LISTENING TO URBAN SOUND: A MIXED-METHOD APPROACH FOR UNDERSTANDING HUMAN MOBILITY, INDIVIDUAL SOUND EXPOSURE, AND PSYCHOLOGICAL WELL-BEING

BY

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DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Geography
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2020

Urbana, Illinois

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ABSTRACT

Researchers in the fields of health geography, urban planning, and environmental health have extensively studied the relationships among human movement, environmental exposure, and their effects on human health. Urbanization brings about ever-growing noise problems in cities. Exposure to high levels of sound is associated with health risks involving annoyance, disturbance, stress, cognitive performance impairment, hearing loss, and cardiovascular diseases. Despite great investment in noise abatement regulations, these regulations do not necessarily control noise pollution or improve urban environments. This is because sound involves not only objective aspects that can be measured in terms of decibels but also socio-psychological aspects that are subjectively perceived by individuals. Urban sound should not merely be considered as an environmental pollutant. Instead, it can be therapeutic resources for human health. Further, individuals' subjective perceptions of whether a sound is a noise are largely influenced by contexts. However, the processes of how people experience urban sound and the mechanisms of how human mobility influences people's perceptions of and responses to sound remain unclear.

This dissertation analyzes the relationships among human mobility, geographic contexts, individuals' objective exposures to and subjective evaluations of sound, and the impacts on their psychological health. It collects individual-based daily movements and sound exposure data at a fine spatiotemporal resolution using survey questionnaires, GPS trackers, portable sound sensors, activity-travel diaries, and geographic ecological momentary assessment. Further, this dissertation also conducts in-depth interviews and geo-narrative analysis to gain a more in-depth understanding of people's lived experiences of urban sound in diverse geographic locations and contexts during their daily movements. Drawing upon the time-geographic approach, it uses mixed methods to advance knowledge of spatiotemporal contexts in understanding individual-based sound exposure and psychological health. This dissertation provides effective approaches to coping with urban noise pollution, resolving tensions between residents and urban sonic environments, and providing a holistic perspective for understanding human-environment interactions from a sonic perspective.

Keywords: Environmental health; noise and health; soundscape; individual exposure assessment; uncertain geographic context problem; mixed methods; geographic ecological momentary assessment; geo-narrative analysis

To my family, for their love and support

ACKNOWLEDGMENTS

I am heartily thankful to my advisor, Dr. Mei-Po Kwan, for her valuable guidance and considerable support at every stage of my doctoral study. I am grateful for the opportunity to conduct fieldwork trips in Chicago with her and learn from her. I have benefited considerably from her critical and timely feedback throughout my doctoral research. Her diligence, passion for research, and dedication to scholarship have been and will continue to inspire me to become an independent researcher. No words could express how grateful I am for having her as my advisor.

I would like to express my gratitude to Dr. Sara McLafferty, Dr. Julie Cidell, and Dr. William Stewart for their efforts of serving as my committee members. They have provided invaluable insights to improve my dissertation and considerable support for me during my doctoral study. I would also like to express my thanks to Dr. Marilyn O'Hara Ruiz, who had fully exemplified the high-quality scholarship to which I aspired. I am grateful to Dr. Yanwei Chai for his help and inspiring discussions during my fieldwork trips in Beijing. I am grateful to Graduate College Dissertation Travel Grant and Ferber and Sudman Dissertation Awards for the funding opportunities for me to conduct the fieldwork.

I gratefully acknowledge my dear friends and colleagues for their help and support. Thanks to all the former and current colleagues in the Space-Time Analysis and Research (S. T. A. R.) Lab. I have especially enjoyed working with Rebecca Shakespeare, Jue Wang, Yoo Min Park, Kangjae Lee, and Xue Zhang to undertake fieldwork trips in Chicago. I would also like to thank Dong Liu, Junghwan Kim, Wataru Morioka, and Xijing Li for their help and support. I owe gratitude to my friends and colleagues in the department, Aida Guhin, Arrianna Planey, and Fikriyah Winata for their support and help.

Finally, I thank my family for their endless love and support. I would like to give special thanks to my beloved one, Dr. Fan Yang. His endless love and support are my constant source of inspiration and courage. He has not only devoted time to actively sharing household responsibilities but also served as the most accessible person who I can turn to for sharing while I developed the ideas of my dissertation. I would like to thank my parents for their long-lasting support and unconditional love. They are the most amazing parents in the world.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 MOTIVATION

Industrialization and urbanization bring about increasing noise pollution. Diverse human-made sounds from traffic, construction, and industrial activities replace the enjoyment of natural sounds such as the singing of birds, the rhythm of the rain, and the whisper of the wind. In addition, urbanization also encourages the pursuit of consumption-oriented and leisure-oriented lifestyles, which further lead to diverse forms of recreational and commercial sound such as jazz festivals and loud music from bars and restaurants. The loud volume of commercial music even becomes a way of capturing attention from consumers and promoting profits. However, one individual's enjoyment of sound can be noise for others. Sound can also easily transcend one's private space and annoy others. The lack of control over sound levels in cities can generate psychosocial tensions for urban residents' quality of life and health.

Studies have shown that individuals' exposure to high levels of sound can negatively impact human health, generate annoyance and disturbance for daily activities, impair cognitive performance, generate physiological and psychological stress, cause acute or chronic hearing loss, and increase risks of cardiovascular diseases (e.g., Cohen and Neil, 1981; Lercher, 1996; Passchier-Vermeer and Passchier, 2000; Basner et al., 2014). However, people frequently underestimate and even neglect the negative health effects and tend to be exposed to sound levels that are higher than the recommended standards. According to a WHO guideline for community noise (1999), the sound level has been recommended to be less than 30 dB (A) to prevent sleep disturbance and less than 40 dB (A) to prevent adverse health effects. A WHO report for European Union (EU) (2011) has shown that approximately 40% of the population in EU countries are exposed to sound levels over 55 dB (A) from road traffic, 20% are exposed to sound levels over 65 dB (A) during the day time, and over 30% are exposed to night noise levels exceeding 55 dB (A). A report from the U.S. Environmental Protection Agency (EPA) has estimated that about 100 million people in the United States, which is about 30% of the U.S. population, had annual exposure to traffic noise that can cause harmful effects to their health (Simpson and Bruce, 1981).

Thus, whether we can effectively mitigate noise problems has become a critical issue to improve urban residents' health and quality of life. Despite great investment in noise abatement measures and noise control regulations, noise remains an ever-growing problem in cities. Noise mitigation approach does not necessarily control noise pollution (Raimbault and Dubois, 2005; Aletta et al., 2016). There are several reasons for the ineffectiveness of the noise mitigation approach. First, sound is not only actual sound levels that are measured in terms of decibels but also a socio-psychological concept that is subjectively perceived and evaluated by individuals. The noise mitigation approach mainly focuses on actual sound levels (Passchier-Vermeer and Passchier, 2000), which can only explain a limited amount of variance in health effects related to sound (Lercher and Schulte-Fortkamp, 2003; Marquis-Favre et al., 2005). How individuals subjectively perceive urban sound and socio-psychological health should be further investigated.

Second, the noise mitigation approach neglects the critical role of contexts in influencing the relationships among individuals' objective exposure to sound, subjective evaluation of the sound, and their effects on human health. The specific contexts largely influence whether a sound is perceived as noise and how the sound impacts individuals' psychological health and well-being (Herranz et al., 2016; Brown et al., 2016). Therefore, it requires a better conceptualization of the contextual effects on people's sound exposure and health outcomes.

Third, existing studies have largely ignored human mobility in assessing individuals' sound exposure. Studies have mainly assessed people's exposure to sound at a particular geographic location. However, people move around to undertake their daily activities in diverse geographic locations and contexts. Therefore, individual-based and person-specific sound exposure should be assessed when investigating the relationship between individuals' sound exposure and health outcomes. Further, individuals encounter different degrees of mobility constraints, which may further influence their daily movements and sound exposures. Thus, how people's mobility patterns and constraints influence their sound exposure and health effects requires more studies.

Using mixed methods combining both quantitative and qualitative analysis, this dissertation advances knowledge of the relationships among human mobility, contextual effects, individual-based objective exposure to sound, subjective evaluation of sound, and psychological health. There are four theoretical contributions in this research. First, in addition to actual sound levels, this dissertation enriches the understanding of socio-psychological aspects of sound and their effects on people's psychological health. Second, this dissertation provides a conceptual framework for understanding geographic contexts and their effects on the relationship between individuals' sound exposure and psychological health. Third, this dissertation adopts a dynamic approach and provides more accurate assessments of individual-based sound exposure and psychological health. Fourth, this dissertation explores the role of both people's actual movements and their potentials for movements in influencing individual sound exposure and psychological health.

1.2 RESEARCH QUESTIONS

The goal of this dissertation is to better understand the relationship between individual-based sound exposure and psychological health by incorporating the role of human mobility, geographic contexts, and subjective perceptions of sound. It seeks to answer the following key research questions:

1. How to understand context? How do contextual effects influence individuals' subjective perceptions of sound? How do contextual effects influence the relationship between individual sound exposure and self-reported psychological stress?
2. How do individuals' subjective perceptions of sound influence the relationship between objective exposures to sound and self-reported psychological stress?
3. In what ways do people perceive and experience urban sound as they undertake their daily activities and trips? Why do people perceive and respond to urban sound in different ways? In what ways and to what extent do different individuals' daily mobility patterns and potentials influence their perceptions and coping strategies of sound?

