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# Noise-induced annoyance and sleep disturbance from military aircraft training

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**ABSTRACT:**
While much is known about the public health impacts of civil aviation noise, only limited research has investigated the consequences of military aviation noise, despite it first being recognized over half a century ago. The present study conducted a social-acoustic survey to quantify levels of annoyance and sleep disturbance associated with military aviation noise among communities surrounding Naval Air Station Whidbey Island, Washington State, USA, which serves as a training facility for EA-18G Growler aircraft. We conducted a social-acoustic survey of 663 respondents residing in households across a representative range of military aviation noise exposure levels. We report evidence that perceived exposure to military aviation noise is consistent with modeled annual sound levels across the study region and that noise exposure is positively associated with annoyance and sleep disturbance. We also found that reported annoyance is strongly influenced by active or past service in the U.S. Armed Forces and by expressed attitudes toward military operations. Aviation noise disrupted several routine household activities and triggered different coping strategies in affected communities. By highlighting the implications for human well-being of military aviation noise, this research raises questions about the appropriateness of conventional community noise metrics and mitigation approaches for military aircraft noise. 
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## I. INTRODUCTION

Aircraft activity is a pervasive and growing source of noise pollution.[1] Military air bases are ubiquitous worldwide, yet, compared with civil aviation, they are among the least understood sources of environmental noise and have received sparse policy attention.[2] This is primarily due to variable noise regulations around military air bases, persistent difficulties in obtaining classified flight records and studying operations with undisclosed schedules, and weak incentives to reduce noise impacts through improved operations or technology.[3–7] Although the consequences of military aviation noise for public communities were well recognized over half a century ago,[8,9] advances in understanding of the health impacts have stalled, despite worldwide growth in military training operations that have often sparked strident community opposition.[4,10,11]

Communities' concerns about military aircraft noise are fueled by several fundamental differences from those of civil aviation. The most evident is the power, speed, and mechanics of military aircraft, which produce extremely loud noise events and low-frequency acoustic energy[12,13] that propagate farther and more readily produce vibrations that penetrate buildings.[14,15] Additionally, whereas civil aviation is relatively consistent and predictable, military operations tend to be variable and intermittent, with potentially large and unpredictable daily and weekly flight schedules.[6,16,17] Finally, depending on the type of operation, military aircraft may routinely fly at much lower altitudes than civil aircraft.[9] These differences in noise strength, onset rate, and intermittency have raised questions about the suitability of applying standard community noise metrics to military aircraft and to abatement strategies, which are mainly informed by civil aviation research.[18,19]

Despite the widespread presence of military air bases worldwide, limited research has examined the human health and well-being implications of this noise pollution source. Annoyance is a well-documented response among communities near military air bases or flight paths,[17,20–22] as well as elevated levels of sleep disturbance.[19,23] For example, noise from U.S. military F-35 aircraft in Okinawa, Japan, is widely reported by residents to cause strong annoyance due to its intensity, low-frequency components, and frequent operations over populated areas. Night and early-morning flights, in particular, disrupt sleep, leading to repeated awakenings and long-term concerns about fatigue and health.[16,22] Evidence for other health impacts, including increases in blood pressure (short-term) and hypertension (long-term), stress and mental health, and children's learning, is also emerging in regions around the world.[24,25] In contrast to civil aviation, military aircraft noise poses a risk of hearing damage and loss due to repeated exposure to extremely loud events.[26] Together,

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research suggests that noise from military aviation elicits more negative responses than noise from civil aviation.[13,22,27,28]

Training operations at Naval Air Station Whidbey Island (NASWI), Washington State, USA, have sparked ongoing debates over the public health and well-being implications of military aviation noise. The consolidation of the U.S. Navy's Boeing EA-18G Growler jet fleet at the airbase from 2016 to 2019, and the subsequent expansion of training activities, led to dramatic increases in the frequency of aviation operations and in the level of noise experienced by surrounding communities.[6,12] Recent research has combined acoustic and aircraft operations data to estimate and map noise exposure across the region and predict health outcomes at the population scale. Using published exposure-response relationships and established guidelines from the World Health Organization (WHO), Jacuzzi *et al.*[13] predicted that over 74 000 people were subjected to potential noise-related health effects, including 21% of the regional population estimated to be highly annoyed, and 9% to be highly sleep disturbed. According to these analyses, average sound levels from military aircraft operations routinely surpass federal agency guidelines for ambient outdoor noise and residential land use, often exceeding WHO guidelines for significant health impacts from nighttime noise. While this prior work does not directly include a primary assessment of population-level health outcomes, it lays the foundation for examining how self-reported health outcomes vary with military noise exposure and in relation to other non-acoustic factors.

Personal, social, contextual, and situational factors (i.e., "non-acoustic factors") are critical for accurately evaluating the health impact of noise pollution and for designing appropriate mitigation strategies.[29–31] The importance of these factors has been documented in numerous social surveys for civil aviation noise, which have demonstrated the influence of diverse factors, including noise sensitivity, coping mechanisms, attitudes related to trust in authorities associated with the noise source, perceived fairness, time of day, and the activities that are disrupted, and the broader residential and neighborhood context.[32] Previous work has suggested that non-acoustic factors are particularly important in modulating responses to military aviation, due to strong associations with patriotism and nationalism;[9,33] although recent investigations are scant. A growing awareness of the influence of non-acoustic factors is being incorporated into noise research in multiple ways, such as the more routine inclusion of personal, social, and situational variables in noise surveys and the development of new international standards for non-acoustic factors.[34] Also, important among these discussions are calls to understand how non-acoustic factors relate to social equity and differences in vulnerability to noise health impacts across demographic groups.[35]

The present study reports findings from a social-acoustic survey conducted in the vicinity of NASWI, which sought to address three research objectives related to the public health implications of military aviation noise. First, we used a standard cross-sectional design to evaluate reported levels of annoyance and sleep disturbance in the context of military aviation. Second, we examined the strength and variation of these reported health impacts relative to both self-reported and modeled noise exposure. Third, we evaluated the role of non-acoustic factors in assessing noise and its health impacts, including demographics, coping strategies, active/past service in the U.S. Armed Forces, and overall impression of NASWI. By integrating results across these three areas of research, we then offer recommendations on the feasibility and efficacy of mitigation opportunities.

## II. METHODS

### A. Study region

The NASWI was constructed in the early 1940s and has a base population of approximately 10 000 soldiers, civilians, and contractors. Military training operations originate from two primary airfields on Whidbey Island, Washington State, USA (Fig. 1). Ault Field is located approximately 5 km from the city of Oak Harbor, the largest community in Island County, while Outlying Landing Field (OLF) Coupeville is located 4 km from the town of Coupeville. Aircraft operations conducted at NASWI range from sessions of repeated closed-pattern routines (including "touch-and-go" field carrier landing practice) to interfacility transfers and arrivals from and departures to off-station areas, including the Olympic Military Operations Area on the Olympic Peninsula that serves as the primary location of electronic warfare and air-to-air combat training.[36] The flight paths for these operations extend across large areas of northwestern Washington, from the Pacific coast to the Cascade Mountains, and into north-central Washington, including the Okanogan region. Although naval flights have been operating in the area for decades, the transition from Northrop Grumman EA-6B Prowlers to Boeing EA-18G Growlers and the consolidation of all Growler training at NASWI have increased military aircraft training in the region.

### B. Survey participants and distribution

The study sample consisted of 10 000 households randomly selected from nine counties (Island, Clallam, Jefferson, San Juan, Skagit, Snohomish, Whatcom, Mason, and Grey's Harbor) in northwest Washington State, USA (Fig. 1). With the intensity of noise events from each operation varying by the type of operation and monitoring location, a wide range of noise readings and military aviation noise exposures have been recorded in the selected Washington State counties.[6,12,13] To ensure representative coverage of potential military aviation noise exposure, we selected 4500 addresses with spatially explicit exposure estimates from a previous study,[13] 4 500 addresses selected with predicted negligible noise exposure, 600 addresses selected in the Olympic Military Operations Area on the Olympic Peninsula (without exposure estimates), and 400 addresses (out of 1 404 addresses) selected in the reservation of the Swinomish Indian Tribal Community on Fidalgo Island. Addresses for households in the study region were extracted from parcel

