Sounding the Alarm on the Disproportionate Distribution of Sirens on Students of Color

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A thesis

submitted to the Faculty of

the Environmental Studies Program

in partial fulfillment

of the requirements for the Bachelor of Arts degree of

Environmental Studies

Boston College
Morrissey College of Arts and Sciences
Undergraduate Program

April 2024

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Noise pollution is highly consequential to children's learning and general well-being (Klatte et al., 2013; Balk et al., 2023; Masud et al., 2020). Sirens emanating from emergency services pose particularly adverse consequences to students' well-being and academic performance (Gheewalla et al., 2021). As signals of danger, sirens are shown to induce psychological and physiological reactions, including emotional distress, changes in blood pressure, and increased heart rate and blood glucose (Lapid Pickman et al., 2021; Manor et al., 2023). Prior studies have shown that schools with higher proportions of students of color are disproportionately exposed to noise pollution. Through this study, I employ a multi-phase, mixed methods approach to examine whether students of color in Massachusetts are disproportionately exposed to sirens in the classroom, potentially compounding existing stressors and contributing to academic disparities. In Phase One, I draw upon spatial data science to determine *which* schools and students in Massachusetts are at risk of experiencing sirens frequently throughout the school day. In Phase Two, I build upon the results from Phase One to survey students and educators attending a school my initial findings deemed were at risk of exposure to emergency sirens to determine *how* sirens impact the learning environment. I find that students of color and schools in urban areas in Massachusetts are disproportionately exposed to sirens. Furthermore, I find that the majority of students report being distracted for at least ten seconds when they hear sirens in the classroom. Finally, I find that sirens can serve as a trigger of past traumatic events in both students and educators, potentially adding additional stressors to the learning environment.

Keywords: Sirens; Environmental Justice; Noise Pollution; Children; Spatial Inequality, Environmental Health

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Thank you Mom and Dad for the countless phone calls and unwavering support. You both inspire me daily and empower me to chase my dreams. Thank you, Gram, Bampa, and Ben for enduring conversations about my thesis at the dinner table and for being there for me every step of the way. I feel so fortunate to have such an incredible family and truly couldn't have done this without you.

I am incredibly grateful for the PULSE Program and the Boston Green Academy. During my time at the Boston Green Academy, I conceptualized this project and began laying the foundations for further research. Thank you to Professor Fried for challenging me to engage in vigorous reflection during my service at BGA and for supporting me during the beginning of this thesis. Thank you to Ms. RH for your wisdom and for welcoming me into your classroom with warmth. I will always cherish my time at BGA!

Thank you to Dr. O'Dwyer for assisting me in the development of the surveys and for helping me navigate the IRB approval process. You went out of your way to support me and I am indebted to your expertise. Thank you to Lester Carver for your help in developing my figures and gaining experience with ArcGIS Pro. Thank you to Dr. Pan for providing me invaluable lessons on Spatial Data Science which were critical to this thesis. Thank you to Dr. Wesner for assisting me with the BPS IRB process. Thank you to Dr. Grandson for serving as the district sponsor for my project and for supporting a fellow Boston College Eagle! Thank you to Dr. Satcher for consulting on my project and helping me refine my methodology. I am also incredibly grateful for Dr. Seiders and Dr. Flynn. Working on a team with you both introduced me to research and instilled in me the skills necessary to conduct this thesis.

Thank you to Melissa McTernan for your invaluable assistance with the Phase One data analysis. Your expertise on zero-inflated models was crucial to this project and I cannot express my gratitude enough for your patience with me as I learned how to use RStudio.

Finally, thank you to Dr. Pisani Gareau. I vividly remember leaving our first meeting during my freshman year knowing that I had found my second home in the Environmental Studies community. I can't even count the number of times that, upon hearing that you were my thesis advisor, my peers and professors spoke glowingly about you. You are universally beloved for good reason and I am so grateful for your constant support, wisdom, and guidance. You were integral not only to this project but also to my positive experience at BC—thank you.

FOREWORD

Throughout my sophomore year, through the PULSE Program, I had the opportunity to serve as a volunteer teacher's assistant at the Boston Green Academy (BGA). BGA is a public middle and high school located in Brighton, Massachusetts. BGA is located near St. Elizabeth's Medical Center, a fire station, a police station, and an ambulance station. Additionally, BGA is within 10 meters of Cambridge Street—a busy street that emergency vehicles frequently use. As a result, BGA is substantially exposed to emergency sirens. At first, I thought nothing of it—BGA is in a large metropolitan area and sirens are part of the soundscape of cities. However, as the weeks went on, I began to notice how students and educators were visibly distracted by the sirens.

As a volunteer teacher's assistant, I had the unique ability to observe the classroom and see firsthand how sirens would prompt nearly half the classroom to stop working on the task at hand and look towards the windows to assess potential danger. On one particularly siren-filled day, I counted six occurrences within a single, 50-minute period. One student, exacerbated by the frequent disruption, muttered, "It is like they are always here." That stuck with me and prompted this study. From that moment on, I embarked on this journey, learning how to utilize spatial data science and software like RStudio to empirically study the phenomenon that I observed at BGA. I hope that, through this project, I will be able to shed light on an issue that has, to my knowledge, never been discussed from an academic perspective. By shedding light on this phenomenon, I aim to eventually influence the adoption of pragmatic policy implementations that balance the needs of emergency services with the needs of students and educators.

TERMS

Environmental Justice (EJ) Population: The Massachusetts Executive Office of Energy and Environmental Affairs (EEA) defines Environmental Justice (EJ) populations as neighborhoods where one or more of the following criteria are true:

1. The annual median household income is 65 percent or less of the statewide annual median household income
2. Minorities make up 40 percent or more of the population
3. 25 percent or more of households identify as speaking English less than "very well"
4. Minorities make up 25 percent or more of the population and the annual median household income of the municipality in which the neighborhood is located does not exceed 150 percent of the statewide annual median household income.

The EEA uses American Community Survey data to determine whether a neighborhood is an Environmental Justice population (Massachusetts Executive Office of Energy and Environmental Affairs, 2022)

Environmental Racism: The "disproportionate distribution of environmental 'goods' and 'bads,' with the burden of the bads and the dearth of the goods falling mainly on racial and ethnic minorities, lower-income populations, and other vulnerable groups" (Chakraborty et al., 2011)

***Highly* Exposed Schools:** Schools that are within the 95th percentile of expected daily siren exposure (i.e. expected daily sirens > 4)

NIMBYism (Not-In-My-Back-Yard-ism): NIMBYism is a phenomenon in which communities with high levels of social capital (typically predominantly white, affluent communities) leverage their social capital to prevent the development of facilities within their locality that are environmentally harmful or hazardous (Burningham, 2012)

Noise: Unwanted or objectionable sound (World Health Organization, 2009)

Post-Traumatic Stress Disorder (PTSD): The National Center for Complementary and Integrative Health defines PTSD as a "mental health condition that some people develop after experiencing or witnessing a traumatic or life-threatening event, like military combat, a natural disaster, a car accident, or assault" (U.S. Department of Health and Human Services, 2020)

Siren-Generated Noise Pollution: Noise pollution emanating from the use of sirens in emergency services

Siren-Generating Facilities: Emergency response centers that dispatch and receive vehicles equipped with emergency sirens

Sonic Environmental Racism: The disproportionate distribution of different forms of noise pollution—both acute and chronic, with the burden of the noise pollution falling primarily upon racial and ethnic minorities and low-income groups (Chakraborty et al., 2011)

Students of Color: Used synonymously with "non-white students"; students of color include those who identify as Black, Hispanic, Asian, Pacific Islander, American Indian/Alaska Native, Native Hawaiian/Other Pacific Islander, and of Two or more races (National Center for Education Statistics, 2023)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 PROBLEM STATEMENT AND JUSTIFICATION FOR RESEARCH

Noise pollution is highly consequential to children's learning (Klatte et al., 2013). Noise pollution includes sounds in the environment that negatively impact health or disturb the behavior of humans and animals (Balk et al., 2023; Manor et al., 2023). There is growing evidence that sirens generated by police, fire, and ambulance services are the most detrimental form of noise pollution to the learning environment (Gheewalla et al., 2021). With a high frequency and volume, sirens are designed to signal danger and capture people's attention to clear roads for emergency services. However, repeated exposure to sirens during school hours may negatively impact students' health and learning (Gheewalla et al., 2021). Additionally, studies have shown that the distribution of noise pollution in the United States falls disproportionately on schools with a high proportion of students of color (Collins et al., 2019), raising the question of whether students of color also disproportionately experience the infiltration of sirens in the classroom. Such a disparity in the exposure to sirens may add to the multitude of stressors that students of color already experience and potentially contribute to the achievement gap.

Outside of the particular harm that sirens pose to learning, sirens have also been shown to elicit psychological and physiological reactions (Manor et al., 2023). Emotional distress has been shown to accompany exposure to sirens, as well as changes in blood pressure and an increase in heart rate and blood glucose (Lapid Pickman et al., 2021; Manor et al., 2023).

1.2 BACKGROUND

1.2.1 Noise Pollution in the Classroom

Noise pollution in the classroom has extensive negative consequences for the learning environment, particularly impairing students' reading and listening comprehension (Klatte et al., 2013; Pujol et al., 2014). External noise pollution has been consistently found to harm academic performance for students of all ages, although students with learning difficulties may be especially impacted (Caviola et al., 2021; Shield & Dockrell, 2008). While the consensus amongst researchers in the past was that sounds could not interfere with mental processes unless they exceeded 80 dB(A), recent studies have shown that noise at 45 dB(A) can be disruptive to mental performance (Macken, 2014).

Noise pollution impacts academic performance primarily through two mechanisms: "interference by process" and "attention capture" (Caviola et al., 2021). Through the interference by process mechanism, students unwittingly attempt to interpret background noise while consciously attempting to focus on the task at hand, leading to a conflict that interferes with performance (Caviola et al., 2021; Macken, 2014). Alternatively, through the attention capture mechanism, noise pollution impairs academic performance by completely capturing a student's attention and distracting them from the task at hand (Bell et al., 2012). Both of these mechanisms help to explain the detrimental effect that noise pollution has on academic performance.

Outside of its impact on distraction, noise pollution can further impair academic performance by seriously impacting students' physical well-being (Onchang & Hawker, 2018). Noise pollution is one of the most prominent public health stressors worldwide (Murphy & King, 2022). Sleep disturbances have been consistently linked with exposure to noise pollution, as well as other health impacts including disruptions to the autonomic nervous and endocrine systems,

which can subsequently lead to long-term damage to cardiovascular health (Balk et al., 2023). The World Health Organization estimates that “at least 1,000,000 healthy life years are lost every year from traffic-related noise in Western Europe" (World Health Organization, 2011). Studies have also demonstrated that chronic exposure to noise pollution can have consequences for children’s cognitive development (Maxwell & Evans, 2000; Shield & Dockrell, 2008). Furthermore, noise pollution can have consequential impacts on emotional health. For example, one study found that noise pollution is severely detrimental to life satisfaction and measures of happiness (Weinhold, 2008). Exposure to noise pollution is often accompanied by increased stress and irritability, which can further inhibit academic achievement (Gupta et al., 2018).

While the academic performance of all students tends to be adversely impacted by noise pollution, certain groups of students are especially vulnerable. One of those groups of students is second-language learners (Goldschagg et al., 2023). In Goldschagg et al. (2023), researchers found that second-language learners reported greater interference and annoyance from noise than first-language learners, likely due to the additional cognitive demands required when processing information in a new language. Another particularly vulnerable group of students to noise pollution is students with Autism Spectrum Disorder (ASD) (Kanakri et al., 2017). Many individuals with ASD feel particularly fearful or anxious about sounds and educators have observed students with ASD cover their ears to reduce exposure to unpleasant sounds (Kanakri et al., 2017; Stiegler & Davis, 2010).

Educators are crucial to the learning environment and are also impacted by the deleterious effects of noise in the classroom. In Bulunuz et al. (2021), researchers found that noisy classrooms had numerous negative impacts on educators including triggering migraines, irritability, and difficulty in communicating and focusing on lessons. The educators deployed a

variety of coping techniques to reduce noise in their classrooms including verbally warning noisy students, plugging their ears, and closing doors and windows to reduce external noise from entering the classroom (Bulunuz et al., 2021). Despite these attempts to minimize noise in the classroom, many of the educators remained frustrated with the noise level in their classrooms and voiced concerns about the acoustic design of their respective schools (Bulunuz et al., 2021).

Educators working in schools with high levels of noise pollution have been shown to have highly negative perceptions of their working environment (Kristiansen et al., 2011). Such negative perceptions of the working environment could be due to the associated lack of motivation and sleepiness that often accompany educators whose classrooms have poor acoustic conditions (Kristiansen et al., 2013). Poor educator morale—which is associated with low levels of motivation and high levels of frustration—can be detrimental to their overall effectiveness in the classroom and potentially further stress the students (Earthman & Lemasters, 2009). It is critical to understand that educators—like students—are adversely impacted by noise pollution, further contributing to the impaired academic performance associated with noisy learning environments.

1.2.2 Sonic Environmental Racism in the United States

The distribution of noise pollution in the United States is not equal. Recent studies on the distribution of transport noise pollution in the contiguous United States have found that the burden of noise pollution stemming from transportation (i.e. highways and airports) falls disproportionately upon communities of color (Casey et al., 2017; Collins et al., 2020), signifying that sonic environmental racism exists in the U.S. (refer to Terms). Similarly, in more localized studies in Montreal, Quebec, and the Twin Cities, Minnesota, researchers have found

further evidence of noise pollution disproportionately falling upon communities of color (Carrier et al., 2016; Nega et al., 2013). The findings in each of these studies are consistent with the theoretical framework of environmental racism. Environmental racism has been broadly defined as the "disproportionate distribution of environmental 'goods' and 'bads,' with the burden of the 'bads' and the dearth of the 'goods' falling mainly on racial and ethnic minorities, lower-income populations, and other vulnerable groups" (Chakraborty et al., 2011).

In the environmental justice literature, researchers have long theorized that unequal access to land-use decision-making has led to the disproportionate siting of environmental hazards in communities of color (Casey et al., 2017). 'NIMBYism' (Not In My Backyard) is a phenomenon in which social capital is leveraged to oppose local initiatives deemed as having negative environmental impacts (refer to Terms); in the context of noise pollution, NIMBYism has been employed to prevent initiatives associated with high levels of noise (Suau-Sanchez et al., 2011). The role that NIMBYism has played historically and currently cannot be ignored if we are to understand how the modern, disproportionate distribution of transport noise pollution has arisen.

As previously explained, children are particularly vulnerable to the deleterious impacts of noise pollution due to the considerable amount of time they spend in school. The exposure of schools to noise pollution is of utmost importance, both from a public health standpoint and from an academic achievement standpoint. A recent study found that in the United States, schools with higher percentages of Hispanic, Black, and Asian students have greater exposure to transport and aviation noise pollution than schools with higher percentages of white students (Collins et al., 2019). Every ten percent increase in a school's composition of Hispanic, Black, Asian Pacific Islander, and other race students was associated with increases in aviation noise pollution of up

to 14.1 percent (Collins et al., 2019). Additionally, Collins et al. (2019) found a similar relationship between the percentage of a school's population being economically deprived and its exposure to noise pollution, with the schools serving the greatest composition of economically deprived students being exposed to the greatest magnitude of noise pollution. Furthermore, a statewide study conducted in Texas similarly found that students attending schools exposed to the highest amount of noise were considerably more likely to be Black, Hispanic, and socioeconomically deprived (Chakraborty & Aun, 2023).

The findings of Collins et al. (2019) and Chakraborty and Aun (2023) have alarming implications for the health and well-being of students and educators attending schools with high compositions of minority students. Furthermore, the findings have salient implications for the achievement gap, since high levels of noise pollution are consistently associated with impaired academic performance (Collins et al., 2019; Shield & Dockrell, 2008).

1.2.3 Distance to the Road: The Impacts of Transport Noise Pollution

There are a variety of factors that can contribute to the level of transport and traffic noise pollution that schools experience. A building's exposure to transport noise pollution is substantially determined by its proximity to the road, as well as the amount of traffic the closest road receives. The findings of von Graevenitz (2018) reveal that noise pollution from a major road peaks within 40 meters of the road and then gradually decreases beyond 200 meters (Figure 1).

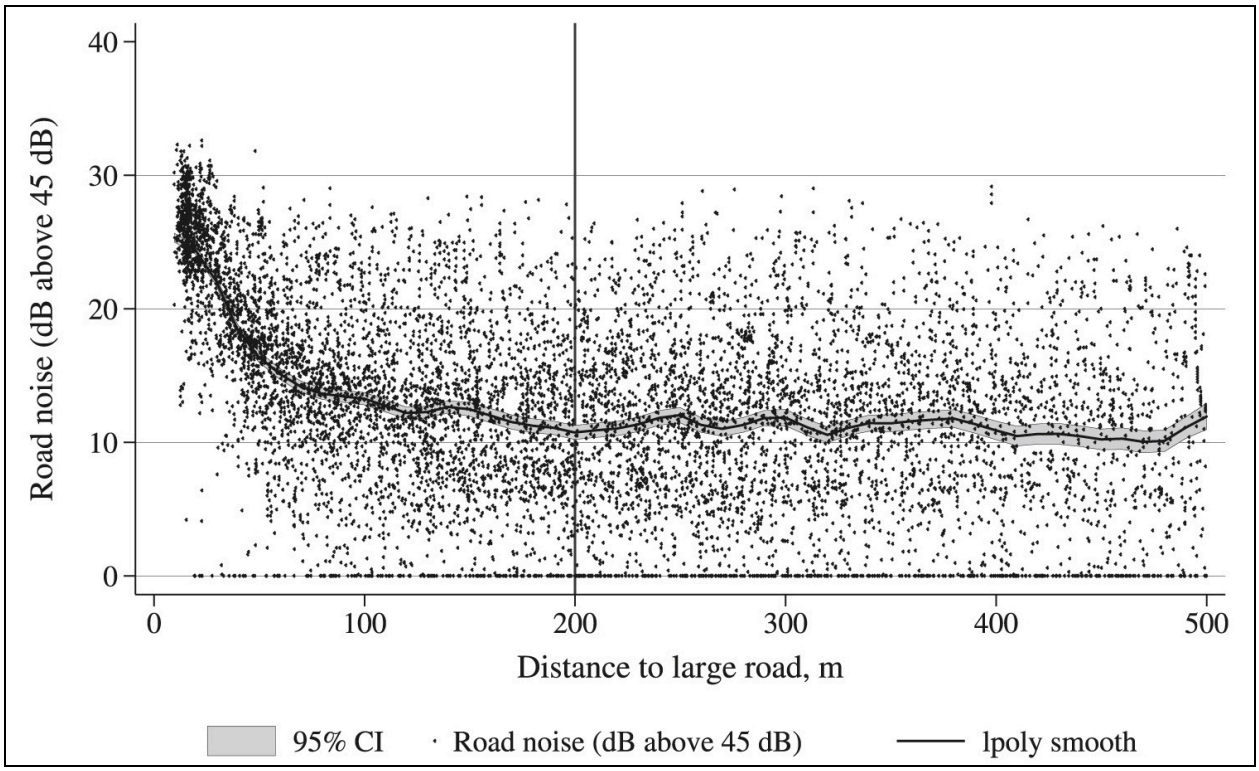


Figure 1. Relationship between distance to the road and the road noise (dB) (from von Graevenitz, 2018).

Another factor that influences the level of exposure that a school has to environmental noise pollution is when it was built. Newer buildings have been consistently shown to have less noise pollution than older buildings (Lam & Chan, 2008; Wang & Norbäck, 2021). Designed with acoustic conditions in mind, newer buildings typically curtail noise pollution by implementing sound-absorbing materials in their walls, ceilings, and insulation (Storozhuk et al., 2021). Other factors like heating systems in new buildings may further reduce noise pollution. For example, schools in older buildings with outdated heating systems may be forced to open the windows to ensure a comfortable temperature is maintained in the classroom, which in turn increases the noise levels from external sources (e.g. a highway or airport). Conversely, schools in new buildings likely have more technologically advanced heating systems that do not require

educators to open windows in the classroom and subsequently decrease the noise levels emanating from external sources.

Schools that are highly exposed to transport noise pollution can be severely impacted. In one study, researchers found that students exposed to traffic noise exceeding 61.8 dB(A) had a 10.9 times greater risk of suffering from psychological health problems (Djaja & Wulandari, 2007). Stress from perceived levels of traffic noise pollution has been linked with lower health status and higher rates of depression (Song et al., 2007). Furthermore, exposure to traffic noise pollution exceeding 60 dB(A) has been found to increase the risk of cardiovascular diseases like myocardial infarction (Babisch, 2005).