To address these research questions, the scope of this research encompasses the following objectives:

1. Using multilevel logistic modeling, this dissertation examines the relationship among people's objective sound exposure, contextual effects, and subjective sound perception at the level of each individuals' daily activities.

2. Using structural equation modeling, it investigates the contextual effects on the relationships among people's objective exposure to sound, subjective perceptions of sound, and psychological stress at a high spatiotemporal resolution.
3. Using geo-narrative analysis, this dissertation explores the processes of how people perceive and respond to urban sound in their everyday lives and the mechanisms of how individuals' different degrees of mobility potentials and constraints influence their perceptions of sound, psychological responses, and coping strategies of sound.
4. Combining both quantitative and qualitative analysis, it seeks to gain a holistic understanding of human-environment interactions from a sonic perspective.

1.3 BACKGROUND

1.3.1 NOISE AND ITS ADVERSE HEALTH EFFECTS

Extensive studies from environmental health, public health, and epidemiology have mainly considered sound as noise pollution and examined the adverse health effects associated with people's noise exposure. First, exposure to high levels of noise can generate acute or chronic hearing loss (Wolfgang, 2005; Seidman and Standring, 2010). It can cause tinnitus, increase hearing threshold, and irreversibly damage hearing cells and nerves (Seidman and Standring, 2010; Akhil and Vishwambhar, 2014). Second, noise also generates annoyance and disturbance for daily activities (Basner et al., 2014). Sleep disturbance caused by noise has been widely discussed (Zaharna and Guilleminault, 2010), with its influence on sleep quality and further influence on moods and performances in the following day (Passchier-Vermeer and Passchier, 2000; Stansfeld and Matheson, 2003). Third, noise annoyance and disturbance can further increase both physiological and psychological stress (Stansfeld and Matheson, 2003; Seidman and Standring, 2010; Basner et al., 2014). Physiological stress leads to increases in blood pressure, heart rate, and stress hormones such as cortisol, epinephrine, norepinephrine in urine or saliva (Ljungberg and Neely, 2007). Psychological stress involves fatigue, stress, and depression (Babisch et al., 2001; Evans and English, 2002). Fourth, noise exposure also impairs cognitive performances, especially for students (Evans et al., 1995; Evans and Johnson, 2000). Studies have shown that exposure to noise impairs students' performance in tasks involving attention, memory, language use, and problem-solving (Evans et al., 1995; Haines et al., 2002; Stansfeld et al., 2005; Clark et al., 2006;

Seidman and Standring, 2010). Lastly, in the long run, chronic noise exposure increases risks for cardiovascular diseases, mainly including hypertension and heart diseases (Wolfgang, 2005). While some studies have shown that individuals can get accustomed to high levels of noise in the long term (Zaharna and Guilleminault, 2010), others studies have noticed the accumulative effects of excessive exposure to noise on people's increasing risks of cardiovascular diseases and mental health problems (e.g., Pirrera et al., 2010).

Existing studies focus mainly on the physical attributes of sound and develop multiple parameters to measure actual sound levels. The frequently used parameters include sound pressure level, A-weighted sound pressure level, and A-weighted equivalent sound level (Cohen and Neil, 1981; Passchier-Vermeer and Passchier, 2000; Basner et al., 2014). The sound pressure level is measured by decibel, which is abbreviated as dB. The A-weighted sound pressure level is measured by A-weighted decibel, which is abbreviated as dB (A). Based on the responses of human individuals' hearing systems to sound with different frequencies, the A-weighted sound pressure level considers sound pressure level with lower and higher frequencies as less important than that with other frequencies (World Health Organization, 1999). The A-weighted equivalent sound level is referred to as $L_{Aeq, T}$ that averages the A-weighted sound pressure level over a period of time T. $L_{Aeq, 24h}$ records over 24-hour of a day. L_{DN} and L_{DEN} also record over 24 hours, but assign different weights according to different periods of a day, since the same amount of the A-weighted equivalent sound levels are considered as more annoying during the night time than those during the day time (Cohen and Neil, 1981; Passchier-Vermeer and Passchier, 2000).

Existing studies use either modeling or monitoring approaches to assessing individuals' actual exposure to a particular source of sound (e.g., road traffic, railway, and aircraft noise) that is outdoor at a specific location (e.g., home, workplace, or school). In terms of the modeling approach, researchers have focused on a particular source of noise and simulate noise levels in different locations based on parameters such as traffic volume, flow, vehicle type, road surface, building height, meteorological conditions, and temporal variations (Steele, 2001; Maisonneuve et al., 2010; Mioduszewski et al., 2011; Brown et al., 2015). Noticeably, the accuracy of the modeling simulation can be influenced by the spatiotemporal resolution of input parameters. In terms of the monitoring approach, researchers have collected noise data that are recorded by fixed sensors and monitoring stations, which are frequently placed at fixed locations together with other sensors for temperature and air pollution (Maisonneuve et al., 2010; Mioduszewski et al., 2011; Gariazzo et al., 2016; Wong et al., 2018). Alternatively, researchers directly use sound level meters to measure actual noise levels in their participants' residential location, workplace, or school determined by their purposes of research (Evans and English, 2002; Babisch et al., 2014). It is noted that a limited number and sparse distribution of the sound level meters and sensors can influence the accuracy of assessment (Mead et al., 2013; Maisonneuve et al., 2009; Kanhere, 2011).

After gathering the data of individuals' exposure to a specific source of noise at a specific location, researchers have used different study designs that include experimental, cross-sectional, cohort, longitudinal, and case-control studies and conducted regression analysis to examine the associations between people's noise exposure and its adverse health effects (Evans and Johnson, 2000; Babisch et al., 2001). The regression analysis enables researchers to understand the statistical relationships between noise and its health effects by controlling confounders such as demographic factors, self-reported health statuses, and household factors (Cohen et al., 1980; Babisch et al., 2014).

However, recent soundscape studies have reflected upon existing literature on noise and its health effects by arguing that sound is not just objective sound levels but also a socio-psychological concept. Objective sound levels can only explain a limited part of the relationship between people's exposure to sound and its health effects. In addition, socio-psychological aspects of sound also play an important role in explaining relationships between sound exposure and health effects (Cohen et al., 1980; Westman and Walters, 1981; Fields, 1993). How socio-psychological aspects of sound influence human health require better conceptualization.

Further, studies have revealed that non-acoustic factors, which can be understood as the contexts, also influence the relationship between people's exposure to sound and its effects on human health (Job, 1988; Wolfgang, 2005). These non-acoustic factors have been understood as both individual and situational factors. Individual factors include individuals' sensitivity to noise (Miedema and Vos, 2003; Van Kamp et al., 2004), attitudes towards noise sources (Job, 1988), perceived predictability and controllability of the noise (Kjellberg, 1990), and their adaptation to noise

(Stansfeld and Matheson, 2003; Schulte-Fortkamp and Fiebig, 2006). Situational factors include spatiotemporal contexts and socio-cultural contexts. The spatiotemporal contexts involve geographic location, physical and social environments of the location (e.g., a restaurant or a shopping mall), and timing and duration of individuals' noise exposure (Lercher, 1996; Fortkamp and Fiebig, 2006; Van Kamp and Davies, 2013). The socio-cultural contexts of noise are associated with social norms and cultural backgrounds that shape individuals' attitudes of and reactions to noise (Lercher, 1996; Passchier-Vermeer and Passchier, 2000; Ising and Kruppa, 2004). However, how to conceptualize the contexts and their effects on the relationship among people's sound exposure, sound perceptions, and human health requires more studies.

1.3.2 INCORPORATING THE SOUNDSCAPE APPROACH IN NOISE-HEALTH STUDIES

Recently, increasing studies advocate incorporating the soundscape approach into the existing studies on noise and its adverse health effects (Lercher and Schulte-Fortkamp, 2003; Schulte-Fortkamp and Fiebig, 2006; Botteldooren et al., 2016; Aletta et al., 2016; Brown et al., 2016; Bild et al., 2016). The soundscape approach allows for a more holistic understanding of the relationships among people's exposures to urban sound, perceptions of sound, and human health. Soundscape was defined by the International Organization for Standardization (2014) as "the acoustic environment as perceived or experienced or understood by a person or people, in context." Compared with existing studies on noise and its adverse health effects, soundscape studies have several advantages.

First, soundscape studies adopt a holistic concept of sound, emphasizing both the positive and negative health effects of sound. Sound provides alternative ways for human bodies to be, feel, and interact in places and environments (Doughty et al., 2016). Thus, sound is not only an environmental pollutant but also a resource that can improve environments and human health in cities (Raimbault and Dubois, 2005; Oldoni et al., 2015). Urban residents are not passive receivers of sound, but they can actively interact with urban environments and gain multisensory urban experiences that are therapeutic for their health (Ge et al., 2009; Steele et al., 2015; Brown et al., 2016; Kogan et al., 2017).

