INVESTIGATING NOISE POLLUTION USING SMARTPHONES AND CITIZEN SCIENTISTS

Christopher J. Traver

Croton-Harmon High School

Croton-on-Hudson, New York

November 2012

ABSTRACT

In 2012, almost 1 billion people worldwide use a smartphone, and they are rapidly becoming a central device in people's lives (eMarketer, Inc. 2012). Sensors in smartphones, in conjunction with downloadable applications, enable environmental data to be collected much more easily and on a larger scale than ever before, particularly with the help of citizen scientists. Many people are not aware of the impact that noise pollution can have on human health, behavior, and the environment. The goal of this experiment was to investigate local noise pollution on both a perceptual and quantitative basis using citizen scientists and smartphones equipped with WideNoise 3.0, an application for the Android and iPhone operating systems that enables users to collect noise samples, and then displays, analyzes, and transmits the data to an interactive website. Pre- and post-study interviews and surveys were conducted with participants to evaluate the effects of the experiment on their perceptions of noise pollution and their willingness to participate in the public decision-making process with respect to noise pollution. Quantitative noise data was used to create a visual noise map covering the Village of Croton-on-Hudson and Town of Cortlandt (New York) and analyzed in an attempt to determine its usefulness as a resource for governmental officials. The results of the experiment show that using WideNoise to collect noise data made participants more aware of noise pollution in their surroundings, impacted their perception of noise as annoying, and was an effective tool to engage them in the public decision-making process with respect to noise pollution. The study also found the noise data collected by citizen scientists using WideNoise could provide needed information and be a valuable resource for government officials on which to base policy decisions.

INTRODUCTION AND REVIEW OF LITERATURE

Research has found that noise pollution not only affects human behavior, state of mind, productivity and long-term health, but also has a significant environmental impact (Commission of the European Communities, 2009). For example, research has found that animals have been chased out of their homes and forced to change their behavior to due to excessive noise in certain areas (E. Yong 2008). It is important to monitor and assess the effects of noise pollution in order to understand how to best alleviate its negative effects (WHO Regional Office for Europe/European Commission Joint Research Centre 2011). However, the establishment of a noise policy is complicated, and can benefit from the participation of the general public (Renn and Wiedeman 1995). Establishing a noise policy is not simply a matter of measuring decibels, but also requires measuring people's attitudes and reactions to noise. For instance, young people living in an urban area may find certain noises acceptable that senior citizens may not. Aside from loudness (decibels), noise has other dimensions such as pitch, duration, and contrast to surrounding typical noises (Zimmerman and Robson, 2011).

Citizen science involves the collection of data by individual volunteers who do not necessarily have any specific scientific training (Burke et al. 2006). The Christmas Bird Count, which began in the early 1900s, was one of the first citizen-science driven experiments (Audubon 2010). Today, advances in technology, such as sensor-equipped smartphones, are further enabling citizen science efforts. Participatory sensing involves the use of personal mobile devices by individuals to collect environmental and other data (Burke et al. 2006). Sensor-enabled smartphones and participatory sensing can provide scientists with a platform to collect data on a large scale beyond the boundaries of a research lab (Schleicher et al. 2010).

Many recent experiments have been conducted that take advantage of mobile data collection. One early experiment, called TextTales, used Short Message Service (SMS) messaging on common mobile phones to transmit data recorded by citizen participants to a central server for storage (Ananny 2004). Paulos, Honick and Goodman used mobile air quality sensors and an on-the-go air quality awareness mobile SMS tool to investigate air pollution in Ghana (Paulos et al. 2007). Another experiment used mobile sensors mounted on street sweepers to measure CO_2 levels in the air around San Francisco (Aoki et al. 2009). In a more recent study, mobile sensors were distributed to participants for placement around Pittsburgh at their discretion, in an attempt to determine the effect of daily pollution levels on one's daily routine (Kuznetsov and Paulos 2010).

Smartphones have become a popular tool utilized in the field of citizen science and participatory sensing. Burke et al. used GPS-enabled smartphones to help monitor traffic in different areas throughout a major city (Burke et al. 2006). White et al. showed that smartphones can be used to automatically detect traffic accidents using accelerometers and acoustic data (White et al. 2011). Kim and Paulos used iPhones to promote awareness of air pollution by connecting a CO_2 sensor to an iPhone to read the level of carbon monoxide in the air, coupled with an application to add a buzzing noise superimposed over audio played on the device when carbon monoxide exceeds a certain level (Kim and Paulos 2010).