1.2.4 Sirens: A Unique Form of Noise Pollution

In the City of Boston Municipal Code, siren-generating vehicles (police and emergency service vehicles) are the only vehicles that are exempt from noise ordinances (Appendices 6.1). Emergency sirens in the United States have a high amplitude and tend to greatly exceed the level of 80 dB(A), often measuring between 120 and 140 dB(A) (Hansen et al., 2017). Compared to other common sounds in the environment, emergency sirens are on the high end of the range of noise amplitude (Figure 2). Additionally, emergency sirens have a high, oscillating frequency, which corresponds to a high, oscillating pitch (Siano & Gonzalez, 2021). The uniquely high levels of amplitude combined with the oscillating frequency in emergency sirens enable them to serve their purpose and alert bystanders of danger (Hansson, 2018). However, the sound emitted from such sirens is not always readily localized due to a variety of factors, the most prominent being the Doppler effect (Oechslin et al., 2008). The Doppler effect describes the relationship between an object's movement in relation to an observer and its direct sound (Oechslin et al.,

2008). Applying the Doppler effect to emergency sirens, research has shown that observers are more likely to accurately localize approaching sirens than those that are receding (Oechslin et al., 2008).

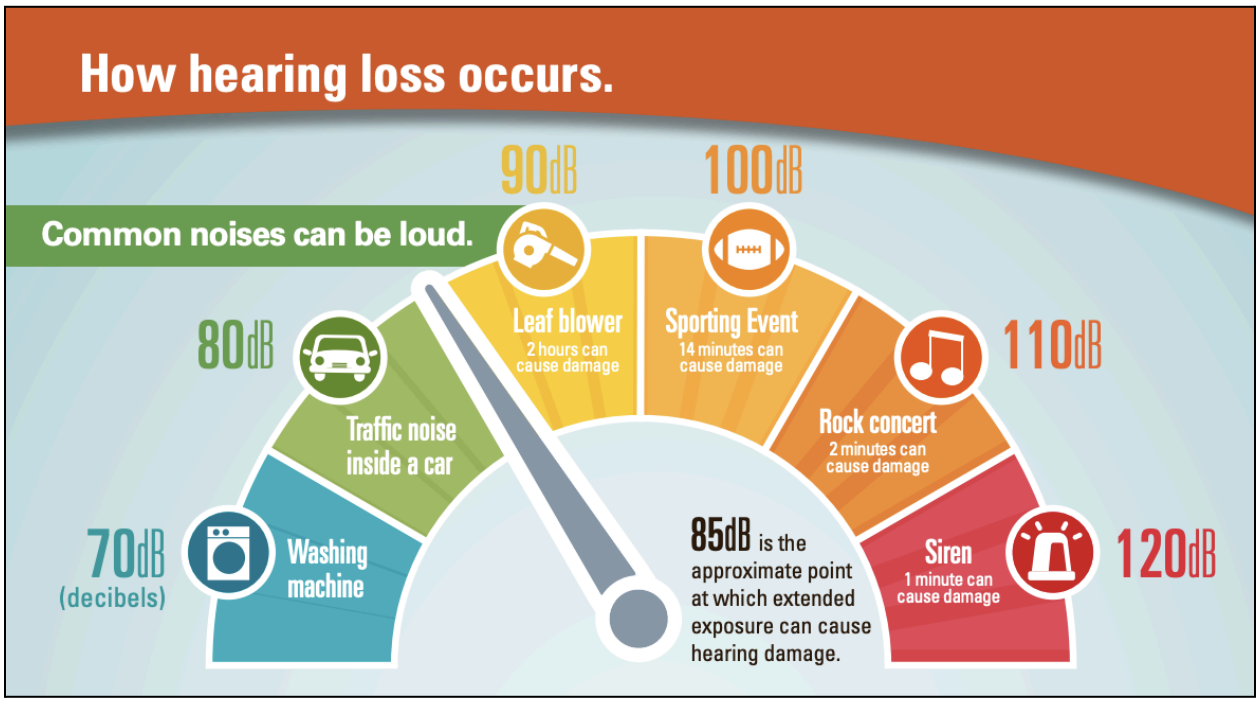


Figure 2. The different amplitude levels of common noises in the environment, measured in decibels (Center for Disease Control and Prevention, 2020).

Emergency sirens are a unique form of noise pollution that have particularly adverse consequences to the learning environment. In Gheewalla et al. (2021), the effects of different distraction conditions on 55 fluent English speakers (aged 18-38) were determined by measuring the time taken to complete certain tasks. Out of all the different noise stimuli tested, sirens were by far the most distracting to the participants' cognitive processing, resulting in far slower completion times for the tasks at hand (Gheewalla et al., 2021). This is consistent with previous research, which has found that the noise from individual external events (e.g. the passing of planes or trains) is most detrimental to reading ability, particularly in older children (Bronzaft & McCarthy, 1975; Cohen et al., 1980; Shield & Dockrell, 2008a). Another study

that examined the arousal effects of a variety of different environmental noises found that sirens prompted greater attention capture than any other common environmental noise (Gomez & Danuser, 2004).

The particular harm to children's learning posed by siren-generated noise pollution may be explained by the unique amplitude and psychological implications associated with sirens (Gheewalla et al., 2021). The purpose of sirens is to serve as a signal of danger and capture attention, necessitating an extremely high, piercing amplitude. Serving as a signal of danger could explain sirens' unique ability to shift students' attention away from their current task. These findings are similar to those in (Klatte et al., 2013), which suggest that the level of attention capture is dependent upon the characteristics of the distraction. Siren-generated noise pollution falls closely in line with the attention-capture mechanism that mediates distraction and impairs academic performance (Bell et al., 2012; Caviola et al., 2021).

Sirens have been shown to have tangible impacts on individuals outside of the learning environments. In some cases, sirens have been shown to prompt emotional distress and physiological changes (Manor et al., 2023). Certain groups, like veterans, are particularly impacted by sirens (Shreck et al., 2020). In Shreck et al. (2020), the authors note that psychologists have observed how constant exposure to sirens in large metropolitan areas like New York City can serve as a trigger for veterans with anxiety and post-traumatic stress disorder (PTSD) (refer to Terms). These observations are consistent with the findings of (Chessell et al., 2019), which found that the sight of police uniforms and the sound of sirens can trigger flashbacks in individuals with PTSD. Another vulnerable group that experiences an acutely adverse reaction to police and ambulance sirens is migraineurs (Ishikawa et al., 2019).

Hypersensitivity to sounds is known to affect between 70 and 80 percent of migraine

patients (Ishikawa et al., 2019). Compared to healthy adults, migraineurs experienced a particularly high level of discomfort when exposed to police and ambulance sirens (Ishikawa et al., 2019). Furthermore, a recent study found that police sirens served as a trigger of flashbacks of past traumatic events for Albanian-speaking immigrants in Switzerland (Shala et al., 2020). Similarly, Ukrainian refugees have been shown to feel physical distress that eventually becomes emotional distress upon exposure to air raid sirens—which also serve as a signal of danger (Rizzi et al., 2023).

While the psychological and physiological impact of sirens on some vulnerable groups like veterans, migraineurs, and immigrants has been researched, other potentially vulnerable groups have received less attention. One potentially vulnerable group to the adverse impacts of sirens is Black youth. Sirens are associated with policing (Fernandes, 2018). However, policing in the United States does not affect all citizens equally; Black Americans are more likely to be the victims of unfair treatment by police than other Americans (Chaney & Robertson, 2013). Unfair treatment by police includes racialized violence and police brutality (Chaney & Robertson, 2013). Black youth have become increasingly aware of unfair treatment by police through both direct exposure (lived experience) and exposure through the media (Anderson et al., 2022). Police killings and subsequent exposure to such killings through the media have been shown to have highly consequential impacts on the mental and physical well-being of Black boys (Browning et al., 2021; Smith Lee & Robinson, 2019; Tynes et al., 2019).

The increased exposure to racialized violence by the police has mediated the unique disapproval that Black youth have been shown to hold toward policing in the United States (Brunson & Weitzer, 2009). Fearing unpleasant or even fatal interactions with the police, Black youth have sometimes modified their behaviors to avoid using public spaces and instead opt to

stay inside (Brunson & Pegram, 2018). When explaining why they modify their behavior, Black children often cite negative past experiences with the police, either first-hand experiences or third-hand experiences shared by the media, and a desire to avoid reliving such experiences upon the sight of police officers (Brunson & Pegram, 2018). Furthermore, Black and Hispanic children have described feeling "on edge" due to frequent police and emergency vehicle sirens in their neighborhoods (Criss et al., 2016).

Due to historical injustices regarding Black Americans' treatment by police officers, as well as the unique modern-day attitudes toward police held by Black youth, I hypothesize that Black children may be a particularly vulnerable group to experiencing adverse reactions to police and emergency service vehicle sirens. However, the academic performance of students of all ages and races has been shown to be impaired by sirens—not just the potentially vulnerable groups. While it is critical to understand and recognize that some groups of students may be especially vulnerable, understanding the deleterious impacts of sirens on the learning environment as a whole is also a foundational aim of this study

Although experimental studies have shown the high levels of distraction that sirens can prompt in students, a qualitative investigation into the extent of impacts (including emotional impacts) on both students and educators has yet to be conducted. Using a mixed methods, multi-phase approach, this study aims to identify the schools most at risk of experiencing siren-generated noise pollution and investigate the extent to which sirens impact students and educators in Massachusetts.

1.3 RESEARCH QUESTIONS

Phase One: Mapping the Distribution of Siren-Generated Noise Pollution in Massachusetts and Identifying the Schools At Risk of Exposure

1. Which schools are most vulnerable to frequent siren exposure in Massachusetts?
2. Are students of color disproportionately exposed to siren-generated noise pollution in Massachusetts?
3. Accounting for geographic clustering, what is the relationship between racial demographics and schools' exposure to sirens?
4. Are students of color disproportionately *highly* exposed to siren-generated noise pollution in Massachusetts?
5. What is the relationship between schools' *highly* exposed to sirens and Environmental Justice neighborhoods?
6. Which counties are the most exposed to sirens?

Phase Two: Assessing the Impacts of Sirens on the Learning Environment

7. To what extent do students and educators report being distracted by sirens?
8. Does racial or gender identity influence students' reaction to the sound of sirens?
9. What is the relationship between a student's attitude toward the police and the extent to which they report being affected by sirens in the classroom?
10. Do sirens remind students and educators of anything in particular and how do educators report sirens impacting the classroom?

2.0 METHODS

2.1 THE RATIONALE BEHIND A MULTI-PHASE APPROACH

To address my research questions, I utilized a mixed methods, multi-phase approach. In Phase One, which is titled "Mapping the Distribution of Siren-Generated Noise Pollution in Massachusetts and Identifying the Schools At Risk of Exposure," I deployed spatial data science to determine *which and what* schools in Massachusetts are exposed to sirens. Mapping the distribution of siren-generated noise pollution in Phase One enabled me to identify a potentially at-risk school to survey for Phase Two. Drawing from the preliminary findings from Phase One, I identified and surveyed an at-risk school in Boston. Through Phase Two, I surveyed both students and educators to discern *how* they perceive emergency sirens and the extent to which they believe sirens impact the learning environment . I designed the survey to query the variety of ways that emergency sirens may impact the learning environment, from distraction to emotional distress. This multi-phased approach helped to ensure that the results from Phase Two were meaningful and representative of schools that are experiencing the infiltration of emergency sirens with some frequency.

2.2 PHASE ONE: MAPPING THE DISTRIBUTION OF SIREN-GENERATED NOISE POLLUTION IN MASSACHUSETTS AND IDENTIFYING THE SCHOOLS AT RISK OF EXPOSURE

2.2.1 Spatial Data Sources

I utilized spatial data analysis conducted in ArcGIS Pro to investigate the relationship between schools' racial makeup and exposure to sirens. Siren-generating facilities are emergency response centers that not only dispatch but also receive vehicles equipped with emergency sirens.

Siren-generating facilities generally include acute-care hospitals, ambulance stations, fire stations, and police stations. For this study, I included acute-care hospitals, ambulance stations, and fire stations in my spatial analysis while excluding police stations. The decision to exclude police stations stems from the fact that when police officers are at the station, they tend to be doing administrative work and not using sirens (Bennett & Lupton, 1992). Only rare emergent events prompt the use of sirens by police officers as they leave the station. As a result, I decided that police stations were not frequently "siren-generating," unlike ambulance stations, fire stations, and acute-care hospitals.

I collected the data for the locations of siren-generating facilities and public and private K-12 schools from the United States Department of Homeland Security's Homeland Infrastructure Foundation-Level Data (HIFLD). The data sets that I gathered from HIFLD were entitled "Emergency Medical Service Stations," "Fire Stations," "Hospitals," "Public Schools," and "Private Schools." I filtered the data set entitled "Hospitals" to include solely acute care hospitals, as the other hospital types initially included in the data set are unlikely to be siren-generating.

The following steps outline the general methods that I utilized to conduct my spatial analysis:

2.2.2 Mapping Procedure

1. After importing the aforementioned five data sets into ArcGIS Pro, I performed a proximity analysis using a buffer zone of 500 meters around each of the schools. A 500-meter buffer zone has been standardly used in prior similar analyses of environmental noise exposure in schools (Collins et al., 2019; Méline et al., 2013).

2. The proximity analysis yielded the number of siren-generating facilities within 500 meters of each school. Next, I exported the resulting table with school names and the accompanying number of siren-generating facilities to Excel.
3. In Excel, I matched the results from the proximity analysis with the publicly available demographic data for each school from the United States Department of Education. The demographic data was from the 2022-2023 academic year. This enabled me to create a comprehensive worksheet with the enrollment data, demographic data, geodata, and count of points for siren-generating facilities for all K-12 schools in Massachusetts.
4. To control for variations in the number of siren-generating calls received at each siren-generating facility, I requested data from the Massachusetts Office of Emergency Medical Services (EMS). The Office of EMS provided me with data for the number of annual emergent calls EMS services responded to using sirens by zip code, which enabled me to assign weights to each EMS station based on an estimate of the average number of daily siren-generating calls each facility received. To calculate and assign weights for each siren-generating facility, I took the annual number of calls that EMS services responded to using sirens for each zip code and divided it by the total number of siren-generating facilities in each respective zip code. For example, if a zip code received 1000 siren-generating calls and had 10 siren-generating facilities, each facility would receive a weight of 100 estimated calls that were responded to using sirens annually.
5. Once I successfully assigned weights to each facility, I produced an estimate for the number of expected daily sirens each school was exposed to. I added the number of expected daily siren-generating calls for each facility within 500 meters of each school in the Excel worksheet. For example, if a school is within 500 meters of an ambulance

station expecting an average of 3 siren-generating calls daily, and an acute care hospital expecting 10 calls daily, its total expected daily sirens would be 13.

6. Next, I divided the total expected daily sirens by 3 to account for the school day typically being only 8 hours—not 24. This yielded the average expected daily sirens each school is exposed to during school hours.

2.2.3 Statewide Data Analysis

2.2.3.1 Schools That Are Exposed to Sirens

Research Question 1: Which schools are most vulnerable to frequent siren exposure in Massachusetts?

To address the first research question, I created a figure in ArcGIS Pro that depicts the number of daily sirens each school is exposed to (as outlined in Section 2.2.2), with larger circles representing more frequent siren exposure (Figure 3).

Bivariate Analysis

Research Question 2: Are students of color disproportionately exposed to siren-generated noise pollution in Massachusetts?

To address the second research question, I followed the bivariate analysis approach outlined in (Collins et al., 2019). First, using the data retrieved from the United States Department of Education, I calculated the proportion of students in Massachusetts (N = 852,139) who belong to each racial/ethnic group. The racial/ethnic groups that I used to calculate the z-test for difference in proportions were: Black, Hispanic, white, Asian Pacific Islander (API), and Other Race (i.e. students who identify as Two or more races, American Indian/Alaska Native, or Native Hawaiian/Other Pacific Islander). Then, I calculated the proportion of students who

attend schools exposed to sirens (i.e. expected daily sirens > 0) (n = 165,567) who belong to each racial/ethnic group. Finally, I performed a z-test for difference in proportions to determine whether students of color are disproportionately exposed to sirens. To perform the z-test for difference in proportions, I used the following equation:

$$z = \frac{p_1 - p_2}{\sqrt{\frac{p_1(1-p_1)}{n_1}} + \sqrt{\frac{p_2(1-p_2)}{n_2}}}$$

Whereby p_1 is the proportion of students (K-12, public and private) in Massachusetts belonging to each racial/ethnic group; p_2 is the proportion of students (K-12, public and private) attending schools exposed to sirens (i.e. expected daily sirens > 0) belonging to each racial/ethnic group; n_1 is the number of students (K-12, public and private) in Massachusetts (N = 852,139); and n_2 is the number of students (K-12, public and private) in Massachusetts attending schools exposed to sirens (i.e. expected daily sirens > 0) (n = 165,567).

Multivariate Analysis

Research Question 3: Accounting for geographic clustering, what is the relationship between racial demographics and schools' exposure to sirens?

To address the third research question, I developed zero-inflated generalized linear mixed models (ZIGLMs) in RStudio (version 2023.12.1+402) to determine the relationship between the racial composition of schools and exposure to sirens. Zero-inflated generalized mixed models can account for geographic clustering and have been used in prior, similar studies (Osei et al., 2022) Before creating the ZIGLMs, I performed a Global Morin's I test of spatial autocorrelation in ArcGIS Pro for expected daily sirens. For the specifications of the Global Moran's I test, I used the inverse distance conceptualization of spatial relationships, the Euclidean distance method, and the row standardization method. The results indicated statistically significant levels

of positive autocorrelation (i.e. the clustering of schools with similar expected daily siren values) (Appendix G). This result is unsurprising; if a school is closely neighboring another school, it is likely to experience similar levels of daily sirens. After performing the Global Moran's I test, I performed the Getis-Ord G test using the same specifications as the Global Moran's I test to determine whether the statistically significant level of clustering was of high or low values. The test indicated a statistically significant level of clustering of high values (i.e. schools that experience frequent siren exposure tend to cluster near each other (Appendix G).

Linear regression models rely on the assumption of independence, which spatial datasets rarely meet (Chakraborty et al., 2011). For my dataset, the positive spatial autocorrelation violated the assumption of independence, rendering linear regression unfit for analysis. As a result, I decided to instead employ ZIGLMs to perform the multivariate analysis, which enabled me to accommodate both geographic clustering and the zero-inflated nature of my dependent variable (expected daily sirens).

As outlined by (Collins et al., 2019), I used school districts to accommodate geographic clustering. I used the spatial join tool in ArcGIS Pro to determine the district that each school in Massachusetts fell in geographically, allowing the inclusion of private schools. Further following the methods outlined in (Collins et al., 2019), I used 2010 U.S. Census data to incorporate another explanatory variable: the proportion of the population living in an urban area within the county containing each school. Additionally, I chose to incorporate the total student population as another predictor variable.

Once I had completed assigning district codes to each school district, I uploaded the dataset to RStudio and installed the glmmTMB package (Appendix H). I created the ZIGLMs using the following predictor variables: proportion Hispanic, proportion Black, proportion white,

proportion urban in the county, and total students. I used the daily expected sirens as the dependent variable. I controlled for geographic clustering by using school districts (N = 209) as the nuisance parameter. I created two ZIGLMs: a zero-inflated Poisson model with a random intercept for the school district and a zero-inflated Negative Binomial model with a random intercept for the school district. Both models fit similarly to my data and both of the results are presented below (Table 2).

2.2.3.2 Schools That Are *Highly* Exposed to Sirens

I define schools that are "*highly* exposed" to sirens as schools within the 95th percentile of expected daily siren exposure (n = 86) (refer to Terms). To address the third and fourth research questions, I performed two different z-tests for differences in proportions.

Research Question 4: Are students of color disproportionately highly exposed to siren-generated noise pollution in Massachusetts?

To address the fourth research question, I followed the bivariate analysis approach outlined in Section 2.2.3.1. First, using the data retrieved from the United States Department of Education, I calculated the proportion of students in Massachusetts (N = 852,139) who belong to each racial/ethnic group. Then, I calculated the proportion of students who attend schools *highly* exposed to sirens (i.e. in the 95th percentile of expected daily sirene exposure) (n = 38,616) who belong to each racial/ethnic group. Finally, I performed a z-test for difference in proportions to determine whether students of color are disproportionately *highly* exposed to sirens.