Second, soundscape studies consider both people's objective exposures to sound (a physical phenomenon) and their subjective perceptions of sound (a perceptual construct) in different urban environments (Raimbault and Dubois, 2005). Studies have increasingly combined objective and subjective data of sound and sonic environments to understand the multifaceted urban sonic environments (Jeon et al., 2011; Cain et al., 2013; Lindborg, 2015; Kang et al., 2016; Herranz et al., 2016). Objective data are obtained through measurement by equipment, and subjective data are collected through survey questionnaires and interviews with research participants (Ge et al., 2009; Herranz et al., 2017).

Third, soundscape studies highlight the importance of context in influencing how human individuals' subjectively perceive and experience sound (Schafer, 1993; Herranz et al., 2016; Brown et al., 2016), The same sound pressure level in different contexts can lead to different evaluations (Schafer, 1993; Saldanha, 2009; Botteldooren et al., 2016; Craig et al., 2017). Understanding contexts has been a focus of soundscape studies. The context has been defined as "the interrelationships between person and activity and place, in space and time" (International Organization for Standardization, 2014). One increasingly popular strand of understanding the context is to use an activity-centric framework (Lercher and Schulte-Fortkamp, 2003; Jennings and Cain; 2013; Steele et al., 2015; Herranz et al., 2010; Herranz et al., 2016; Herranz et al., 2017; Bild et al., 2016; Bild et al., 2018; Aburawis and Dokmeci, 2018). This is because human activities are the major sources of sounds in urban environments (Liu et al., 2013). Human individuals spontaneously categorize their daily soundscapes in relation to their activities (Steele et al., 2015).

Although progress has been made in the soundscape studies compared with previous studies on noise and its health effects, there are still several research gaps. First, existing studies have mainly focused on people's exposure to sound and perception of sound in specific geographic locations (e.g., urban parks and squares). However, people are mobile and exposed to diverse sources of sound in multiple geographic locations and contexts. Second, how people perceive urban sound during their daily movements requires further investigation. Third, how to understand context and how the context influences relationships among people's objective exposures to sound, subjective perceptions of sound, and human health also require further conceptualization.

1.3.3 RELEVANT THEORETICAL AND METHODOLOGICAL ADVANCEMENTS

Relevant theoretical and methodological advancements provide considerable potential for bridging existing research gaps. Previous studies have largely adopted a place-based approach to assessing individuals' sound exposure. For instance, studies on noise and its health effects mainly examine individuals' exposure to a specific source of sound in a particular geographic location. Soundscape studies focus largely on how visitors perceive sound in urban parks and public squares (Herranz et al., 2016; Bild et al., 2016). However, as individuals move around to undertake their daily activities and trips (Kwan, 2009; 2013), they are exposed to diverse sources of sound and their subjective experiences of sound can be different depending on their specific daily movements. The neglect of individuals' daily movements and spatiotemporal variations of urban sound can lead to the uncertain geographic context problem (UGCoP) and the neighborhood effect averaging problem (NEAP). The UGCoP is caused by both spatial and temporal uncertainties (Kwan, 2012a,b). The spatial uncertainties are caused by limited knowledge of the precise spatial configuration of areal units that have contextual effects on human health. The temporal uncertainties are due to that the timing and duration in which individuals are exposed to environmental risk factors are not considered. The NEAP refers to that considering people's daily mobility and individuals' mobility-dependent exposures will lead to an overall tendency towards the mean value of the population of a study area (Kwan, 2018b). Both the UGCoP and the NEAP may further lead to erroneous results of individual-based environmental exposure and its health effects (Park and Kwan, 2017; Kwan, 2018a,b; X. Ma et al., 2020; Kim and Kwan, 2020).

Therefore, a dynamic approach is needed to consider not just where people live, but also where they visit, and when and how much time they spend at each particular location (Kwan, 2012a,b). The development of Global Positioning System (GPS) tracking and real-time environmental sensing technologies provides opportunities for adopting the dynamic approach and recording real-time data of individual-based and person-specific daily movements and sound exposures (Maisonneuve et al., 2009; Maisonneuve et al., 2010; Liu et al., 2013).

Furthermore, an activity-based approach can provide insights into the relationships among the context, objective and subjective sound, and human health and well-being. Activity-travel diaries have been widely used in time-geographic studies (Kwan, 1998; Ellegård, 1999, 2018). Activity-travel diaries collect detailed information about people's daily activities and trips such as the start time, duration, geographic location, type, and companion in sequence over the 24 hours of a day (Schweizer et al., 2007; Chen et al., 2011). Further, using activity-travel diaries individuals' subjective evaluations of sound can also be collected at the level of each activity and trip of individuals. Therefore, activity-travel diaries provide a powerful space-time perspective for understanding contextual information of individuals' daily activities and trips, acting as a powerful tool to integrate individual-level and activity-level data.

Moreover, geographic ecological momentary assessment (GEMA) can be another important approach to provide contextualized information. The GEMA combines conventional ecological momentary assessment (EMA) with global positioning systems (GPS). EMA is a collection of methods that gather real-time assessments of respondents' perceptions, feelings, moods, and behaviors in real-life situations using phone messages or smartphone applications (Schwartz and Stone, 1998; Shiffman et al., 2008), which helps to minimize recall bias and maximize ecological validity (Shiffman, 2009). The GEMA can be time-based or event-based. The time-based GEMA prompts at fixed or random temporal intervals (Schwartz and Stone, 1998), and the event-based GEMA records health-related behaviors (e.g., alcohol use, smoking, binge eating, and physical activities) as they occur during the study period (Shiffman et al., 2008). GEMA not only enriches the EMA data with spatial information but also generates more contextualized information for the GPS data, which provides insight into studies on individual-based environmental exposure and health outcomes (Mitchell et al., 2014; Kirchner and Shiffman, 2016; Mennis et al., 2018).

In addition, studies on critical GIS provides reflective thoughts on data generated by geospatial technologies (Kwan, 2007; Kwan and Ding, 2008). These studies argue that human subjects are more than dots on maps, and a more in-depth understanding of their thoughts, feelings, emotions, subjectivities, and lived experiences should be understood (Kwan, 2007; Kwan and Ding, 2008). In addition, these studies also advocate understanding people's everyday lived experiences in contexts (McLafferty, 2005; Kwan and Ding, 2008). Therefore, in addition to statistical analysis, qualitative methods can be used to facilitate the contextual understanding and situated knowledge of how people perceive sound and health outcomes, processes of people's ongoing negotiation and coping strategies of sound, and mechanisms of how people's daily mobility patterns and potentials shape their sound exposure and health outcomes.

Together, the integration of GPS trackers, portable sound sensors, activity-travel diaries, GEMA, and qualitative methods will contribute to triangulation and cross-validation among different data sources and approaches. In terms of data analysis, a mixed-method approach allows for the complementation of strengths of both quantitative and qualitative methods (Cresswell, 2013). Quantitative methods have strengths in explaining statistical relationships (Cresswell, 2003), and qualitative methods provide nuanced and reflective explanations of individual's subjective perceptions and experiences, daily coping strategies, and situated socio-cultural understandings (Kwan & Knigge, 2006). This dissertation adopts a mixed-method approach for a better understanding of complex relationships among contextual effects, individual-based sound exposure, sound perception, and their effects on human health.

1.4 THESIS ORGANIZATION

This dissertation comprises three main chapters that center on expanding the existing theoretical understanding of individual-based exposures to urban sound and their effects on people's psychological health. Due to reasons such as access to and quality of data, the first of these chapters (Chapter 2) used data collected in the Chicago study area, and the second and third chapters (Chapters 3 and 4) used data collected in the Beijing study area. Although the study areas of the three main chapters are different, the Chicago and Beijing studies are comparable given that the two are megacities and the data have been collected in both study areas following the same protocol. Further, the use of different study areas does not influence the process of generating new knowledge of individual-based sound exposures and psychological health.

Chapter 2 conceptualizes how individuals' objective exposure to sound and specific geographic contexts influence their subjective evaluation of sound. Using an activity-based approach and multilevel logistic modeling, it focuses on how individual demographics, activity-related contexts, and people's objective exposure to sound are related to their subjective evaluation of sound at the level of each individual's activities. The chapter finds that whether a sound is considered as a noise is largely influenced by the particular contexts in which individuals' daily activities were situated.

The finding supports that, to better understand sound, one should consider not only people's objective exposure to actual sound levels but also the resulting subjective evaluation of the sound. In mitigating noise pollution in cities, it is inadequate to simply reduce sound levels, and it can also be helpful to adopt a human-centric and context-aware approach. Such an approach allows for a clearer understanding of specific activity-related contexts in which a sound is perceived as noise, allowing urban planners and policy-makers to manage the sounds according to specific activity-related contexts (e.g., who, where, when, and with whom resident's specific daily activities are undertaken).

