Social support from family and friends, landlords (including financial support) or pest controllers, were related to a greater risk of high-level bed bug-related stress. We provide three lines of arguments for this seemingly paradoxical finding. First, social support may be seen first and foremost as a sign of the severity of an infestation rather than a protective factor. Second, the IES-R does not assess features that may be directly related to social support, such as low mood, guilt, shame, lack of pleasure or feeling distant or cut-off from others.[46] Therefore, positive impacts of social support may have been hidden in our analysis. Third, social support may have particularly beneficial effects in extremely adverse circumstances. Indeed, our interaction plots suggest that the effect of social support decreases the likelihood of a high level of bed bug-related stress when the bed bug infestation is spread throughout the participant's unit or in case of an ineffective treatment. Interestingly, being in a relationship may result in an opposite interaction effect: when the infestation is disseminated or difficult to treat, living with a partner *increases* the likelihood of a high level of bed bug-related stress. One hypothesis is that in case of a severe infestation, sustaining an intimate relationship represents an additional mental burden to the individual.

4.5 Strengths and limitations

Our study has a number of strengths. First, we excluded participants with a nonrecent bed bug infestation in order to minimize recall bias. Second, we used a large number of features that were predictive of bed bug-related stress. Third, we included a series of items aiming to confirm bed bug infestations. This increases the level of evidence that our population had been recently experiencing infestations by bed bugs rather than any other pests, although of course the level of proof is lower than on-site inspections. Fourth, we used a naive Bayes algorithm along with a stringent cross-validation scheme to provide a fair estimation of performance accuracy. This algorithm performed well at classifying participants with a high level of bed bug-related stress. Fifth, we leveraged SHAP values to describe the contribution of each feature on the occurrence of high-level bed bug-related stress. The SHAP method is described as the only model-agnostic explanation method with a solid theoretical foundation.[30]

Our study also has a number of limitations. First, we used a convenience, nonprobability sample, which may not match with the target population. For instance, our sample was over-represented by females, and unemployment was present in 25% of participants, whereas a probability nonconvenience sample showed a lower rate of females and a higher rate of unemployment.[4] Also,

despite our efforts in reaching precarious populations, our sample was relatively highly educated because 50% of participants had at least a Bachelor's degree (≈20% in the general population).[47] Selection is therefore a possibility and inferences may be drawn with caution. Nonetheless, our study design incorporated elements to help mitigate this concern. Although individuals scoring high in bed bug-related stress may have underlying stress tendencies, including current or past psychiatric issues as a predictor helped mitigate this potential confounding effect on other predictors.

Second, the cross-sectional nature of this survey makes it difficult to draw causal inferences from our results. A comparison between individuals experiencing bed bug infestations and a control group without infestation history could provide stronger causal evidence of the impact on mental health. We see our study as a foundation to deploy longitudinal investigations within a causal framework.

A third limitation is the relatively small sample size. The recruitment challenges which we faced were significant, primarily owing to the sensitive nature of bed bug infestations and the associated stigma. Many participants were excluded because they had a bed bug infestation for more than a year before they filled up the survey. Even though our approach allowed for rich data collection from each participant, providing a nuanced understanding of their experiences, some participants complained that the survey was too long and some did not complete it. We acknowledge that limitations remain regarding generalization to different populations. However, we believe our study provides valuable initial insights into the understudied area of bed bug-related stress and provides a solid foundation for future research in this area. In particular, the use of cross-validation enables greater confidence in our model performance and applicability to independent observations. Likewise, our relatively small sample did not prevent our model from performing well at classifying those with a high *versus* low level of bed bug-related stress. Overall, we view this study as exploratory, offering important preliminary data and highlighting key areas for further investigation with larger samples.

Fourth, despite the fact that our survey covered a number of potential predictors, we were not in a position to investigate how other variables (e.g. other stressful events) might be associated with bed bug-related stress. These variables might have further increased the predictive power of our model. For instance, sleep disturbances caused by bed bug infestations have a substantial impact on the quality-of-life of those affected, and can exacerbate stress.[10]

Fifth, we focused on mental health effects within 1 year of infestation to minimize recall bias. Future studies could explore longer-term impacts and compare short-term *versus* long-term effects of bed bug infestations.