To perform the z-test for difference in proportions, I used the following equation:

$$z = \frac{p_1 - p_2}{\sqrt{\frac{p_1(1-p_1)}{n_1}} + \sqrt{\frac{p_2(1-p_2)}{n_2}}}$$

Whereby p_1 is the proportion of students (K-12, public and private) in Massachusetts belonging to each racial/ethnic group; p_2 is the proportion of students (K-12, public and private) attending schools *highly* exposed to sirens (i.e. expected daily sirens > 4) belonging to each racial/ethnic group; n_1 is the number of students (K-12, public and private) in Massachusetts (*N* = 852,139); and n_2 is the number of students (K-12, public and private) in Massachusetts attending schools exposed to *highly* sirens (i.e. expected daily sirens > 4) (*n* = 38,616).

Research Question 5: What is the relationship between schools' highly exposed to sirens and Environmental Justice neighborhoods?

To address the fifth research question, I utilized the "summarize within" tool in ArcGIS Pro. First, I uploaded a shapefile to ArcGIS Pro with the locations of the 86 schools in the 95th percentile of expected siren exposure. Next, in ArcGIS Pro, I imported a layer from MassGIS entitled "Environmental Justice areas;" this layer contained the neighborhoods deemed by the Massachusetts Executive Office of Energy and Environmental Affairs as Environmental Justice (EJ) areas. Then, I overlaid the *highly* exposed schools with the EJ areas and performed a "summarize within" test. The results of the "summarize within" test yielded the number of *highly* exposed schools located in EJ areas. Next, I used the "summarize within" tool again, but this time on all schools in the dataset (*N* = 1713)—not just the schools *highly* exposed to sirens. Using the "summarize within" tool, I determined that 726 out of 1713 schools in Massachusetts are within EJ areas. Finally, I performed a z-test for the difference in proportions between the proportion of schools in Massachusetts in EJ areas and the proportion of schools *highly* exposed to sirens in EJ areas.

To perform the z-test for difference in proportions, I used the following equation:

$$z = \frac{p_1 - p_2}{\sqrt{\frac{p_1(1-p_1)}{n_1}} + \sqrt{\frac{p_2(1-p_2)}{n_2}}}$$

Whereby p_1 is the proportion of schools (K-12, public and private) in Massachusetts within Environmental Justice neighborhoods (refer to Terms); p_2 is the proportion of schools (K-12, public and private) that are *highly* exposed to sirens (i.e. expected daily sirens > 4) within Environmental Justice neighborhoods; n_1 is the number of schools (K-12, public and private) in Massachusetts (N = 1713); and n_2 is the number of schools *highly* exposed to sirens in Massachusetts (n = 86).

2.2.4 County-Level Analysis

Research Question 6: Which counties are the most highly exposed to sirens?

To address the sixth research question, I performed spatial analysis using county boundaries. First, I collected the county boundary data from MassGIS and imported the layer (entitled 'Counties') into ArcGIS Pro. In ArcGIS Pro, I performed a "summarize within" test to determine the sum of expected daily siren exposure in each county (Figure 5). Next, I normalized the sum of expected daily sirens for each county by population under 20 years old, since this is the age population typically attending K-12 schools (Figure 5). I collected the data for the population under 20 years old in each county from the 2020 U.S. Census. Then, I further normalized the data by the total area of each county to account for the stark differences in county sizes in Massachusetts (Figure 5). Finally, I used the results of each step of normalization to identify the counties that are most substantially exposed to sirens.

Once I identified the three counties most exposed to sirens, I created figures in ArcGIS Pro using the clipping tool and the Map Layout function that excluded data outside of the specific county's borders. These figures provide a closer visual representation of the specific

schools and student demographics most heavily impacted by sirens in each of the most impacted counties.

2.3 PHASE TWO: ASSESSING THE IMPACTS OF SIRENS ON THE LEARNING ENVIRONMENT

2.3.1 Participants

80 individuals participated in this study, 72 of which were students and 8 of which were educators. Student and educator participants were all adults—as specified by the Boston College IRB. All participants were recruited from the same school in Boston with the approval of the Boston Public Schools (BPS) Research Team. Drawing from the results from Phase One, the sampled school expected roughly four sirens daily. I recruited student participants using flyers and with the assistance of administrators within the school. The sampled school has a high proportion of English as a second language students, so I translated the student survey from English into the following languages using Qualtrics' Translation Service: Haitian Creole, Spanish, Dari, Vietnamese, Ukrainian, Portuguese, Chinese, Arabic, and Cape Verdean Creole. Native speakers reviewed each language of the translated survey and provided feedback. I updated each translated survey accordingly to ensure accurate translations were conveyed to the participants. Student participants completed the survey under the supervision of educators during class time.

2.3.2 Confidentiality and Risk

The Boston College IRB and the BPS Research Team approved the methods for this study. I designed this study to minimize risk to participants in accordance with the CITI

Research, Ethics, Compliance, and Safety guidance. I met with the Head of School at the sampled school to ensure that minimal risk was imposed on participants and that the survey was as accessible as possible to the school's diverse population. Participants were assured that participation was voluntary and that refraining from answering a specific question would not nullify a respondent's other responses (Appendix C). All participants remained completely anonymous and the relatively large number of respondents minimized the risk of deductive disclosure. Additionally, the Head of School disseminated the survey to both cohorts and neither the PI nor the Co-PI had any direct or indirect contact with the participants. To proceed with the survey, each respondent had to affirm that they were at least eighteen years old. Furthermore, to proceed with the survey, each participant had to read the informed consent, which was translated into each of the previously outlined languages (refer to Section 2.3.1) using Google's Translation Service to ensure that every participant understood the risks. Finally, to further minimize the risks imposed by this study, I have ensured that the school surveyed remains anonymous.

2.3.3 Survey Procedure

1. Upon approval of the study by the BPS Research Team, the survey was disseminated to participants in both cohorts by the Head of School at the sampled school.
2. Participants received emails from the Head of School approved by the Boston College IRB (Appendix C). In the email, each participant received information about the study and an anonymous link to the survey.
3. Participants in the student cohort completed the survey during class time under the supervision of educators, who assisted when questions arose.

4. The survey remained open for four weeks, providing the sampled school with flexibility and ensuring the maximum number of responses were received.
5. Once the survey was closed, the de-identified responses were retrieved from Qualtrics and stored in a secure, departmental server.
6. The quantitative data were analyzed in SPSS, while the qualitative data (open-ended responses) were translated using Google Translate and analyzed in the software NVivo.V.14. The raw qualitative data without translations is available for reference in the Appendix (Appendix F).
7. Upon completion of the data analysis, the sampled school, the BPS Research Team, and the BPS Office of the Superintendent were provided with copies of the data.

2.3.4 Data Analysis

I designed the survey using a mix of both closed-ended (quantitative) and open-response (qualitative) questions to best gauge the impact of sirens on the learning environment. I primarily utilized the closed-ended questions to address the seventh, eighth, and ninth research questions, while I used the open-ended question to address the tenth research question.

2.3.4.1 Quantitative Data Analysis

To address the seventh, eighth, and ninth research questions, I utilized SPSS.V.29 to perform a variety of statistical analyses on the quantitative data for both the student and educator surveys. With the exception of a few nominal questions, the majority of the questions in both the student and educator surveys utilized a 5-point Likert scale.

First, I coded and assigned values to each quantitative variable in SPSS.V.29, following the scales used in the questionnaire. Next, I removed responses with zero percent completion for the entire survey (n = 16 in the student survey, n = 0 in the educator survey). I included all responses with greater than zero percent completion for the non-demographic questions. Then, I assigned values to missing cells due to nonresponse in SPSS to ensure that the data was preserved and further analysis could be performed. I analyzed survey responses using a combination of descriptive and inferential statistics for ordinal variables and qualitative coding of open-ended text responses.

Research Question 7: To what extent do students and educators report being distracted by sirens?

To address the seventh research question, I first calculated the frequency of responses for the following question: *on a typical school day, how often do you hear sirens while you are in class?* By determining the frequency of responses for this question, I was able to provide the necessary context to interpret the frequency of responses for the following questions in the student survey: *How distracted from your schoolwork are you when you hear sirens? How long does your distraction persist?*

Next, I calculated the frequency of responses for the following questions in the educator survey: *How long does your distraction persist? To what extent do you observe students being distracted by sirens in the classroom?* By calculating the frequency of responses, I was able to determine the general attitudes held by students and educators regarding sirens in the classroom.

Research Question 8: Does racial or gender identity influence students' reaction to the sound of sirens?

To address the eighth research question, I performed a Kruskal-Wallis H Test, using racial and gender identity as the independent variables. For the dependent variables, I selected the following questions that assess attitudes toward the sound of sirens: *On a typical day, how does the sound of sirens in your classroom make you feel? How annoyed are you when you hear sirens in your classroom? How distracted from your schoolwork are you when you hear sirens? How long does your distraction persist? To what extent does siren noise affect how well you learn?*

Research Question 9: What is the relationship between a student's attitude toward the police and the extent to which they report being affected by sirens in the classroom?

To address the ninth research question, I performed ordinal regression analysis in SPSS.V.29. I selected the following question as the dependent variable: *To what extent does siren noise affect how well you learn?* For the explanatory variables (i.e. factors), I selected the following variables that assessed attitudes toward the police: *Police protect people's basic rights; Police can be trusted to do what's right for my neighborhood; Officers treat all people with respect; Laws protect everyone equally; Police protect my safety;* and *I trust the police*. By performing ordinal regression analysis using these explanatory variables, I was able to assess the relationship between students' attitudes toward the police and the extent to which they report being affected by sirens in the classroom.

2.3.4.2 Qualitative Data Analysis

Research Question 10: Do sirens remind students and educators of anything in particular and how do educators report sirens impacting the classroom?

To address the tenth research question, I used NVivo to examine respondents' answers to the open-ended questions. For the qualitative data from the student survey, I translated the responses to English from the language that the respondent completed the survey in using Google Translate. I then uploaded the student and educator survey responses (in both the original and translated form) to NVivo.V.14.

After uploading the student and educators' responses to NVivo.V.14, I created a word frequency cloud. The word frequency cloud, along with prior research, informed the identification of themes across the responses and subsequently enabled me to assign codes to each response. Finally, I used the coding classifications and the frequency of responses in each classification to address the tenth research question.

3.0 RESULTS

3.1 PHASE ONE FINDINGS

3.1.1 Statewide Findings

3.1.1.1 Schools That Are Exposed to Sirens

Research Question 1: Which schools are most vulnerable to frequent siren exposure in Massachusetts?

I found that 369 K-12 schools in Massachusetts are within 500 meters of a siren-generating facility and expect sirens daily. As Figure 3 depicts, the frequency of siren exposure that each school experiences varies greatly across the state. Factors including the number of siren-generating facilities within 500 meters of each school, as well as the number of siren-generating calls that each of such facilities receives on average, account for the variance in exposure. Furthermore, I found that the range of expected daily sirens is from 0 daily sirens to approximately 16 daily sirens. As Figure 3 also demonstrates, schools located in urban areas are much more likely to be exposed to sirens than schools located in suburban or rural areas (Figure 3 and Table 2).

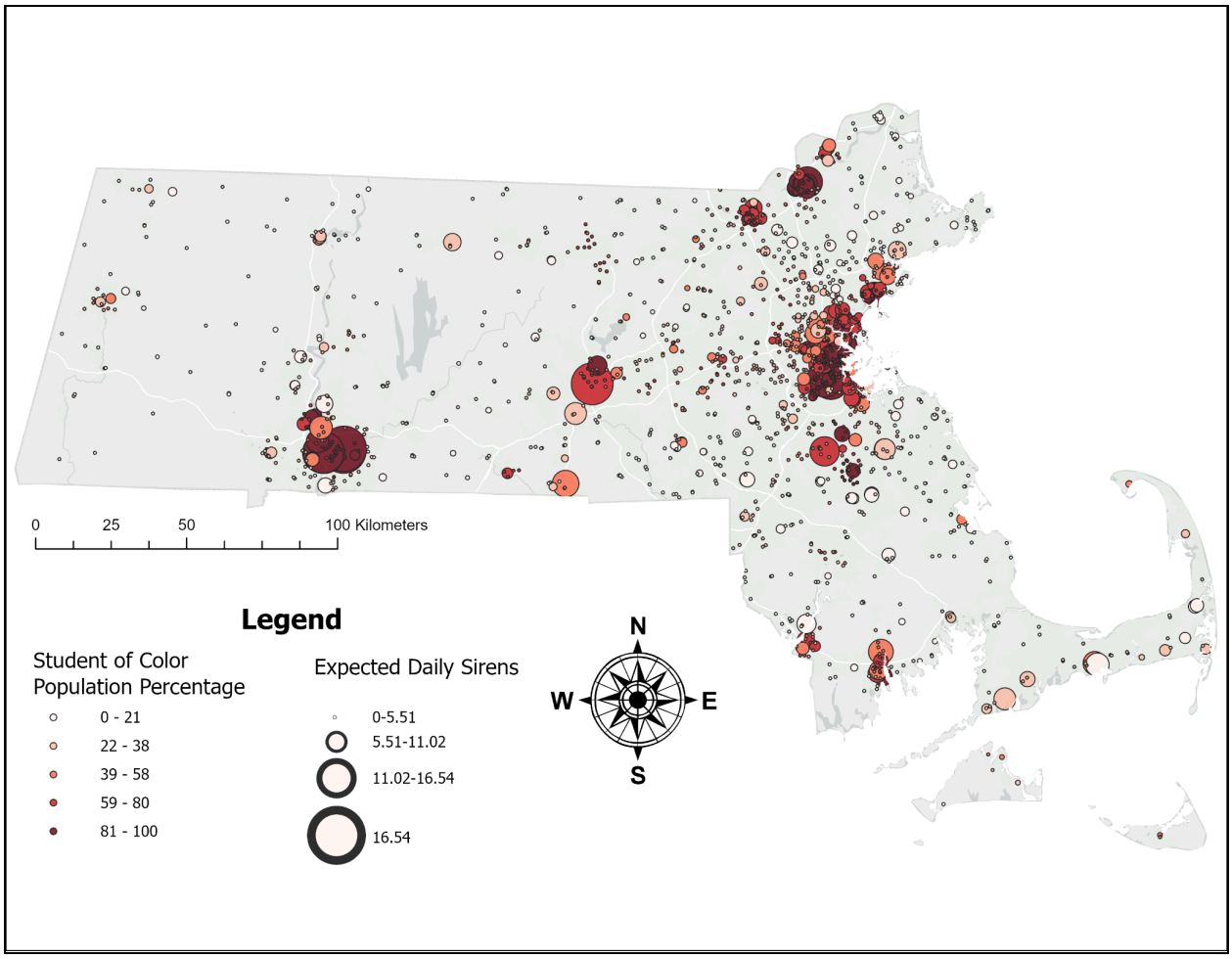


Figure 3. The expected daily sirens and students of color percentage for each K-12 public and private school in Massachusetts. The size of the circle on the map represents the number of expected daily sirens for each specific K-12 school, with larger circles indicating more frequent siren exposure. Additionally, the circle's color represents the percentage of students of color in the school's population, with the darker color on the continuous red spectrum indicating higher percentages of students of color within the school's population.

Research Question 2: Are students of color disproportionately exposed to siren-generated noise pollution in Massachusetts?

Inferential statistics reveal that students of color are disproportionately exposed to emergency sirens. Table 1 shows that Black, Hispanic, and Asian Pacific Islander (API) students are disproportionately exposed to sirens while white students are disproportionately shielded from sirens. For example, as Table 1 depicts, Hispanic students comprise 22.4% of all students in

Massachusetts, yet they represent 30.8% of the students exposed to sirens, resulting in a positive difference (p_2-p_1) between proportion of students in Massachusetts (p_1) and proportion of students exposed to sirens (p_2). White students, on the other hand, comprise 56.6% of all students in Massachusetts, yet represent only 46.2% of students exposed to sirens, resulting in a negative difference (p_2-p_1). The results for the z-test for difference in proportions are statistically significant at the $p < .05$ level for each racial/ethnic variable and are highly statistically significant (i.e. significant at the $p < .001$ level) for the Black, Hispanic, and white racial/ethnic categories.

Table 1. Results of a z-test for differences in proportions comparing students exposed to sirens daily to all Massachusetts students (public and private K-12) ($N = 852,139$) based on race/ethnicity.

Variable	**Proportion of Students in Massachusetts**	**Proportion of Students Exposed to Sirens**	**Difference**	***Z***	***p***
API	0.072	0.079	0.008	-3.053	**.00228****
Black	0.092	0.107	0.015	-6.164	**< .00001*****
Hispanic	0.224	0.308	0.084	39.126	**< .00001*****
White	0.566	0.462	-0.104	53.868	**< .00001*****
Other Race	0.046	0.044	-0.002	0.703	**.047***
**** p < 0.05***	***** p < 0.01***	****** p < 0.001***			

Note: "API" stands for Asian Pacific Islander

Research Question 3: Accounting for geographic clustering, what is the relationship between racial demographics and schools' exposure to sirens?

Accounting for geographic clustering, I found that an increase in the proportion of white students was significantly associated with a decrease in exposure to sirens (Table 2). For an

example of how to interpret Table 2, both Model 1 and Model 2 found the incidence rate ratio for Prop. White was less than 1.0 (0.99) and statistically significant, indicating that schools with higher proportions of white students are at decreased risk for experiencing sirens.

The zero-inflated aspect of the models predicts zeros, which in this case can be interpreted as expecting zero sirens daily. Thus, in the case of the Zero-Inflated aspect of the models, an incidence rate ratio of less than 1 indicates a decreased likelihood of a school being shielded from daily sirens, while an incidence rate ratio of over 1 indicates an increased likelihood of experiencing daily sirens. In predicting zeros, I found that the proportion of Hispanic students and the proportion of urban population in the school's county were both statistically significantly associated (at the $p < .05$ and $p < .001$ levels, respectively) with a decrease (incidence rate ratio < 1.0) in zeros. This indicates that an increase in the proportion of urban population in the school's county, as well as an increase in the proportion of Hispanic students in a school, is associated with a statistically significant decrease in a school's likelihood of *not* being exposed to sirens.

Table 2. The results of a zero-inflated Poisson model with a random intercept for school districts (Model 1) and a zero-inflated Negative Binomial model with a random intercept for school districts (Model 2) predicting the number of daily sirens.

	Model 1			**Model 2**		
Predictors	Incidence Rate Ratios	Lower 95% CI to Upper 95% CI	*p*	Incidence Rate Ratios	Lower 95% CI to Upper 95% CI	*p*
(Intercept)	17.18	2.83 – 104.18	**.002****	18.28	2.74 – 122.02	**.003****
Prop. Hispanic	1.00	0.99 – 1.01	.555	1.00	0.99 – 1.01	.867
Prop. Black	1.00	0.99 – 1.01	.532	1.01	1.00 – 1.02	.254
Prop. White	0.99	0.98 – 1.00	**.002****	0.99	0.98 – 1.00	**.009****
Prop. Urban in County	0.20	0.04 – 1.06	.058	0.16	0.03 – 0.88	**.035***
Total Students	1.00	1.00 – 1.00	**.005****	1.00	1.00 – 1.00	**.031***
Zero-Inflated Model (Intercept)	83.02	8.13 – 847.88	**<.001*****	92.13	8.63 – 983.49	**<.001*****
Prop. Hispanic	0.99	0.98 – 1.00	**.041***	0.99	0.98 – 1.00	.052
Prop. Black	1.00	0.99 – 1.02	.651	1.00	0.99 – 1.02	.594
Prop. White	1.01	0.99 – 1.02	.376	1.01	0.99 – 1.02	.418
Prop. Urban in County	0.02	0.00 – 0.17	**<.001*****	0.02	0.00 – 0.14	**<.001*****
Total Students	1.00	1.00 – 1.00	**.008****	1.00	1.00 – 1.00	**.007****
Random Effects						
σ2		0.65			1.69	
τ00		0.32 Districts			0.23 Districts	
ICC		0.33			0.12	
N		209 Districts			209 Districts	
Observations		1713			1713	
Model Fit						
Marginal R^2/Conditional R^2		0.121 / 0.407			0.091 / 0.199	
AIC		2834.1			2811.7	
BIC		2904.9			2880	
logLik		-1404			-1391.9	
Deviance		2808.1			2783.7	
***p<0.05*	***p<0.01*	****p<0.001*				

3.1.1.2 Schools That Are *Highly* Exposed to Sirens

Research Question 4: Are students of color disproportionately highly exposed to siren-generated noise pollution in Massachusetts?

I found that Black and Hispanic students in Massachusetts are disproportionately *highly* exposed to siren-generated noise pollution. Table 3 shows the results from the z-test for difference of proportions between the the proportion of students attending schools that are *highly* exposed to sirens (p_2) and the proportion of students in Massachusetts (p_1) based on race/ethnicity. As previously stated, students are considered *highly* exposed to sirens if they attend schools within the 95th percentile of expected daily siren exposure ($n = 86$). Table 3 shows that Black and Hispanic students are disproportionately *highly* exposed to sirens (i.e. there is a positive difference between p_2 and p_1) at a statistically significant level ($p < .001$). Furthermore, Table 3 depicts that white and other races students are disproportionately shielded from sirens (i.e. there is a positive difference between p_2 and p_1) at a statistically significant level ($p < .001$ and $p < .05$, respectively). However, there is not a statistically significant difference in the proportions of Asian Pacific Islander students *highly* exposed to sirens and the proportion of Asian Pacific Islander students in Massachusetts (Table 3).