Research has shown that mobile sensors in smartphones are a feasible way to collect data about noise without the need for a fixed infrastructure (Rana et al. 2010). Previous experiments involving the smartphone applications NoiseTube and WideNoise have shown that they can achieve the same accuracy as standard noise mapping techniques, but in addition also allow the monitoring of subjective opinions about noise through the use of tagging (D'Hondt et al. 2011;

Casali, 2009). Currently, Europe is at the forefront when it comes to noise assessment. In the United States, community noise maps are very rare. For example, as of November 2012, there have been more than 19,500 noise samples collected in Europe using the WideNoise platform, compared to only approximately 850 in the United States, of which my study represents approximately 15%.

HYPOTHESES

Hypothesis 1 (Awareness of noise): Study participants will become more aware of noise pollution in their communities.

Hypothesis 2 (Annoyance about noise): Study participants' "annoyance" with respect to noise will not change as a result of increased awareness of noise.

Hypothesis 3 (Public action): Study participants will be more likely to participate in the public decision-making process with respect to noise pollution.

PURPOSE OF EXPERIMENT

The purpose of this experiment was to see whether participating as a citizen scientist and recording noise data using a smartphone app would raise awareness of noise pollution, impact perceptions of noise, and arouse interest in participating in the regulatory process among the participants. In addition, the data was also analyzed to determine its usefulness in governmental planning and regulation. The experiment is intended to be an exploratory study designed to test the feasibility of collecting local noise data using a smartphone app, to develop preliminary measures of the behavioral dimensions of reactions to noise pollution, and to test and refine hypotheses for further research.

OVERVIEW OF EXPERIMENTAL DESIGN

There are two kinds of data in this study: behavioral data and "objective" noise data measured in decibels. There are also two samples in this study: a sample of individuals recruited as citizen scientists to use their smartphones to collect noise data (and to complete a pre- and post- study survey on attitudes towards noise), and a sample of objectively measured noise samples from a suburban New York community that includes decibel level and, in some instances, user tags describing the noise and reaction to the noise. Both of these samples are samples of convenience suitable for a project with the purposes described above.

To test my hypotheses, the WideNoise application, which is capable of recording, displaying, analyzing, and transmitting data recorded using a smartphone's onboard microphone, was used by 26 volunteer citizen scientists (primarily high school students) to record noise samples throughout the local Croton-on-Hudson and Town of Cortlandt area. These noise samples were then uploaded to and stored on a publicly accessible website at http://cs.everyaware.eu/event/widenoise/map, enabling users to view the data. Pre- and post-study interviews and surveys were conducted with participants to evaluate the effects of the experiment on their perceptions of noise and willingness to participate in the public decision-making process with respect to noise pollution. At the conclusion of the study, both the behavioral data and objective noise data was collected and analyzed. The objective noise data was used to create a noise map of the Village of Croton-on-Hudson and Town of Cortlandt (New York), and analyzed to determine its usefulness for governmental planning and regulation.

METHODS

Recruitment

Volunteers from the Croton-on-Hudson and Town of Cortlandt area who were willing to participate in the study were recruited by using word of mouth and social media such as Facebook, Twitter, and text messaging. Each participant was informed about the project's purpose and schedule. All participants (and the parents of participants younger than the age of 18) signed written informed consent forms.

Pre-Study Interview and Survey

A pre-study interview was conducted with each participant to explain how the WideNoise application and website works and what was expected of them throughout the duration of the experiment, including any potential risks. Participant were directed to download either the iPhone or Android version of the WideNoise application based on the type of smartphone (iPhone/Android) they had and asked to complete a pre-study survey made available to them via SurveyMonkey.

Recording Noise Sample Data

Each participant was asked to use the WideNoise application to record noise samples as they went about their daily routines, and if possible, to take measurements at different times during the day, and in different locations throughout Croton-on-Hudson and the Town of Cortlandt. They were also asked to take a variety of samples, not just loud noises. They were also asked to characterize their reaction to the noise by using the Qualify Noise button in the application and to add tags to describe the noise.

