Assessing the impact of blast noise on communities near U.S. Army installations

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INTRODUCTION

In the United States, the number of people living near military installations is steadily growing. Land that was once sparsely populated is seeing a drastic increase in development. This suburban sprawl, combined with the escalation of military activities over the past decade, has heightened the potential for noise generated by U.S. military installations to negatively impact the surrounding communities. One of these sources of noise, military blast noise, has for many years been the cause of community disturbances around and legal actions against U.S. Army installations. Blast noise—the noise generated from large weapons, artillery, and explosions—is unique in that it is both impulsive and high energy, with the majority of the sound energy being concentrated from 10–100 Hz. Because of the high levels at low frequencies, blast noise is notoriously difficult to mitigate and can propagate long distances with minimal attenuation. The noise footprint from any blast-creating training or testing exercise on an installation thus has the potential to extend many tens of kilometers into the surrounding communities. Furthermore, due to the strong dependence upon immediate atmospheric conditions, this footprint can be highly anisotropic—levels in opposing directions can vary by as many as 50 dB un-weighted peak level (ZPk), so while one neighborhood may be barely able to hear the blasts, another may be exposed to peak levels in excess of 130 dB ZPk. To compound the problem, blast noise occurs intermittently; there are typically short periods of intense activity followed by long periods of relative silence, and so relating average noise levels to community response reveals an inaccurate picture of how blast noise is impacting the community on a daily, weekly, or even monthly time scale.

Nevertheless, to assess the impact of these activities on the surrounding communities, U.S. military noise impact standards are currently based on the percent of the population highly-annoyed (%HA) as a function of the C-weighted yearly average noise level (CDNL) (Department of the Army 2007), similarly to the %HA-ADNL relationship that is used to assess transportation noise impacts (Schultz 1978). Army regulations also recommend supplementing this metric with single event peak measurements to predict the risk of receiving blast noise complaints. Neither method, however, fully meets the United States Army's noise management needs and has proven unsatisfactory for predicting both blast noise annoyance and complaints. This is not a moot point; both large and small-scale complaint actions and community annoyance have resulted in the cessation or postponement of testing and training activities, and in some cases have closed down active ranges altogether. More adequate prediction and assessment methods are therefore necessary to protect public welfare and quality of life, while at the same time maintaining the combat readiness of troops.

To address this problem, a large-scale field study is underway at three U.S. military installations. Four research protocols are employed in this project: personal interviews with residents living near the installation, a survey of complainants and their neighbors, a general survey of the community surrounding the installation, and a detailed study of a small number of residents' responses to single blast events *in situ*. The aim of this paper is to provide an overview of each aspect of this project and provide an update on the results obtained since those presented at ICBEN 2008. As noted in 2008, all findings in this project thus far indicate that the number, timing, and level of discrete blast events are important for predicting the human response to blast noise. More recently, and perhaps more importantly, we have demonstrated that there is a large spatial variation in both noise environment and annoyance to blast noise, and that current noise metrics correlate poorly with annoyance.

OVERVIEW OF RESEARCH PROTOCOLS

Personal interviews

In order to determine the language that residents used to describe noise in their environment, and to validate concepts that were subsequently used in the *in situ* study and general community annoyance survey instruments described below, a series of personal interviews were conducted with residents living around 3 U.S. military installations. These installations were located in three geographically different regions (Northeast US, Southeast US, and Western US), to ensure there were no local dialect or language differences. In total, 26 interviews were conducted. The interviews were recorded, transcribed verbatim, and qualitatively compared for common observations, terminology, and types of complaints.

Complaint survey (correlation of complaints and annoyance)

Although decisions made by an installation regarding whether to suspend activities or close facilities due to noise are typically driven by complainants, there is still some debate as to whether complainants can be used as measures of general community annoyance (Fidell 2003; Maziul et al. 2005; Nykaza et al. 2005). To investigate this in detail, a survey of complainants and their neighbors was performed. Each time a complaint was registered to one of our participating installations over a 7 month time period, the complainant and 9 neighboring households were telephoned and asked to participate in a survey. The survey asked a total of 43 questions, including two annoyance questions, a variety of questions about the respondents' neighborhood and environment, and specific questions about the complaint-related blast event (CRBE). The survey used the set of noise-reaction questions recommended by ICBEN, although to reduce the burden on respondents, only the 5-point verbal reaction questions were asked. The complainant-matched samples were chosen based on proximity to the complainant's household under the assumption that these individuals would have been exposed to approximately the same noise environment. The study results, full survey instrument, and further details regarding the methods for this study can be found in Nykaza et al. (2011).