Table 3. Results of a z-test for differences in proportions comparing students attending schools that are *highly* exposed to sirens (i.e. expected daily sirens > 4) to all Massachusetts students (public and private K-12) (N = 852,139) based on race/ethnicity.

Variable	**Proportion of Students in Massachusetts**	**Proportion of Students Highly Exposed to Sirens**	**Difference**	***Z***	***p***
API	0.072	0.066	-0.006	1.115	.267
Black	0.092	0.157	0.065	-16.480	**< .00001*** **
Hispanic	0.224	0.45	0.226	-66.441	**< .00001*** **
White	0.566	0.293	-0.273	57.844	**< .00001*** **
Other Races	0.046	0.034	-0.012	1.991	**.047***
***** $p < 0.05$	****** $p < 0.01$	******* $p < 0.001$			

Note: "API" stands for Asian Pacific Islander

Research Question 5: What is the relationship between schools' highly exposed to sirens and Environmental Justice neighborhoods?

I found that 76 out of 86 schools (88.4%) in the 95th percentile of expected daily siren exposure are located in Environmental Justice neighborhoods, as defined by the Massachusetts Executive Office of Energy and Environmental Affairs (refer to Terms) (Figure 4).

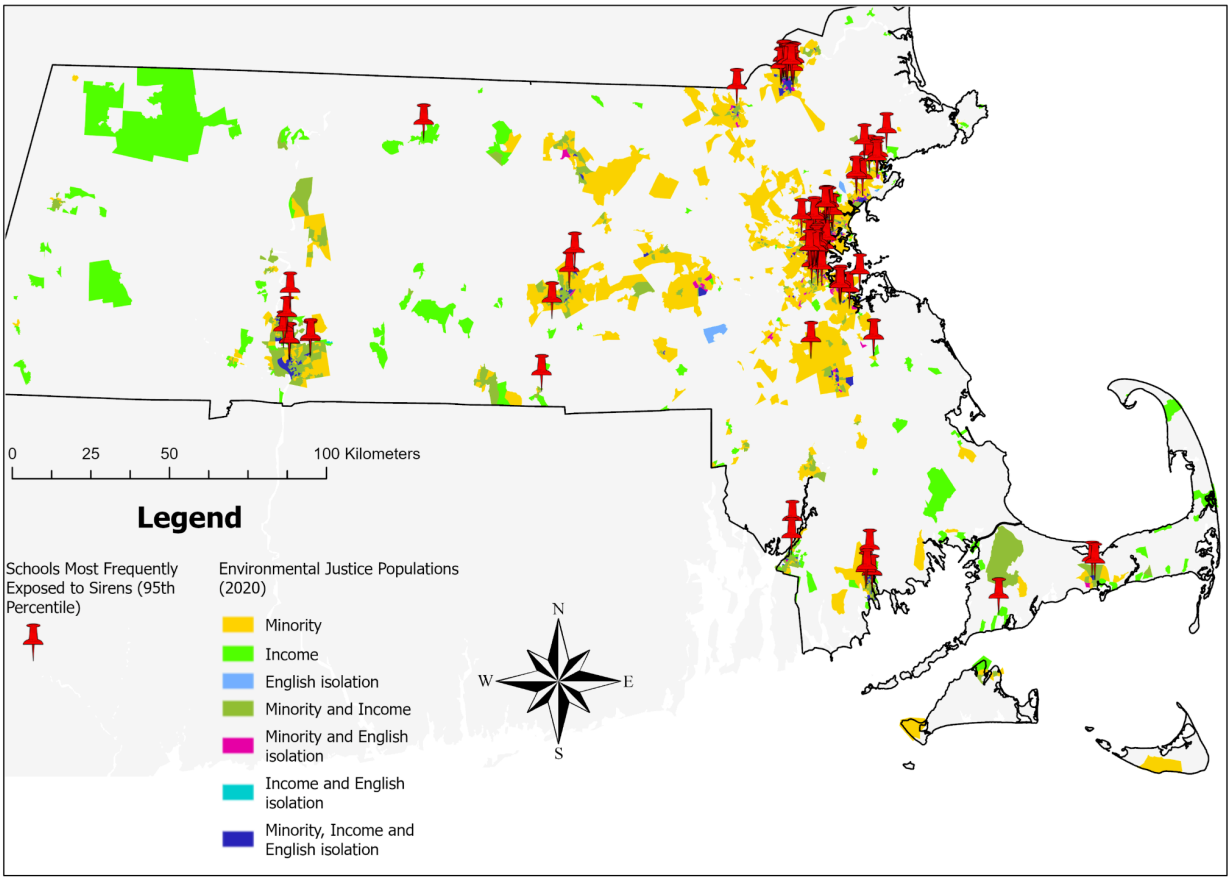


Figure 4. Schools that are *highly* exposed to sirens and Environmental Justice neighborhoods as defined by the Massachusetts Executive Office of Energy and Environmental Affairs.

As Table 4 shows, schools that are *highly* exposed to sirens are disproportionately located in EJ neighborhoods compared to all schools in Massachusetts. While 88.4% of all schools that are *highly* exposed to sirens are located in EJ neighborhoods, only 42.4% of all schools in Massachusetts (n = 1713) are located in EJ neighborhoods. As Table 4 depicts, the results from the z-test for difference of proportions are highly statistically significant ($p < .00001$).

Table 4. Results of a z-test for differences in proportions comparing the proportion of schools *highly* exposed to sirens (i.e. expected daily sirens > 4) located in EJ neighborhoods to the proportion of all schools in Massachusetts located in EJ neighborhoods.

Variable	**Proportion of Schools in Massachusetts**	**Proportion of Schools Highly Exposed to Sirens**	**Difference**	***Z***	***p***
Schools in Environmental Justice Neighborhoods	0.424	0.884	0.460	-8.373	**<.00001*** **

*** ***p*** **< 0.001**

3.1.2 County-Level Findings

Research Question 6: Which counties are the most highly exposed to sirens?

I found that Suffolk, Hampden, and Essex counties are the most exposed counties to daily sirens in Massachusetts (upper left Figure 5). When normalized by the population under 20 years old and area, Suffolk, Hampden, and Essex counties comprise three of the four most substantially exposed counties.

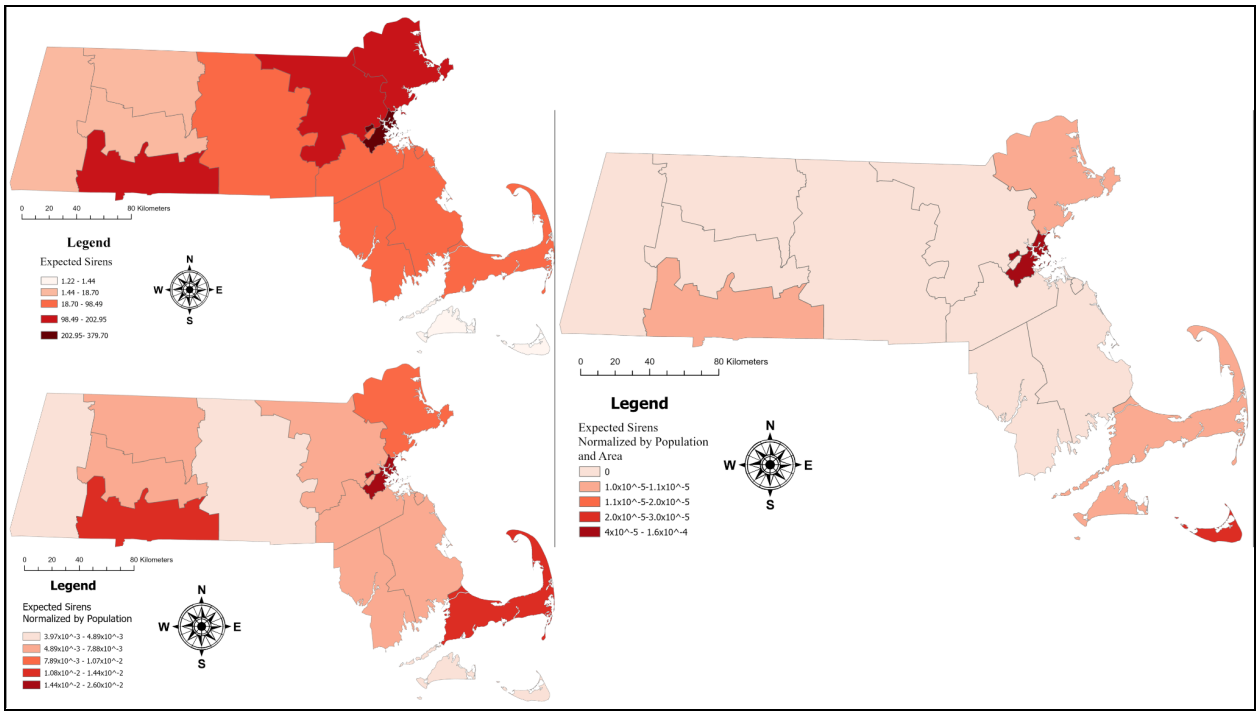


Figure 5. [Upper Left] The total number of expected daily sirens at schools in each county in Massachusetts. [Lower Left] The expected total number of daily sirens at schools in each county in Massachusetts, normalized by population under 20 years old. [Right] The expected total number of daily sirens at schools in each county in Massachusetts, normalized by population under 20 years old and the county's area.

3.1.2.1 Suffolk County

With a population of 797,936, Suffolk County is the fourth most populated county in Massachusetts (U.S. Census Bureau, 2020). Figure 6 shows that within this populated county, the schools with the highest volume of daily sirens (larger circles) tend to have a higher proportion of students of color (indicated by the circle's color). Furthermore, Figure 6 shows that the schools exposed to the highest number of daily sirens in Suffolk County tend to be within the towns of Dorchester and Roxbury. In Dorchester, Black, Hispanic, and API represent 36%, 14% and 12% of the population, respectively (U.S. Census, 2020), while in Roxbury, Black, Hispanic, and API represent 56%, 30%, and 1% of the population, respectively (U.S. Census, 2020).

Finally, Figure 6 shows that the schools within Suffolk County that are the most highly exposed to sirens experience approximately 17 daily sirens.

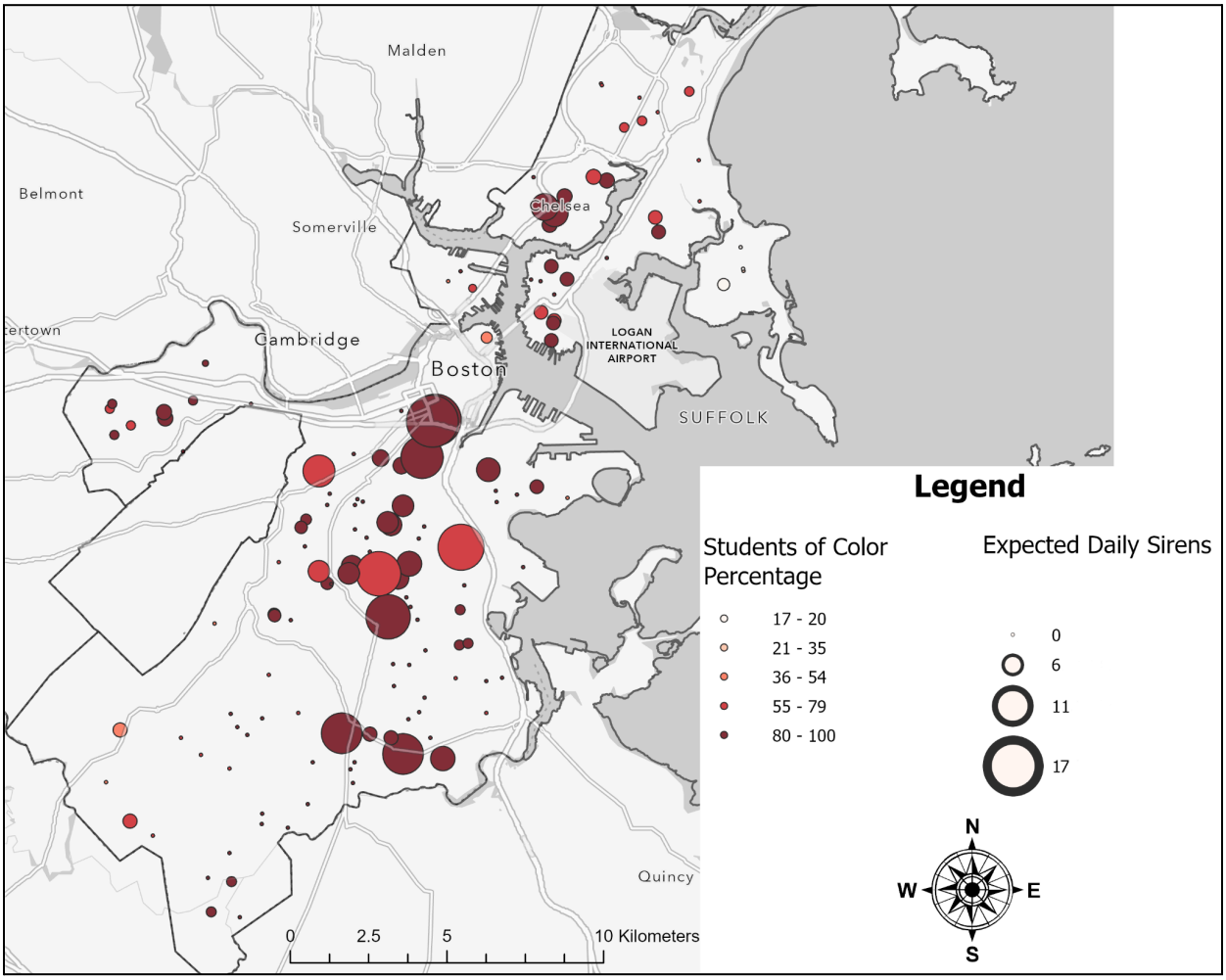


Figure 6. The expected daily sirens and students of color percentage for each K-12 public and private school in Suffolk County. The size of the circle on the map represents the number of expected daily sirens for each specific K-12 school, with larger circles indicating more frequent siren exposure. Additionally, the circle's color represents the percentage of students of color in the school's population, with the darker color on the continuous red spectrum indicating higher percentages of students of color within the school's population.

3.1.2.2 Hampden County

With a population of 465,825, Hampden County is the eighth most populated county in Massachusetts (U.S. Census, 2020). The City of Springfield comprises 33% of the population of

Hampden County. As Figure 7 shows—similar to Suffolk County—the schools within Hampden County with the highest volume of daily sirens (larger circles) tend to have a higher proportion of students of color (indicated by the color of the circle). Furthermore, Figure 7 shows that the schools within Hampden County that are most exposed to sirens tend to be clustered within the town of Springfield. In Springfield, Black, Hispanic, and API represent 18%, 48%, and 3% of the population, respectively (U.S. Census, 2020). Finally, Figure 7 shows that the schools within Hampden County that are the most exposed to sirens experience approximately 14 daily sirens.

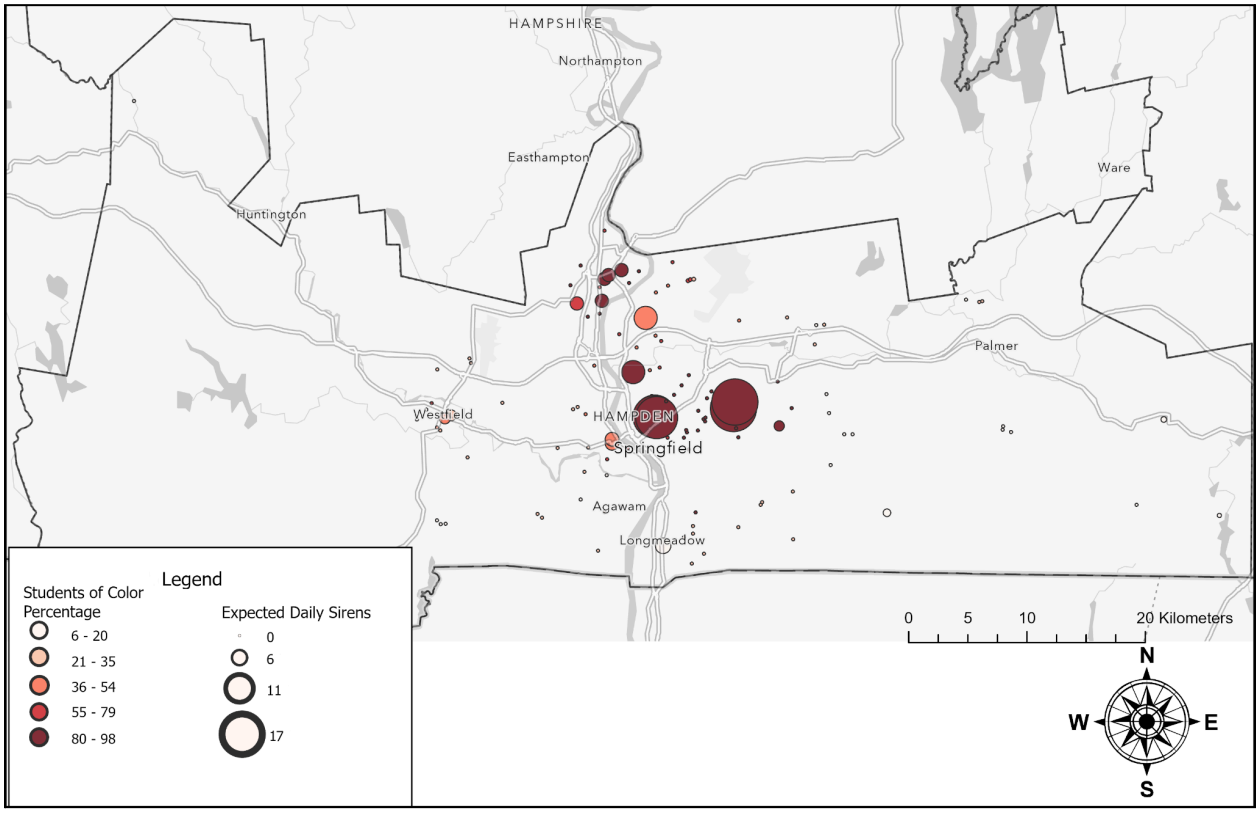


Figure 7. The expected daily sirens and students of color percentage for each K-12 public and private school in Hampden County. The size of the circle on the map represents the number of expected daily sirens for each specific K-12 school, with larger circles indicating more frequent siren exposure. Additionally, the circle's color represents the percentage of students of color in the school's population, with the darker color on the continuous red spectrum indicating higher percentages of students of color within the school's population.

3.1.2.3 Essex County

With a population of 809,829, Essex County is the third most populated county in Massachusetts (U.S. Census, 2020). Within this populated county—like Suffolk and Hampden counties—the schools with the highest volume of daily sirens (larger circles) tend to have a higher proportion of students of color (indicated by the circle's color). Furthermore, Figure 8 shows that the most substantially exposed schools in Essex County tend to be clustered in the towns of Lawrence and Lynn, which are located in the Northwest and Southwest of the county, respectively. In Lawrence, Black, Hispanic, and API represent 5%, 82%, and 2% of the population, respectively (U.S. Census, 2020), while in Lynn, Black, Hispanic, and API represent 13%, 43%, and 6% of the population, respectively (U.S. Census, 2020). Finally, Figure 8 shows that the schools in Essex County that are most exposed to sirens experience approximately 6 sirens daily, which is substantially less than the most exposed schools in Suffolk and Hampden counties experience (Figures 6 and 7).