Chapter 3 conceptualizes the role of contextual effects and people's subjective perceptions of sound in influencing relationships between people's objective exposure to sound and self-reported psychological stress. This chapter investigates how real-time geographic contexts and subjective sound perceptions influence individuals' momentary objective exposure to sound and momentary psychological stress. Using geographic ecological momentary assessment, recall bias and maximizes ecological validity are reduced when compared to previous studies that used retrospective survey questionnaires in assessing people's environmental exposure and psychological stress. Using structural equation modeling, the chapter shows that momentary sound exposure influences psychological stress through the mediating effects of momentary sound perception. Further, real-time geographic contexts that involve activity, social, and temporal aspects influence individuals' momentary sound exposure, sound perception, and psychological stress.

Chapter 4 investigates the mechanisms of how individuals' daily mobility patterns and potentials influence their daily movements, objective exposure to sound, subjective perceptions of sound, psychological responses, and coping strategies against loud sound. Using geo-narrative analysis, the chapter explores each individual's objective sound exposure, subjective sound perceptions, and psychological responses at particular geographic locations and times. It argues that in addition to people's sound exposure at their home locations, their sound exposures at their workplace, other locations, and during their travel should also be considered. Further, the combination of people's objective exposure to sound and subjective perception of sound provides a holistic understanding of how people interact with sonic environments in their everyday lives. Most importantly, the chapter identifies three groups of mobility-constrained individuals who are stuck in high levels of sound exposure and/or psychological annoyance and stress. The chapter provides important policy implications based on the mobility constraints of these vulnerable individuals to avoid high levels of sound exposure and improve sonic environments in spatiotemporal situations where they are constrained.

Finally, Chapter 5 concludes the dissertation with a discussion of the significant findings, study contributions, and future directions for research.

CHAPTER 2: THE EFFECTS OF ACTIVITY-RELATED CONTEXTS ON INDIVIDUAL SOUND EXPOSURES: AN ACTIVITY-BASED APPROACH TO SOUNDSCAPE STUDIES

2.1 INTRODUCTION

Noise is prevalent in cities. It has multiple sources such as traffic (including road, rail and air traffic), industries, construction activities, commercial activities (such as loud music and conversation in bars and restaurants), recreational activities (such as music festivals), and neighborhood activities (such as ringing phones, crying babies, and barking dogs). Noise can disturb our daily activities, produce annoyance, lead to psychological stress and disorders, impair cognitive performance, and increase the risk for cardiovascular disease (Lercher, 1996; Passchier-Vermeer and Passchier, 2000; World Health Organization, 2011; Basner et al., 2014). Overall, noise can adversely influence urban residents' health and quality of life.

Despite great investment in noise abatement measures, noise pollution is an ever-growing problem in cities. Noise mitigation approach does not necessarily control noise pollution or improve urban environments (Raimbault and Dubois, 2005; Aletta et al., 2016). Despite previous attempts to use the standard dose-response framework to assess the relationships between the levels of noise and annoyance (Miedema and Vos, 1998; Ouis, 2001), studies have pointed out that actual noise levels can only explain a limited amount of the variance in noise annoyance (Lercher and Schulte-Fortkamp, 2003; Marquis-Favre et al., 2005). This is perhaps because noise is not only a physical feature that can be measured in terms of decibels but also has a socio-psychological aspect that is subjectively evaluated and perceived by individuals. Further, the specific context of a sound largely influences whether the sound is perceived to be noise and how annoying it is (Herranz et al., 2016; Brown et al., 2016).

Recent studies suggest that a soundscape approach can complement the noise mitigation approach and provide a more holistic approach to understanding the relationships among urban sounds, residents, and environments (Schulte-Fortkamp and Fiebig, 2006; Botteldooren et al., 2016; Aletta et al., 2016; Bild et al., 2016). The soundscape approach considers sound as resources that can improve urban environments and urban residents' health and quality of life (Raimbault and Dubois, 2005). The soundscape approach advocates a human-centric and subjectivity-based approach, emphasizing individuals' own perceptions and subjective evaluations of sound in different urban environments (Raimbault and Dubois, 2005). It argues that urban residents are not passive receivers of sound. Instead, they can actively interact with urban environments and gain multisensory urban experiences (Ge et al., 2009; Steele et al., 2015; Brown et al., 2016). The soundscape approach also promotes a context-aware approach to urban planning, design, and management. The conventional noise mitigation approach is inadequate, and it requires more detailed information about in what situations and by whom a sound is considered as noise (Bild et al., 2016).

Soundscape was defined by the International Organization for Standardization (2014) as "the acoustic environment as perceived or experienced or understood by a person or people, in context." First, this definition of soundscape highlights both the objective acoustic environment as a physical phenomenon and the soundscape as a perceptual construct. Combining objective and subjective data of sound improves our understanding of the multifaceted aspects of sound in urban environments (Jeon et al., 2011; Kang et al., 2016). Objective data of sound are obtained through measurement by equipment, and subjective data are largely collected through survey questionnaires and interviews with research participants (Zhang and Kang, 2007; Ge et al., 2009). Second, it suggests that context has a significant influence on people's subjective perceptions and evaluations of sound (Herranz et al., 2016; Brown et al., 2016). The same objective sound in different contexts can lead to different subjective evaluations by individuals (Schafer, 1993; Botteldooren et al., 2016). However, how to conceptualize context, and to what extent context plays a role in influencing the objective and subjective attributes of sound need more studies.

Among different strands of understanding the role of context in soundscape studies, an activity-centric framework for understanding context and its roles in influencing individuals' perceptions of sound has become popular (Lercher and Schulte-Fortkamp, 2003; Jennings and Cain; 2013; Steele et al., 2015; Herranz et al., 2010; Herranz et al., 2016; Herranz et al., 2017; Bild et al., 2016; Bild et al., 2018). This is because human activities are the major sources of sounds in urban environments (Hong et al., 2019). Further, humans spontaneously categorize their daily soundscapes in relation to their activities (Steele et al., 2015).

Although studies based on the activity-centric framework are still in the exploratory stage (Bild et al., 2016), the activity-centric framework for understanding context frequently involves "the interrelationships between person and activity and place, in space and time" (The International Organization for Standardization, 2014). Person, activity, place, and their interrelationships are key elements for understanding the influence of context on humans. With respect to the person, important attributes include individuals' demographic backgrounds and personal sound-related experiences such as their sensitivity to sound and their adaptation to sound. With regard to activity, important attributes include activity types and the presence of a companion(s) during the activity. For instance, whether an activity requires attention and quietness influences people's perception of ambient sound (Bild et al., 2016). Place is frequently understood in terms of the space and time associated with individuals' activities that influence their perceptions of sound. Space involves different geographic locations where individuals' different activities take place. Time involves people's preferred time and duration for performing specific activities. The activity-centric framework provides insights into how these activity-related contexts (space and time) influence individuals' subjective evaluation of sound.

However, existing studies have been conducted largely in urban parks and public squares (Zhang and Kang, 2007; Herranz et al., 2016; Bild et al., 2016; Bild et al., 2018), and their findings mainly pertain to and explain people's recreational activities in outdoor public spaces. As individuals undertake different activities with different companions at multiple locations over the 24 hours of a day, the neglect of their daily activities and the spatiotemporal variations in their exposure to sound can lead to the uncertain geographic context problem (UGCoP) (Kwan, 2012, 2018). Therefore, the diversity of individuals and the richness of their daily activities should be considered. Further, activity-related contexts may involve individual attributes, as well as the type, companion, location, and time of individuals' daily activities. How these different aspects of activity-related contexts influence the subjective assessments of sound requires further conceptualization.

Considering these conceptual and methodological issues, the combination of activity diaries, Global Positioning System (GPS) technologies, and portable real-time sound sensors provides new opportunities for understanding individuals' subjective assessments of sound in relation to their objective exposures to sound and various activity-related contexts based on the activity-centric framework. In particular, activity diaries have been widely used in transportation and time-geographic studies (Kwan, 1998; Ellegard, 1999). They collect detailed information about people's daily activities at different geographic locations and times over the 24 hours of a specific day (Schweizer et al., 2007; Chen et al., 2011). Further, the data collected with GPS trackers and portable sound sensors can complement activity diary data (Stewart et al., 2016). Together, these data enable researchers to triangulate (cross-validate) among different datasets, obtain more accurate assessments of individual sound exposure, and understand how various activity-related contexts influence individuals' subjective evaluations of sound as their daily activities unfold in their everyday life. Pertinent activity-related contexts in this chapter include individual attributes, activity type, the presence of activity companion(s), activity location, and activity time.

Specifically, this chapter addresses the following research questions. First, how do the objective exposures to and subjective evaluations of sound relate to each other? Second, how are activity-related contexts associated with individuals' subjective evaluations of sound (whether a sound is noise)? Third, what are the possible reasons for the associations between activity-related contexts and subjective evaluations of sound? The subsequent sections of this paper are organized as follows. The methodology section describes in greater detail the data, variables, and statistical methods used in this chapter. The results section presents the results of the descriptive analysis and multilevel logistic modeling. This is followed by a discussion of the conceptual and methodological contributions of the study. Subsequently, practical implications for a multisensory, human-centric, and context-aware urban planning and development agenda are elucidated. The conclusion summarizes the major findings, study limitations, and avenues for future research.