General community survey

To determine how blast noise levels affect general community annoyance and how this reaction changes over time, a General Community Survey (GCS) was administered to individuals living in close proximity to the installations. The GCS consisted of a cross-sectional sample of individuals composed of different households each time, as well as a panel sample of households composed of the same households surveyed at different times. Whereas the cross-sectional survey was designed to examine the general community response as a function of time, the panel sample was designed to illuminate changes in the individual households' responses over time. The survey was administered over a 9-month period, with a target of approximately 50 respondents being surveyed each month for the cross-sectional portion of the survey. The panel sample was designed to re-interview up to 150 individuals in months 6 through 9 who were first interviewed in months 1 through 3 (a random subset of 50 from each of the first three months). This paper will only present preliminary results from the cross-sectional survey at the first of three study sites.

The GCS was developed in conjunction with and is very similar to the survey used in the Complaint Survey protocol. The GCS, too, asked a total of 43 questions. The categories of questions on the survey included questions of annoyance to noise sources over the past 4 weeks and 12 months, as well as general questions about the neighborhood and environment, the importance of the installation to the respondent/community, and the characteristics of the respondent household. Noise data for the corresponding 9-month time period were recorded by an array of noise monitors surrounding the installations, and levels were extrapolated to each respondent's household using these data. In this way, the approximate blast noise environment of each respondent could be assessed.

To date, the survey has been completed in communities near two installations. At the first installation, 771 total surveys were completed. At the second installation, 661 surveys were completed. The GCS for the third installation is scheduled to commence in the fall of 2011.

In situ study

The protocols described above were aimed at obtaining a general view of the community's response to blast noise. To improve the current assessment procedures, however, what is arguably needed is more data regarding how *individuals* respond to individual blast events as they go about their daily lives. To address this, individual community members were recruited and their homes instrumented with microphones outdoors, indoors, and accelerometers on the windows and foundation. The accelerometer data are important for developing metrics that can subsequently be related to rattle, which has previously shown to affect noise complaints (Luz et al. 1983; Schomer 1978), laboratory judgments of blast annoyance (Schomer & Averbuch 1989) and homeowner judgments of actual blasts (Luz 1994). Each individual participates for 3 months. The system is triggered by events exceeding 100 dB ZPk; 5 seconds of acoustic and vibration data are collected for *each* event occurring within the 3 month participation period. In addition to the noise and vibration data recorded, the participants are asked to fill out a short web-based survey (employing the ICBEN 11-point annoyance scale) each time they hear a blast or a series of blasts, thus providing immediate responses to events via time-tagged questionnaires. Residents are also asked to fill out the same survey at the beginning and end of each day, to obtain cumulative day and night annoyance measures. At the first installation, 36 individuals were recruited and data collected over the course of a year. Another 32-36 individuals are planned for the second installation, which will start collection in the fall of 2011.

RESULTS TO DATE

Personal interviews

The main objective of the personal interview protocol was to capture the language that residents living around Continental United States (CONUS) military installations use to describe their community, environment, and noise in their own words. It was found that the residents in all three regions used similar language to describe their environment, noise in general, and blast noise in specific. In addition, their language was similar to the language used by the research community (e.g., the language in scientific presentations and papers), and most importantly, to the survey questions that were designed for all of the protocols encompassed within this large field study effort.

The interviews also uncovered that the majority of residents are aware of the installation and the noise it produces, like their community and neighborhood, do not notice quieter military noise events, but do notice loud events and events that induce rattle and vibration. A comparison of the percentage of the respondents mentioning the content categories given in Luz et al. (1983; Table 1) was not significantly different than responses given in Luz et al. (1983) and Nykaza et al. (2008). Approximately half of the residents mention rattling and vibration and one-third of the residents mention annoyance and fear of damage to one's home.