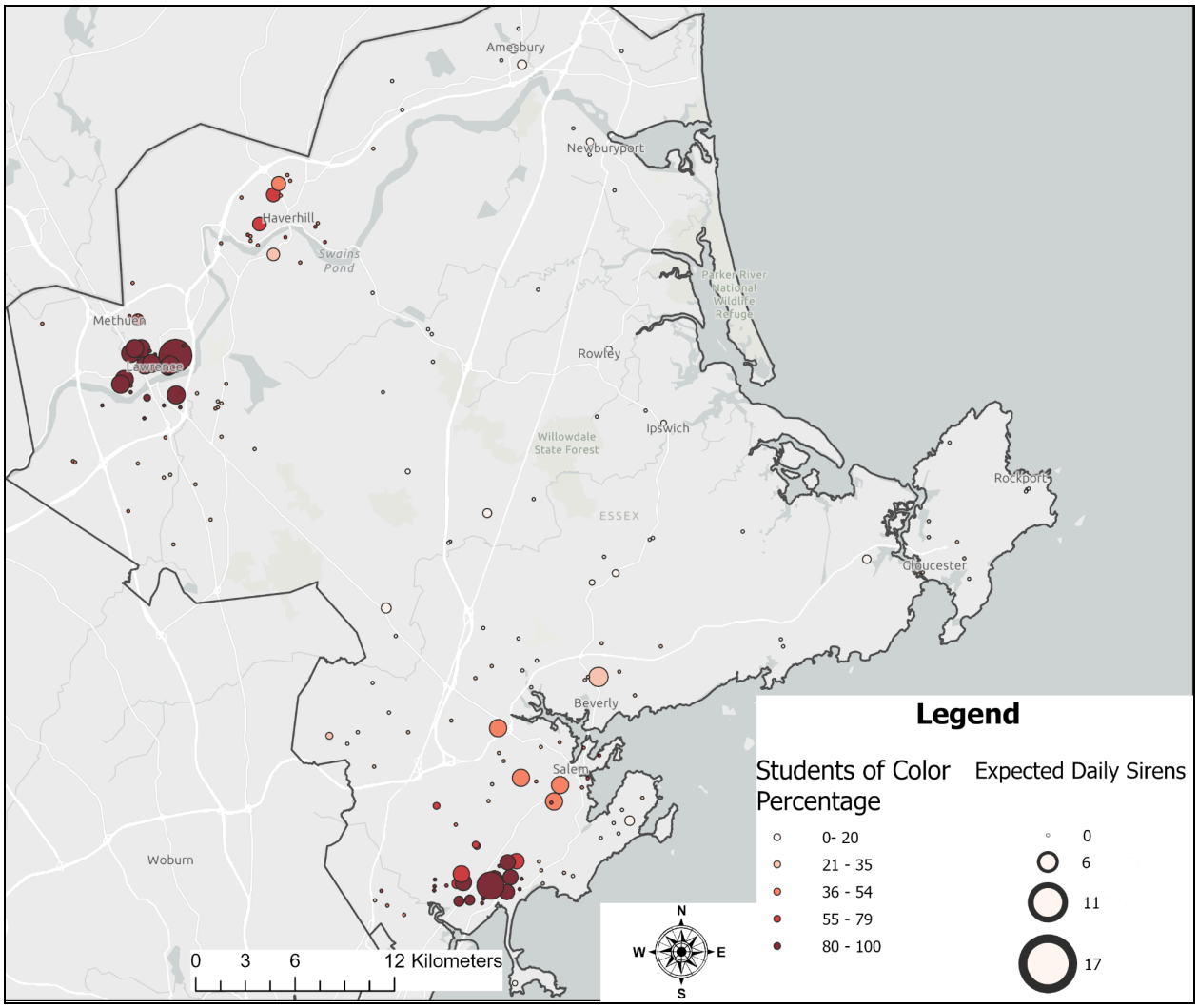


Figure 8. The expected daily sirens and students of color percentage for each K-12 public and private school in Essex County. The size of the circle on the map represents the number of expected daily sirens for each specific K-12 school, with larger circles indicating more frequent siren exposure. Additionally, the color of the circle represents the percentage of students of color in the school's population, with the darker color on the continuous red spectrum indicating higher percentages of students of color within the school's population.

3.2 PHASE TWO FINDINGS

3.2.1 Quantitative Findings

Research Question 7: To what extent do students and educators report being distracted by sirens?

I found that approximately 45 percent of students at the sampled school report hearing sirens in the classroom with some frequency (Figure 9). Additionally, I found that the majority of students (approximately 61 percent) report that sirens do not distract them at all (Figure 10). However, these findings conflict with Figure 11, which shows that the majority of student respondents reported being distracted by sirens for between ten seconds and over a minute (Figure 11). Furthermore, I found that 75 percent of educators reported that they observe students being "extremely" distracted by sirens (Figure 12), a stark contrast from the self-reporting by the students. Finally, I found that the majority of students (30 out of 59) are at least somewhat receptive to administrators working to reduce the sound of sirens in the classroom (Figure 13).

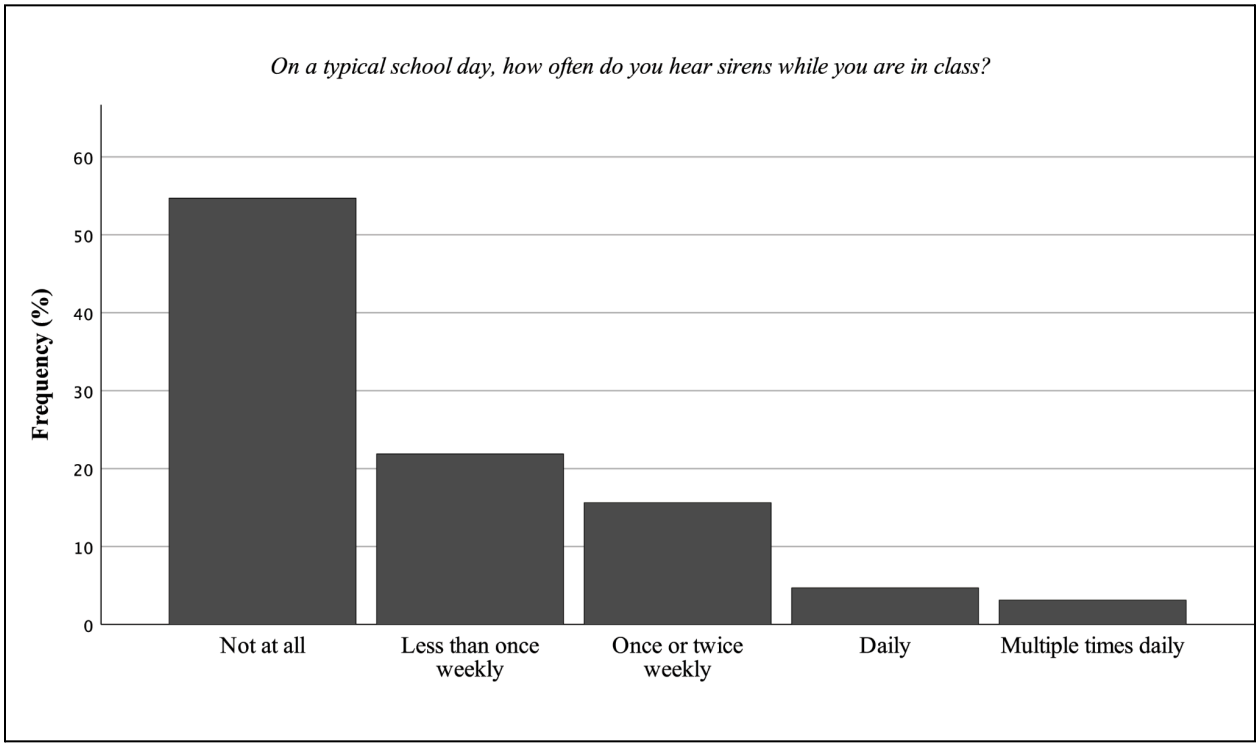


Figure 9. Frequency of responses from students (n = 67) regarding how often they hear sirens while they are in class.

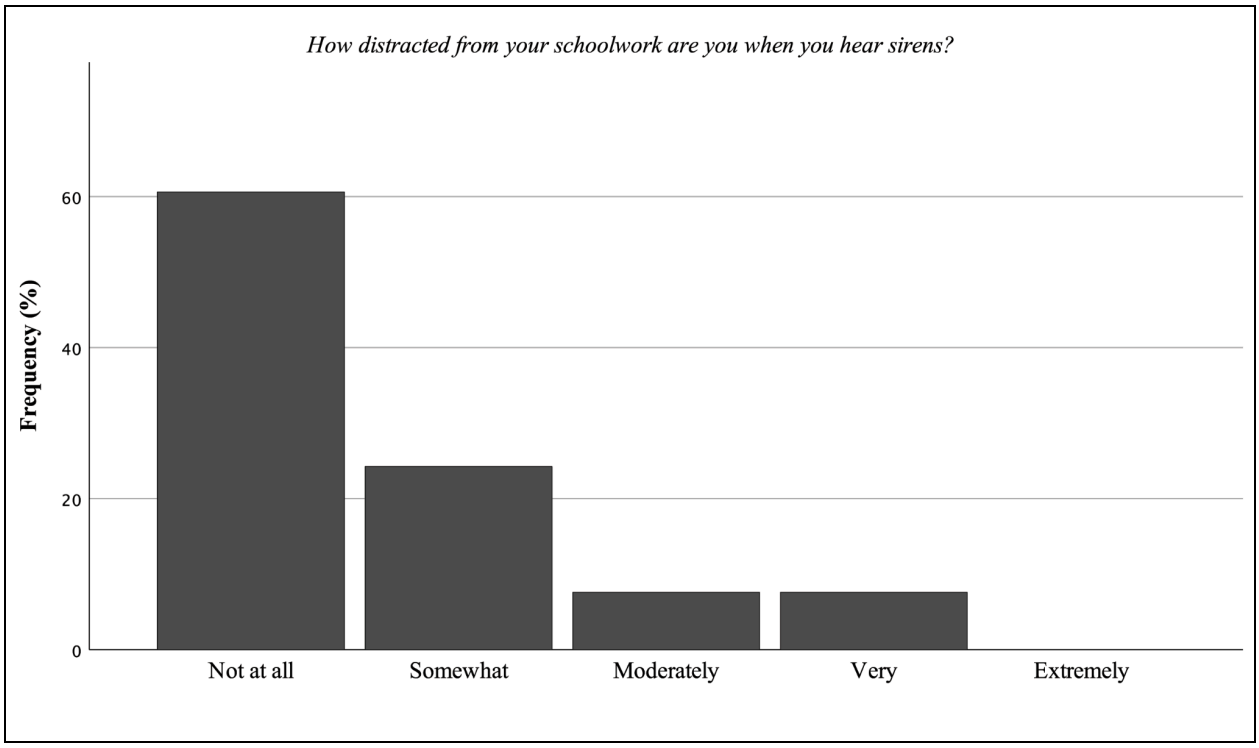


Figure 10. Frequency of responses from students (n = 67) regarding how distracted they are when they hear sirens while in class.

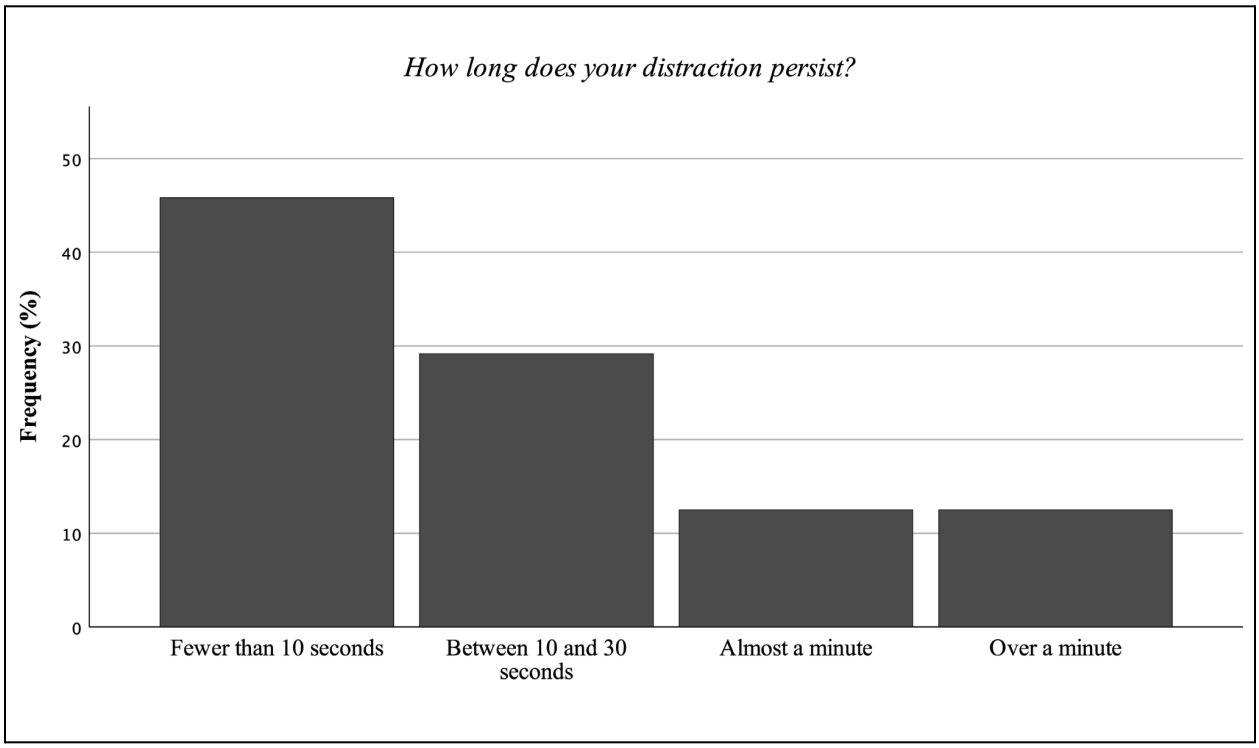


Figure 11. Frequency of responses from students (n = 67) regarding the length that their distraction from emergency sirens lasts.

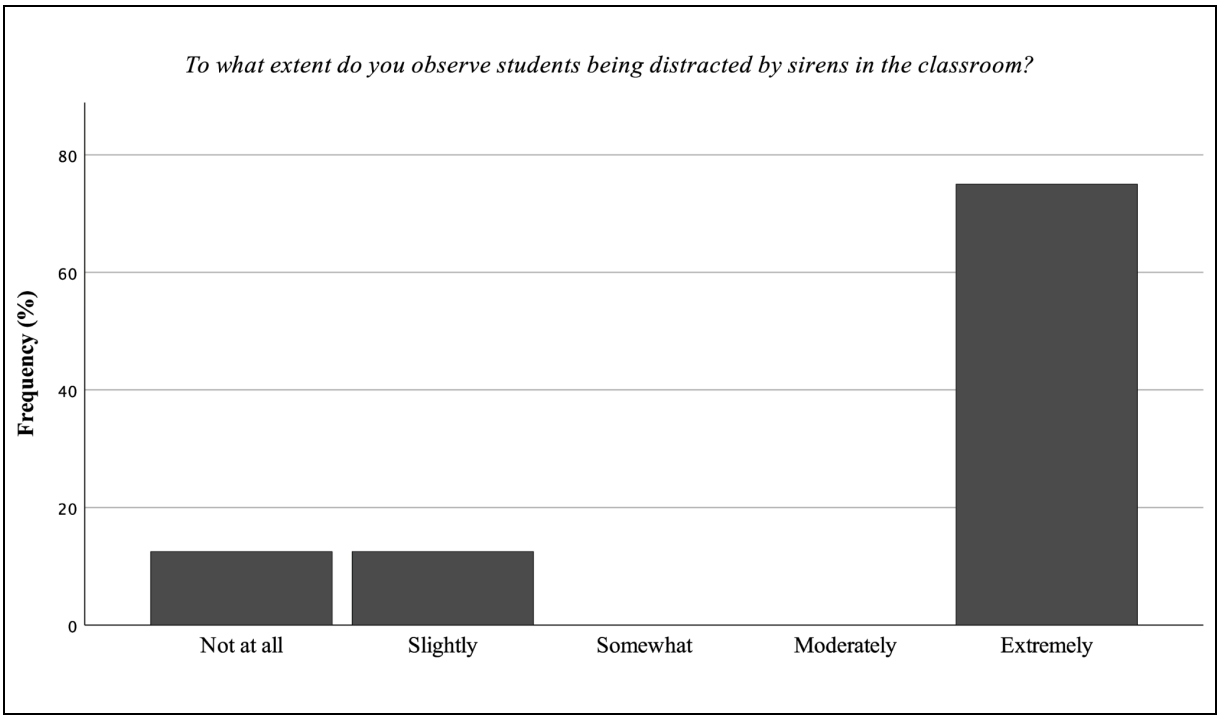


Figure 12. Frequency of responses from educators (n = 8) regarding the extent to which they notice students being distracted by sirens in the classroom.

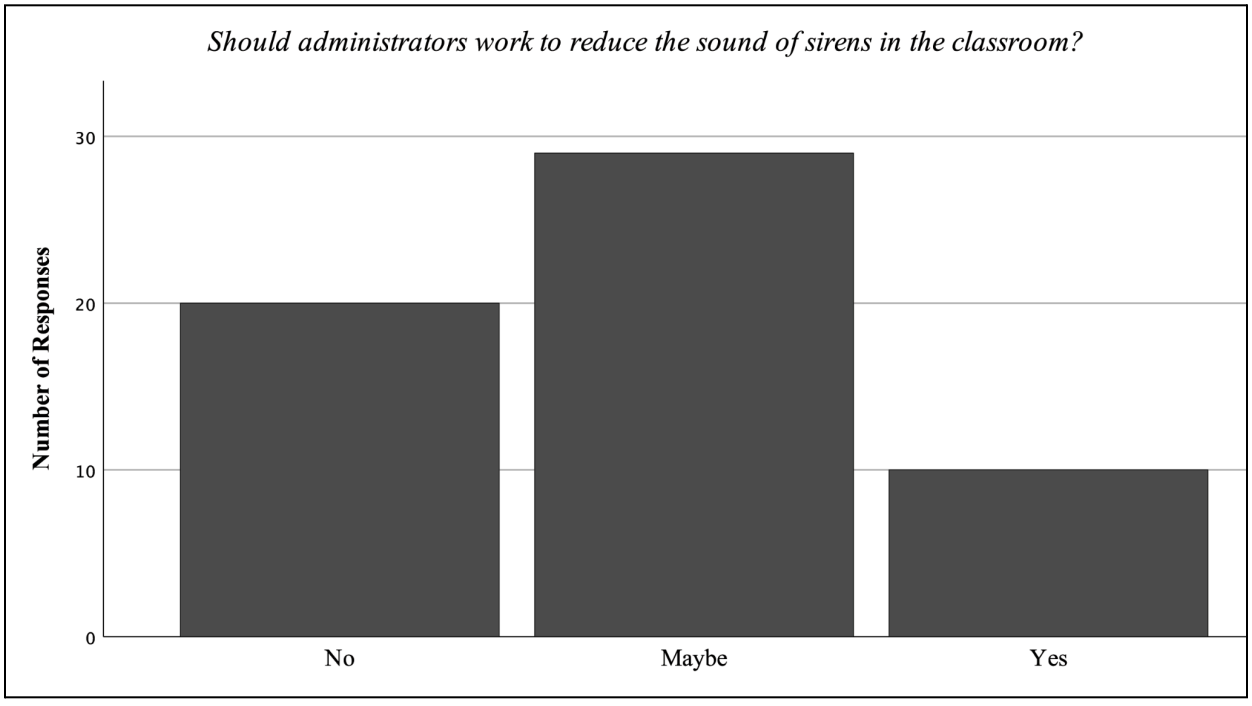


Figure 13. Number of responses from students (n = 59) regarding whether they believe that administrators should work to reduce sirens in the classroom.

Research Question 8: Does racial or gender identity influence students' reaction to the sound of sirens?

I found no statistically significant difference between the reaction to the sound of sirens across different racial and gender identities (Appendix I).

Research Question 9: What is the relationship between a student's attitude toward the police and the extent to which they report being affected by sirens in the classroom?

I found that there is not a statistically significant relationship between students' attitudes towards the police and the extent to which they report being affected by sirens in the classroom (Appendix I). However, I found that the majority of students at the sampled school hold favorable attitudes toward law enforcement (Figure 14).