2.2 METHODS

2.2.1 DATA COLLECTION

The data used in this chapter were collected from October to December 2017 in the Humboldt Park neighborhood in Chicago, USA. First, survey questionnaires were used to collect demographic information and self-reported health status from the participants. Second, each participant carried a GPS-equipped mobile phone and a portable sound sensor for two days: one weekday and one weekend day. The GPS dataset recorded the time and geographic coordinates of participants' movement trajectories at a resolution of 1 meter or 3 seconds, whichever came first. The sound sensors, which are data-logging sound level meters, recorded the sound level in A-weighted decibels (dBA) every minute during the survey days. The sound sensors meet the standards of IEC61672 Type 2 and ANSI S1.4 Type 2 Sound Level Meter with an accuracy of < 1.5dBA error and a measurement range from 30 to 130 dBA. Each sound sensor was calibrated using a CEM SC-05 Sound Level Calibrator at both C-weighted and A-weighted 94dB and 114dB to ensure accuracy before being distributed to a participant. Third, each participant was also asked to fill out an activity diary for the two survey days. Each activity diary recorded all daily activities of each participant in sequence over the 24 hours of each survey day. The diaries included questions on activity type, companions, location, start time, duration, and the subjective evaluations of whether noise is a problem for that particular activity. Data cleaning was conducted after the data were collected. The geographic locations in the activity diaries of each participant were geo-coded. The data collected from the activity diaries and the GPS trajectories were checked and triangulated based on the precise spatial and temporal data. In total, 46 participants were recruited, among whom 33 participants completed the two-day GPS trajectories, sound exposures, and activity diaries data collection process. This analysis used data from the 33 participants with 504 activity records. On average, each participant has about 15 records of activities for the two survey days.

2.2.2 VARIABLES AND MEASURES

This analysis focuses on how objective measures of sound and activity-related contexts influence subjective evaluations of sound. It defines the objective measure of sound as each participant's actual exposure to sound as measured by the sound sensors. The subjective evaluations of sound refer to participants' evaluations of whether their surrounding sound disturbs each of their daily activities. To tighten the prose, objective measures of sound are called "objective sound" and subjective evaluations of sound are called "subjective sound".

2.2.2.1 ACTIVITY-RELATED CONTEXTS

The activity-related contexts include individual attributes (attributes of the person who conducted the activity), activity location, time, type, and the presence of activity companion(s).

Individual attributes consider demographic characteristics such as race/ethnicity, gender, and education, which were observed to influence people's perceptions of sound in past studies (Jennings and Cain, 2013; Bild et al., 2016). For instance, individuals of different ethnicity may attribute different socio-cultural meanings to sound, which may in turn lead to different levels of sensitivity to and tolerance for noise (Herranz et al., 2010). Females are more sensitive to certain sources of noise when compared with males (Van Kamp and Davies, 2013). People with relatively high educational backgrounds tend to have a higher awareness of noise problems and are more easily disturbed by noise (Yu and Kang 2008).

Activity location is classified into three categories in this analysis: home, workplace, and other locations. The activity-based approach emphasizes activities both at and outside people's home (Ellegard, 1999). Furthermore, individuals have limited flexibility, such as changing visit time and location, at their workplace when compared to other locations outside of their home (Kwan, 1999). Individuals' familiarity with and control over a location may influence their expectations of sound and its controllability at that location, which further influence their subjective evaluations of sound (Jeon et al., 2011). In addition, at different geographic locations, people may have different purposes and motivations for activities, which further influence their perceptions of sound at these locations (Herranz et al., 2010).

Activity time is categorized into day (from 7 am to 7 pm), evening (from 7 pm to 11 pm), and night time (from 11 pm to 7 am). Such division of activity time corresponds to the noise metric LDEN that divides the 24 hours of a day into day, evening, and night periods. This analysis only follows the division of time of LDEN but chooses not to add a penalty for the measured sound levels by the sensors. This is because LDEN has considered that people during evening and nighttime are more annoyed by the same levels of noise when compared to daytime (World Health Organization, 1999). Instead, this analysis intends to examine the effects of different periods of a day on how individuals evaluate sound when undertaking their activities. Further, these three different time periods indicate people's different activity patterns during a day, which may influence their subjective sound in important ways (Bild et al., 2018). For instance, during daytime, people may undertake work or other types of activities outside of their home. In the evening, they may undertake diverse types of activities at home or other locations. During nighttime, they normally sleep at home.

Different types of activity may require different levels of individual attention, which may further influence whether they are more or less easily disturbed by noise (Lercher, 1996; Herranz et al., 2010). The activities recorded in our participants' activity diaries are divided into four main categories. The first category includes study and work. These activities involve more attention and are more easily interfered with by noise. The second category includes maintenance activities such as cleaning, preparing meals, and taking care of children or family members. These activities are assumed to be not easily interfered with by noise. The third category includes shopping and recreational activities that primarily include watching TV, using the phone and social media, and visiting friends or relatives for our participants. Note that Herranz et al. (2017) has found that when people are undertaking recreational activities that make them happy and relaxing, they tend to have a higher tolerance for noise. This category of activity is assumed to be least bothered by noise. The last category is sleep, which is an indispensable activity for each of our participants and sleep disturbance is one of the major health concerns of noise (World Health Organization, 2011). Thus, sleep activity is treated as a unique group.

The presence of companion(s) when conducting an activity is treated as a binary variable in this analysis: alone and with others. Bild et al. (2018) have found that solitary participants are more likely to be disturbed by noise when compared to their socially engaged counterparts in urban parks.

2.2.2.2 OBJECTIVE MEASURES OF SOUND

The actual sound levels of each activity for each participant were calculated based on every one-minute sound levels that are recorded by the sound sensors through aggregating these records over the time duration of each activity into an equivalent sound level. It follows the calculation of A-weighted equivalent continuous sound level of each activity ($L_{Aeq, Activity}$). $L_{Aeq, Activity}$ is based on a similar idea as the A-weighted equivalent continuous sound level over a period of time ($L_{Aeq,T}$), which is widely used to evaluate continuous environmental sound (World Health Organization, 1999). $L_{Aeq,T}$ is calculated using a logarithm function to aggregate the fluctuating sound levels over a period of time T (Passchier-Vermeer and Passchier, 2000). It transforms the every-minute A-weighted sound levels through exponentiation, computing the arithmetical average, and logarithm for the A-weighted equivalent continuous sound levels. $L_{Aeq,Activity}$ further considers the time period

T as the duration of each activity and it is calculated based on Formula (1) introduced by Neitzel et al. (2004), where n_{ij} is the number of minutes that subject *j* conducted activity *i*. L_{Aeqijk} is the per-minute A-weighted sound level recorded by the sound sensor for subject *j* with activity *i* at time *k*. Other calculations are similar to the calculations of $L_{Aeq,T}$, with the transformations of exponentiation, arithmetical average, and logarithm.

$$L_{Aeq_{A_{ij}}} = 10\, lg \frac{1}{n_{ij}} \sum_{K=1}^{N} 10^{0.1*L_{Aeq_{ijk}}} \qquad (1)$$

2.2.2.3 SUBJECTIVE EVALUATIONS OF SOUND

With respect to subjective sound, the study asked participants the question "Is noise a problem?" when they were performing each activity. The reason why we did not ask participants to rate the sound level is that we intend to assess the relationships between activity-related contexts, objectives sound, and subjective sound in natural daily situations. Instead of soliciting participants' self-rated subjective sound levels, we focus on whether the sound interfered with their activities or whether they did not even notice the sound while they were undertaking different kinds of daily activities. In this way, participants could focus more on their daily activity experiences rather than trying to specify the subjective sound levels (Bild et al., 2018). It thus helps to minimize the attentive listening triggered by sound-specific questions (Botteldooren et al., 2016). In the activity diaries, subjective noise is scored from 1 to 4, 1 means "noise is not at all a problem". From 2 to 4, the level of noise is a problem: "a slight problem" (2) to "a moderate problem" (3) to "a major problem" (4). In the analysis reported below, these are recoded into a binary variable as "noise is or is not a problem for an activity".

2.2.3 STATISTICAL ANALYSIS

Multilevel logistic regression was employed to examine how objective measures of sound and activity-related contexts are related to subjective evaluations of sound due to the following reasons. First, since subjective sound is the dichotomous response variable (i.e., "noise is/ is not a problem"), a logistic model is needed to constrain estimates of the dependent variable to values ranging from 0 to 1. Second, since the analysis is based on participants' activities and each participant performed more than one activity, the activity records are not independent (i.e., some activities were performed by the same participant). This violates the assumption of regression models that every observation (activity) is independent of each other. Thus, a multilevel design is needed. This analysis employed a two-level multilevel model that includes individual-level socio-demographic data and activity-level characteristics. The multilevel logistic regression modeling was implemented using Ime4 package in R.

2.3 RESULTS

2.3.1 DESCRIPTIVE ANALYSIS

This analysis focuses on the relatively low-income minority populations in a suburban area in the study area. As observed in past studies, these population groups are often exposed to higher levels of environmental pollution and health risks (Morello et al., 2001; Evans and Kantrowitz, 2002). The key demographic characteristics of the 33 participants are shown in Table 2.1. Over half of them are Hispanics. A majority of the participants is relatively low-income and rents apartment, which is because we recruited our participants largely from low-income housing (apartments) in the Humboldt Park neighborhood in Chicago with the help of a non-governmental affordable housing organization. About sixty percent of the participants do not have a regular job.