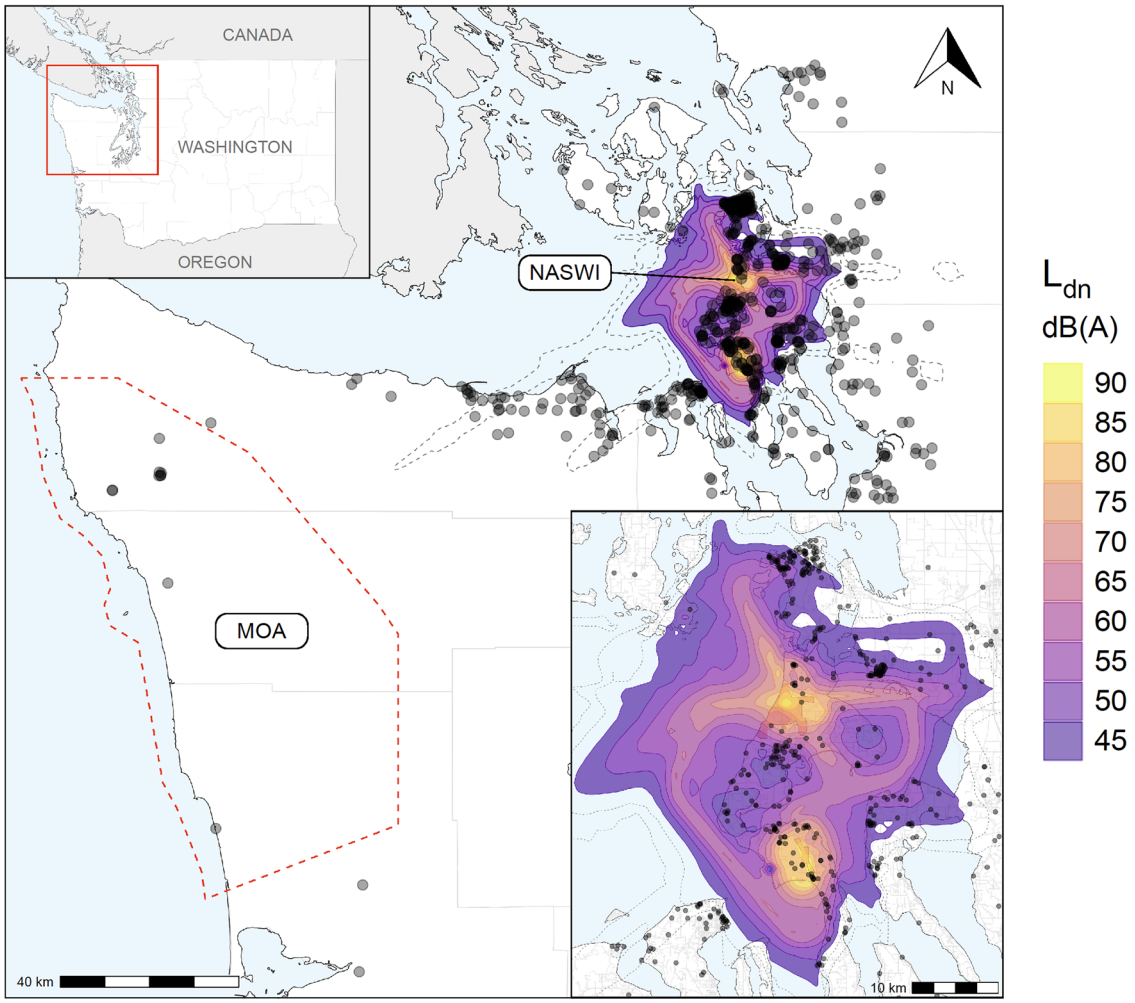


FIG. 1. Location of survey responses (black dots) in relation to military aviation noise exposure according to model-predicted day-night average sound level ($L_{dn}$) from Jacuzzi *et al.* (Ref. 13) Noise exposure is displayed as contours in 5 dB increments, with values below 45 dB shown as dotted lines. NASWI indicates the location of Naval Air Station Whidbey Island, comprising two primary airfields: Ault Field and Outlying Landing Field. Survey responses with no addresses are not displayed. "MOA" refers to the Olympic Military Operating Area, where air-to-air combat and electronic warfare operations out of NASWI are conducted.

records from county websites and entered into the U.S. Census Geocoder to ensure their validity.[37]

An online questionnaire, implemented in Qualtrics and administered over two months (April 24 to June 27, 2024), was distributed to the selected households via postcard invitations mailed to each address. Each postcard included the household's unique six-digit code, a description of the project, and a URL to a webpage with more information. The online survey could be completed on either a computer or a mobile device. Upon visiting the online questionnaire, potential study participants were screened for eligibility. Inclusion criteria required that participants be adults aged 18 years or older and reside in one of the selected counties. The human subjects protocol for the study was approved by the University of Washington's Institutional Review Board (STUDY00019725).

### C. Survey

A social acoustic survey was developed to assess perceived exposure to military aviation noise and self-reported health outcomes. Prior studies and survey instruments on noise exposure, along with the identified themes, informed the survey design. Major themes were selected based on their impact on human health and presented as survey sections. Participant location data were collected using the household code, which was verified by requesting participants to provide their address or ZIP code.

Required and optional sections were created to reduce participant burden. The following (required) survey themes were examined in this study: self-reported noise exposure from military aviation, annoyance and sleep disturbance from military aviation noise, disruption of household activities by noise, strategies used to cope with military aviation noise, and various non-acoustic factors that included demographics (age, gender, race/ethnicity, education, income), service in the U.S. Armed Forces (either active duty or veteran), and overall impression of NASWI (Table I). The following themes were optional after completing the required survey sections and were not explored further in this study: general noise exposure, perceived stress, and general health. Aircraft noise annoyance was assessed using the questions recommended by the ISO/ICBEN (International Commission on the Biological

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TABLE I. Social-acoustic survey questions examined in this study.

| Question | Answer |
|---|---|
| **Noise exposure** | |
| How would you describe the noise level from each of the following sources of noise at your home? Roadway traffic, Commercial aviation, Military aviation, Neighborhood, Boat/ship, Other | No noise at all \| Little noise \| Somewhat noisy \| Quite noisy \| Very noisy |
| Can you distinguish between military aviation noise and commercial aviation noise? | Yes \| No |
| Do you think that military aviation is a contributor to the overall noise at your home? | Not at all \| Slightly \| Moderately \| Very \| Extremely |
| If military aviation was indicated as a contributor to noise (slightly, moderately, very, extremely): | |
| How frequently do you experience military aviation noise at your home? | Less than once a week \| Several times a week \| Several times a day \| More than several times a day |
| How would you describe the loudness that you experience from military aviation at your home? | No noise at all (1) – Extremely loud (4) [Scale: 1–4] |
| How would you describe the pitch of sound that you experience military aviation noise at your home? | Low (deep, rumble) (1) – High (shrill) (4) [Scale: 1–4] |
| How many flyovers (a single aircraft passing overhead or nearby) do you typically experience in a day when the military aircraft are flying? | 1–5 \| 6–10 \| 11–15 \| 16–20 \| More than 20 |
| **Annoyance Level** | |
| Thinking about the last 12 months, how much does military aviation noise bother, disturb, or annoy you at home? | Not at all \| Slightly \| Moderately \| Very \| Extremely |
| If military aviation noise was indicated as annoying (slightly, moderately, very, extremely): | |
| On days when you experience military aviation noise, are there any time periods when it is particularly annoying? Select all that apply. | Morning (7 am–12 pm) \| Afternoon (12 pm–7 pm) \| Evening (7 pm–10 pm) \| Night (10 pm–7 am) \| No particular time period |
| Does noise from military aviation bother, disturb, or annoy you more in certain seasons or all year round? Select all that apply. | Autumn \| Winter \| Spring \| Summer \| No particular season |
| **Sleep Disturbance and Disruption of Activities** | |
| Thinking about the last 12 months, military aviation noise has disturbed you at home in which of the following ways: Sleeping (trying to fall or stay asleep); Socializing with others; Engaging in work activities; Listening to music, watching videos, or having a personal conversation on the phone or online; Engaging in quiet leisure activities, such as reading, writing, or resting (not including sleeping); Spending time outdoors, such as gardening or time on the balcony/deck/patio. | Not at all \| Slightly \| Moderately \| Very \| Extremely |
| How often do you have trouble getting to sleep or staying asleep? | Almost never \| Sometimes \| Often |
| **Non-acoustic Factors** | |
| What is your year of birth? | [calendar year] |
| What gender do you identify as? | Male \| Female \| Non-binary/non-conforming \| Transgender \| Prefer not to respond |
| Choose the race/ethnicity that you consider yourself to be: | White \| Black or African American \| American Indian or Alaska Native \| Asian \| Native Hawaiian or Pacific Islander \| Spanish, Hispanic, or Latino \| Other (open answer) |
| What is the highest level of school you have completed or the highest degree you have received? | No high school degree \| High school graduate \| Some college but no degree \| College graduate \| Graduate or Professional Degree |
| Please indicate your entire household income (the previous year) before taxes to the best of your ability. | Less than $19 999 \| $20 000 to $49 999 \| $50 000 to $74 999 \| $75 000 to $99 999 \| $1 00 000 to $1 49 999 \| $1 50 000 to $1 99 999 \| $200 000 or more |
| Have you ever served in the U.S. Armed Forces? | Yes \| No |
| What is your overall impression of the Naval Air Station Whidbey Island operations? | Very unfavorable \| Somewhat unfavorable \| Indifferent \| Somewhat favorable \| Very favorable |
| **Coping Strategies and Other** | |
| How much do you agree with each of the following statements? I know that I can protect myself quite well against noise. Sometimes, I really feel helpless due to the noise. I perceive the noise, but I have just mentally switched it off. I do not perceive the noise anymore because I am somewhat desensitized. | Not at all \| Slightly \| Moderately \| Very \| Extremely |
| Which of the following strategies do you use when experiencing military aviation noise? Select all that apply. | Close windows or doors \| Retreat into a quieter area of the house \|Avoid the use of the garden, balcony, patio or deck |

TABLE I. *(Continued.)*

| Question | Answer |
|---|---|
| | Invested in sound insulation to reduce the noise \| Speak more loudly with others \| Increase the volume of your electronic device \|Use earplugs or headphones \| Use sleep-aid supplements or meditation (e.g., melatonin, sleeping pills) \| Other (open answer) |
| If you own a pet, are they frightened (for example: shivering, cowering, vocalizing, being woken up) by military aviation noise? | Not scared at all \| Slightly scared \| Scared \| Very scared \| Extremely scared |

Effects of Noise).[38] Sleep disturbance (daily sleep status, difficulty initiating or maintaining sleep) was assessed according to Trieu *et al.*[39]

### D. Data analysis

Average noise exposures for each household were estimated using the spatially explicit maps of military aircraft noise exposure generated by Jacuzzi *et al.*[13] Briefly, acoustic data spanning seven years of monitoring efforts were integrated with detailed flight operations data from the Naval Facilities Engineering Systems Command for four-week-long monitoring periods in 2020 and 2021, and with a Department of Defense noise simulation model to characterize the noise regime. These data were collected by the Department of Defense to accurately reflect typical annual noise exposure across a range of flight operational volumes and seasonal conditions, to inform impact assessment and long-term land-use planning.[40] The model predicted day-night average sound level ($L_{dn}$), with a +10 dB penalty applied to nighttime periods (22:00–07:00) and expressed as A frequency weighting. The model produced 5 dB contours for $L_{dn}$, which were validated by field monitoring and mapped to estimate the noise burden at the respondent's residence based on the reported address or zip code (mapped to the centroid of the associated region). Operational schedules indicate that flight activity remained largely consistent between the periods of noise exposure modeling and community surveying (see Table S1 in the supplementary material).

The following data summaries and statistical analyses were conducted to address the study objectives. Likert Chi-square tests were used to assess differences in proportions of respondents reporting levels of annoyance and sleep disturbance (conducted separately) between two self-reported military aviation noise groups: less reported noise (no noise at all, little noise, or somewhat noisy) and more reported noise (quite and very noisy). Spearman's rank correlation analysis was used to assess the association between respondents' reported levels of annoyance and sleep disturbance. Differences in reported exposure, annoyance level, and sleep disturbance were also examined for several non-acoustic factors, including demographics, service in the U.S. Armed Forces (active/past military personnel vs civilian), and overall impression of NASWI. Additionally, annoyance levels for military personnel and civilians were compared between low ($<60\,L_{dn}$) and high ($>=60\,L_{dn}$) modeled noise exposure at the respondent's residential location, to assess self-reported annoyance relative to actual vs self-reported military aviation noise. We conducted ordinal regression to assess the relationship between self-reported military aviation noise groups—less reported noise (no noise at all, little noise, or somewhat noisy) and more reported noise (quite and very noisy) (the exposure)—and Likert level responses in annoyance (the annoyance outcome) and sleep disturbance (the sleep disturbance outcome), conducted separately. These models also included respondent age, gender, military service, and impression of NASWI. All statistical analyses were performed using R Statistical Programming Language, version 4.4.1.