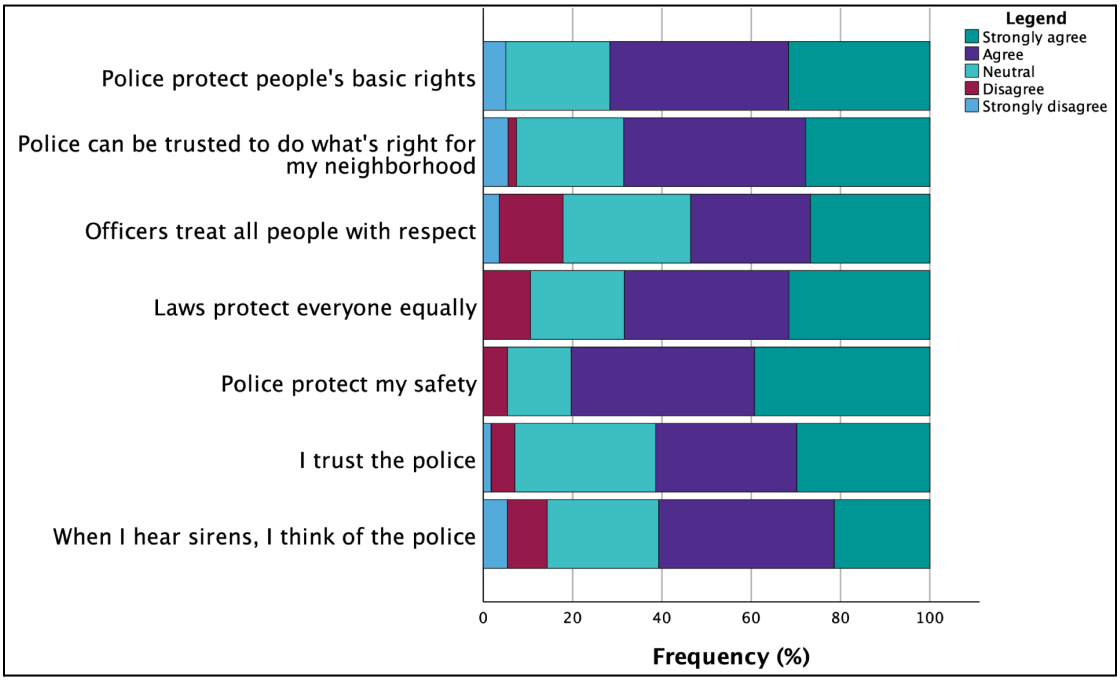


Figure 14. Frequency of responses from students (n = 65) regarding their attitudes towards law enforcement.

3.2.2 Qualitative Findings

Research Question 10: Do sirens remind students and educators of anything in particular and how do educators report sirens impacting the classroom?

Out of the students (n = 26) and educators (n = 4) who responded to the open-ended question regarding whether sirens prompt specific memories, half of the students (n = 13) and all of the educators (n = 4) reported sirens prompting particular memories. The other 13 students who responded to the question each reported that sirens did *not* remind them of anything in particular. For those who reported memories associated with the sound of sirens (n = 17), I coded the memories into the following themes: emergency services, potentially traumatic past events, and miscellaneous. Of the 17 responses, 8 were coded in the emergency services category, 3 in the potentially traumatic previous events category, and 6 in the miscellaneous category. Figure 12 depicts the most frequently used words across these three categories. One of the broader findings was that a sense of nearby, imminent danger was widely prompted by the sirens. One of the student respondents stated, “When I hear sirens, I think there could be a danger near me” (S39).

Figure 15. Word cloud depicting the most frequently used words by student (n = 26) and educator (n = 4) respondents in response to the question regarding whether or not sirens remind them of anything in particular. Larger font sizes represent words with more frequent responses.

Three of the four educators who responded to the following prompt—*Please describe the effects that you have noticed sirens having on the classroom environment*—concurred that sirens have tangible impacts on their classroom. One of the educators described themselves stopping instructions and waiting for the noise to pass, while another described how educators look out the window, potentially to assess the situation and ensure they are not in danger (Appendix F). However, one of the four educators responded that the sirens don't lead to any changes in the learning environment. Finally, one of the educators described themselves as tending to "block out siren noises unless they are fire alarms" (Appendix F).

Table 5. Responses by students and educators, sorted by coding category, to the question *Do sirens remind you of anything in particular?*

Responses by Coding Category

Emergency Services	Potentially Traumatic Previous Event	Miscellaneous
When there is an accident	My grandfather's death	It reminds me of Haiti
Hospitals	When my uncle died	It reminds me of my country Haiti
Ambulance		When I hear sirens, I think there could be a danger near me
Fire, ambulance		Problems
Some type of emergency		Fire alarm
Traffic accidents or medical emergencies		They are so common in the city that I block them out

4.0 DISCUSSION

4.1 THE DISPROPORTIONATE DISTRIBUTION OF SIRENS ON STUDENTS OF COLOR

The present study investigated the distribution of siren-generated noise pollution in Massachusetts, as well as identified the impacts of sirens on the learning environment. I found that approximately 166,00 students in Massachusetts are exposed to emergency sirens with some frequency and approximately 39,000 students in Massachusetts are exposed to emergency sirens four times daily (on average). Findings suggest there is disparate exposure based on race/ethnicity, with the burden of sirens falling disproportionately upon Black, Hispanic, and API students (Tables 1 and 3). Additionally, in the multivariate analysis that accounted for geographic clustering, the strongest predictor of being shielded from sirens was the proportion of white students in the schools, indicating that predominantly white schools are disproportionately shielded from sirens (Table 2). Furthermore, the strongest predictor for exposure to sirens in the multivariate analysis was the proportion of the urban population in the county, indicating that schools in urban areas are more likely to experience sirens than schools in suburban or rural areas (Table 2).

These findings indicate that students of color are disproportionately exposed to emergency sirens in Massachusetts (Figure 3, Tabe 1, and Table 3). Additionally, the findings indicate schools sited in Environmental Justice neighborhoods are disproportionately *highly* exposed (i.e. expected daily sirens > 4) to emergency sirens (Figure 4 and Table 4), demonstrating the relationship between race/ethnicity, socioeconomic status, and exposure to sirens. The amplified exposure to sirens that Black, Hispanic, and API students experience aligns with recent research that has found that people of color are disproportionately exposed to

transport noise pollution (Nega et al., 2013). Additionally, these findings closely align with the findings of Collins et al. (2019) and Chakraborty et al. (2023), which found that students of color in the United States and Texas, respectively, are disproportionately exposed to transportation and aviation noise pollution at school.

The disproportionate exposure to environmental bads that communities of color in the United States experience has been extensively documented (Brulle & Pellow, 2006; Faber & Krieg, 2002; Pellow & Park, 2002; Ringquist, 2005). Communities of color in the United States are disproportionately exposed to air and water pollution, as well as deprived of important resources like grocery stores and parks (Bae & Lynch, 2023; Grineski & Collins, 2018; Satcher, 2022). Emergency sirens are a unique form of an environmental bad. Sirens are often utilized by emergency services as they perform critical societal goods; however, the externality of those societal goods—a high-decibel noise intended to capture attention—is antithetical to the learning environment. As a result, the disproportionate exposure to an environmental bad—sirens—that students of color experience, along with the dearth of exposure that white students experience, aligns with the broader framework of environmental racism (Chakraborty et al., 2011).

Multiple plausible factors could have contributed to the disparate exposure to sirens that students of color in Massachusetts experience. Siren-generating facilities tend to be placed in population-dense areas as rural residents use Emergency Medical Services (EMS) less frequently than urban residents (Lishner et al., 2000). There is an extensively documented pattern in which white residents rapidly departed urban areas in the United States, particularly throughout the 1950s and 1960s (Gibbons, 2024). This “white flight” left an indelible imprint on the modern racial composition of cities (Wade, 2017). In Massachusetts, the “vast majority of intensely segregated non-white schools are segregated in urban districts like Boston and Springfield”

(Schneider et al., 2020). As Figures 5, 6, and 7 show, Boston and Springfield are the two most substantially exposed cities to sirens in Massachusetts. The predominance of intensely segregated non-white schools in highly urban areas like Boston and Springfield likely contributes to the disproportionate exposure to sirens that students of color in Massachusetts experience.

NIMBYism (refer to Terms) is another plausible contributing factor to the disproportionate exposure to sirens that students of color in Massachusetts experience. Prior studies have shown that communities with high levels of social capital have successfully mobilized to prevent unwanted noise from infiltrating their community (Suau-Sanchez et al., 2011). While hospitals, ambulance stations, and fire stations are all necessary facilities, it is plausible that predominantly white communities with high social capital have prevented the siting of schools near siren-generating facilities, or vice versa. Additionally, past research has shown that sites neighboring noisy facilities are generally devalued (von Graevenitz, 2018), which could explain the disproportionate siting of schools serving marginalized students near siren-generating facilities

Regardless of the causes of the disparate exposure to sirens that students of color in Massachusetts experience, the implications are substantial. Noise pollution has been consistently shown to impair academic performance (Basner et al., 2017; Collins et al., 2019; Klatte et al., 2017; Shield & Dockrell, 2008). Furthermore, noise pollution has been repeatedly linked with decreased physical and emotional well-being in children (Balk et al., 2023; Murphy & King, 2022; Onchang & Hawker, 2018). Sirens have been shown to be the most detrimental form of noise pollution to the learning environment (Gheewalla et al., 2021). As a result, the disparate exposure to sirens that students of color experience may be severely detrimental to academic

performance and overall well-being, serving as a compounding stressor alongside the myriad of other stressors that students of color are exposed to.

The disparities of siren exposure across counties is notable. In two of the most exposed counties—Suffolk and Hampden—some *highly* exposed schools experience between 11 and 17 sirens daily (Figures 6 and 7). Consequently, students in these counties are increasingly likely to hear sirens at some point during their day and likely hear sirens multiple times throughout the day. According to the Occupational Safety and Health Administration (n.d), repeated exposure to sirens over time may cause permanent hearing loss as well as create physical and psychological stress, reduce productivity, and interfere with communication and concentration. It is also possible that students and educators can become desensitized to the sound of sirens (Cooley and Lorion, 1999). Becoming desensitized to the sound of sirens may serve as a protective function for students and educators at *highly* exposed schools, particularly for those who are reminded of negative past events when exposed to sirens (Cooley and Lorion, 1999). More research is needed to know if students in *highly* exposed schools are effectively tuning out sirens such that they are able to be productive or are being harmed by them to the detriment of their learning.

4.2 IMPLICATIONS FOR THE LEARNING ENVIRONMENT

My findings from student and educator survey responses suggest that the impact of sirens on the classroom environment widely varies. Fascinatingly, students most frequently reported that they were not distracted by sirens, while educators most frequently reported observing students being "extremely" distracted by sirens (Figures 10 and 12). It is plausible that students don't necessarily notice that they are being distracted when, in reality, they are. Alternatively, the small sample size of educator respondents may make the contradictory responses between the two groups negligible.

Of the findings, the most salient may be the time of distraction that students reported experiencing, with over half of the respondents reporting that their distraction from sirens persisted for at least ten seconds. This could have negative implications for the learning environment, particularly in schools that are *highly* exposed to sirens. Similar to the effect of multi-tasking that has been well reported on (Alkahtani et al., 2016), when students are distracted by a siren and have to refocus their attention on the educational task at hand, they may miss pertinent information leading them to not learn the curriculum, miss important instructions (e.g. how or when to complete assignments), or feel confused (Cotten and Junco, 2012).

Two of the student respondents reported that sirens reminded them of the death of a loved one. These findings align with past research, which has demonstrated that sirens can serve as a trigger of past events that may have been emotionally distressing (Chessell et al., 2019; Rizzi et al., 2023; Shala et al., 2020; Shreck et al., 2020). The implications of sirens triggering memories of potentially traumatic past events are also severely consequential to the learning environment. Imagine a student is reminded of the death of a loved one each time they hear sirens and they attend a school that is exposed to sirens approximately ten times daily. Is that conducive to their academic achievement, let alone their emotional well-being?

Another fascinating theme was sirens reminding students of Haiti (Figure 15). In 2021, the intentional homicide rate in Haiti was approximately six times greater per 100,000 than the intentional homicide rate in Massachusetts (National Center for Health Statistics, 2023; *United Nations Office on Drugs and Crime*, 2021). At the time of this study, Haiti is undergoing a period of intense political turmoil; gangs that own 80 percent of the country's capital have forced the closure of airports, freed over 4,000 inmates, and killed many Haitians (Coto & Sanon, 2024). It is interesting that, amidst a period of intense chaos and instability in Haiti, students in the United

States are reminded of their home country when they hear sirens. Perhaps, the prevalence of violent crime in Haiti and the associated use of sirens mediates students' memory of Haiti when they hear sirens in the classroom.

It is also worth noting the differences in responses to sirens that the educators described. When asked to describe the effect they notice sirens having on the classroom, two of the educators (E4 and E8) described how they allow the sirens to have a space in the classroom, pausing their instruction to assess the danger and wait for the noise to pass (Appendix F). Alternatively, one of the other educators (E5) described how they "block out" the sirens, implying that they attempt to teach through the disruption. It is unclear which of these two opposing reactions to sirens is more beneficial to the learning environment. There are plausible benefits to giving the sirens space in the classroom and not attempting to instruct students while a distraction is occurring. However, as Figure 10 shows, many students report that sirens do not distract them at all, which provides support for E5's approach to sirens—ignoring them and continuing to teach. Future research into these two different techniques may shed more light on the impacts of sirens in the classroom and guide educators at *highly* exposed schools.

4.3 POLICY CONSIDERATIONS

Massachusetts has been declared the nation's leader in promoting overall child well-being (The Annie E. Casey Foundation, 2022). However, these findings suggest that a hidden stressor—exposure to emergency sirens—is not being adequately considered. To further its leadership, Massachusetts should aim to be a frontrunner in developing policies that address the impact of sirens on the learning environment and children's well-being.

The findings in Phase One of this study indicate that approximately 166,000 students are exposed to sirens with some frequency; as a result, policies must be implemented that aim to protect the learning environment and promote improved academic achievement and overall well-being. Additionally, 66% of students in the survey responded either "maybe" or "yes" when asked whether administrators should work to reduce the sound of sirens, indicating that there is majority support from students to make policy changes (Figure 13). Vulnerable groups, such as students who are reminded of past traumatic events when exposed to sirens, must be placed at the forethought of policies aimed at reducing sirens in the classroom. It is also important that such policies do not restrict the ability of EMS providers to deliver crucial societal goods. City policies must balance the needs of the classroom with the needs of EMS providers. I believe a multi-pronged policy that focuses on mitigation (reducing sirens at the source) and adaptation (reducing the impact of sirens at the school-level) would ensure that such a balance is met.

To mitigate the number of sirens that schools are exposed to, policymakers should consider implementing a policy that requires EMS providers to, whenever possible, use lights only—not sirens—when within 500 meters of a school. All ambulances in Massachusetts are legally required to be equipped with Global Position Services (GPS) technology (Massachusetts Office of Emergency Medical Services, 2016), which could be programmed to alert EMS providers when they are within 500 meters of a school. Additionally, territorial knowledge (i.e. knowing the region) could help ensure that EMS providers minimize siren usage near schools without bearing any additional burden. If it is not possible to only use lights, the EMS providers would be able to use sirens at their discretion. Prior studies have shown that the time that sirens save is *statistically significant*, but often not *clinically significant* since the number of cases that are affected by the time saved by sirens is extremely low (Murray & Kue, 2017). I believe that

EMS providers would be receptive to such a policy, especially since it could have tangible, positive impacts on the learning environment.

Barring a radical change in emergency response systems, sirens will remain foundational to the soundscape of the American city. As a result, school districts must implement policies that aim to adapt to exposure to sirens. To do so, school districts must prioritize designing or remodeling schools with acoustic design in mind, adding vegetation barriers surrounding the school property, and ensuring heating and cooling systems are technologically advanced. Designing or remodeling schools to utilize sound-absorbing materials in the ceilings, floors, and walls may substantially reduce the impact of sirens on the learning environment (Bulunuz et al., 2021). Additionally, strategically implemented vegetation barriers have been shown to attenuate outdoor sounds like sirens (Oliveira et al., 2022). Increasing vegetation surrounding schools may provide other benefits, including cleaner air, decreased surface temperatures—which could be particularly beneficial in hot urban areas during the summertime, and improved psychological well-being (Kaplan, 2001; Klingberg et al., 2017; Melaas et al., 2016). Finally, ensuring that schools' heating and cooling systems are up-to-date will prevent educators from being forced to open the window to maintain a temperature conducive to learning and inadvertently inviting traffic noise pollution (as well as sirens) into the classroom.

Educator training should be adapted to prepare educators for the potential for sirens to distract students, as well as serve as triggers of previous distressing or traumatic events. Educators, particularly those who work in urban areas, should be aware of the myriad of impacts that sirens can have on the learning environment and should have a plan in place to manage the distraction the sirens may provoke.

Finally, policymakers and educators alike should pay particular attention to the populations that are most vulnerable to experiencing severely negative reactions to sirens in the classroom. As I have already mentioned, potentially vulnerable groups include second-language learners, students with ASD, migraineurs, veterans, immigrants, and Black youth. It is critical that the potential for sirens to uniquely impact vulnerable groups is understood and explicitly accounted for through pragmatic policymaking.

4.4 LIMITATIONS

Although this research contributes preliminary insights into a phenomenon that has yet to be studied, it is not without limitations. In Phase One, due to legal restrictions, the estimates for average daily sirens at each school are based on the average number of siren-generating calls by zip code—not by each specific siren-generating facility. The average number of sirens in each zip code was then divided by the number of siren-generating facilities in each zip code to reach an estimate for each facility. However, this estimate may overestimate the number of sirens at particular facilities and underestimate the number of sirens at others. Additionally, this study fails to incorporate natural barriers (i.e. berms or other forms of vegetation) that may decrease the number of sirens that each school is exposed to. This study also fails to incorporate differences in the distance to the closest road, which may also lead to overestimates and underestimates in the number of sirens certain schools experience daily. Finally, this study does not account for schools' acoustic designs, which may lead to an underestimate of the number of sirens that socially disadvantaged students experience since students of color are more likely to attend schools with poor-quality acoustic designs (Collins et al., 2019).

Phase Two of this study also has several limitations. First of all, only 29 students and 5 educators at the sampled school reported hearing sirens with frequency, which limited the number of responses regarding the widespread impacts that sirens can pose to the learning environment. Hence, these findings may not adequately capture and characterize the entire range of responses that sirens can prompt. Additionally, the relatively small number of respondents, particularly the small number of white respondents, limits the interpretability of the differences in reaction to sirens across racial demographics. As a result, these results merely provide a snapshot into a particular school's experience of this phenomenon and should not be taken to reflect the entirety of schools that are exposed to sirens.

5.0 CONCLUSION

To conclude, this is the first study to examine the distribution of siren-generated noise pollution in schools, as well as the first study to ascertain the impacts that sirens can have on the emotional well-being of students and educators. Building upon the work of Gheewalla et al. (2021), which found that emergency sirens are a uniquely distracting form of noise pollution, my findings provide further evidence that sirens pose considerable threats to the learning environment through the distraction they prompt and the memories they can trigger. Similar to Collins et al. (2019), findings from this study indicate that students of color and students attending schools in urban areas are disproportionately exposed to sirens in Massachusetts, while white students are more likely to be shielded from siren exposure. Through mapping the distribution of sirens in Massachusetts' schools, I found that an additional, hidden stressor and form of environmental injustice is being placed upon students of color that, before this study, had yet to be identified.

Urgent action is needed to address the exposure to sirens that approximately 166,000 students in Massachusetts experience. Specific policies aimed at reducing EMS usage of sirens within 500 meters of schools are crucial. Schools must look to adapt to exposure to sirens by implementing sound-absorbing materials in their classrooms and increasing vegetation barriers surrounding their property. Finally, it is imperative that policymakers address the disparate exposure to sirens that students of color experience to ensure equitable access to healthy and thriving classrooms that promote well-being—not detract from it.

6.0 APPENDICES

6.1 APPENDIX A: CITY OF BOSTON NOISE ORDINANCE

16-26.1 General Prohibition and Definitions.

No person shall make or cause to be made any unreasonable or excessive noise in the City, by whatever means or from whatever means or from whatever source.

As used herein, the following terms shall have the following meanings:

a. *dBa* shall mean A-weighted sound level in decibels, as measured by a general purpose sound level meter complying with the provisions of the American National Standards Institute, "Specifications for Sound Level Meters (ANSI S1.41971)", properly calibrated, and operated on the "A" weighting network.

b. *Loud amplification device or similar equipment* shall mean a radio, television, phonograph, stereo, record player, tape player, cassette player, compact disc player, loud speaker, or sound amplifier which is operated in such a manner that it creates unreasonable or excessive noise.

c. *Unreasonable or excessive noise* shall mean

1. Noise measured in excess of 50 dBa between the hours of 11:00 p.m. and 7:00 a.m., or in excess of 70 dBa at all other hours; or

2. In the absence of an applicable noise level standard or regulation of the Air Pollution Control Commission, any noise plainly audible at a distance of three hundred (300') feet or, in the case of loud amplification devices or similar equipment, noise plainly audible at a distance of one hundred (100') feet from its source by a person of normal hearing.

(Ord. 714 § 354; Ord. 1991 c. 4 § 1) Penalty, see subsection 16-32.6

16-26.13 Exemptions.

The following are exempted from the provisions of Section 16-26 and shall not be considered unreasonable or excessive noise for purposes of this section:

a. Noise from law enforcement motor vehicles.

b. Noise from emergency vehicles which is emitted during an actual emergency.

c. Noise which a person is making or causing to be made where such person has received and maintains a valid license or permit therefor from any department, board or commission of the City authorized to issue such license or permit; provided, however, that such noise shall be permitted only to the extent allowed by the license or permit.