Using the WideNoise Application

To begin using the WideNoise application, participants click the WideNoise icon on their smartphone. They can then begin sampling by clicking the “Take Noise Sample” button as shown in Figure 1.

Figure 1: This shows the initial screen of the WideNoise application on an iPhone.

As the noise levels are being recorded, participants can also extend their readings for up to 30 additional seconds by clicking the “Extend Sampling” button shown in Figure 2.

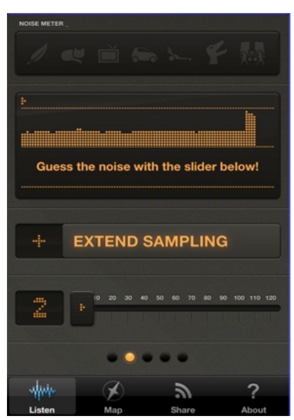

Figure 2: This shows the screen that users are presented with during the process of taking a noise sample.

The slider below the “Extend Sampling” button allows participants to guess what the decibel level of their recording will be and compare it to the actual reading after it is recorded. The series of shadowed images at the top of the app’s screen compares the decibel level of the sample recorded to certain objects in real life. For instance, if the decibel level is 90 dB, the small icon of the car lights up, since a car produces a sound that ranges from 80-100 dB. For example, even though noise is being created by a lawnmower, the decibel levels might be comparable to a car. This allows participants to gain a better appreciation of the levels of noise to which they are being subjected. After they have taken the noise sample, participants can indicate how they perceive the sound they just sampled, using the slider bars illustrated in Figure 3.

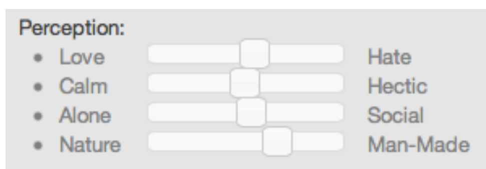

Figure 3: Participants can use the sliders pictured above to characterize the types of noise they are recording.

Next the participant is prompted to add a tag (description) further describing the sound. They type the text into a text box that appears, and when finished, click the “Done” button. Each time a participant records a noise sample with the WideNoise application, data such as the decibel level, geo-tagged location, and noise characteristics are collected by the application and then uploaded to the participant’s personal account via Wi-Fi or cellular data transmission. This data can then be shared in the form of a real-time noise map and also represented on an interactive map of the area in the application itself (Figure 4).

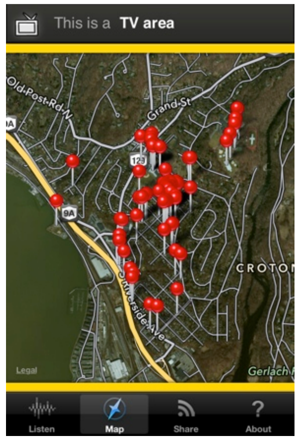

Figure 4: The image above shows a sample map in the WideNoise application. A red pin represents individual data recordings. The toolbar at the bottom of the screen also shows a Share option, which can be used to transfer recorded data to other participants in the study.

Users can also visit the WideNoise website and click individual data samples to view what other users are recording and their characterizations of noises.

Post-Study Interview and Survey

At the conclusion of the experiment, a post-study interview was conducted. Each participant was asked to complete another survey to determine the change in the behavioral dimensions in the study (awareness, annoyance, and participation in public efforts), if any, compared to the pre-study survey.

RESULTS AND DISCUSSION

(1) Behavioral Survey Data

H1 (Awareness of noise): The data supports the hypothesis that participants would become more aware of noise pollution in their communities. Tables 1 to 5 show that awareness of noise increased after participation in this research. Specifically, the survey data shows:

- Increased perceptions of noise levels in their neighborhood.

- Increased valuation of the importance of living in a quiet neighborhood.
- Increased reported self-awareness of noise in their surroundings.
- Higher perceived frequency of noise.
- Over 80% of participants indicated that participating in the study changed their perception of noise in their neighborhoods.