## III. RESULTS

The questionnaire was completed by 663 study participants, yielding a response rate of approximately 7% (Table I). Respondents tended to be older, identified as male and White, college graduates, and reported relatively high annual household incomes (Table II). For comparison, residents of Island

TABLE II. Summary of the survey respondents concerning age, gender identity, race, highest educational degree, and annual household income in USD. Reported values are the mean (standard deviation) for age and the number of respondents (percent of total) for all other variables.

| Attribute | Respondents ($n = 663$) |
|---|---|
| **Age (years)** | |
| Mean (SD) | 61.6 (14.5) |
| **Gender identity** | |
| Female | 248 (37.4%) |
| Male | 355 (53.5%) |
| Non-binary/non-conforming | 5 (0.8%) |
| Prefer not to respond | 55 (8.3%) |
| **Race** | |
| White | 572 (86.3%) |
| Asian | 12 (1.8%) |
| Spanish, Hispanic, or Latino | 9 (1.4%) |
| American Indian or Alaska Native | 5 (0.8%) |
| Black or African American | 3 (0.5%) |
| Native Hawaiian or Pacific Islander | 1 (0.2%) |
| Other (open answer) | 61 (9.2%) |
| **Education level** | |
| No college degree | 133 (20.1%) |
| College graduate | 287 (43.3%) |
| Graduate or Professional degree | 243 (36.7%) |
| **Household income (USD)** | |
| $74 999 or less | 176 (26.5%) |
| $75 000 to $149 000 | 282 (42.5%) |
| $150 000 or more | 205 (30.9%) |

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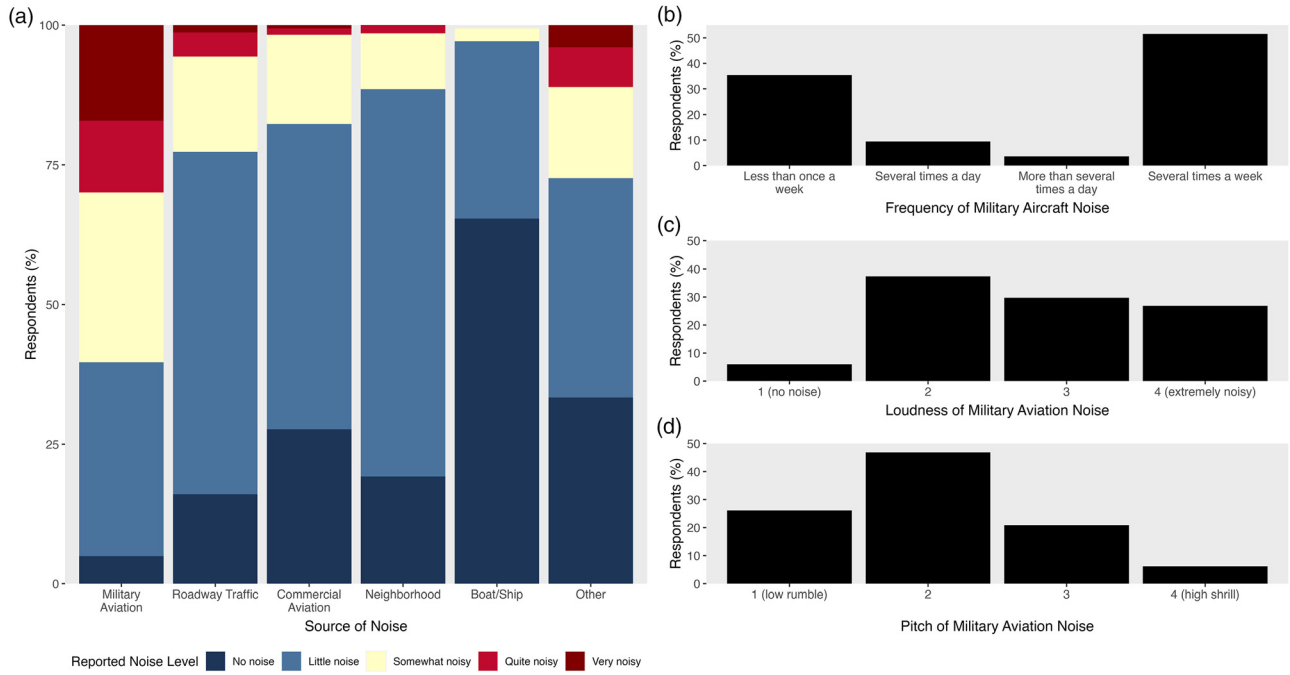


FIG. 2. Sources and levels of noise (a), and the frequency (b), loudness (c), and pitch (d) of military aviation noise.

County, where the most responses were received, are predominantly older (median age is 46 years), male (54% male in our included age group), White (86%), college graduates or higher (36%), and have higher incomes (median household income $81 783/year).[41] The spatial distribution of respondents (Fig. 1) was consistent with the areas targeted for study recruitment and is distributed across a gradient of previously modeled noise levels ($L_{dn}$) estimated at the location of the respondent's residence.[13] Additional analyses revealed no evidence for respondent or non-respondent bias. First, we found no evidence that people experiencing the highest noise ($L_{dn}$) had the highest response rates; in fact, there was a negative association ($R = -0.83$, $P < 0.001$). Second, comparison of finished ($n = 663$) vs unfinished surveys ($n = 197$) showed no difference in reported noise level ($T = 0.09$, $P = 0.573$). The percentage of respondents who reported having served in the U.S. Armed Forces, currently or previously, was 31%, reflecting that military families often live near Ault Field and Outlying Landing Field.

## A. Noise exposure

Military aviation was reported as the predominant source of household noise. Approximately one-third of respondents (30%) indicated military aircraft as the cause of "quite" or "very noisy" conditions at home; a level exceeding all other sources of noise such as roadway traffic, commercial aviation, neighborhood activities, and boat traffic [Fig. 2(a)]. Respondents overwhelmingly (96%) responded that they could distinguish the sound produced by military versus civilian aircraft. Over half of the respondents (51%) reported experiencing military aircraft noise several times per week [Fig. 2(b)], and three-quarters (66%) of respondents reported experiencing, on average, 1–10 flyover events (i.e., an aircraft passing overhead or nearby) on days of military training. The loudness of military aviation noise was most commonly reported as being high or extremely high [57%, Fig. 2(c)], and most respondents indicated the noise as low, deep, and rumbling as opposed to high and shrill [73%, Fig. 2(d)]. Respondent's self-reported exposures to military aviation noise were positively associated with modeled day-night average sound levels ($L_{dn}$).[13] Estimated household $L_{dn}$ increased with each ordinal self-reported noise exposure level, with the largest difference seen between those reporting "very noisy" (half of respondents experiencing $L_{dn} > 55$ dB) compared to those reporting "little noise" from military aviation (Fig. 3). However, the degree of variation in $L_{dn}$ across categories of reported noise level was high, suggesting that intermittency of noise events and non-acoustic factors may be playing a mediating role.

## B. Annoyance level

Military aviation noise was consistently indicated as a primary cause of annoyance. One-third (35%) of respondents reported being moderately, very, or extremely bothered, disturbed, or annoyed at home by military aviation noise over the last year. Over three-quarters of the respondents (78%) experiencing exposure to very noisy military aircraft disclosed being very or extremely annoyed by the noise (Fig. 4). Even 15% respondents reported moderate or higher annoyance despite indicating exposure to somewhat noisy conditions from military aviation (Fig. 4). Significantly higher proportions of respondents reported moderate, very, and extreme annoyance when more exposed to military

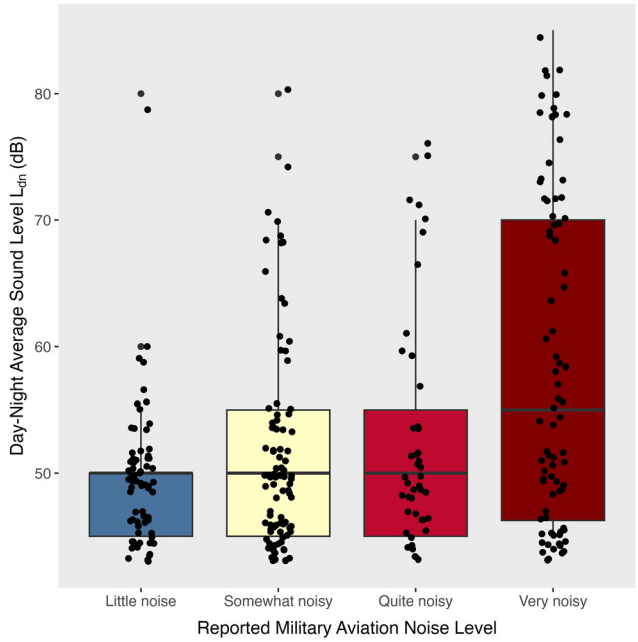


FIG. 3. Reported levels of military aviation noise according to the modeled day-night average sound levels at the respondent's residential location ($L_{dn}$, see Fig. 1). Boxplots report median (centerline), interquartile range (box), and 95% CIs (whiskers). Data points (jittered) are presented.

aviation noise (quite or very noisy) compared to less exposed (little noise or somewhat noisy) (Table III). Annoyance with military noise was reported at all times of day, but was highest in the evening (29%). Similarly, respondents reported annoyance by military noise throughout the year, with the highest levels reported in the summer months (22%).