Table 5: Content categories and percentage of respondents mentioning content (from Luz et al. 1983)

Content category	*% Respondents Luz et al. (1983)*
Vibration, rattling, shaking, etc.	54
Putative, fear or actual damage to house	32
Objectionable, irritating, annoying sound	30
Objects falling from shelves or walls	14
Sleep disturbance	13
Disturbance of children	10
Disturbance of animals	5
Fear/physiological distress/adverse health effects	4
Damage to wells	2

Complaint survey (correlation of complaints and annoyance)

The main objective of the complaint survey was to get a better understanding of the relationship between individuals' complaint response and community's annoyance response to blast noise. Two annoyance questions were asked in this study; annoyance to the complaint-related blast event (CRBE) and annoyance to general military noise. In both cases it was found that those who file complaints (complainants) were more annoyed by noise than those who do not (non-complainants - also referred to as "matched-sample"). That is, complainants were more annoyed than their neighbors who were home at the time of the CRBE (Figure 1a), and in general complainants were more annoyed to general military noise than the non-complainants (Figure 1b). As shown in Figure 1b, the mean annoyance between complaint statuses increased as the number of reported complaints increased. That is, there was an increase in mean annoyance between those who did not file complaints (non-complainants), first time complainants, and repeat complainants. A similar increasing response with complaint status trend was found with noise sensitivity (not shown).

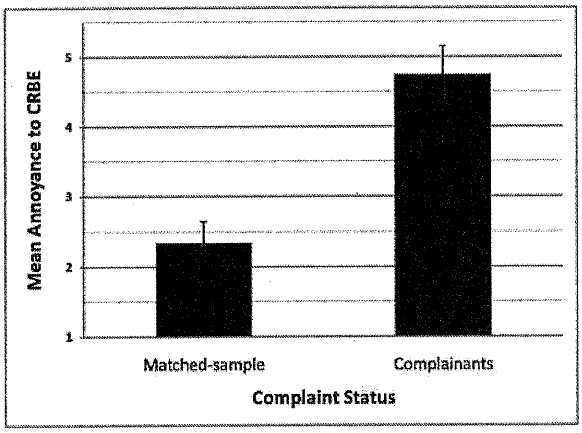

Figure 1a: Mean annoyance of complainants and their neighbors in regards to the CRBE

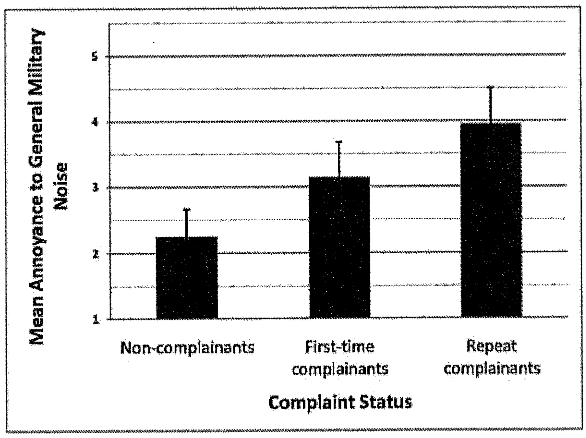

Figure 1b: Mean annoyance of first-time and repeat complainants as compared to their neighbors in regards to general military noise

This study also looked at the correlation among response variables and reported annoyance. It was found that, regardless of complaint status, those who reported higher annoyance to general military noise typically reported that their neighborhood was noisy, felt that the installation had little importance on local economy, and were more noise sensitive than those who report less annoyance.

In viewing all of the respondents together, it was found that 89 % reported hearing military noise, 84 % rate their neighborhood as a good or excellent place to live, and 68 % report that their neighborhood is quiet. Of the respondents that were home during the CRBE, 87 % mentioned rattle or vibration and 78 % of those respondents reported that their windows rattled.