(Ord. 1991 c. 4 § 3)

6.2 APPENDIX B: IRB APPROVAL

6.2.1 Boston College

BOSTON COLLEGE
Institutional Review Board
Office for Research Protections
Waul House, 2nd Floor
Phone: (617) 552-4778, fax: (617) 552-0498

IRB Protocol Number: 23.231.01e

DATE: April 27, 2023

TO: Jonathan Strang

CC: Gareau, Tara Pisani

FROM: Office of Research Protections

RE: Sirens, Schools, and Sonic Environmental Racism: An Exploratory, Mixed Methods Analysis

---

Notice of Evaluation – [Exempt 45 CFR 46] 2

The Office for Research Protections (ORP) has evaluated the project named above. This is a minimal risk study that has been granted an exemption from Boston College IRB review in accordance with 45 CFR 46. 2. This designation is based on the assumption that the materials that you submitted to the ORP contain a complete and accurate description of all the ways in which human subjects are involved in your research.

This exemption is given with the following conditions:

1. You will conduct the project according to the plans and protocol you submitted;
2. No further contact with ORP is necessary unless you make changes to your project, in which case you must submit these changes to ORP for IRB review. You must also report any adverse events or injuries to ORP.

Please remember to complete a project closure form in CyberIRB to close this project once it is complete. The University appreciates your efforts to conduct research in compliance with the federal regulations that have been established to ensure the protection of human subjects in research.

Date of Exemption: Thursday, April 27, 2023

If you are conducting research using an online survey (e.g. Survey Monkey, Qualtrics), the IRB requires that the approval dates appear on the online consent page of your survey. Please copy and paste the statement below onto your survey:

The Boston College IRB approved this protocol on April 27, 2023.

Sincerely,

Guillermo Nunez
Executive Director of Research Administration

Enclosures

CH

Boston College
IRB Approved
Exempt
April 27, 2023

6.2.2 Boston Public Schools

Office of Data and Accountability
Apryl Clarkson, Senior Executive Director
Bruce C. Bolling Municipal Building
2300 Washington Street
Roxbury, Massachusetts 02119 617-635-9450
research@bostonpublicschools.org
bostonpublicschools.org

10/27/2023
Jonathon (Jack) Strang
Boston College

Dear Jonathon (Jack) Strang,

I am in receipt of your research proposal entitled *RA-260: "Schools, Sirens, and Sonic Environmental Racism: An Exploratory, Mixed Methods Analysis ."* **Your research application has been approved.**

If your study involves primary data collection at a school site, your next step is to complete the CORI application for each researcher who intends to collect primary data with students. CORI applications can be submitted at www.bostonpublicschools.org/cori. Additional details for submitting a CORI review can be found here. For virtual observations, please select "Office of Data and Accountability" as the volunteer location.

If your study requires an administrative data request, your next step is to submit a Non-Disclosure Agreement Request Form to request a new NDA or to renew a previous NDA. Once your request is received, our ODA team will work with you to execute a non-disclosure agreement with mutually agreed upon administrative data elements. NDAs must be renewed annually.

Enclosed you will find a copy of the Research Proposal Review Form, which must be completed by a school leader if you are intending to do primary research within a school. It is your responsibility to have this form signed by the leader of each school in which you plan to conduct research. Please share a copy of your executive summary (max. of 1 page) along with this Review Form with each intended school site. Approval for this study in each school is contingent upon your returning the signed review forms to the Office of Data and Accountability via email to research@bostonpublicschools.org.

Your study is approved for one year from the date listed above. If you wish to continue your study longer than one year, you must re-submit your application within 1 year's time.

If you have any questions about this matter, please feel free to contact our office at research@bostonpublicschools.org.

Sincerely,

Apryl Clarkson
Senior Executive Director
Office of Data & Accountability

6.3 APPENDIX C: EMAIL TEMPLATES

6.3.1 Student Template

Subject: Survey of BPS Students on Siren-Generated Noise Pollution

I am a researcher at Boston College studying the ways in which sirens affect educational performance. I am writing to you to request your participation in a brief, completely anonymous online survey. Your responses to this survey will help me evaluate the extent to which sirens affect students in the classroom.

The survey is very brief and should only take between 5 to 10 minutes to complete. It consists of both multiple-choice and open-ended questions. If you decide to complete the survey but feel uncomfortable answering a certain question, you are welcome to skip the question.

Survey Link:

Your participation in this survey is completely voluntary—you are not required to take it. If you elect to take the survey, all of your responses will be kept confidential. No personally identifiable information will be associated with your responses. To reiterate, your identity will not be ascertained as this survey is completely anonymous. This study has been approved by the Boston College Institutional Review Board. If you have questions or concerns about this survey, please feel free to contact me at strangj@bc.edu or 541-410-7214.

Thank you very much for your time and cooperation. Your honest feedback is very important to this study.

Sincerely,
Jack Strang
Primary Investigator, Boston College

6.3.2 Educator Template

Subject: Survey of BPS Teachers on Siren-Generated Noise Pollution

I am a researcher at Boston College studying the ways in which sirens affect educational performance. I am writing to you to request your participation in a brief, completely anonymous online survey. Your responses to this survey will help me evaluate the extent to which sirens affect students in the classroom. As a teacher, you are in an ideal position to give valuable first-hand information on the impacts that sirens have on students and teachers in the classroom.

The survey is brief and should only take 10 minutes to complete. It consists of both multiple-choice and open-ended questions. If you decide to complete the survey but feel uncomfortable answering a certain question, you are welcome to skip the question.

Survey Link:

Your participation in this survey is completely voluntary—you are not required to take it. If you elect to take the survey, all of your responses will be kept confidential. No personally identifiable information will be associated with your responses. To reiterate, your identity will not be ascertained as this survey is completely anonymous. This study has been approved by the Boston College Institutional Review Board. If you have questions or concerns about this survey, please feel free to contact me at strangj@bc.edu or 541-410-7214.

Thank you very much for your time and cooperation. Your honest feedback is very important to this study.

Sincerely,
Jack Strang
Primary Investigator, Boston College

6.4 APPENDIX D: INFORMED CONSENT

6.4.1 Student Informed Consent

Informed Consent to Participate in Research

Study title: Sirens, Schools, and Sonic Environmental Racism: An Exploratory, Mixed Methods Analysis

Researchers: Jack Strang (Primary Investigator) and Dr. Pisani Gareau (Co-Primary Investigator)
We're inviting you to take a survey for research. This survey is completely voluntary. There are no negative consequences if you don't want to take it. If you start the survey, you can always change your mind and stop at any time.

What is the purpose of this study?
We want to understand the impact of sirens on educational performance.

What will I do?
This survey will ask questions about your distraction level when exposed to sirens, your experience with noise in the classroom, and your general attitudes toward law enforcement. The survey will take about 5-10 minutes to complete.

Risks

- Some questions may be personal or upsetting. You can skip them or quit the survey at any time.

Possible benefits:

- Your responses will provide valuable information to the field of education about the impact of sirens on educational performance
- You may enjoy answering these questions or elaborating on your experience with this phenomenon

How long will it take? 5-10 minutes

Compensation:
Due to Boston Public School policy, there will be no compensation for this survey.

Confidentiality and Data Security
We will collect no identifying information from any participants in this survey. it is fully anonymous.

Where will data be stored?
Data will be stored on Boston College's secure departmental server, and only the primary investigator (Jack Strang) and the co-primary investigator (Dr. Pisani Gareau) will have access to it. To reiterate, none of the data will include identifying information.

Who can see my data?

- We (the researchers) will have access to the de-identified data. is so we can analyze the data and conduct the study.
- Agencies that enforce legal and ethical guidelines, such as ○ The Institutional Review Board (IRB) at Boston College ○ The Office for Research Protections (ORP) at Boston College
- We may share our findings in publications or presentations. Once again, the results will be completely de-identified.

Questions about the research, complaints, or problems: Jack Strang: 541-410-7214, or strangj@bc.edu

Questions about your rights as a research participant, complaints, or problems: Contact the Boston College IRB (Institutional Review Board) at 617-552-4778, irb@bc.edu

The Boston College IRB approved this protocol on April 27, 2023.

Agreement to Participate

Your participation is completely voluntary, and you can withdraw at any time.
To take this survey, you must be:

- At least 18 years old

If you meet these criteria and would like to take the survey, click the "yes" below to start. If you do not meet the criteria, or do not want to take the survey, please click "no" below.

6.4.2 Educator Survey Informed Consent

Informed Consent to Participate in Research

Study title: Sirens, Schools, and Sonic Environmental Racism: An Exploratory, Mixed Methods Analysis

Researchers: Jack Strang (Primary Investigator) and Dr. Pisani Gareau (Co-Primary Investigator)
We're inviting you to take a survey for research. This survey is completely voluntary. There are no negative consequences if you don't want to take it. If you start the survey, you can always change your mind and stop at any time.

What is the purpose of this study?
We want to understand the impact of sirens on educational performance.

What will I do?
This survey will ask questions about your distraction level when exposed to sirens, your experience with noise in the classroom, your observations of students' behavior when exposed to sirens, and your general attitudes toward law enforcement. The survey will take about 10 minutes to complete.

Risks

- Some questions may be personal or upsetting. You can skip them or quit the survey at any time.

Possible benefits:

- Your responses will provide valuable information to the field of education about the impact of sirens on educational performance
- You may enjoy answering these questions or elaborating on your experience with this phenomenon

How long will it take? 10 minutes

Compensation:
There will be no compensation for this survey.

Confidentiality and Data Security
We will collect no identifying information from any participants in this survey. it is fully anonymous.

Where will data be stored?
Data will be stored on Boston College's secure departmental server, and only the primary investigator (Jack Strang) and the co-primary investigator (Dr. Pisani Gareau) will have access to it. To reiterate, none of the data will include identifying information.

Who can see my data?

- We (the researchers) will have access to the de-identified data. is so we can analyze the data and conduct the study.
- Agencies that enforce legal and ethical guidelines, such as ○ The Institutional Review Board (IRB) at Boston College ○ The Office for Research Protections (ORP) at Boston College
- We may share our findings in publications or presentations. Once again, the results will be completely de-identified.

Questions about the research, complaints, or problems: Jack Strang: 541-410-7214, or strangj@bc.edu

Questions about your rights as a research participant, complaints, or problems: Contact the Boston College IRB (Institutional Review Board) at 617-552-4778, irb@bc.edu

The Boston College IRB approved this protocol on April 27, 2023.

Agreement to Participate

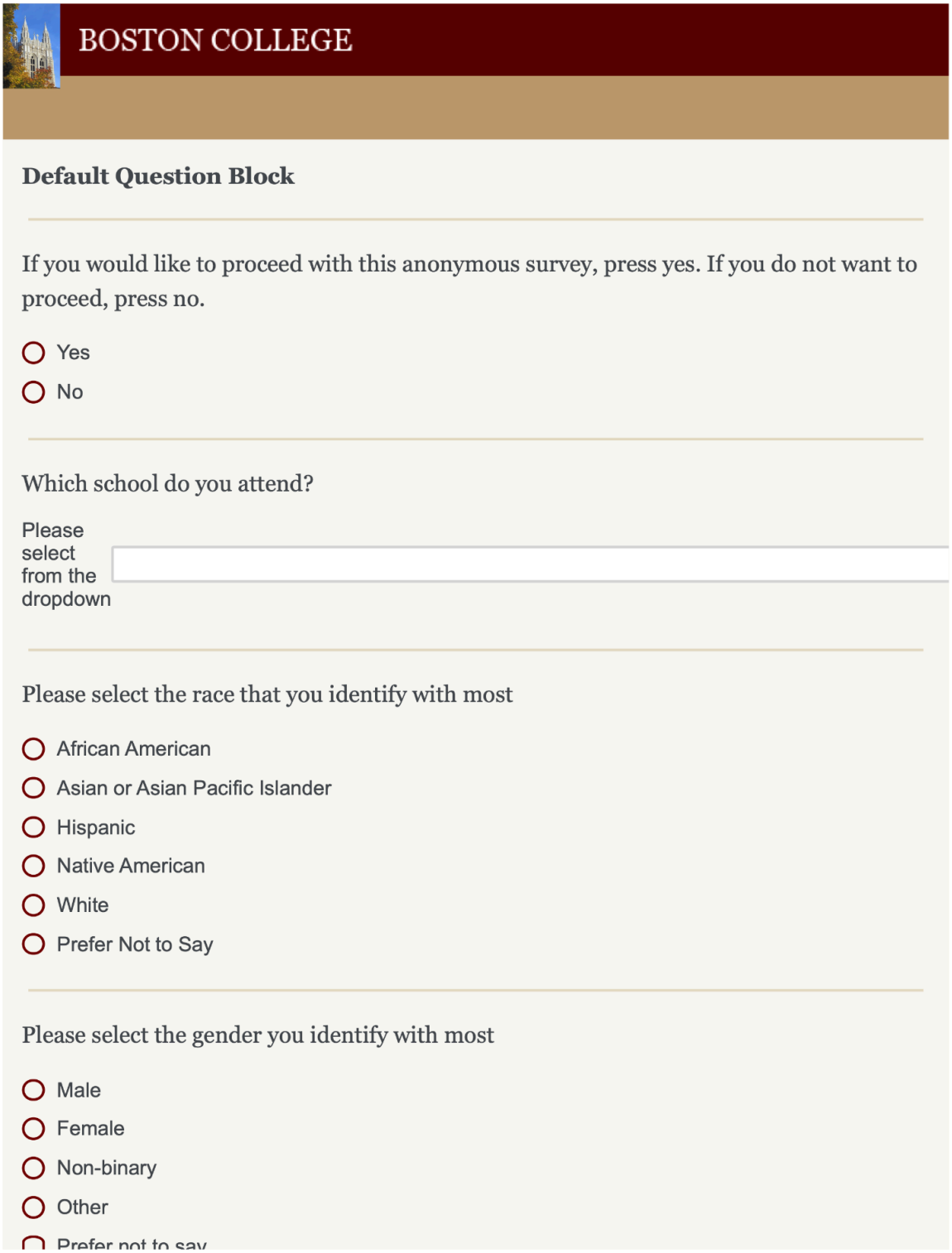
Your participation is completely voluntary, and you can withdraw at any time. To take this survey, you must be:

- At least 18 years old
- A BPS teacher

If you meet these criteria and would like to take the survey, click the "yes" below to start. If you do not meet the criteria, or do not want to take the survey, please click "no" below.

6.5 APPENDIX E: QUESTIONNAIRE

6.5.1 Student Questionnaire



BOSTON COLLEGE

Default Question Block

If you would like to proceed with this anonymous survey, press yes. If you do not want to proceed, press no.

- ○ Yes
- ○ No

Which school do you attend?

Please select from the dropdown

Please select the race that you identify with most

- ○ African American
- ○ Asian or Asian Pacific Islander
- ○ Hispanic
- ○ Native American
- ○ White
- ○ Prefer Not to Say

Please select the gender you identify with most

- ○ Male
- ○ Female
- ○ Non-binary
- ○ Other
- ○ Prefer not to say

To what extent does the **general noise level** during your lessons affect how well you learn?

- ○ Not at all effected
- ○ Somewhat effected
- ○ Moderately effected
- ○ Very effected
- ○ Extremely effected

On a typical school day, how often do you hear sirens while you are in class?

- ○ I do not hear sirens
- ○ I hear sirens less than once per week
- ○ I hear sirens once or twice a week sometimes
- ○ I hear sirens every day
- ○ I hear sirens multiple times per day

On a typical day, how does the sound of **sirens** in your classroom make you feel?

How annoyed are you when you hear **sirens** in your classroom?

Not annoyed	Somewhat annoyed	Moderately annoyed	Very annoyed	Extremely annoyed
1	2	3	4	5

How distracted from your schoolwork are you when you hear sirens?

- ○ Not at all distracted
- ○ Somewhat distracted
- ○ Moderately distracted
- ○ Very distracted
- ○ Extremely distracted

How long does your distraction persist?

- ○ Fewer than 10 seconds
- ○ Between 10 and 30 seconds
- ○ Almost a minute
- ○ Over a minute

To what extent does **siren noise** affect how well you learn?

- ○ Not at all effected
- ○ Somewhat effected
- ○ Moderately effected
- ○ Very effected
- ○ Extremely effected

Does the sound of sirens remind you of something particular? If so, please write what you are reminded of

---

In general, how would you describe your encounters with the police?

- ○ Negative
- ○ Mostly Negative
- ○ Neutral

- ○ Mostly Positive
- ○ Positive

Have you ever witnessed someone being handcuffed or arrested?

- ○ No
- ○ Maybe
- ○ Yes

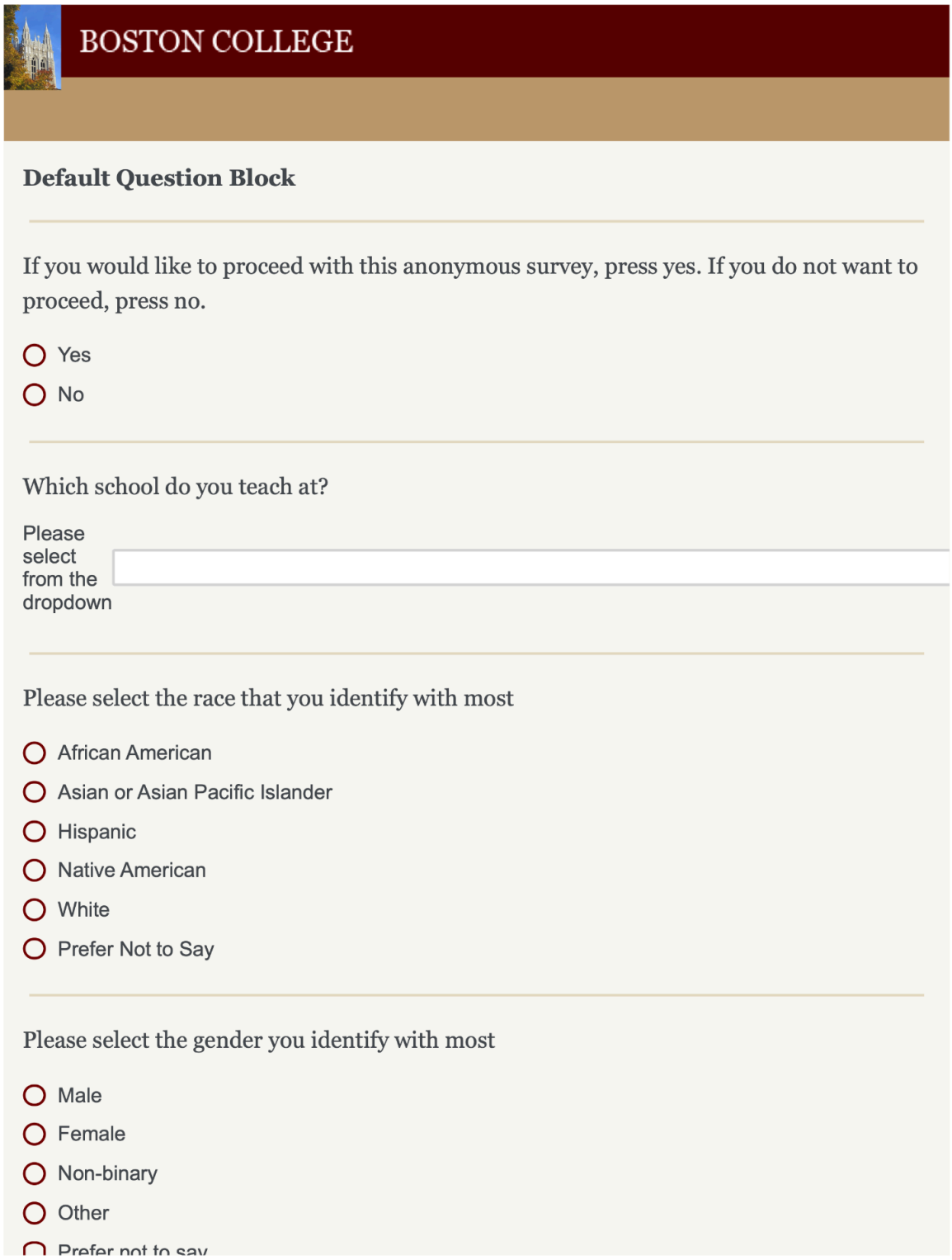
Please indicate the extent to which you agree with the following statements

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Police protect people's basic rights	○	○	○	○	○
Police can be trusted to do what's right for my neighborhood	○	○	○	○	○
Officers treat all people with respect	○	○	○	○	○
Laws protect everyone equally	○	○	○	○	○
Police protect my safety	○	○	○	○	○
I trust the police	○	○	○	○	○
When I hear sirens, I think of the police	○	○	○	○	○

Should administrators work to reduce the sound of sirens in the classroom?