## C. Sleep disturbance

Military aviation noise was reported to disrupt several routine household activities. Respondents revealed that noise was moderate to extremely disruptive to spending time outdoors (33%), engaging in quiet leisure activities (30%), listening to audio (28%), socializing (27%), working (23%), and sleeping (23%) (Fig. 5). The level of reported sleep disturbance varied as a function of self-reported noise from military aviation. Respondents expressed markedly higher sleep disturbance, ranging from moderate to extreme, when indicating exposure to quite noisy (35%) and very noisy (68%) military aviation (Fig. 6). By contrast, 38% of respondents indicated no sleep disturbance when also reported little exposure to military aviation noise (Fig. 6). Respondents reporting higher exposure to noisy conditions (quite or very) also noted higher sleep disturbance compared to the less noise-exposed group (Table III). Also, one-quarter of respondents (26%) indicated often having trouble getting or staying asleep when experiencing very noisy conditions from military aviation. Pets were also reported as

TABLE III. Annoyance and sleep disturbance levels for respondents reporting high (quite or very noisy) versus low (little noise, or somewhat noisy) exposure to military aviation noise. Chi-square test statistics and significance ($p$-values) for comparisons are reported.

| | Reported military aviation noise level | | |
|---|---|---|---|
| | High ($n = 207$) | Low ($n = 450$) | Chi-Sq ($p$-value) |
| **Annoyance** | | | |
| Extremely | 59 (28.8%) | 1 (0.3%) | 284.7 ($p < 0.0001$) |
| Very | 54 (26.3%) | 9 (2.6%) | |
| Moderately | 46 (22.4%) | 24 (7.1%) | |
| Slightly | 31 (15.1%) | 83 (24.4%) | |
| Not at all | 15 (7.3%) | 223 (65.6%) | |
| **Sleep Disturbance** | | | |
| Extremely | 34 (17.0%) | 2 (0.6%) | 190.6 ($p < 0.0001$) |
| Very | 40 (20.0%) | 5 (1.5%) | |
| Moderately | 33 (16.5%) | 11 (3.3%) | |
| Slightly | 36 (18.0%) | 35 (10.6%) | |
| Not at all | 57 (28.5%) | 276 (83.9%) | |

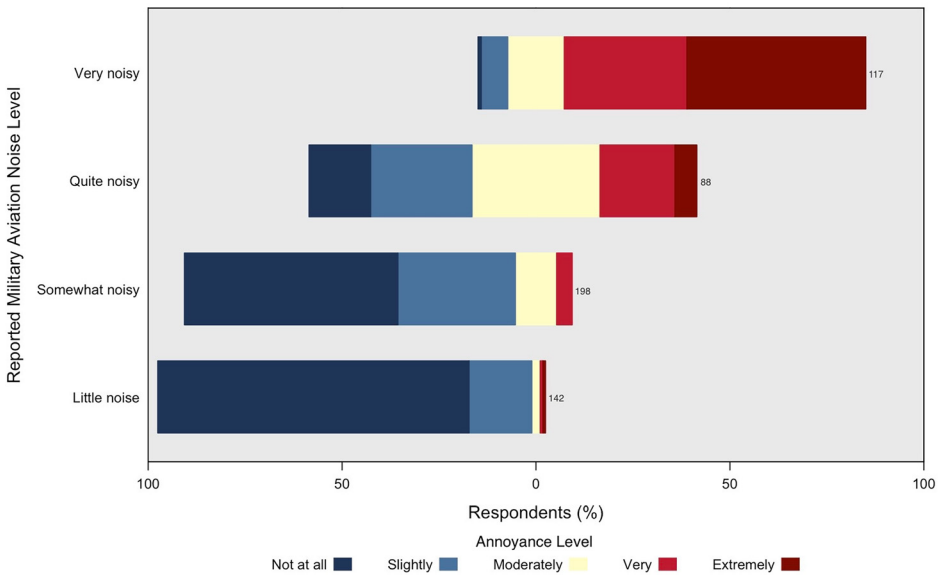


FIG. 4. Annoyance level among respondents reporting military aviation noise. The number of respondents is displayed to the right of the bar.

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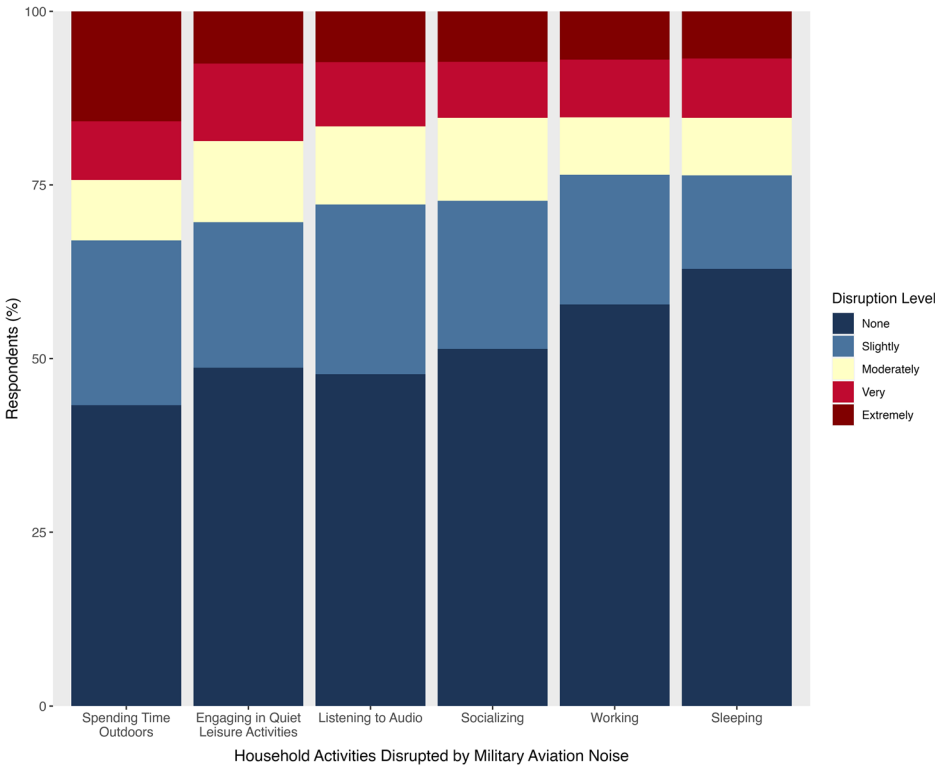


FIG. 5. Disruption in household activities due to military aviation noise among respondents reporting noise.

being frightened (for example: shivering, cowering, vocalizing, being woken up) by military aviation noise by 13% of the respondents. We also found a positive association between respondents who reported higher levels of annoyance and those who reported greater sleep disturbance (Spearman rank correlation $= 0.75$, $p < 0.001$). The majority of respondents (86%) who reported being very or extremely annoyed by military aviation noise also reported moderate to extreme sleep disturbance, whereas almost all respondents (95%) who reported no annoyance also reported no sleep disturbance (Table IV).

### D. Effects of non-acoustic factors

The results provide evidence for several non-acoustic factors that influence reported military noise levels and their perceived annoyance. Respondents who identified as active duty or veterans of the U.S. Armed Forces were less likely to report experiencing highly (quite and very) noisy military aviation conditions (20%) compared to those who have not served [Fig. 7(a)]. Similarly, this same group was less likely to agree with the statement that military aviation contributes to house noise (13%) compared to civilians (18%). Respondents with increasingly more favorable impressions

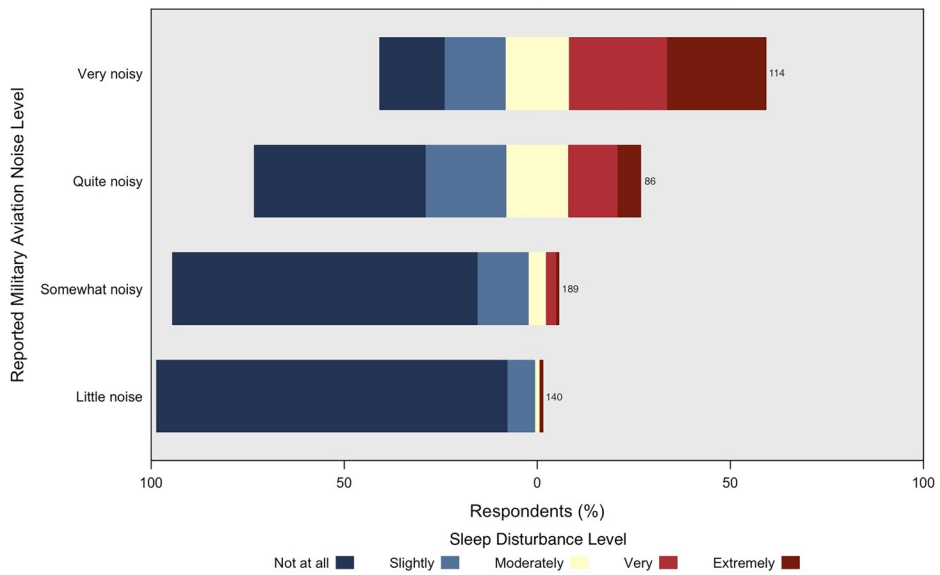


FIG. 6. Sleep disturbance level among respondents reporting military aviation noise. The number of respondents is displayed to the right of the bar.

TABLE IV. Correspondence between annoyance and sleep disturbance level for those respondents reporting military aviation noise.

| | Annoyance | | | | |
|---|---|---|---|---|---|
| | Extremely ($n=59$) | Very ($n=63$) | Moderately ($n=67$) | Slightly ($n=106$) | Not at all ($n=234$) |
| **Sleep Disturbance** | | | | | |
| Extremely | 25 (42.4%) | 9 (14.3%) | 2 (3.0%) | 0 (0%) | 0 (0%) |
| Very | 16 (27.1%) | 17 (27.0%) | 10 (14.9%) | 2 (1.9%) | 0 (0%) |
| Moderately | 10 (16.9%) | 16 (25.4%) | 12 (17.9%) | 6 (5.7%) | 0 (0%) |
| Slightly | 6 (10.2%) | 12 (19.0%) | 16 (23.9%) | 26 (24.5%) | 11 (4.7%) |
| Not at all | 2 (3.4%) | 9 (14.3%) | 27 (40.3%) | 72 (67.9%) | 223 (95.3%) |

of NASWI generally were less likely to report military aviation as a source of noise, with the exception of the "very unfavorable" category, with demonstrated mixed reported levels of noise [Fig. 7(b)]. Interestingly, at lower levels of modeled noise exposure (<60 $L_{dn}$) at the respondent's residential location, active duty and veterans less frequently reported moderate to extreme annoyance compared to civilians (Fig. 8). By contrast, when residing in locations experiencing higher levels of modeled noise exposure (>=60 $L_{dn}$), military and civilian respondents reported similarly high levels of being very and extremely annoyed by military aviation noise.