Table 2.1 Key Demographic characteristics of the 33 participants

Variables	Categories	Count	Proportion (%)
Gender	Female	15	45%
	Male	18	55%
Race	White American	2	6%
	African American	13	39%
	Hispanic American	18	55%
Education	High School and less	19	58%
	College and higher	14	42%
Age	18-24	2	6%
	25-34	5	15%
	35-44	5	15%
	45-54	8	24%
	55-65	11	33%
Income	$35,000 and lower	24	73%
	$35,000 - $75,000	6	18%
	$75,000 and higher	1	3%
Employment	Unemployed	20	61%
	Employed	13	39%

Table 2.1 (cont.)

Variables	Categories	Count	Proportion (%)
Marriage Status	Married	4	12%
	Others (Single, Divorced, Widowed)	29	88%
Car Ownership	Not Own	24	73%
	Own	9	27%
Tenure	Rent	28	85%
	Buy	3	9%

Table 2.2 provides the mean values and standard deviation of both the objective and subjective sound of the 504 activities recorded in the survey in different groupings. It shows that when participants are conducting activities during day time, the mean values of both the actual and the subjective sound tend to be higher than those during the night time. This indicates that attention should be given not only to sound during the evening and night hours but also to more details of how individuals are exposed to sound during the day time. Further, when people are conducting activities at locations other than home or workplace, the mean values of both the actual and the subjective sound scores are higher compared to those at home and workplace. This indicates that examining sound only at home or work locations is inadequate; instead, sound at different geographic locations should be included. Moreover, when people are undertaking work or study-related activities, on average they are exposed to higher levels of actual and subjective sound than when they are doing other types of activities. Additionally, people experience higher average levels of actual and subjective sound when they conduct the activity with companion(s) than when they conduct the activity alone.

Table 2.2 Sound levels of the 504 activities in different contextual groupings

Variable	Category	Number of records	Mean of LAeq (dBA)	SD	Mean of Subjective Sound (1-4)	SD
Activity Location	Home	371	54.5	10.7	1.3	0.5
	Work	25	58.5	8.8	1.5	0.5
	Other Locations	108	61.4	8.7	1.8	0.8
Activity Time	Day	316	58.4	10.2	1.6	0.7
	Evening	91	54.4	9.6	1.3	0.5
	Night	97	50.9	10.7	1.2	0.5
Activity Companion	Alone	306	53.7	10.4	1.3	0.6
	With Others	198	60.0	9.8	1.6	0.7

Table 2.2 (cont.)

Variable	Category	Number of records	Mean of LAeq (dBA)	SD	Mean of Subjective Sound (1-4)	SD
Activity Type	Study/Work	33	59.7	9.2	1.8	0.9
	Maintenance	237	57.7	10.8	1.5	0.6
	Recreation/ Shopping	126	57.6	9.9	1.4	0.6
	Sleep	108	50.4	9.4	1.2	0.4

Note: SD refers to standard deviation.

Table 2.3 shows more information about activity companions, objective sound and subjective sound. Note that activities conducted with children and other persons are the two categories with the highest average subjective sound scores. Among the 23 records of activities conducted with children, 20 are maintenance activities that include taking care of children while performing other housework such as cleaning their apartment or cooking meals. Other such activities mainly include taking care of children such as picking up the children at school, helping the children in taking a shower, and getting ready for bed. These results suggest that either taking care of children or doing housework with an eye on the children can sometimes lead to pressure, and in these situations, people are more easily bothered by noise. It is also interesting that activities conducted with other people are frequently associated with more noise problems. Potentially, people could have a lower tolerance for an annoying sound produced by other persons compared to that produced by their family members, relatives, or friends.

Table 2.3 Details of Activity Companions, and Objective and Subjective Sound

Categories of Companions	Number of records	Mean of LAeq (dBA)	SD	Mean of Subjective Sound	SD
Alone	306	53.7	10.4	1.3	0.6
Children	23	57.3	9.6	1.7	0.6
Family and Relative	124	60.2	10.5	1.6	0.6
Friend	29	59.6	7.1	1.3	0.6
Other People	22	62.1	8.9	2.0	1.0

Note: SD refers to standard deviation.

Table 2.4 shows more information about activity locations, objective sound and subjective sound. Noticeably, there are only 15 records of outdoor activities, with the remaining 489 activities having been conducted in indoor microenvironments. At places such as shopping malls and grocery stores, although the actual sound levels are relatively high, individuals do not consider the sound as annoying noise. One possible explanation is that when people are indoor in shopping malls or grocery stores for shopping or recreational activities, their attention is drawn by attractions other than the sound in the environment. In addition, urban residents regard the sounds of music and crowds as part of commercial activities. People tend to perceive these sounds positively rather than considering them as noise problems. It also shows that individuals may have certain expectations of their surrounding sound according to the normal usage of various types of spaces. Those places that are supposed to be quiet such as hospitals and health centers, higher levels of sound can easily bother people's activities and be perceived as annoying noise. For instance, in hospitals or clinics where individuals expect to have quiet healthcare service, the same levels of actual sound as other non-healthcare locations can be regarded as noise in these so-called quiet places.

Table 2.4 Details of Activity Locations, Objective and Subjective Sound

Categories of Locations	**Number of records**	**Mean of LAeq (dBA)**	**SD**	**Mean of Subjective Sound**	**SD**
Home	372	54.5	10.7	1.3	0.5
Workplace	25	58.5	8.8	1.5	0.5
Bank, School, Church	14	57.0	8.0	1.9	0.6
Grocery Stores	24	63.8	8.0	1.7	0.6
Restaurants	15	62.1	8.7	1.9	0.7
Outdoor	15	58.9	10.8	1.8	1.0
Hospital, health Center	8	64.2	6.5	2.1	1.0
Friend's House	25	60.1	7.7	1.6	0.9
Shopping Mall	6	68.2	8.4	1.7	0.5

Note: SD refers to standard deviation.

2.3.2 MULTILEVEL LOGISTIC MODELING RESULTS

Multilevel logistic models reveal the extent to which subjective evaluations of whether a sound is noise due to activity-level actual sound levels and activity-related contexts. Table 2.5 presents the random and fixed effects in two random-intercept multilevel logistic regression models in explaining subjective sound. Model 1 considers individual characteristics and actual sound levels of each activity. Model 2 further adds four categorical variables in terms of activity-related contexts. It is notable that when adding the activity-related contexts variables, the actual sound levels of each activity are no longer statistically significant. This suggests that adding the activity-related contextual variables eliminates the significance of the actual sound levels in explaining subjective sound. In other words, activity-related contexts including activity time, activity location, activity type, and the presence of companion(s) play more significant roles in explaining subjective sound. Although individual characteristics including race, education and gender are insignificant determinants of participants' subjective evaluations of sound, these variables are important covariates that should be controlled.

The individual-level variance indicates the random effect of each model, which is unexplained variation at the level of individuals after controlling for the explanatory variables. The higher individual-level variance indicates the larger variation between individuals in explaining the response variable (i.e., subjective evaluations of sound). The individual-level variance, which is equal to 4.22 in the final model (Model 2), indicates a relatively large variation between individuals in their subjective evaluations of whether a sound is noise. The residual intra-class correlation coefficient can be interpreted as the proportion of remaining variance due to individual differences after controlling for the explanatory variables (Snijders and Bosker, 2012). The residual intra-class correlation, which is equal to 0.56 in Model 2, indicates that the variance of about 56% is influenced by individual differences and the other 44% is affected by the activities performed by the same individual in explaining subjective sound.

In terms of the significant variables in the final model (Model 2), there are several major findings. First, when other variables are controlled, the odds of a participant considering noise as a problem when conducting an activity during daytime is 4.432 times of that during nighttime. A possible reason is that during daytime, participants undertook more activities and were exposed to more sources of sound. Further, the diverse sources of sound for the participants during the daytime are often unexpected, and they might have limited control of the noise. In contrast, during nighttime, participants spent most of the time sleeping at home, and as a result, there are far fewer noise sources when compared with that during daytime. Thus, participants were more easily disturbed by noise during daytime than during night time. This result has an important implication: while past studies have paid much attention to the sleep disturbance caused by noise during nighttime, interferences by noise when conducting daytime activities, given its significant influence on subjective sound, should also be examined.

Second, the odds of a participant considering noise as a problem when conducting an activity with companion(s) is 1.692 times of that when the participant is alone. This is different from the findings of a previous study that focused on recreational activities in urban public parks (Bild et al., 2018). That study found that activities conducted with others contribute more to people's pleasant experiences of sound. However, our study observed that the presence of companion(s) when conducting daily activities does not necessarily contribute to participants' pleasant experiences of sound in different daily life situations. The content and purpose of social interactions matter. For example, as mentioned above, household activities and personal affairs conducted with children or other persons can generate more pressure and less tolerance for noise.