Table 1

How would you characterize the noise in your neighborhood?	**Pre-Study %**	**Post-Study%**	**Diff of %**	**T-test (p)**
Very quiet	20.7%	3.8%	16.9%	6.51 E-13**
Pretty quiet	69.0%	7.7%	61.3%	8.66 E-18**
Somewhat noisy	6.9%	46.2%	-39.3%	2.17 E-12**
Pretty noisy	0.0%	30.8%	-30.8%	1.99 E-05**
Very noisy	3.4%	11.5%	-8.1%	2.60 E-11**

*=<.05 **=<.01 *(Note: P-value below 0.05 is generally considered statistically significant)*.

Overall, participants changed their perceptions of their neighborhood noise levels, namely, as a result of their participation, they were more likely to say their neighborhood was somewhat, pretty, or very noisy.

Table 2

How important is living in a quiet neighborhood to you?	**Pre-Study %**	**Post-Study %**	**Diff of %**	**T-test (p)**
Not important	17.2%	7.7%	9.5%	3.51 E-13**
Somewhat important	48.3%	23.1%	25.2%	1.64 E-12**
Important	27.6%	46.2%	-18.6%	.00535264*
Very important	6.9%	23.1%	-16.2%	6.54 E-09**

*=<.05 **=<.01*(Note: P-value below 0.05 is generally considered statistically significant)*.

As a result of participating in the project, participants indicated a greater appreciation of the importance of living in a quiet neighborhood.

Table 3

How would you characterize your awareness of noise in your surroundings?	**Pre-Study %**	**Post-Study %**	**Diff of %**	**T-test (p)**
Not very aware	13.8%	7.7%	6.1%	2.60 E-11**
Somewhat aware	44.8%	34.6%	10.2%	6.51 E-13**
Very aware	41.4%	57.7%	-16.3%	.00793532*

*=<.05 **=<.01*(Note: P-value below 0.05 is generally considered statistically significant)*.

As a result of the research, participants increased their self-reported awareness of noise.

Table 4

How frequently do you hear the following noises?	**Mean Pre-Study**	**SD Pre-Study**	**Mean Post-Study**	**SD Post-Study**	**Difference of Means**	**Significance (p-value)**
Traffic: Cars	3.20690	1.04810	3.82759	0.84806	0.62069	0.008171258*
Traffic: Heavy trucks/buses	2.27586	0.95978	3.58621	0.90701	1.31034	8.70 E-07**
Traffic: Police/fire sirens	2.93103	0.96106	3.44828	0.73612	0.51724	0.0127019*
Traffic: Garbage/recycling pickup	2.34483	0.93640	4.06897	1.03272	1.72414	6.54 E-09**
Aircraft (heard from ground)	2.41379	0.90701	3.86207	0.87522	1.44828	3.77 E-08**
Train noise	2.93103	1.33446	3.82759	0.92848	0.89655	0.0022842**
Yard noise: Lawnmowers	2.68966	0.84951	4.13793	0.87522	1.44828	1.72 E-08**
Yard noise: Leaf blowers	2.34483	0.66953	3.96552	0.90565	1.62069	1.67 E-10**
Yard noise: Weed whackers	2.17241	0.80485	4.00000	0.84515	1.82759	7.67 E-12**
Yard noise: Wood chippers	1.82759	0.71058	3.79310	0.90156	1.96552	6.51 E-13**
Yard noise: Snow blowers	1.93103	0.59348	4.13793	0.74278	2.20690	8.66 E-18**
Construction noise	1.96552	0.86531	3.93103	0.84223	1.96552	2.17 E-12**
Barking dogs	3.24138	1.05746	4.31034	0.71231	1.06897	1.99 E-05**
Loud music	2.24138	1.05746	4.20690	0.67503	1.96552	2.60 E-11**
People on street	2.51724	1.12188	4.13793	0.87522	1.62069	5.58 E-08**

Neighbors in yard/parties	2.34483	1.00980	4.06897	0.79871	1.72414	1.01 E-09**
Children playing	2.82759	1.13606	4.06897	0.79871	1.24138	6.98 E-06**
Babies crying	1.82759	1.07135	4.03448	0.77840	2.20690	2.21 E-12**

*=<.05 **=<.01*(Note: P-value below 0.05 is generally considered statistically significant)*.

For all the types of sounds, participants showed higher perceived frequency (awareness) after their participation.

Table 5

Has participating in this study changed your perception of noise?	**Percent**
Yes	80.8%
No	19.2%

Over 80% of participants reported that participating in the research changed their perception of noise.