General community survey

The objective of the general community survey (GCS) was not only to look at the correlation between community response (i.e., annoyance) and the blast noise environment, but to answer the question of whether the annoyance response to blast noise changes as the noise environment changes. For the 9 months data collection at study site 1, it was found that both the annoyance response and the blast noise environment change over time; that is, the mean annoyance to blast noise over the 4 weeks preceding the survey varies temporally along with the C-weighted Day-Night Level (CDNL) calculated from all blast events in that time period (data not shown). In general, there was a weak correlation between annoyance response and some of the most common blast noise metrics, e.g., CDNL, number of shots above a given unweighted peak level, and sound exposure level (SEL) (Table 2). Mean annoyance also varies spatially, as expected due to the anisotropy in blast noise propagation (Figure 2). Interestingly, the spatial variation of blast noise annoyance differed from that of military aircraft and all other noise sources addressed in the survey.

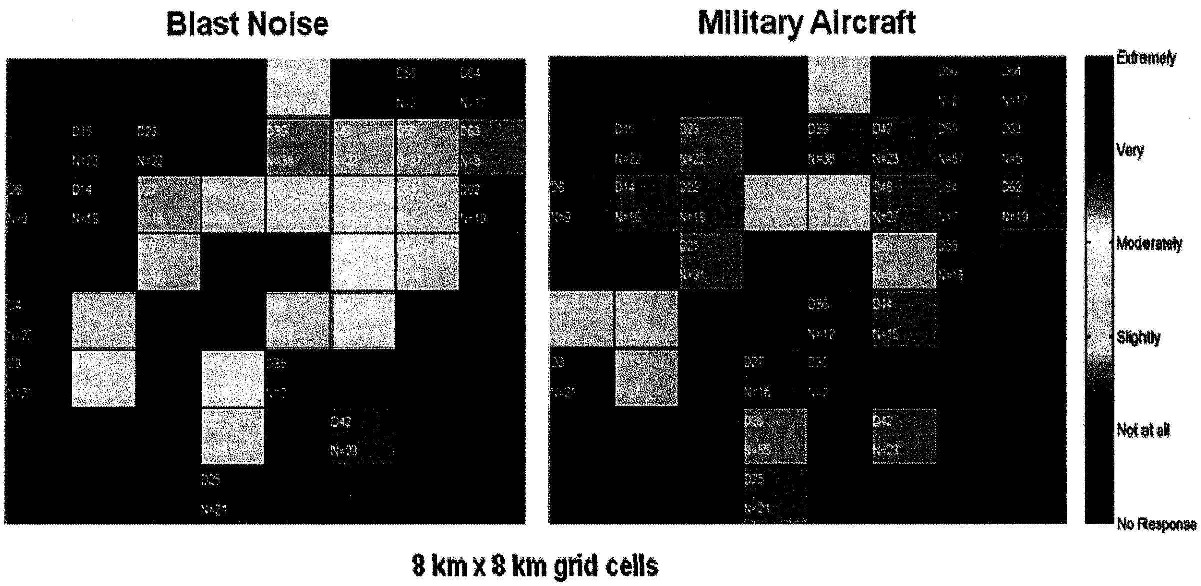

Figure 2: Spatial variation of mean annoyance for blast noise (left panel) and military aircraft (right panel). Numbers of respondents are shown in each grid cell. Each area is an 8 km x 8 km area. The installation is located approximately in the center of each plot.

Table 6: Raw correlations between annoyance over the specified time period, and the corresponding noise metric for that same time period

	Number of blasts above 110 dB Z_{pk}	**Number of blasts above 115 dB Z_{pk}**	**CDNL**	**Maximum un-weighted peak level (Z_{pk})**	**Maximum CSEL**
12 month annoyance	0.32	0.31	0.31	0.19	0.18
4 week annoyance	0.18	0.12	-0.01*	0.16	0.15

*not significant at the 0.05 level

Among all the noise sources that survey respondents at site 1 were asked to rate their annoyance, blast noise was the most annoying (Figure 3). Further, those who self-report having a high propensity to habituating to noise have a lower mean annoyance to all noise sources than those who self-report having a low propensity of habituating to noise.