The results of the ordinal regression models confirmed the descriptive findings, indicating a strong relationship between perceived military aviation noise exposure and annoyance and sleep disturbance. Respondents reporting high military noise (quite and very) were over 25 times and 11 times more likely to report higher annoyance and sleep

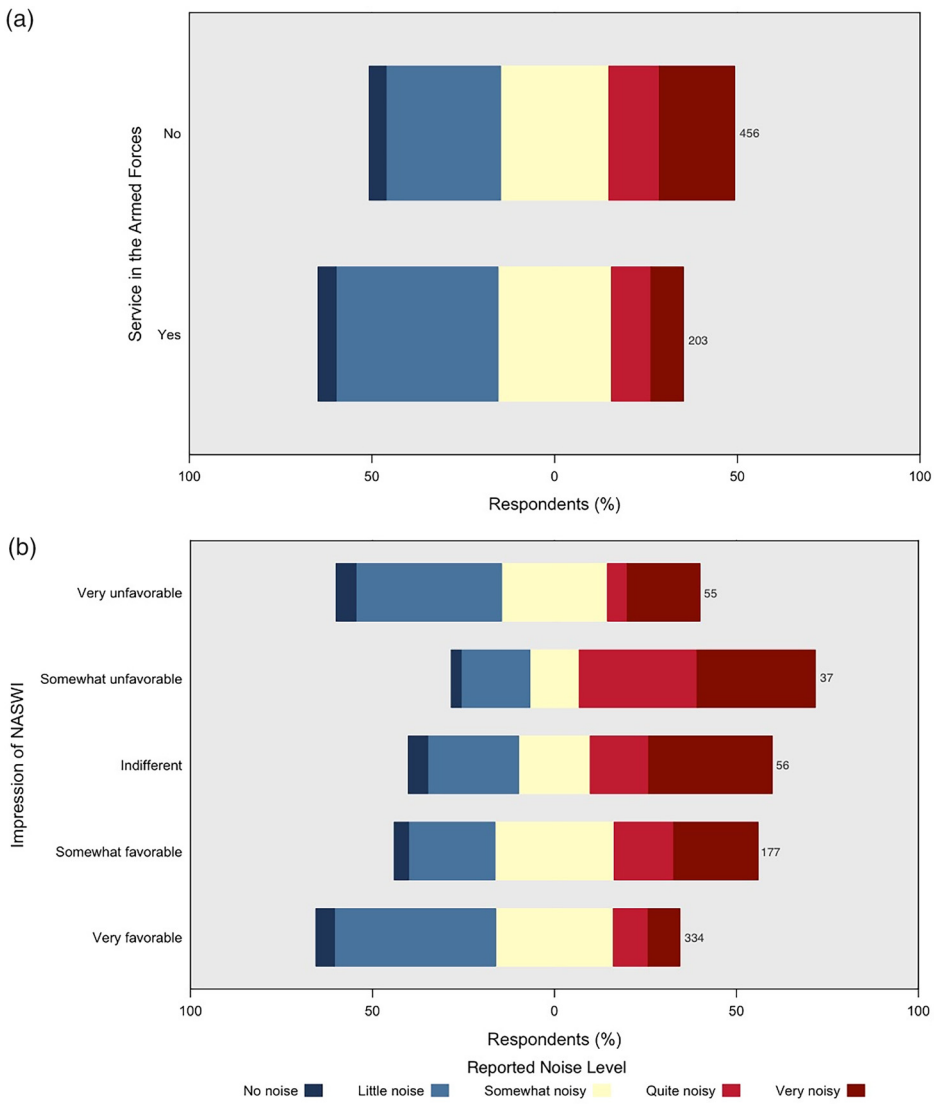


FIG. 7. Reported levels of military aviation noise according to the history of serving in the Armed Forces (a) and the impression of Naval Air Station Whidbey Island (NASWI) (b). The number of respondents is displayed to the right of the bar.

https://doi.org/10.1121/10.0043064

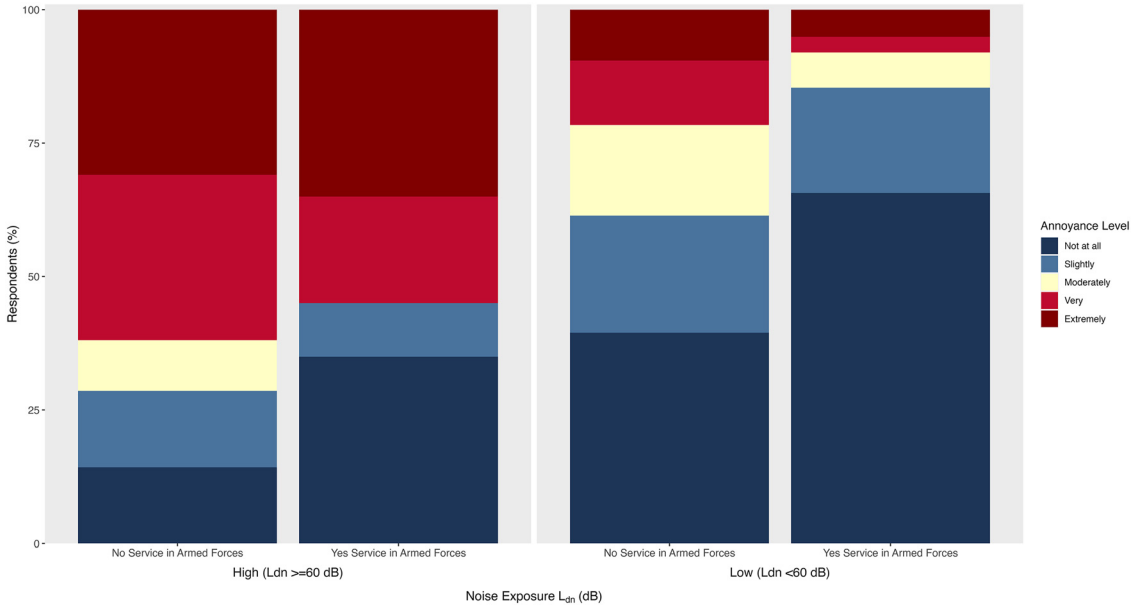


FIG. 8. Annoyance level according to the history of serving in the Armed Forces, comparing high ($L_{dn}$, >=60 dB) and low ($L_{dn}$, <60 dB) modeled day-night average sound levels at the respondent's residential location.

disturbance, respectively, after accounting for age, gender, Armed Forces service, and impression of NASWI (Table V). A positive attitude towards NASWI, in particular, was associated with a lower likelihood of reporting annoyance or sleep disturbance from military aviation (Table V).

Respondents reported using a number of coping strategies when experiencing military aviation noise, including closing windows or doors (18%), speaking more loudly with others (14%), avoiding the use of the garden, balcony, patio, or deck (13%), increasing the volume of electronic devices (e.g., phone, computer, TV) (12%), using earplugs or headphones (7%), retreating into a quieter area of the house (6%), investing in sound insulation to reduce the noise (e.g., wall or ceiling panels, windows) (3%), and using sleep-aid supplements or mediation (e.g., melatonin, sleeping pills) (3%).

TABLE V. Ordinal regression models of annoyance and sleep disturbance levels from perceived military aviation noise exposure, accounting for respondents' age, gender, military service, and impression of NASWI. Odds ratio of being more likely to be annoyed or sleep disturbed with 95% confidence intervals in parentheses. Perceived exposure is defined as self-reported responses of "quite" or "very" noisy. Respondent's impression of NASWI is defined as "very" or "somewhat" favorable.

| Variable | Annoyance Odds ratio | Sleep disturbance odds ratio |
|---|---|---|
| Military aviation noise exposure | 25.44 (15.95, 41.51) | 11.20 (7.18, 17.74) |
| Age (years) | 1.02 (1.00, 1.03) | 1.00 (0.98, 1.01) |
| Gender (male) | 0.65 (0.44, 0.97) | 0.62 (0.40, 0.96) |
| Serviced in U.S. Armed Forces (yes) | 0.75 (0.48, 1.18) | 1.10 (0.66, 1.82) |
| Impression of NASWI (favorable) | 0.21 (0.14, 0.31) | 0.30 (0.20, 0.46) |

## IV. DISCUSSION

There is a growing need to elevate awareness and develop national noise policies to reduce the public health, social, and economic consequences of military aviation noise.[7,42] The present study sought to address this knowledge gap by administering a social-acoustic survey across a gradient of military aviation noise intensity to examine associations between self-reported noise exposure and human health outcomes. We report evidence that perceived exposure to military aviation noise is consistent with modeled annual sound levels across the study region[13] and that noise exposure is positively associated with annoyance and sleep disturbance. We also found evidence that reported annoyance is strongly influenced by active or past service in the U.S. Armed Forces and expressed attitudes toward military operations at NASWI. Although population-based surveys are a standard approach in noise exposure studies, they have been rarely implemented in association with military airfields.

### A. Military aviation noise is linked to annoyance and sleep disturbance

The impact of military aviation on communities has long been recognized,[8,9] yet it remains among the least-studied and most poorly studied sources of noise pollution. The present study contributes to a small but growing body of research highlighting the human health implications of military aircraft noise.[13,22,27,28,43] Although noise can negatively affect multiple aspects of quality of life, both annoyance and sleep disturbance are considered critical indicators of community health, often precursors to physiological effects that can lead to more severe health outcomes.[44] This is supported by decades of research on how aviation noise

generally impacts human health, which has demonstrated that exposure to aircraft noise results in sleep disturbance, physiological stress, compromised childhood learning, and memory and cognitive losses.[45–49] Aircraft noise exposure also increases the risk of serious cardiovascular impacts, including hypertension, stroke, and ischemic heart disease;[45,50,51] recent research has even implicated nighttime aircraft noise exposure with acute cardiac events and death.[52,53] The challenge, however, is translating these results and outcomes to military aviation and operations, which differ substantially from civil aviation in the intensity, duration, and periodicity; and as our and other studies show, perceived noise and reported impacts of military aviation can vary substantially among people.[21,22,33,54,55]

Military aircraft noise can cause significant human annoyance due to its high intensity and unpredictability; operations are highly variable, ranging from periodic single events to repetitive events that extend over many hours.[6,12] The powerful engines and afterburners used in military jets produce noise levels far exceeding those of commercial aircraft, often resulting in sudden, disruptive sound events that can propagate over long distances and affect a large geographic area. Beyond annoyance and sleep disturbance, study respondents reported that military noise from NASWI disrupted other routine activities, such as spending time outdoors, engaging in quiet leisure activities, listening to audio, socializing, and working. More than one-third of respondents reported being moderately to extremely bothered, disturbed, or annoyed at home by military aviation noise over the past year. Such findings are supported by past work showing that noise containing low-frequency components can be more annoying than noise without them,[14,56,57] and the combined effects of noise and vibration on annoyance can be substantial.[58] The unpredictability of military operations exacerbates the issue, as residents cannot readily anticipate or avoid exposure to noise by quickly implementing coping strategies; this may explain why only a small number of survey respondents in this study reported closing windows or using earplugs or headphones. Another likely reason is the ineffectiveness of many coping strategies to reduce the rumbling low-frequency energy from Growlers.