H2 (Annoyance about noise): I assumed at the start of the research that participants' tolerance of noise or "annoyance" levels would be stable throughout the research period. Instead, I found that the participants' increased awareness of noise as a result of the study, reported above, appeared to increase their "annoyance" with noise. Specifically, Tables 6 to 9 indicate that:

- Participation in the study increased the overall level of annoyance with noises.
- The rank order of annoying sounds was relatively stable from pre-survey to post-survey
- Participant's "time tolerance" for noise annoyance went down (participants indicated that they would become annoyed about noise more quickly).
- Time of day and persistence (duration of noise) were the most irritating dimensions of noise.

Table 6

Pre-Study Survey: Rank your annoyance level from 1-5	**Mean Pre-Study**	**SD Pre-Study**	**Mean Post-Study**	**SD Post-Study**	**Difference of Means**	**Significance (p-value)**
Traffic: Cars	1.93103	1.06674	3.65517	0.93640	1.72414	1.05 E-08**
Traffic: Heavy trucks/buses	2.27586	1.19213	3.48276	0.68768	1.20690	1.16 E-05**
Traffic: Police/fire sirens	2.72414	1.38607	3.86207	0.74278	1.13793	0.0001685**
Traffic: Garbage/recycling pickup	2.10345	1.14470	3.96552	0.98135	1.86207	7.18 E-09**
Aircraft (heard from ground)	2.06897	1.16285	3.89655	0.81700	1.82759	3.84 E-09**
Train noise	2.20690	1.29227	4.13793	0.78940	1.93103	6.95 E-09**
Yard noise: Lawnmowers	3.20690	1.34641	4.13793	0.69303	0.93103	0.0009604**
Yard noise: Leaf blowers	2.96552	1.32241	4.10345	0.55709	1.13793	6.36 E-05**
Yard noise: Weed whackers	3.06897	1.30742	4.17241	0.84806	1.10345	0.0001957**
Yard noise: Wood chippers	2.93103	1.30742	4.10345	0.81700	1.17241	8.24 E-05**
Yard noise: Snow blowers	2.89655	1.34549	4.17241	0.71058	1.27586	2.47 E-05**
Construction noise	3.34483	1.26140	4.48276	0.57450	1.13793	3.79 E-05**
Barking dogs	3.10345	1.26335	4.10345	0.55709	1.00000	0.0001869**
Loud music	2.34483	1.14255	4.03448	0.77840	1.68966	1.42 E-08**
People on street	2.44828	1.27016	4.10345	0.72431	1.65517	1.17 E-07**
Neighbors in yard/parties	2.20690	1.08164	4.00000	0.65465	1.79310	5.02 E-10**
Children playing	2.06897	1.16285	4.17241	0.84806	2.10345	1.12 E-10**
Babies crying	2.89655	1.44778	4.37931	0.72771	1.48276	6.96 E-06**

*=<.05 **=<.01*(Note: P-value below 0.05 is generally considered statistically significant)*.

Overall, participants' annoyance levels increased for all noises.

Table 7

Post-study Survey: Rank your annoyance level from 1-5		**Pre-Study Mean**		**Post-Test Mean**	**Difference**	**Significance (p)**
Babies crying	1	1.931	2	3.655	-1	1.12 E-08**
Children playing	2	2.069	1	3.483	1	1.42 E-08**
Neighbors in yard/parties	3	2.069	3	3.862	0	0.0001685**
People on street	4	2.103	5	3.966	-1	7.18 E-09**
Loud music	5	2.207	4	3.897	1	2.34 E-09**
Barking dogs	6	2.207	12	4.138	-6	6.95 E-09**
Yard noise: Snow blowers	7	2.276	13	4.138	-6	0.0009604**
Construction noise	8	2.345	8	4.103	0	6.36 E-05**
Yard noise: Wood chippers	9	2.448	14	4.172	-5	0.0001957**
Yard noise: Weed whackers	10	2.724	9	4.103	1	3.84 E-09**
Yard noise: Leaf blowers	11	2.897	15	4.172	-4	0.0001869**
Yard noise: Lawnmowers	12	2.897	18	4.483	-6	3.39 E-05**
Aircraft (heard from ground)	13	2.931	10	4.103	3	7.45 E-05**
Train noise	14	2.966	7	4.034	7	5.42 E-08**
Traffic: Garbage/recycling pickup	15	3.069	11	4.103	4	2.17 E-07**
Traffic: Heavy trucks/buses	16	3.103	6	4	10	1.16 E-05**
Traffic: Police/fire sirens	17	3.207	16	4.172	1	3.12 E-10**
Traffic: Cars	18	3.345	17	4.379	1	6.96 E-06**
*=<.05 **=<.01						Rho =0.8828 n.s

Overall, the rank order correlation of annoyance with respect to particular sounds from pre- to post-study is (0.8828). Over time, there is good stability in this measure of annoyance.