- ○ No
- ○ Maybe
- ○ Yes

6.5.2 Educator Questionnaire


BOSTON COLLEGE

Default Question Block

If you would like to proceed with this anonymous survey, press yes. If you do not want to proceed, press no.

- ○ Yes
- ○ No

Which school do you teach at?

Please select from the dropdown

Please select the race that you identify with most

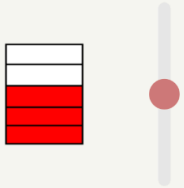
- ○ African American
- ○ Asian or Asian Pacific Islander
- ○ Hispanic
- ○ Native American
- ○ White
- ○ Prefer Not to Say

Please select the gender you identify with most

- ○ Male
- ○ Female
- ○ Non-binary
- ○ Other
- ○ Prefer not to say

Prefer not to say

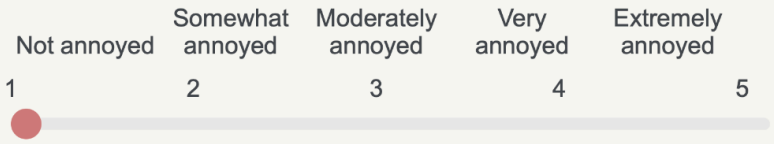
On a typical day, what is the **noise** level in your classroom (1 being extremely low, 5 being extremely high)? Include noise from inside as well as outside the classroom.



On a typical day, how well can you hear your students during lessons?

- ○ I do not hear well at all
- ○ I have difficulty in hearing
- ○ I hear normally
- ○ I hear well
- ○ I hear very well

On a typical day, how annoyed are you with the **noise level** in your classroom?



To what extent does the **general noise level** during your lessons affect how well you learn?

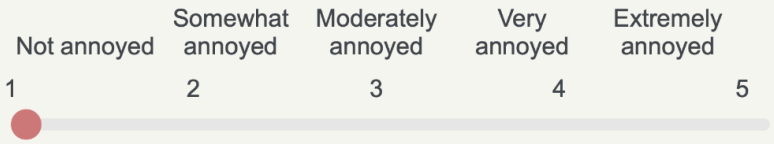
- ○ Not at all effected
- ○ Somewhat effected
- ○ Moderately effected
- ○ Very effected

- ○ Extremely effected

On a typical school day, how often do you hear sirens while you are instructing class?

- ○ I do not hear sirens
- ○ I hear sirens less than once per week
- ○ I hear sirens once or twice a week sometimes
- ○ I hear sirens every day
- ○ I hear sirens multiple times per day

How annoyed are you when you hear **sirens** in your classroom?



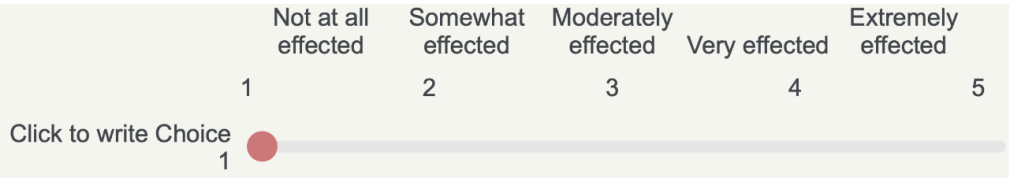
How distracted from teaching when you hear sirens?

- ○ Not at all distracted
- ○ Somewhat distracted
- ○ Moderately distracted
- ○ Very distracted
- ○ Extremely distracted

How long does your distraction persist?

- ○ Fewer than 10 seconds
- ○ Between 10 and 30 seconds
- ○ Almost a minute
- ○ Over a minute

To what extent is your ability to teach effected by **siren noise**?



Does the sound of sirens remind you of something particular? If so, please write what you are reminded of

To what extent do you observe students being distracted by sirens in the classroom?

- Not at all
- Slightly
- Somewhat
- Moderately
- Extremely

How long does their distraction persist?

- Fewer than 10 seconds
- Between 10 and 30 seconds
- Almost a minute
- Over a minute

Please describe the effects that you have noticed sirens having on the classroom environment.

In general, how would you describe your encounters with the police?

- Negative

Yes

Powered by Qualtrics

6.6 APPENDIX F: OPEN-ENDED RESPONSES

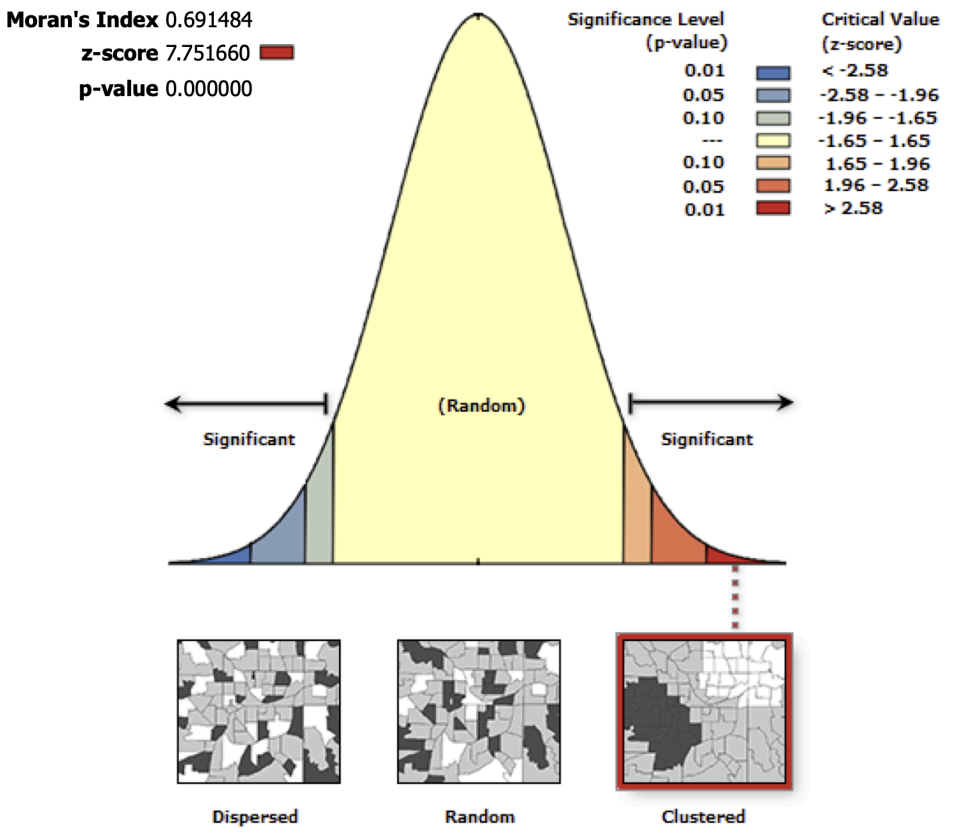
6.6.1 Student Responses

Unique ID	Does the sound of sirens remind you of something particular?
S5	No
S11	bao chay
S15	n
S19	Problemas
S20	Ambulancia
S29	The sound of the sirens doesn't remind me of anything.
S30	non
S32	sa raplem Haiti
S33	son siren lan pa few sonje anyen
S37	i haven't heard it yet so idk
S38	no
S39	When i hear siren i think their could be a danger near me.
S42	no
S43	no
S45	no
S47	cuando hay un accidente.
S48	no para nada
S49	yes when my uncle died
S53	non
S55	la muerte de mi abuelo
S58	no molesto
S59	it reminds me of my country Haiti
S60	no
S61	end of period
S64	anyen di tou
S66	Hospitals

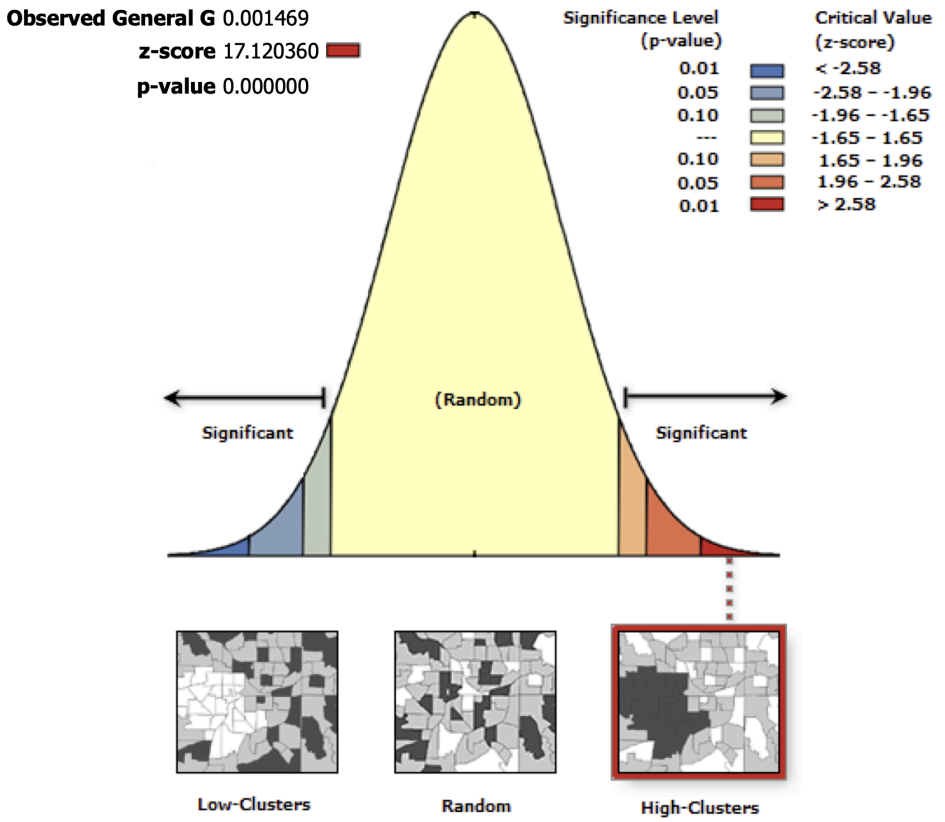
6.6.2 Educator Responses

UniqueID	Does the sound of sirens remind you of something particular?	Please describe the effects that you have noticed sirens having on the classroom environment
E4	Traffic accidents or medical emergencies	We generally stop and wait for the noise to pass. luckily this happens infrequently
E5	They are so common in the city that I block them out.	I block out siren noises unless they are fire alarms.
E7	Some type of emergency.	Nothing really.
E8	Fire, ambulance	Look out the window

6.7 APPENDIX G: SPATIAL AUTOCORRELATION RESULTS



Given the z-score of 7.75166, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.



Given the z-score of 17.12036045625905, there is a less than 1% likelihood that this high-clustered pattern could be the result of random chance.

6.8 APPENDIX H: RSTUDIO.V.2023.12.1+402 CODE

```
## Poisson Model ##
install.packages("glmmTMB")
library(glmmTMB)
fit_zipoisson <-
glmmTMB(Integer~HispanicStudentsPercentage+BlackorAfricanAmericanPercentage+WhiteStudentsPercentage+UrbanProp+TotalStudents+
                  (1|DISTRICT_N),
                data=SchoolsByDistrict,

ziformula=~HispanicStudentsPercentage+BlackorAfricanAmericanPercentage+WhiteStudentsPercentage+UrbanProp+TotalStudents,
                family=poisson)
summary(fit_zipoisson)
## NEGATIVE BINOMIAL MODEL ##
fit_zinegbin <-
glmmTMB(Integer~HispanicStudentsPercentage+BlackorAfricanAmericanPercentage+WhiteStudentsPercentage+UrbanProp+TotalStudents+
                  (1|DISTRICT_N),
                data=SchoolsByDistrict,

ziformula=~HispanicStudentsPercentage+BlackorAfricanAmericanPercentage+WhiteStudentsPercentage+UrbanProp+TotalStudents,
                family=nbinom2)
summary(fit_zinegbin)
## PRESENTATION ##
install.packages("sjPlot")
library(sjPlot)
tab_model(fit_zinegbin)
tab_model(fit_zipoisson)
```

6.9 APPENDIX I: RESULTS OF STATISTICAL TESTS

6.9.1 Kruskal-Wallis H Test

Ranks

	Please select the gender you identify with most	N	Mean Rank
On a typical day, how does the sound of sirens in your classroom make you feel?	Male	16	19.78
	Female	21	20.10
	Prefer not to say	2	20.75
	Total	39	
How annoyed are you when you hear sirens in your classroom?	Male	14	21.79
	Female	26	20.04
	Prefer not to say	1	35.00
	Total	41	
How distracted from your schoolwork are you when you hear sirens?	Male	24	34.33
	Female	40	32.56
	Prefer not to say	2	42.25
	Total	66	
How long does your distraction persist?	Male	9	13.00
	Female	14	11.64
	Prefer not to say	1	20.00
	Total	24	
To what extent does siren noise affect how well you learn?	Male	23	30.76
	Female	38	32.30
	Prefer not to say	2	40.50
	Total	63	

Test Statistics[a,b]

	On a typical day, how does the sound of sirens in your classroom make you feel?	How annoyed are you when you hear sirens in your classroom?	How distracted from your schoolwork are you when you hear sirens?	How long does your distraction persist?	To what extent does siren noise affect how well you learn?
Kruskal-Wallis H	.017	1.855	.729	1.570	.897
df	2	2	2	2	2
Asymp. Sig.	.991	.396	.694	.456	.638

a. Kruskal Wallis Test

b. Grouping Variable: Please select the gender you identify with most

NPar Tests

Kruskal-Wallis Test

Ranks

	Please select the race that you identify with most	N	Mean Rank
On a typical day, how does the sound of sirens in your classroom make you feel?	African American	19	20.29
	Asian	2	20.75
	Hispanic	11	14.82
	Prefer not to say	7	27.14
	Total	39	
How annoyed are you when you hear sirens in your classroom?	African American	22	20.84
	Asian	1	40.50
	Hispanic	12	20.38
	Prefer not to say	6	19.58
	Total	41	
How distracted from your schoolwork are you when you hear sirens?	African American	30	32.50
	Asian	6	40.58
	Hispanic	17	35.21
	Prefer not to say	12	27.50
	Total	66	
	White	1	64.00
How long does your distraction persist?	African American	11	14.09
	Asian	2	14.50
	Hispanic	8	11.13
	Prefer not to say	3	9.00
	Total	24	
To what extent does siren noise affect how well you learn?	African American	30	31.53
	Asian	6	36.42
	Hispanic	17	31.09
	Prefer not to say	10	32.30
	Total	63	

Test Statistics[a,b]

	On a typical day, how does the sound of sirens in your classroom make you feel?	How annoyed are you when you hear sirens in your classroom?	How distracted from your schoolwork are you when you hear sirens?	How long does your distraction persist?	To what extent does siren noise affect how well you learn?
Kruskal-Wallis H	5.433	3.224	6.203	2.001	.679
df	3	3	4	3	3
Asymp. Sig.	.143	.358	.185	.572	.878

a. Kruskal Wallis Test

b. Grouping Variable: Please select the race that you identify with most

6.9.2 Ordinal Regression

PLUM - Ordinal Regression

Warnings

There are 119 (72.6%) cells (i.e., dependent variable levels by observed combinations of predictor variable values) with zero frequencies.
The log-likelihood value is practically zero. There may be a complete separation in the data. The maximum likelihood estimates do not exist.
The PLUM procedure continues despite the above warning (s). Subsequent results shown are based on the last iteration. Validity of the model fit is uncertain.

Case Processing Summary

		N	Marginal Percentage
To what extent does siren noise affect how well you learn?	Not at all effected	39	75.0%
	Somewhat effected	5	9.6%
	Moderately effected	6	11.5%
	Very effected	2	3.8%
Police protect my safety	Disagree	3	5.8%
	Neutral	8	15.4%
	Agree	21	40.4%
	Strongly agree	20	38.5%
Police protect people's basic rights	Strongly disagree	1	1.9%
	Neutral	14	26.9%
	Agree	19	36.5%
	Strongly agree	18	34.6%
Police can be trusted to do what's right for my neighborhood	Strongly disagree	2	3.8%
	Disagree	1	1.9%
	Neutral	13	25.0%
	Agree	21	40.4%
	Strongly agree	15	28.8%
Officers treat all people with respect	Strongly disagree	2	3.8%
	Disagree	7	13.5%
	Neutral	16	30.8%
	Agree	14	26.9%
	Strongly agree	13	25.0%
Laws protect everyone equally	Disagree	6	11.5%
	Neutral	12	23.1%
	Agree	18	34.6%
	Strongly agree	16	30.8%
I trust the police	Strongly disagree	1	1.9%
	Disagree	3	5.8%
	Neutral	17	32.7%

Case Processing Summary

		N	Marginal Percentage
	Agree	15	28.8%
	Strongly agree	16	30.8%
Valid		52	100.0%
Missing		21	
Total		73	

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	76.615			
Final	.000	76.615	20	<.001

Link function: Logit.

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	37.608	100	1.000
Deviance	36.362	100	1.000

Link function: Logit.

Pseudo R-Square

Cox and Snell	.771
Nagelkerke	.958
McFadden	.903

Link function: Logit.

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% … Lower Bound
Threshold	[Q14 = 1]	12.818	6.040	4.504	1	.034	.980
	[Q14 = 2]	14.015	6.134	5.220	1	.022	1.992
	[Q14 = 3]	16.390	6.364	6.633	1	.010	3.917
Location	[Q19_5=2]	-15.730	1692.260	.000	1	.993	-3332.499
	[Q19_5=3]	-9.582	4.883	3.851	1	.050	-19.151
	[Q19_5=4]	-4.669	3.900	1.433	1	.231	-12.312
	[Q19_5=5]	0[a]	.	.	0	.	.
	[Q19_1=1]	-3.486	6793.897	.000	1	1.000	-13319.279
	[Q19_1=3]	3.020	3.590	.708	1	.400	-4.016
	[Q19_1=4]	1.460	1.568	.867	1	.352	-1.612
	[Q19_1=5]	0[a]	.	.	0	.	.
	[Q19_2=1]	-7.218	3863.836	.000	1	.999	-7580.198
	[Q19_2=2]	-13.340	3863.834	.000	1	.997	-7586.315
	[Q19_2=3]	3.838	3.761	1.041	1	.308	-3.534
	[Q19_2=4]	3.302	2.436	1.838	1	.175	-1.472
	[Q19_2=5]	0[a]	.	.	0	.	.
	[Q19_3=1]	-.166	4037.157	.000	1	1.000	-7912.847
	[Q19_3=2]	-2.113	2.744	.593	1	.441	-7.492
	[Q19_3=3]	.100	2.340	.002	1	.966	-4.485
	[Q19_3=4]	-2.179	2.089	1.088	1	.297	-6.274
	[Q19_3=5]	0[a]	.	.	0	.	.
	[Q19_4=2]	-9.193	1170.231	.000	1	.994	-2302.805
	[Q19_4=3]	5.066	3.504	2.091	1	.148	-1.801
	[Q19_4=4]	8.887	4.857	3.348	1	.067	-.633
	[Q19_4=5]	0[a]	.	.	0	.	.
	[Q19_6=1]	0[a]	.	.	0	.	.
	[Q19_6=2]	8.336	6.033	1.909	1	.167	-3.489
	[Q19_6=3]	8.383	4.860	2.975	1	.085	-1.142
	[Q19_6=4]	7.169	4.774	2.255	1	.133	-2.188
	[Q19_6=5]	0[a]	.	.	0	.	.

Parameter Estimates

		95% ... Upper Bound
Threshold	[Q14 = 1]	24.657
	[Q14 = 2]	26.038
	[Q14 = 3]	28.863
Location	[Q19_5=2]	3301.040
	[Q19_5=3]	-.012
	[Q19_5=4]	2.974
	[Q19_5=5]	.
	[Q19_1=1]	13312.307
	[Q19_1=3]	10.055
	[Q19_1=4]	4.532
	[Q19_1=5]	.
	[Q19_2=1]	7565.762
	[Q19_2=2]	7559.635
	[Q19_2=3]	11.210
	[Q19_2=4]	8.076
	[Q19_2=5]	.
	[Q19_3=1]	7912.516
	[Q19_3=2]	3.266
	[Q19_3=3]	4.686
	[Q19_3=4]	1.915
	[Q19_3=5]	.
	[Q19_4=2]	2284.418
	[Q19_4=3]	11.934
	[Q19_4=4]	18.406
	[Q19_4=5]	.
	[Q19_6=1]	.
	[Q19_6=2]	20.160
	[Q19_6=3]	17.907
	[Q19_6=4]	16.526
	[Q19_6=5]	.

Link function: Logit.

a. This parameter is set to zero because it is redundant.

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