Although limited in number, studies comparing annoyance from military and civilian aircraft indicate greater annoyance from military aviation noise.[15,17,27,28,59] Some of this increased reaction appears due to differences in the intensity of the sound level: a study conducted in Norway that compared annoyance from civilian and military operations found that annoyance was better predicted by descriptors of the noisiest events that day (i.e., typically military) and that even a small number of loud events could cause high annoyance.[17] This is additionally supported by Kim *et al.*[15] A series of studies conducted by the U.S. Air Force found a strong effect of the fast-onset rate (i.e., the "surprise factor"), leading the U.S. Department of Defense to add a penalty in modeling noise from operations that exceed a certain speed.[60] This same study also examined the effects of the numbers and sporadicity of daily flight events, finding no effect of either; however, the maximum number of events each day was 20 (mean of 12), which may be of minimal relevance for airfields like NASWI, where daily operations and exposure to noise events can be tenfold that amount.[6] Collectively, although there is evidence of increased annoyance in response to military aviation, much remains unknown about the relative importance of its acoustic characteristics and their interactions with non-acoustic factors.

The sleep disturbances reported by respondents warrant particular concern, given their implications not only for overall quality of life but also for increased risk of chronic health conditions.[28] Given that nighttime awakening is shown to be triggered by aircraft sounds as low as 35 dB $L_{night}$,[61] the intense sound from even a single military jet event at night can potentially impact a large number of people, and readily cause awakenings, prevent the onset of sleep, and lead to frequent arousals, reducing overall sleep quality. Consistent with this, we found that respondents reported diminished sleep quality, as indicated by increased sleep disturbance and difficulty falling asleep or staying awake, with increasing levels of military noise. Specifically, more than two-thirds of respondents reported moderate to extreme sleep disturbance, and one-quarter reported often having difficulty getting or staying asleep in very noisy conditions associated with military aviation. Our results are supported by prior work demonstrating that nighttime noise exposure near military airfields substantially reduced sleep quality.[19,23] For example, a German social survey reported a 49% rate of sleep disturbance due to low-altitude military flight noise.[62] Similarly, in a study of the community impacts of aviation noise, Banks and O'Rourke[28] reported that the likelihood of adverse effects and heightened perceptions and concerns was greatest among respondents exposed primarily to military aircraft. Finally, the short-term consequences of sleep disturbance for public health include increased annoyance, tiredness, and reduced functioning the next day,[23] while ongoing disrupted and fragmented sleep is implicated in the development of chronic sleep disorders, cardiovascular disorders, stroke, and diabetes.[63]

As with annoyance, community studies are needed to better understand how specific characteristics (e.g., sound level, fast onset, duration) of military aviation impact sleep, and how these characteristics contrast with the impacts of commercial aviation and other (better-studied) transportation noise.[27] Specifically, there is a critical need to determine whether the impacts can be appropriately assessed using the same measurement standards and noise-dose indicators as for civilian aircraft. Studies conducted at a scale to address these questions are rare but suggest that averaged noise levels inadequately capture the impacts of military aviation noise in general, and sleep in particular. Tagusari *et al.*[64] developed a nighttime noise index based on a neurophysiological study of volunteer residents living near Kadena Air Base in Okinawa, Japan. Importantly, this study assessed responses to the high noise levels and variable durations that typify military aircraft. Above 60 dB, they found that a 1-dB increase in noise level increased the risk

of awakening by 5%, and that a 10-dB increase was equivalent to a sleep disturbance in terms of risk, as if it were an almost doubling of duration. The extent to which this increased risk is experienced and realized in communities can be assessed through social surveys, such as the present study, which evaluate subjectively reported sleep disturbance relative to estimated noise exposure.[23,28]

### B. Military attitudes modulate self-reported noise levels

Individual responses to noise can be influenced by personal and situational context, including noise sensitivity, medical history [e.g., post-traumatic stress disorder (PTSD), overall health], and attitudes toward the noise source.[34] As early as the 1960s, based on thousands of interviews with residents near civilian airports and military bases, Borsky and colleagues[9,33] developed a multi-phase framework of 57 factors in community reactions to general and military aviation operations, of which only eight pertained to the acoustic stimulus. The so-called non-acoustic factors, which include a community's prior exposure and history with the noise source, economic dependence on the noise-generating activity, and social attitudes, may all play important modifying roles in self-reported reactions to noise[34,65] and even in objectively measured health outcomes.[66]

Here, we found that respondents with a history of service in the U.S. Armed Forces reported much lower perceived exposure to military aviation noise and lower levels of annoyance and sleep disturbance, after controlling for previously modeled noise levels estimated at the respondent's residence.[13] Our study respondents included a relatively high proportion (31% of survey respondents, compared to 6% of the general population) who had served in the military at some point, allowing us to characterize differences in self-assessment of both noise conditions and responses. Active-duty or veterans of the U.S. Armed Forces were less likely to report experiencing highly (quite and very) noisy military aircraft operations than those who have not served. Interestingly, we found that this relationship varied with the level of noise exposure—a question initially raised in the 1960s[33] that has not been addressed since. At lower levels of modeled residential noise exposure ($<60\,L_{dn}$), active duty and veterans were half as likely to report high levels of annoyance. However, at higher levels of modeled noise exposure ($>=60\,L_{dn}$), responses from those who have served in the military were more polarized, with similarly high levels of very and extremely annoyed, as reported by civilians.

Respondents who had a more favorable impression of NASWI—perhaps because of the benefits to national security or local economies—were also less likely to report military aviation as a source of noise. Interestingly, however, this pattern was dampened among those who expressed a "very unfavorable" impression of NASWI. While this result is based on only 8% of respondents, we can offer two potential explanations. First, this finding may indicate the role of bias awareness and adjustment: individuals who recognize their own unfavorable or biased views seek to modulate their expressed viewpoints to reduce bias.[67] Second, studies have demonstrated that reported annoyance to civilian aircraft noise can be influenced by an individual's perception of a fair and trusted relationship between the airport and the surrounding residents.[68] In this case of our study, some respondents in the "very unfavorable" category may have an unfavorable impression of NASWI, but nevertheless believe that the US Navy is attempting, in good faith, to reduce or mitigate aircraft noise. Alternatively, these respondents may value the fact that military training operations are critical to national safety and, despite a negative impression of the noise generated by these operations, are resigned to their necessity and thus report a dampened perception of noise.

Although research on non-acoustic factors specific to military aviation is limited, their importance has long been recognized. Previous work has suggested that non-acoustic factors are more important in modulating responses to military aviation than to civilian aviation noise, owing to a strong association with patriotism and nationalism.[9] As part of efforts to identify a conceptual scheme and validated survey instrument to assess community reactions to military aviation operations, Borsky[9,33] uncovered a complex and diverse array of modulating attitudinal factors, which included the belief that the noise source is unavoidable or unchangeable, attitudes toward the mission of the airbase, the military, and national defense, and concern that complaints will be considered socially improper. The history of increased military aviation in the region may also affect residents' reported annoyance levels. While military flight activity remained largely stable during the survey and modeling periods, this followed a period of dramatic increase in operations coinciding with the consolidation of the US Growler fleet to NASWI from 2016–2019. Previous research has reported lower tolerance for noise in communities residing near such "high rate of change" airfields.[69] Relatedly, public discourse and expectations of future increases in aircraft noise can increase annoyance rates.[70] The complexity of non-acoustic factors that modulate responses to military aviation noise was further supported by Barbosa and Paul,[55] who reported reduced annoyance among active-duty military personnel compared with civilian residents near a Brazilian airbase. This is believed to stem from a range of interacting factors, including the benefits of base access that compensated for noise, better knowledge and expectations of operations, and a stronger belief that noise was inevitable. Interestingly, Barbosa and Paul[55] also found that military personnel and their families employed a greater number and greater diversity of coping strategies.

Both this study and previous research demonstrate the critical importance of capturing attitudinal data toward the military in general and at individual military bases in particular when conducting noise studies, particularly those based on self-reported outcomes. Our findings underscore the difficulty of defining a single, policy-relevant exposure–response curve when non-acoustic factors are both highly influential

and dynamically related to noise exposure and annoyance. In the context of military aviation, where attitudes toward the source and the institution producing the noise are particularly salient, presenting a single exposure–response relationship could oversimplify a complex, context-dependent phenomenon. Additionally, noise research increasingly demonstrates the physiological pathways by which noise stress can influence objectively measured health outcomes, including sleep disturbance,[61,64] blood pressure,[66] cortisol and inflammation,[71] and cardiovascular health.[52] Ideally, future investigations will expand our understanding of the context-dependence of exposure-response curves associated with military aircraft noise and examine whether non-acoustic factors apply equally to both self-reported and objectively measured health outcomes.

### C. Mitigation strategies

By evaluating the implications of military aviation noise across a large geographic region and varying levels of exposure among diverse demographic groups, our research extends work initiated decades ago but has since been largely neglected. After funding the initial work to develop a robust assessment method for community noise reactions, Borsky[33] reported "Air Force research activity in this area was de-emphasized." This "de-emphasis" has persisted, despite calls to address the problems of military aviation noise, which include impacts on the health and quality of life of people in surrounding communities and on military personnel.[2,3,10,11] Even though the costs of military jet noise resulting from liability in lawsuits, potential alterations in operations or infrastructure, and hearing disability claims (i.e., the largest source of veteran claims) run into many billions of dollars,[3,4,11] there has been very little attention or progress on either assessment or mitigation.[10]

Pervasive noise pollution from NASWI exposes communities to an array of risks and impacts on human health and well-being, as shown by this study and others.[13] Despite this, policy and regulatory provisions for mitigating impacts from military airfields and airspaces in the U.S. are largely limited to the Environmental Impact Statement (EIS) process, resulting in a substantial policy or regulatory gap in which communities have few options other than legal petitions.[4,72] This is the case for Naval Air Station Whidbey Island. Since 2013, community groups, tribes, and agencies have sponsored their research, lobbied legislators for relief, negotiated with the Navy, and taken legal action.[72] An EIS, conducted under the National Environmental Protection Act, identified issues including community annoyance, interference with speech and classroom activities, increased likelihood of awakening, and potential hearing loss from military aircraft noise. Despite these findings, the assessment of health impacts faced criticism. In 2017, the Washington State Board of Health deemed the data insufficient to evaluate the effect of the proposed operational increases and called for a full public health risk assessment. A later review supported this, noting that operations and noise levels around NASWI exceeded levels reported in health-related studies of military flights globally.[6] A 2019 lawsuit led to a 2022 ruling that the Navy failed to adequately consider the impacts on childhood learning, resulting in an order to reconduct the EIS process.