5 CONCLUSION

Bed bug infestations have risen in the past decades, yet to the best of our knowledge, no previous studies had investigated predictors of bed bug-related stress, a potentially prevalent condition. Bed bug-related stress may be described as an equivalent of adjustment disorder or PTSD with a nonlife-threatening stressful event. We showed that a high level of bed bug-related stress was predicted by sociodemographic factors such as being of a young age and female sex, social isolation, and infestation- and treatment-related factors such as the unclear use of pesticides.

Although some factors contributing to bed bug-related stress, such as age or sex, are nonmodifiable, this should not deter efforts to target specific populations and provide tailored support. Social isolation is a common reaction to bed bug infestations,[8,15,48] and in France, the use of pesticides is still the first line option for eliminating bed bugs.[3] Our study suggests that social isolation and unclear use of pesticides should be limited to mitigate the risk of bed bug-related stress. Additionally, our findings underscore the need for specific psychological and social interventions to support individuals affected by bed bug infestations.

ACKNOWLEDGEMENTS

CONFLICT OF INTEREST

CT is the co-owner of a local business for canine detection of bed bugs (Société Lyonnaise de Détection Canine). In addition to bed bug detection, his day-to-day work consists in stakeholder education and in the development of nonchemical treatments.

Other authors declare no conflict of interest.

ETHICS STATEMENT

In accordance with the French legislation, approval by an Ethics Comittee or an institutional review board were not required for this study, in the absence of any collection of « sensitive » information. Rather, the present analysis fell within the scope of France's MR-004 reference methodology. The study was approved by a hospital committee with competency for research not requiring approval by an institutional review board, but that verified that the study complied with the MR-004 requirements (Le Vinatier Hospital, Bron, France, MR004-2022). The study was conducted according to the guidelines of the Declaration of Helsinki.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

AUTHOR CONTRIBUTIONS

GB had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

We certify that all authors:

(1) Have made a substantial contribution to the concept or design of the article; or the acquisition, analysis, or interpretation of data for the article; AND.

(2) Drafted the article or revised it critically for important intellectual content; AND.

(3) Approved the version to be published; AND.

(4) Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conceptualization: GB, VB, NF.
Data curation: GB.
Formal analysis: GB.
Funding acquisition: N/A.
Investigation: VB.
Methodology: GB, CT.
Project administration: GB, VB.
Resources: VB.
Software: GB.
Supervision: NF.
Validation: NF.
Visualization: GB, VB, Nf.
Writing – original draft: GB.
Writing – review & editing: GB, VB, CT, NF.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

REFERENCES

1 Akhoundi M, Sereno D, Durand R, Mirzaei A, Bruel C, Delaunay P *et al.*, Bed bugs (Hemiptera, Cimicidae): overview of classification, evolution and dispersion. *Int J Environ Res Public Health* **17**:4576 (2020).

2 Doggett SL and Lee C-Y, Historical and contemporary control options against bed bugs, Cimex spp. *Annu Rev Entomol* **68**:169–190 (2023).

3 Anses, Maisons-Alfort 286 (2023).

4 IPSOS, 4,7 millions de Français ont été confrontés à des punaises de lit depuis 2016, 16 March 2021 https://www.ipsos.com/fr-fr/47-millions-de-francais-ont-ete-confrontes-des-punaises-de-lit-depuis-2016 [accessed 28 March 2024].

5 Cara G, Punaises de lit: plus de 70 000 consultations en un an en France métropolitaine. Salle Presse Inserm, 27 July 2020 (2020). https://presse.inserm.fr/punaises-de-lit-plus-de-70-000-consultations-en-un-an-en-france-metropolitaine/40418/ [accessed 28 March 2024].

6 O'Malley S and Feighery C, Putting the bug to bed: untangling perspectives on France's bedbug crisis. *Clin Exp Dermatol* **49**:271–272 (2024).

7 Akhoundi M, Zumelzu C, Sereno D, Marteau A, Brun S, Jan J *et al.*, Bed bugs (Hemiptera, Cimicidae): a global challenge for public health and control management. *Diagnostics* **13**:2281 (2023).

8 Susser SR, Perron S, Fournier M, Jacques L, Denis G and Tessier F, Mental health effects from urban bed bug infestation (Cimex lectularius L.): a cross-sectional study. *BMJ Open* **2**:e000838 (2012).