Table 8

How long does an "annoying" noise need to persist in order for you to find it annoying?	**% in Pre-Study**	**% in Post-Study**	**Difference**	**Significance (p)**
Less than one minute	6.90%	57.70%	50.80%	7.84 E-06**
More than one minute	31.00%	19.20%	-11.80%	6.25 E-08**
More than two minutes	24.10%	19.20%	-4.90%	0.000460469**
More than five minutes	17.20%	3.80%	-13.40%	6.36 E-05**
Other	20.70%	0.00%	-20.70%	0.000197417**

*=<.05 **=<.01 *(Note: P-value below 0.05 is generally considered statistically significant)*.

As a result of participation in the project, and the increase in awareness of noise (above), respondents shortened their "time tolerance" for noise, i.e. they became annoyed much more quickly.

Table 9

Rank the following characteristics of noise on a 1 to 5 scale, from least annoying (1) to most annoying (5).	**Pre-Study Score**	**Post-Study Score**	**Difference**	**Significance (p)**
Loudness	99	85	-14	0.000197417**
Pitch	90	87	-3	3.25 E-08**
Persistence (duration in time)	116	98	-18	0.000460469**
Contrast with surroundings	91	103	12	6.36 E-05**
Time of day	110	115	5	6.25 E-08**

*=<.05 **=<.01
Note*: the scores were arrived at by converting ranks to scores by multiplying the number of people who chose a given rank, by the rank absolute value, e.g. if 3 people ranked pitch as rank=5, then they contribute 15 points to the overall score. Similarly for rank = 1, 2, 3, 4. The total score reflects the annoyance caused by various sound dimensions for the whole sample.*

The most powerful irritating dimensions of noise in the pre-study survey were persistence, time of day, and loudness. In the post-study survey, the most powerful irritating dimensions of noise were time of day, contrast with surroundings, and persistence. Time of day and persistence were among the leading irritating dimensions of noise in both periods.

H3 (Public action): The survey data indicates that participants will be more likely to participate in the public decision-making process with respect to noise pollution. Specifically, 50% of participants reported they were “more likely to participate in public decision making. This question was not included in the pre-study survey, so it cannot be definitively determined whether this sentiment increased (or decreased) due to participation in the research, although I believe that it did.

(2) Objective Noise Data

A total of 124 individual noise samples throughout Croton-on-Hudson and the Town of Cortlandt were collected. The noise samples were uploaded to the WideNoise website to create a noise map as shown below in Figure 5.