Some other interesting findings from the survey were that most respondents report that they can adapt to noise over time and believe that most other people can adapt to noise over time. It was also found that most residents were aware of the installation and the noise produced by the installation before they moved into the area, would not consider moving because of noise, and felt that blast noise does not interfere with conversation. For a more detailed discussion of this study, including analysis methods and results, readers should refer to the project website:

http://www.serdp.com/Program-Areas/Weapons-Systems-and-Platforms/Noise-and-Emissions/Noise/WP-1546

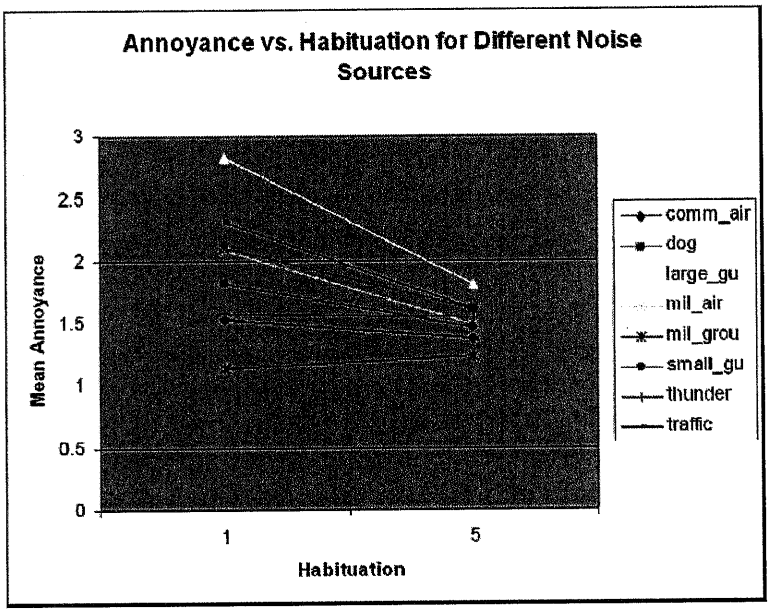

Figure 3: Mean annoyance vs. self-reported habituation. Results from an ANCOVA showed a signficant interaction between noise source and habituation. In addition, blast noise ("large_gu" in the legend) was the most annoying noise source out of the 8 on the survey, and seemed to be a source that respondents felt could be habituated to most easily.

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The adapted Vos' model to predict total noise annoyance due to an industrial noise with a main spectral component in middle frequencies combined with a background noise

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INTRODUCTION

Noise from industrial sources such as ventilation systems may cause considerable concern, even at low or moderate sound pressure levels (Berglund & Lindvall 1995). A previous study (Alayrac et al. 2010) has highlighted that different indicators, led by spectral feature type, are necessary to predict noise annoyance due to exposure to various steady and permanent industrial noises. However, when people live close to an industrial plant, they are exposed to a combination of industrial noise and background noise due to other noises in the environment. The current study, a part of Alayrac's PhD work (Alayrac 2009; Alayrac et al. 2011), focuses on determining total annoyance indicators in laboratory conditions for different ambient noises composed of one industrial noise and a background noise.

The type of industrial noises, the type of background noises and the sound emergence level of the industrial noise (Viollon et al. 2004) have a significant effect on noise annoyance. The sound emergence level is an index used by the French legislation standards to assess the noise impact of industrial noises; it is the difference between the A-weighted sound pressure level of the ambient noise (combination of industrial noise and background noise) and the A-weighted sound pressure level of the background noise (AFNOR NF S 31-010 1996). Concerning background noise, some previous works (e.g. Lim et al. 2008) concluded that the background noise has a significant effect on annoyance judgments for aircraft noises, whereas other studies (e.g. Fields 1998) did not support this conclusion. Consequently, the effect of the type of background noise, the type of industrial noise and the sound emergence level of the industrial noise are studied to assess noise impact of industrial plant and to propose total noise annoyance indicators.

This communication is organized as follows. Firstly, the experimental procedure carried out is detailed. Secondly, the assessment of total annoyance indicators is described. Finally, the conclusions are given.

EXPERIMENT

Stimuli

The industrial noises were studied in Alayrac et al. (2010). They were recorded in the vicinity of the sources using a stereophonic system (ORTF technique) and filtered to take into account one situation of noise propagation between the recording point and a virtual dwelling.