9 Mekonnen D, Zenebe Y, Derbie A, Adem Y, Hailu D, Mulu W *et al.*, Health impacts of bedbug infestation: a case of five towns in Amhara region, Ethiopia. *Ethiop J Health Dev* **31**:251–258 (2017).

10 Fung EHC, Chiu SW, Lam H-M, Chung RY-N, Wong SYS, Chan SM *et al.*, The impact of bedbug (Cimex spp.) bites on self-rated health and average hours of sleep per day: a Cross-sectional study among Hong Kong bedbug victims. *Insects* **12**:1027 (2021).

11 Goddard J and de Shazo R, Psychological effects of bed bug attacks (Cimex lectularius L.). *Am J Med* **125**:101–103 (2012).

12 American Psychiatric Association, *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition: DSM-5*, 5th edn. American Psychiatric Publishing, Washington, D.C (2013).

13 Cameron A, Palm K and Follette V, Reaction to stressful life events: what predicts symptom severity? *J Anxiety Disord* **24**:645–649 (2010).

14 van den Berg LJM, Tollenaar MS, Spinhoven P, Penninx BWJH and Elzinga BM, A new perspective on PTSD symptoms after traumatic vs stressful life events and the role of gender. *Eur J Psychotraumatol* **8**:1380470 (2017).

15 Ashcroft R, Seko Y, Chan LF, Dere J, Kim J and McKenzie K, The mental health impact of bed bug infestations: a scoping review. *Int J Public Health* **60**:827–837 (2015).

16 Perron S, Hamelin G and Kaiser D, *Mental Health Impacts, Advances in the Biology and Management of Modern Bed Bugs*. John Wiley & Sons, Ltd, New Jersy, United States, pp. 127–132 (2018).

17 Sheppard C, Roche B, Austen A and Hitzig S, "When the bedbugs come, that's another problem": exploring the lived experiences of bedbug infestations among low-income older adults and service providers who support them. *Perspect Public Health* **144**:17579139221118777 (2022).

18 Sheele JM, Associations between bed bugs and mental illness among emergency department patients. *Cureus* **13**:e15024 (2021).

19 Brunet A, St-Hilaire A, Jehel L and King S, Validation of a French version of the impact of event scale-revised. *Can J Psychiatry* **48**:56–61 (2003).

20 Weiss DS and Marmar CR, The impact of event scale—revised, in *Assessing Psychological Trauma and PTSD*. The Guilford Press, New York, NY, US, pp. 399–411 (1997).

21 Weathers FW, Litz BT, Herman DS, Huska JA and Keane TM, The PTSD checklist (PCL): reliability, validity, and diagnostic utility. Annu Conv Int Soc Trauma Stress *Stud San Antonio TX* **462** (1993).

22 Creamer M, Bell R and Failla S, Psychometric properties of the impact of event scale—revised. *Behav Res Ther* **41**:1489–1496 (2003).

23 Tennant R, Hiller L, Fishwick R, Platt S, Joseph S and Weich S, The Warwick-Edinburgh mental well-being scale (WEMWBS): development and UK validation. *Health Qual Life Outcomes* **5**:63 (2007).

24 Maheswaran H, Weich S, Powell J and Stewart-Brown S, Evaluating the responsiveness of the Warwick Edinburgh mental well-being scale (WEMWBS): group and individual level analysis. *Health Qual Life Outcomes* **10**:156 (2012).

25 van Buuren S, Groothuis-Oudshoorn K, Vink G, Schouten R, Robitzsch A, Rockenschaub P *et al.*, MICE: multivariate imputation by chained equations R (2023).

26 Kuhn M, Wing J, Weston S, Williams A, Keefer C, Engelhardt A *et al.*, caret: Classification and Regression Training (2023).

27 Wikipedia, Naive Bayes classifier. Wikipedia (2024).

28 Phillips RV, van der Laan MJ, Lee H and Gruber S, Practical considerations for specifying a super learner. *Int J Epidemiol* **52**:1276–1285 (2023). https://doi.org/10.1093/ije/dyad023.

29 Kuhn M, Futility analysis in the cross-validation of machine learning models, ArXiv Prepr ArXiv14056974 (2014).

30 Lundberg SM and Lee S-I, A unified approach to interpreting model predictions. *Adv Neural Inf Process Syst* **30**:1–10 (2017).