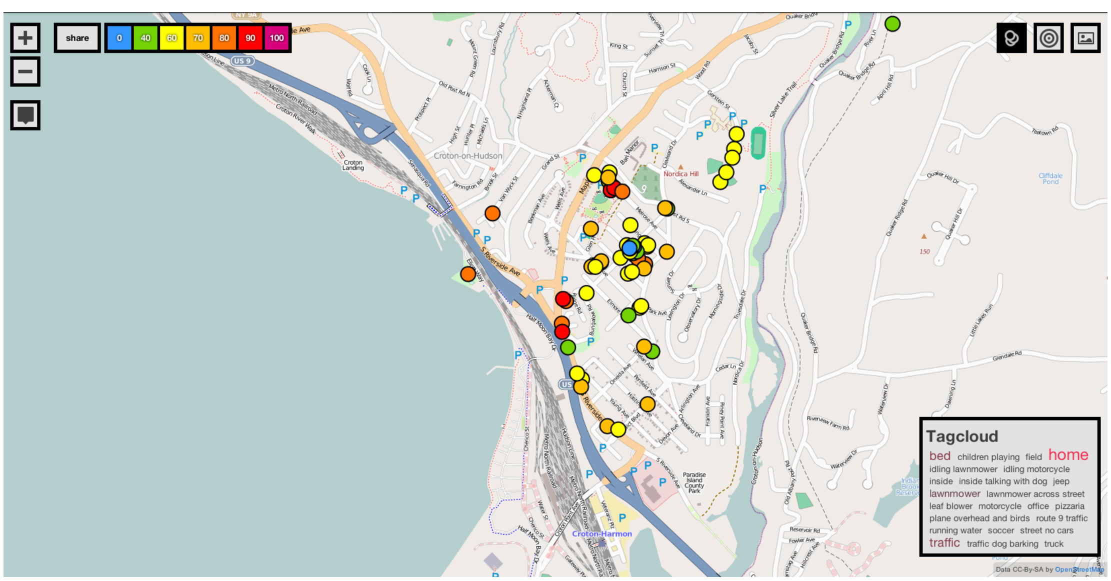

Figure 5: The image above shows a screen shot of the WideNoise website (http://cs.everyaware.eu/event/widenoise/map). Colored circles represent individual data

recordings. The colors represent the magnitude of the decibel level recorded: the darker the color, the higher the decibel level, as seen in the scale in the top left corner of the image.

The dB values of the samples reflected on the noise map range from a high of 91.56dB to a low of 17.12dB. The mean decibel level of the noise samples collected was 66.59dB. Participants could also choose to "tag" or describe their recordings. For example, some of the tags used were: bed, children playing, crickets, field, home, idling lawnmower, idling motorcycle, jeep, lawnmower, street, leaf blower, motorcycle, nature, office, pizzeria, plane overhead, birds, route 9, traffic, etc. Participants could also choose to use a slider bar to indicate perceptions of the noise with respect to the following dimensions: Love/Hate; Calm/Hectic; Social/Alone; and Man-Made/Nature. This data could provide useful information to government officials on which to base policy decisions. For instance, they now have access to data about dB levels generated by a variety of different things, such as lawn mowers, leaf blowers, motorcycles, heavy trucks, traffic, coupled with a real-time assessment of those noises by someone within hearing distance. Many of the readings were in the 70 to 80dB range, which some people might find annoyingly loud (Industrial Noise Control, Inc., 2010). For instance, a sound tagged as "loud truck" was 85.6dB. A leaf blower was 81.72dB. Both of these sounds had the slider bar pushed toward the "Hate" reading. On the other hand, "music in bar with door open" was 86.78dB and "music outside bar" was 85.84dB, but neither of these were associated with "Hate."

CONCLUSION

The major behavioral findings of this research are that providing a noise measurement instrument to people increases their awareness of noise and also increases their annoyance with noise. Once aware and annoyed, they are more likely to engage in the political process of regulating noise. One of the most common complaints from citizens that government officials receive are those involving excessive and unacceptable noise, whether from construction projects, sirens, horns, or motorcycles. Many communities have noise ordinances that restrict certain loud activities, such as construction, to certain hours of the day. Some communities have adopted regulations that define acceptable dB levels by time of day. Enforcement of noise ordinances based on dB levels can be difficult because enforcement agents (usually local police) typically do not have tools to measure decibel levels and are often not present when the noise occurs. Prohibition of certain activities during certain hours, such as street music, parties, or construction, may not be necessary if these noises do not in fact annoy local residents. Moreover, the noise generated during "allowable" hours may still be unacceptable to the community. Government officials should encourage citizen groups to measure objective levels of noise to increase community awareness of noise and to develop a noise map as a motivational tool to promote community action. Policy makers should consider doing surveys of their populations to establish what noises are annoying, and what features of these noises are annoying.

FUTURE EXPERIMENTS

I envision that in the future, citizen science using smartphones will become a leading method of investigating both social science and environmental issues. In the future, I would like to create a similar study employing a much larger group of people of all ages, and employ additional methods to incentivize them to take more noise samples in order to create a more comprehensive and extensive noise map. One of the limitations of my thesis was the difficulty of sharing personal data with others. Although there was a website that all noise data was collected and displayed on, it is difficult to pinpoint individual readings and show others what you had collected personally. I believe that the ability to share readings with other participants is very important as it promotes teamwork and encourages participants to collect even more data. I think that creating similar studies like this will contribute to increasing the collective wisdom of our society. For example, not only does recording noise pollution data allow participants to become more aware of the problem, it also provides support for governqment agencies in creating noise ordinances.