Third, when other variables are held constant, the odds of a participant considering noise as a problem at locations other than workplace or home is 4.896 times of that when compared with that when the participant is at home. One possible explanation may be that after years of residence, individuals may become familiar with and accustomed to the sound at home. In contrast, at locations other than the workplace or home, there are more sources of noise and some of them are unexpected or unpredictable. Furthermore, individuals tend to have less control over the sources of noise at locations other than the workplace or home when compared to the sources of noise at their home.

Lastly, compared to the odds of a participant considering noise as a problem during a study or work-related activity, the odds of that during a maintenance activity, sleep, and a recreational or shopping activity is 0.263 time, 0.222 times, and 0.177 times, respectively. This suggests that when people are conducting recreational and shopping activities, they are least likely to be disturbed by noise. This is consistent with the finding of Herranz et al. (2017) that when people are doing recreational activities that make them happy and relaxing, they have more tolerance for noise. When people are conducting work and study-related activities, they are most likely to be disturbed by noise, even compared to when they are sleeping. Potentially, this is because the activity of sleep is associated with a relatively low level of actual sound levels, and sleep mainly happens at people's own home where noise is easier to predict and control. Work and study-related activities usually happen at other locations where the actual sound levels are relatively high, and participants have relatively low control of the sources and volume of sound.

Table 2.5 Detailed Results of the Multilevel Logistic Modeling

Models / **Variables**		**Model 1**		**Model 2: Final Model**			
		Est.	S.E.	Est.	S.E.	Odd Ratio	95% Confidence Interval
Intercept		-2.389	1.033	-0.032	1.450	0.969	0.057-16.616
Race	Hispanic	Reference		Reference		1.000	Reference
	Non-Hispanic	-0.233	0.671	-0.185	0.845	0.831	0.159-4.352
Education	High School and Below	Reference		Reference		1.000	Reference
	Beyond High School	-0.469	0.685	-.0.489	0.861	0.614	0.113-3.319
Gender	Female	Reference		Reference		1.000	Reference
	Male	-0.671	0.655	-0.504	0.827	0.604	0.119-3.052
Actual Sound Level		0.039**	0.013	-0.009	0.016	0.991	0.960-1.022
Activity Time	Night Time			Reference		1.000	Reference
	Evening Time			0.269	0.456	1.308	0.536-3.195
	Day Time			1.489***	0.443	4.432	1.861-10.552
Activity Location	Home			Reference		1.000	Reference
	Work			-0.404	0.744	0.668	0.155-2.868
	Other location			1.588***	0.392	4.896	2.269-10.561
Activity Companion	Alone			Reference		1.000	Reference
	With Others			0.526*	0.311	1.692	0.920-3.112
Activity Types	Work/Study			Reference		1.000	Reference
	Maintenance			-1.334**	0.669	0.263	0.071-0.977
	Recreation/ Shopping			-1.731**	0.710	0.177	0.044-0.713
	Sleep			-1.505**	0.754	0.222	0.051-0.975

Table 2.5 (cont.)

Models	Model 1	Model 2: Final Model
Individual-level Variance	2.57	4.22
Residual Intra-class Correlation Coefficient	0.43	0.56
Number of Variables	6	14
Degree of freedom	498	490
Log Likelihood	-270.4	-236.4
Deviance	540.7	472.8
AIC	552.7	500.8
BIC	578.1	559.9

Note: (1) Est. indicates parameter estimate and S.E. indicates standard error.
(2) Significance level: *** P-Value < 0.01, ** P-Value < 0.05, * P-Value < 0.1.

2.4 DISCUSSION

This chapter explores the relationships between objective sound measured by real-time sound sensors and subjective sound perceived by individuals as they perform their daily activities. It finds that activity-related contexts that include activity location, activity time, activity type, and the presence of activity companion(s) play significant roles in influencing individuals' subjective evaluations of sound. When activity-related contexts are taken into account, the actual sound levels that individuals are exposed to when performing an activity is no longer significant in influencing their subjective evaluations of sound. This supports the notion that sound is not just a physical feature but also a socio-psychological percept, and as a result, actual sound levels can only explain a very limited amount of noise annoyance people experienced in their daily life (Lercher and Schulte-Fortkamp, 2003; Marquis-Favre et al., 2005). Instead, the subjective evaluations of whether a sound is noise depend highly on specific activity-related contexts.

This chapter has several conceptual contributions. First, it contributes to a people-based approach to assessing individuals' objective exposure to and subjective evaluations of sound in different urban environments. While conventional place-based soundscape studies focus on sound in outdoor environments in urban open spaces and public parks (Bild et al., 2016; Bild et al., 2018), this chapter provides more accurate assessments of person-specific sound exposures at different geographic locations and times both indoors and outdoors. This greatly enriches our understanding of human-centric soundscapes through emphasizing how individuals undertake their daily activities and how they perceive sound as they perform their daily activities.

Second, this chapter argues that adopting an activity-based and time-geographic approach advances understanding of the emerging activity-centric framework in soundscape studies. The activity-based and time-geographic approach provides a powerful space-time perspective to enhance our understanding of people's daily activities and their objective exposures to and subjective evaluations of sound at the level of each person's daily activities. This helps us develop an analytical framework that can be used in future studies for understanding various activity-related contexts and their different effects on subjective sound.

Based on the analytical framework of the activity-related contexts, this chapter contributes to the empirical findings of soundscape studies. While previous studies have widely discussed noise problems at home or work location (Miedema and Vos, 1998; Ouis, 2001; Basner et al., 2014), this chapter argues that other locations at which individuals undertake their daily activities are also important, since at these locations other than home and workplace, people are more easily disturbed by noise. Similarly, individuals' activities during daytime should also be considered since they are more easily bothered by noise when compared to those activities during night time.

Further, previous studies have shown that solitary respondents have higher levels of disruption due to the surrounding noise when compared to socially engaged respondents in urban public parks (Bild et al., 2016; Bild et al., 2018). However, this analysis has a different finding: when individuals conduct daily activities with others, they tend to be more easily bothered by noise when compared to when they are alone. The different findings are potentially due to the different activity-related contexts. For instance, Bild et al. (2018) focused on socially engaged respondents who perform recreational activities with friends in pleasant environments such as urban parks, which increase their tolerance for noise. Alternatively, our study considers participants' diverse daily activities with different companions at multiple locations. Specifically, our study finds that when people are undertaking maintenance activities such as doing household (especially when they have to fulfill other responsibilities at the same time, such as taking care of their children or companions), they are more easily disturbed by noise. Thus, the purpose of activities, type of companions, the specific situations, and individuals' tolerance for noise can make a difference in individuals' subjective perceptions and evaluations of sound. It is therefore essential to understand the effects of diverse activity-related contexts on individuals' evaluations of sound in urban environments.

In addition to conceptual contributions, this chapter also makes methodological advancements through integrating methods of activity diaries, GPS tracking, and real-time sound sensing. First, the mixed methods enable us to collect accurate individual-based and person-specific data of objective measures and subjective evaluations of sound during participants' daily activities. A relatively standard protocol to collect data and cross-validation among different datasets improve the accuracy of data collected from each participant. This further contributes to a dynamic approach to capturing individuals' daily activities and the spatiotemporal dynamics of sound in various urban microenvironments, which helps mitigate the uncertain geographic context problem (Kwan, 2012, 2018). Second, the mixed methods provide contextualized information about individuals' actual exposures to and subjective evaluations of sound as their life unfolds in real-life settings and situations. This contributes to existing methodologies of *in-situ* soundscape evaluation studies by capturing the complexity of and richness in people's activities and sound-related phenomena in their everyday life. Last, by using multilevel modeling that considers both individual-level and activity-level data, it helps control individual-level differences in subjective evaluations of sound and examine the associations between individual-level demographic data and activity-level contextual and sound-related data.

The results of this chapter also have important practical implications for multisensory, human-centric, and context-aware urban planning and development. First, sound is an integral part of the urban environment. In addition to vision-based urban design, urban designers and planners should create restorative urban sound and encourage positive sound-related urban experiences. Second, urban planners should respect urban residents' diverse perspectives of sound and increase urban residents' participation in the process of planning and designing sound-related urban environments. In addition to mapping actual noise levels and implementing noise control policies, urban planners should also be sensitive to how urban residents perceive sound during their daily activities and how sound disturbs or supports certain activities in urban environments. Third, it is crucial to adopt a contextual approach to managing sound-related urban environments according to urban residents' perceptions of sound in diverse contexts. It is important to understand in what circumstances a sound is perceived as noise by different urban residents as their daily activities unfold at specific geographic locations and time. This provides valuable guidance for improving urban environments, facilitating urban residents' daily activities, and constructing livable and healthy cities.

2.5 CONCLUSIONS

This chapter adopts an activity-based and time-geographic approach to developing an activity-centric framework for understanding the effects of activity-related contexts on people's perceptions and evaluations of sound in urban areas. These activity-related contexts include individual attributes, activity type, the presence of companion(s), activity time, and activity location of each activity. This chapter has shown that whether a sound is perceived to be noise largely depends on the specific activity-related context. When considering the activity-related context, the actual sound levels of each activity of an individual are no longer significant in influencing his/her subjective evaluations of sound. When controlling the actual sound levels of each activity, different aspects of the activity-related contexts significantly are associated with individuals' subjective evaluations of sound. When individuals are undertaking a work- or study-related activity, and when they are undertaking an activity during daytime, at other locations other than home and work, or with companion(s), they have a higher tendency to consider their ambient sound as noise.