31 Nesterko Y, Jäckle D, Friedrich M, Holzapfel L and Glaesmer H, Factors predicting symptoms of somatization, depression, anxiety, post-traumatic stress disorder, self-rated mental and physical health among recently arrived refugees in Germany. *Confl Health* **14**:44 (2020).

32 Kessler RC, Ressler KJ, House SL, Beaudoin FL, An X, Stevens JS *et al.*, Socio-demographic and trauma-related predictors of PTSD within 8 weeks of a motor vehicle collision in the AURORA study. *Mol Psychiatry* **26**:3108–3121 (2021).

33 Eshel Y, Kimhi S, Marciano H and Adini B, Predictors of PTSD and psychological distress symptoms of Ukraine civilians during war. *Disaster Med Public Health Prep* **17**:e429 (2023).

34 Gallup, Women Still Handle Main Household Tasks in U.S., *Gallup.com*. 29 January 2020 https://news.gallup.com/poll/283979/women-handle-main-household-tasks.aspx [accessed 28 March 2024].

35 Bogic M, Ajdukovic D, Bremner S, Franciskovic T, Galeazzi GM, Kucukalic A *et al.*, Factors associated with mental disorders in long-settled war refugees: refugees from the former Yugoslavia in Germany, Italy and the UK. *Br J Psychiatry* **200**:216–223 (2012).

36 Song SJ, Subica A, Kaplan C, Tol W and de Jong J, Predicting the mental health and functioning of torture survivors. *J Nerv Ment Dis* **206**:33 (2018).

37 Georgiadou E, Zbidat A, Schmitt GM and Erim Y, Prevalence of mental distress among Syrian refugees with residence permission in Germany: a registry-based study. *Front Psychiatry* **9**:12 (2018).

38 Stein DJ, Karam EG, Shahly V, Hill ED, King A and Petukhova M, Post-traumatic stress disorder associated with life-threatening motor vehicle collisions in the WHO world mental health surveys. *BMC Psychiatry* **16**:1–14 (2016).

39 Kazantzis N, Kennedy-Moffat J, Flett RA, Petrik AM, Long NR and Castell B, Predictors of chronic trauma-related symptoms in a community sample of New Zealand motor vehicle accident survivors. *Cult Med Psychiatry* **36**:442–464 (2012).

40 Singh N, Wang C, Zha C, Cooper R and Robson M, Testing a threshold-based bed bug management approach in apartment buildings. *Insects* **8**:76 (2017).

41 Simpson WM and Schuman SH, Recognition and management of acute pesticide poisoning. *Am Fam Physician* **65**:1599–1604 (2002).

42 Strid A, Leytem A, Perez J, Buhl K and Cross A, Pesticides misused for bed bug control: comparing professional and nonprofessional applications reported to the National Pesticide Information Center, 2013–2017. *Am J Public Health* **111**:1513–1515 (2021).

43 US EPA O, Stay Legal and Safe in Treating for Bed Bugs. 13 August 2013 https://www.epa.gov/bedbugs/stay-legal-and-safe-treating-bed-bugs [accessed 28 March 2024].

44 Anses, Only use chemicals as a last resort to eradicate bed bugs, Anses - Agence Natl Sécurité Sanit L'alimentation L'environnement Trav, 21 December 2022 https://www.anses.fr/en/content/chemicals-resort-eradicate-bed-bugs [accessed 28 March 2024].

45 Giacco D, Laxhman N and Priebe S, Prevalence of and risk factors for mental disorders in refugees. *Semin Cell Dev Biol* **77**:144–152 (2018).

46 Zalta AK, Tirone V, Orlowska D, Blais RK, Lofgreen A, Klassen B *et al.*, Examining moderators of the relationship between social support and self-reported PTSD symptoms: a meta-analysis. *Psychol Bull* **147**:33–54 (2021).

47 Maurin L, 23% de la population dispose d'un diplôme supérieur à bac + 2. *Cent Obs Société*, 11 January 2021 https://www.observationsociete.fr/education/donnees-generales/population-par-diplome/ [accessed 12 March 2024].

48 Rieder E, Hamalian G, Maloy K, Streicker E, Sjulson L and Ying P, Psychiatric consequences of actual versus feared and perceived bed bug infestations: a case series examining a current epidemic. *Psychosomatics* **53**:85–91 (2012).