Mitigating population exposure to and the resulting health impacts of military aircraft noise can be most effectively achieved by strategically discontinuing or modifying flight paths for operations with the greatest impacts, such as field carrier landing practice, and by reducing the overall volume of these activities. While significant changes to flight operations are unlikely given military training requirements, adjusting the timing of operations to avoid sensitive periods, such as nighttime and/or optimizing vertical flight profiles, may be more feasible to reduce health impacts. Past studies have demonstrated that operational schedule adjustments can reduce annoyance, even if noise dose levels remain unaltered.[73] Efforts are also underway to reduce the noise footprint of military jets through improved engine design, aerodynamics, and the use of noise-reducing materials, including those developed by the U.S. Office of Naval Research, Science and Technology.

Beyond changes to flight training operations, additional mitigation measures may include establishing subsidy programs for home soundproofing or purchasing properties in areas of high exposure. For some military airfields overseas, federal mitigation programs that provide soundproofing, relocation, or the purchase of highly impacted homes do exist,[19,22] but in the U.S., military engagement in land-use management is limited to providing land-use recommendations to local jurisdictions based on noise exposures.[4] U.S. households near commercial airports, often home to underserved and marginalized communities, may have access to federal funds to soundproof their homes, but this program does not apply to military bases. However, an additional challenge is that while soundproofing has proven effective in reducing indoor exposure to traffic and commercial aircraft noise,[74] prior studies question its effectiveness in mitigating the high-intensity, low-frequency noise generated by military aircraft.[19]

## V. CONCLUSION

The sound of military aviation is unlike any other source of noise. Growlers emit intense noise, with rumbling low-frequency energy that penetrates windows, shakes walls, and can elicit more severe responses than civil aviation. While realistic training operations are an important part of combat readiness, the need to consider and mitigate the public health consequences of military aviation noise remains paramount. By deploying a social-acoustic survey across a gradient of military aviation noise intensity, we found strong positive associations between noise exposure and annoyance and sleep disturbance. Active military personnel and veterans of the U.S. Armed Forces reported lower perceived exposure to military aviation noise and reduced levels of annoyance and sleep disturbance;

however, this group indicated elevated annoyance in locations where modeled (actual) noise levels were high. More broadly, this suggests that assessments of community responses to military aviation noise and the public's willingness to accept or recognize the potential health implications are highly dependent on individuals' impressions of the activities that generate the noise.

## SUPPLEMENTARY MATERIAL

See the supplementary material for the annual summary of scheduled field carrier landing practice (FCLP) for Ault Field and Coupeville OLF.

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## AUTHOR DECLARATIONS

### Conflict of Interest

The authors declare no conflict of interest.

### Ethics Approval

The need for consent to participate was waived by the University of Washington's Institutional Review Board (STUDY00019725). The study adhered to the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Participants.

## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

[1]G. G. Fleming and I. de Lépinay, *Environmental Trends in Aviation to 2050* (International Civil Aviation Organization, Montreal, Canada, 2019).
[2]I. A. Waitz, S. P. Lukachko, and J. J. Lee, "Military aviation and the environment: Historical trends and comparison to civil aviation," J. Aircraft **42**, 329–339 (2005).
[3]S. Martens and J. T. Spyropoulos, "Practical jet noise reduction for tactical aircraft," in *Proceedings of the ASME Turbo Expo 2010: Power for Land, Sea, and Air* (2010), pp. 389–399.
[4]R. Appel and T. Smith, "Compatible land use near military installations: The problem and the local government response," Plann. Environ. Law **63**, 3–10 (2011).
[5]C. B. Pepper, M. A. Nascarella, and R. J. Kendall, "A review of the effects of aircraft noise on wildlife and humans, current control mechanisms, and the need for further study," Environ. Manage. **32**, 418–432 (2003).
[6]L. M. Kuehne, C. Erbe, E. Ashe, L. T. Bogaard, M. Salerno Collins, and R. Williams, "Above and below: Military aircraft noise in air and under water at Whidbey Island, Washington," J. Mech. Sci. Eng. **8**, 923 (2020).
[7]L. M. Kuehne, E. Habtour, T. M. Echenagucia, and S. J. Orfield, "Technology-forcing to reduce environmental noise pollution: A prospectus," J. Expo. Sci. Environ. Epidemiol. **35**, 6–10 (2025).
[8]A. C. Pietrasanta and K. N. Stevens, "Procedures for estimating noise exposure and resulting community reaction from air base operations," J. Acoust. Soc. Am. **29**, 779 (1957).
[9]P. N. Borsky, *Community Reactions to Air Force Noise. Part 1: Basic Concepts and Preliminary Methodology* (University of Chicago, Chicago, IL, 1961).
[10]Naval Research Advisory Committee, *Report on jet engine noise reduction* (NRAC, Arlington, VA, 2009).
[11]Y. Tokuda and P. B. Barnett, "Constructing a new U.S. military base: A health threat to Okinawan people," Environ. Justice **10**, 23–25 (2017).
[12]L. M. Kuehne and J. D. Olden, "Military flights threaten the wilderness soundscapes of the Olympic Peninsula, Washington," Northwest Sci. **94**, 188–202 (2020).
[13]G. Jacuzzi, L. M. Kuehne, A. Harvey, C. Hurley, R. Wilbur, E. Seto, and J. D. Olden, "Population health implications of exposure to pervasive military aircraft noise pollution," J. Expo. Sci. Environ. Epidemiol. **35**(1), 91–103 (2025).
[14]B. Berglund, P. Hassmén, and R. F. Job, "Sources and effects of low-frequency noise," J. Acoust. Soc. Am. **99**, 2985–3002 (1996).
[15]K. Kim, J. Hong, and S. Lee, "Comparison study of annoyances from military and civilian aircraft noise," in *Proceedings of Inter-Noise 2011*, Osaka, Japan (2011).
[16]I. Yamamoto, M. Morinaga, H. Tsukioka, K. Makino, I. Yamada, and M. Matsumoto, "Military aircraft noise prediction model in Japan," in *Proceedings of Inter-Noise 2013*, Innsbruck, Austria (2013).
[17]F. B. Gelderblom, T. T. Gjestland, I. L. N. Granøien, and G. Taraldsen, "The impact of civil versus military aircraft noise on noise annoyance," in *Proceedings of Inter-Noise 2014*, Melbourne, Australia (2014).
[18]G. Kerry, P. D. Wheeler, C. Lomax, and D. J. James, "The assessment of noise from low flying military jet aircraft in the community," in *Proceedings of Inter-Noise 1998*, Christchurch, New Zealand (1998).
[19]T. Matsui, "A report on the aircraft noise as a public health problem in Okinawa" (Okinawa Prefectural Government, Okinawa, Japan, 1999).
[20]T. Gjestland, K. H. Liasjø, and I. L. N. Granøien, "Community response to noise from short-term military aircraft exercise," J. Sound Vib. **182**, 221–231 (1995).
[21]M. Morinaga, I. Yamamoto, H. Tsukioka, K. Makino, S. Kuwano, and M. Matsumoto, "The comparison of psychological evaluation between military aircraft noise and civil aircraft noise," in *Proceedings of Inter-Noise 2014*, Melbourne, Australia (2014).
[22]M. Morinaga, T. Sakuma, K. Kawai, and K. Makino, "Aircraft noise annoyance around military airfields in Japan," in *Proceedings of Inter-Noise 2016*, Hamburg, Germany (2016).
[23]S. J. Kim, S. K. Chai, K. W. Lee, J. B. Park, K. B. Min, H. G. Kil, C. Lee, and K. L. Lee, "Exposure–response relationship between aircraft noise and sleep quality: A community-based cross-sectional study," Osong Public Health Res. Perspect. **5**, 108–114 (2014).
[24]T. Matsui, T. Uehara, T. Miyakita, K. Hiramatsu, and T. Yamamoto, "Dose-response relationship between hypertension and aircraft noise exposure around Kadena airfield in Okinawa," in *Proceedings of the ICBEN Congress* (2008).
[25]K. Baek, C. Park, and J. Sakong, "The impact of aircraft noise on the cognitive function of elementary school students in Korea," Noise Health **25**, 83–91 (2023).
[26]B. Ludlow and K. Sixsmith, "Long term effects of military jet aircraft noise exposure during childhood on hearing threshold levels," Noise Health **2**, 33–40 (1999).
[27]S. Yokoshima, M. Morinaga, S. Tsujimura, K. Shimoyama, and T. Morihara, "Representative exposure-annoyance relationships due to transportation noises in Japan," IJERPH **18**, 10935 (2021).
[28]J. L. Banks and B. P. O'Rourke, "Community impacts of aviation noise: A pilot survey," J. Expo. Sci. Environ. Epidemiol. **35**, 80–90 (2025).
[29]R. F. S. Job, "Community response to noise: A review of factors influencing the relationship between noise exposure and reaction," J. Acoust. Soc. Am. **83**, 991–1001 (1988).
[30]J. M. Fields, "Effect of personal and situational variables on noise annoyance in residential areas," J. Acoust. Soc. Am. **93**, 2753–2763 (1993).
[31]M. Kroesen, E. J. E. Molin, and B. van Wee, "Policy, personal dispositions and the evaluation of aircraft noise," J. Environ. Psychol. **31**, 147–157 (2011).
[32]S. Bartels, I. Richard, B. Ohlenforst, S. Jeram, J. Kuhlmann, S. Benz, D. Hauptvogel, and D. Schreckenberg, "Coping with aviation noise: Non-acoustic factors influencing annoyance and sleep disturbance from noise," in *Aviation Noise Impact Management: Technologies, Regulations, and Societal Well-Being in Europe* (Springer, London, 2022), pp. 197–218.