ACKNOWLEDGEMENTS

I am very grateful for the guidance of Professor Kenneth Laudon. I would also like to thank my parents for being so supportive and helpful along with Professor Jules White and Ms. Donna Light-Donovan for their continued support and guidance.

LITERATURE CITED

- Ananny, M. and C. Strohecker. "Designing Public Spaces for Democratizing Stories." SRMC'04. New York: ACM. 47-50. (2004).
- Aoki, Paul M., R.J. Honicky, Alan Mainwaring, Chris Myers, Eric Paulos, Sushmita Subramanian, and Allison Woodruff. "A Vehicle for Research: Using Street Sweepers to Explore the Landscape of Environmental Community Action." Association for Computing Machines (2009).
- Audubon. The 110th Christmas Bird Count: Citizen Science in Action. http://www.audubon.org/Bird/cbc. (2010).
- Burke, J., M. Hansen, A. Parker, N. Ramanathan, S. Reddy, and M.B. Srivastava, "Participatory Sensing” WSW'06 at SenSys. Boulder: ACM (2006).
- Casali, Davide, “The WideNoise Project.” http://www.slideshare.net/folletto/the-widenoise-project, (December 14, 2009).
- Commission of the European Communities. In *Green Paper on Future Noise Policy*. Technical Report COM (96) 540, EU, (November 1996).

- D'Hondt, Ellie, Mattias Stevens, and Ann Jacobs. "Participatory Noise Mapping Works! An Evaluation of Participatory Sensing as an Alternative to Standard Techniques for Environmental Monitoring." http://noisetube.net/publications/partnoisemaps.pdf (2011).
- E. Yong. City songbirds change their tune. The New Scientist, 197(2649): 33–35, (March 2008).
- eMarketer, Inc. "Smartphone Users Worldwide, by Region and Country, 2010-2016." (April 17, 2012).
- EveryAware: Enhancing Environmental Awareness through Social Information Technologies," http://www.everyaware.eu/wp-content/uploads/2011/04/EveryAware.pdf (April 2011).
- Industrial Noise Control, Inc. "Comparative Examples of Noise Levels." http://www.industrialnoisecontrol.com/comparative-noise-examples.htm (2010)
- Kim, Sunyoung and Eric Paulos. "Listening to Air Quality." Human Computer Interaction Institute. Paulos.net. (January 26, 2010).
- Kuznetsov, Stacey, and Eric Paulos. "Participatory Sensing in Public Spaces: Activating Urban Surfaces with Sensor Probes." Human Computer Interaction Institute. Paulos.net. (October 26, 2010).
- Paulos, Eric, R.J. Honicky, and Elizabeth Goodman. "Sensing Atmosphere." Paulos.net (2007).
- Rana, Rajib Kumar, Chung Tung Chou, Salil S. Kanhere, Nirupama Bulusu, and Wen Hu. Ear-Phone: An End-to-End Participatory Urban Noise Mapping System. In *IPSN'10*, (2010).
- Renn, O., T. Webler, and P. Wiedemann. A need for discourse on citizen participation. In *Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse*, Chapter 1. Kluwer Academic Publishers, (October 1995).
- Schleicher, R., Alireza Sahami Shirazi, Michael Rohs, Sven Kratz, and Albrecht Schmidt. WorldCupinion: Experiences with an Android App for RealTime Opinion Sharing during World Cup Soccer Games. International Journal of Mobile Human Computer Interaction, Volume 3, Issue 4, (2011).
- White, Jules, Chris Thompson, Hamilton Turner, Brian Dougherty, and Douglas C. Schmidt, "WreckWatch: Automatic Traffic Accident Detection and Notification with

Smartphones.” Journal of Mobile Networks and Applications. Volume 16, Issue 3, (June 2011).

- WHO Regional Office for Europe/European Commission Joint Research Centre. Burden of disease from environmental noise. Quantification of healthy life years lost in Europe,” Report, (2011).

- Zimmerman, Thomas and Christine Robson. “Monitoring Residential Noise for Prospective Owners and Renters.” Pervasive ’11 Proceedings of the 9th International Conference on Pervasive Computing.” Pages 34-49, (2011).