[33]P. N. Borsky, *Community Reactions to Air Force Noise. Part 2: Data on Community Studies and Their Interpretation* (University of Chicago, Chicago, IL, 1961).
[34]B. Fenech, L. Lavia, G. Rodgers, and H. Notley, "Development of a new ISO technical specification on non-acoustic factors to improve the interpretation of socio-acoustic surveys," in *Proceedings of the ICBEN Congress on Noise as a Public Health Problem*, Stockholm, Sweden (2021).
[35]N. Riedel, I. van Kamp, S. Dreger, G. Bolte, T. Andringa, S. R. Payne, D. Schreckenberg, B. Fenech, L. Lavia, H. Notley, R. Guski, D. Simon, H. Köckler, S. Bartels, M. Weber, and M. Paviotti, "Considering 'non-acoustic factors' as social and environmental determinants of health equity and environmental justice," Transp. Res. Interdiscip. Perspect. **11**, 100445 (2021).
[36]U.S. Department of the Navy, *Final Environmental Impact Statement for EA-18G Growler Airfield Operations at Naval Air Station Whidbey Island Complex* (U.S. Department of the Navy, Washington, DC, 2018).
[37]J. Cambon, D. Hernangómez, C. Belanger, and D. Possenriede, "tidygeocoder: An R package for geocoding," JOSS **6**, 3544 (2021).
[38]J. M. Fields, R. G. De Jong, T. Gjestland, I. H. Flindell, R. F. S. Job, S. Kurra, P. Lercher, M. Vallet, T. Yano, R. Guski, U. Felscher-Suhr, and R. Schumer, "Standardized general-purpose noise reaction questions for community noise surveys," J. Sound Vib. **81**, 499–502 (2001).
[39]B. L. Trieu, T. L. Nguyen, Y. Hiraguri, M. Morinaga, and T. Morihara, "How does a community respond to changes in aircraft noise? A comparison of two surveys conducted 11 years apart in Ho Chi Minh City," IJERPH **18**, 4307 (2021).
[40]U.S. Department of the Navy, *Report to Congress: Real-Time Aircraft Sound Monitoring Final Report* (U.S. Department of the Navy, Washington, DC, 2021).
[41]U.S. Census Bureau, "Island County, Washington," in *2020 Decennial Census and 2023 American Community Survey 1-Year Estimates* (U.S. Census Bureau, Washington, DC, 2023).
[42]C. L. Elkins and J. L. Banks, "Shaping a 21st century federal noise control program," J. Expo. Sci. Environ. Epidemiol. **35**(1), 3–5 (2025).
[43]H. Ising, E. Rebentisch, F. Poustka, and I. Curio, "Annoyance and health risk caused by military low-altitude flight noise," Int. Arch. Occup. Environ. Heath. **62**, 357–363 (1990).
[44]T. Münzel, M. Molitor, M. Kuntic, O. Hahad, M. Röösli, N. Engelmann, M. Basner, A. Daiber, and M. Sorensen, "Transportation noise pollution and cardiovascular health," Circ. Res. **134**, 1113–1135 (2024).
[45]S. Morrell, R. Taylor, and D. Lyle, "A review of health effects of aircraft noise," Aust. N. Z. J. Public Health **21**, 221–236 (1997).
[46]S. A. Stansfeld, B. Berglund, C. Clark, I. Lopez-Barrio, P. Fischer, E. Ohrström, M. M. Haines, J. Head, S. Hygge, I. van Kampo, and B. F. Berry, "Aircraft and road traffic noise and children's cognition and health: A cross-national study," Lancet **365**, 1942–1949 (2005).
[47]M. E. Beutel, C. Jünger, E. M. Klein, P. Wild, K. Lackner, M. Blettner, H. Binder, M. Michal, J. Wiltink, E. Brähler, and T. Münzel, "Noise annoyance is associated with depression and anxiety in the general population—The contribution of aircraft noise," PLoS One **11**, e0155357 (2016).
[48]M. Basner, M. Witte, and S. McGuire, "Aircraft noise effects on sleep—Results of a pilot study near Philadelphia International Airport," IJERPH **16**, 3178 (2019).
[49]A. Li, E. Martino, A. Mansour, and R. Bentley, "Environmental noise exposure and mental health: Evidence from a population-based longitudinal study," Am. J. Prev. Med. **63**, e39–48 (2022).
[50]A. Kourieh, L. Giorgis-Allemand, L. Bouaoun, M. Lefèvre, P. Champelovier, J. Lambert, B. Laumon, and A. Evrard, "Incident hypertension in relation to aircraft noise exposure: Results of the DEBATS longitudinal study in France," Occup. Environ. Med. **79**, 268–276 (2022).
[51]X. Fu, L. Wang, L. Yuan, H. Hu, T. Li, J. Zhang, Y. Ke, M. Wang, Y. Gao, W. Huo, Y. Chen, W. Zhang, J. Liu, Z. Huang, Y. Zhao, F. Hu, M. Zhang, Y. Liu, X. Sun, and D. Hu, "Long-term exposure to traffic noise and risk of incident cardiovascular diseases: A systematic review and dose-response meta-analysis," J. Urban Health **100**, 788–801 (2023).
[52]C. C. Topriceanu, X. Gong, M. Shah, H. Shiwani, K. Eminson, G. O. Atilola, C. Jephcote, K. Adams, M. Blangiardo, J. C. Moon, A. D. Hughes, J. Gulliver, A. V. Rowlands, N. Chaturvedi, D. P. O'Regan, A. L. Hansell, and G. Captur, "Higher aircraft noise exposure is linked to worse heart structure and function by cardiovascular MRI," J. Am. Coll. Cardiol. **85**, 1113–1125 (2025).
[53]N. Itzkowitz, X. Gong, G. Atilola, G. Konstantinoudis, K. Adams, C. Jephcote, J. Gulliver, A. L. Hansell, and M. Blangiardo, "Aircraft noise and cardiovascular morbidity and mortality near Heathrow Airport: A case-crossover study," Environ. Int. **177**, 108016 (2023).
[54]R. F. Wemheuer, *Analysis of the Relationship between Community Attitude toward Military Aircraft Noise, Safety and Economic Factors Associated with the Operation of Marine Corps Air Station, El Toro, California, and the Community Attitude toward the Continued Operation of the Installation* (Pepperdine University, Los Angeles, CA, 1980).
[55]A. R. Barbosa and S. Paul, "Interplay of noise and non-noise aspects in the quality of life of an airbase neighborhood," in *Proceedings of Inter-Noise 2012*, New York, NY.
[56]H. G. Leventhall, "Low frequency noise and annoyance," Noise Health. **6**, 59–72 (2004).
[57]J. A. Alves, F. N. Paiva, L. T. Silva, and P. Remoaldo, "Low-frequency noise and its main effects on human health – A review of the literature between 2016 and 2019," Appl. Sci. **10**, 5205 (2020).
[58]R. Paulsen and J. Kastka, "Effects of combined noise and vibration on annoyance," J. Sound Vib. **181**, 295–314 (1995).
[59]Y. Maekawa, D. Nonaka, S. Kawamoto, Y. Maeda, and Y. Toyama, "Association of military aircraft noise exposure with mental well-being and sleep disturbance near a military air base in Okinawa, Japan: An ecological study," IJERPH **23**, 54 (2025).
[60]E. Stusnick, K. A. Bradley, M. A. Bossi, J. A. Molino, and D. G. Rickert, *The Effect of Onset Rate on Aircraft Noise Annoyance* (Defense Technical Information Center, Washington, DC, 1993).
[61]M. G. Smith, S. Rocha, M. Witte, and M. Basner, "On the feasibility of measuring physiologic and self-reported sleep disturbance by aircraft noise on a national scale: A pilot study around Atlanta airport," Sci. Total Environ. **718**, 137368 (2020).
[62]Allensbacher Berichte, *Belästigung Tiefflieger* (Nuisance from low-flying aircraft) (Institut für Demoskopie, Allensbach, Germany, 1980).
[63]M. Basner and M. G. Smith, "The effects on sleep play a critical role in the long-term health consequences of noise exposure," Sleep **47**, 1–3 (2024).
[64]J. Tagusari, M. Takakusaki, and T. Matsui, "Development of a new nighttime noise index: Integration of neurophysiological theory and epidemiological findings," Noise Health **22**, 1–9 (2020).
[65]S. Fidell, V. Mestre, P. Schomer, B. Berry, T. Gjestland, M. Vallet, and T. Reid, "A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure," J. Acoust. Soc. Am. **130**, 791–806 (2011).
[66]T. L. Nguyen, B. L. Trieu, Y. Hiraguri, M. Morinaga, T. Morihara, and T. Yano, "Effects of changes in acoustic and non-acoustic factors on public health and reactions: Follow-up surveys in the vicinity of the Hanoi Noi Bai International Airport," IJERPH **17**, 2597 (2020).
[67]D. Schreckenberg, R. Schuemer, A. Schuemer-Kohrs, B. Griefahn, and U. Moehler, "Attitudes toward noise source as determinants of annoyance," in *Proceedings of Euronoise* (1998).
[68]D. Hauptvogel, S. Bartels, D. Schreckenberg, and T. Rothmund, "Aircraft noise distribution as a fairness dilemma—A review of aircraft noise through the lens of social justice research," IJERPH **18**, 7399 (2021).
[69]F. Gelderblom, T. Gjestland, S. Fidell, and B. Berry, "On the stability of community tolerance for aircraft noise," Acta Acustica **103**, 17–27 (2017).
[70]E. M. van Kempen and I. van Kamp, "Annoyance from air traffic noise: Possible trends in exposure-response relationships," RIVM report (RIVM, Bilthoven, Netherlands, 2005).
[71]T. Münzel, M. Sørensen, and A. Daiber, "Transportation noise pollution and cardiovascular disease," Nat. Rev. Cardiol. **18**, 619–636 (2021).
[72]J. Kelly, "The sound of freedom at Naval Air Station Whidbey: Environmental impact review under the National Historic Preservation Act and National Environmental Policy Act," Villanova Environ. Law J. **31**, 113–142 (2020).
[73]U.S. Environmental Protection Agency, *Military Aircraft, Airport Noise, and Opportunities for Reduction without Inhibition of Military Missions* (USEPA, Washington, DC, 1973).
[74]J. Xie, L. Zhu, and H. M. Lee, "Aircraft noise reduction strategies and analysis of the effects," IJERPH. **20**, 1352 (2023).