This research has several limitations that need to be addressed in future studies. Given the difficulties involved in collecting individual-level GPS data (e.g., costly, time-consuming, labor-intensive, and privacy concerns), the sample size of the analysis is small. However, the study is still fruitful in that it shows that the conceptual framework and innovative mixed methods are useful for enhancing our understanding of urban soundscapes. More studies with larger samples utilizing the analytical framework and methods proposed in this article are needed to further corroborate the findings of this research. Second, considering the rich socio-cultural meanings associated with sound that may also influence individuals' perceptions of sound, comparative studies of different socio-cultural contexts should be conducted to further enrich our understanding of the role of activity-related contexts in different socio-cultural backgrounds. Third, qualitative methods can be used to provide a more contextualized and nuanced understanding of how individuals perceive sound differently in diverse urban environments.

CHAPTER 3: HOW INDIVIDUAL NOISE EXPOSURE INFLUENCES PSYCHOLOGICAL STRESS: A STUDY USING REAL-TIME GEOGRAPHIC ECOLOGICAL MOMENTARY ASSESSMENT (GEMA) APPROACH[1]

3.1 INTRODUCTION

Noise is prevalent in everyday life. Industrialization and urbanization bring about diverse sources of noise, such as industrial, construction, traffic, and recreational activities. Noise poses threats to human health. Acute and chronic noise exposure can generate both physiological and psychological stress, which can further lead to stress-related symptoms such as cardiovascular diseases (e.g., hypertension, ischemic heart diseases, and stroke) and mental disorders (Babisch, 2002; Basner et al., 2014; Dzhambov et al., 2017). Associations of noise exposure with physiological stress have been well observed, which include higher levels of blood pressure, heart rate, and stress hormones such as epinephrine, norepinephrine, and cortisol (Evans et al., 2000; Babisch, 2002; Basner et al., 2014; Walker et al., 2016). However, what is less known is the relationship between noise exposure and psychological stress.

Studies on noise exposure and its effect on psychological stress have focused primarily on children and yielded inconsistent findings. Some have shown significant associations between noise exposure and psychological stress. For instance, both Evans et al. (2000) and Haines et al. (2001) observed that chronic exposure to aircraft noise was associated with higher levels of psychological stress in children. In contrast, Stansfeld et al. (2005) and Clark et al. (2013) found that children's chronic exposure to traffic noise was insignificantly associated with psychological stress. Considering the inconsistent findings and the prevalence of noise exposure among adult populations, more studies on noise exposure and psychological stress among adults are needed.

Several conceptual and methodological issues may explain the inconsistent findings of the associations between noise exposure and psychological stress. Specifically, past studies on noise and psychological stress tend to assume that objectively measured sound level is the most relevant characteristic for examining the health effects of noise exposure (Haines et al., 2001). However,

[1] Reprint, with permission, from Kou, L. R., Tao, Y. H., Kwan, M. -P., & Chai, Y. W. (2020). Understanding the relationships among individual-based momentary measured noise, perceived noise, and psychological stress: a geographic ecological momentary assessment (GEMA) approach. Health & Place, forthcoming.

in addition to objectively measured noise, subjectively perceived noise also seems to play a crucial role in influencing people's psychological health (Lercher, 1996; Passchier-Vermeer and Passchier, 2000; Lercher and Schulte-Fortkamp, 2003; Ma et al., 2018). Studies have noted that the same level of measured sound can be subjectively perceived as noise by some but not by others, which can lead to different extents of adverse effects on people's psychological health (Westman and Walters, 1981; Walker et al., 2016). Although people's subjective evaluation of or reaction to noise has been defined as "noise annoyance" (Schultz, 1978; Fields, 1993), it has been frequently considered as an outcome of people's objective noise exposure (Evans et al., 2000; Haines et al., 2001; Stansfeld et al., 2005). Instead, recent studies have argued for the use of "subjective noise" as a term to more comprehensively understand people's subjective perception and evaluation of noise (Lercher and Schulte-Fortkamp, 2003; Schulte-Fortkamp and Fiebig, 2006). It focuses on people's subjective perceptions of whether a sound is noise and whether the noise interferes with their daily activities and social interactions (Bild et al., 2018). In addition, although noise annoyance is revealed as a mediator between noise exposure and people's psychological stress (Babisch, 2002; Van Kamp and Davies, 2008; Riedel et al., 2015; Klompmaker et al., 2019), the potential direct and indirect pathways of how objectively measured and subjectively perceived noise influence people's psychological stress remain unknown and require further investigation.

Another conceptual issue is that existing studies have largely neglected the role of contexts in influencing the relationships among objectively measured noise, subjectively perceived noise, and psychological stress levels. Although studies have revealed that both personal and situational characteristics may influence people's noise exposure and its related health outcomes (Leather et al., 2003; Walinder et al., 2007; Basner et al., 2014), there is a lack of clear conceptual knowledge of how to understand contexts and their effects on individuals' noise exposure and psychological health (Van Kamp and Davies; 2008). Only a few studies have considered the potential role of contexts in influencing individuals' perceptions of noise and psychological stress. For example, Lercher (1996) found that when people conducted different types of daily activities, they were more or less easily interfered with by noise, leading to different effects on their health. For instance, Bild et al. (2016) found that when people performed particular activities at different times of a day with different purposes, they had different perceptions of the surrounding sound and moods. Besides, Bild et al. (2018) revealed that those respondents who conducted activities alone in urban public parks were more easily disturbed by the surrounding noise when compared to their socially engaged counterparts. In addition, Mennis et al. (2018) have noticed that psychological stress is influenced by the activity and social contexts in which the respondents are engaged at that moment. Certain types of daily activities and social interactions in different geographic locations and times can influence people's psychological stress. Therefore, more studies are needed to conceptualize context and examine the mechanisms through which context influences individuals' objective noise exposure, subjective noise perception, and psychological stress.

In addition to these conceptual issues, two methodological issues help further explain the inconsistent findings of past studies on the relationship between noise exposure and its health impacts. First, previous studies have mainly focused on individuals' chronic noise exposure to a specific source of noise (e.g., aircraft, railway, or road traffic) at a particular geographic location (e.g., home, workplace, or school) (Evans et al., 2000; Basner et al., 2014; Klompmaker et al., 2019). However, as individuals move around to undertake their daily activities and trips in their everyday life, they are exposed to diverse sources of noise in multiple geographic locations and contexts (e.g., work, school, a grocery store, on a bus, or in a car) (Kwan, 2009, 2013). The neglect of individuals' daily movement and the spatiotemporal dynamics of environmental pollutants is a major source of the uncertain geographical contextual problem (UGCoP) and the neighborhood effect averaging problem (NEAP) (Kwan, 2012a,b; Kwan 2018b), which may lead to erroneous assessments of individuals' environmental exposure and its health impacts (Park and Kwan, 2017; Kwan, 2018a; Ma et al., 2020). To address these methodological issues, recent studies have increasingly advocated a dynamic approach that incorporates the spatiotemporal dynamics of people's daily movements and environmental pollutants to more accurately examine the relationships between individual-based environmental exposures and health outcomes (Perchoux et al., 2013; Yoo et al., 2015; Park and Kwan, 2017; Helbich, 2018). Therefore, taking into account people's daily mobility when examining individual-based and person-specific noise exposure helps to mitigate the UGCoP and the NEAP, which in turn would help improve the accuracy in assessments of the relationships between noise exposure and psychological stress.

Another methodological issue is that previous studies have mainly used self-reported recalled survey questionnaires and retrospective assessments to examine individuals' psychological stress

(Evans et al., 2000; Haines et al., 2001). Although recalled surveys can help understand the relationships between chronic noise exposure and the overall state of individuals' psychological stress (Mackensen et al., 1999), they can be biased when examining the relationships between momentary noise exposure and psychological stress in the short run because both noise exposure and psychological stress are highly dynamic. Considering that the accumulation of daily momentary psychological stress can further cause mental health problems (Van Kamp and Davies, 2008; Klompmaker et al., 2019), individuals' momentary psychological stress should be taken into account. However, very few studies to date have considered the extent to which objectively measured and subjectively perceived noise levels influence people's momentary psychological stress. Therefore, more studies are needed to understand the relationships among individuals' momentary objectively exposed noise, subjectively perceived noise, and psychological stress.

Based on these considerations, the development of geographic ecological momentary assessment (GEMA) provides new opportunities to solve the methodological issues and bridge the conceptual gaps of existing studies. GEMA integrates conventional ecological momentary assessment (EMA) with global positioning systems (GPS). EMA is a collection of methods for obtaining repeated assessments of respondents' real-time behaviors, perceptions, feelings, emotions, and stress levels (Schwartz and Stone, 1998). It involves prompting respondents to respond to short questionnaires, often using mobile phone applications, in their usual environments at different time intervals per day throughout the study period (Li et al., 2018; Beute and De Kort, 2018). By collecting real-time repeated measurements from people's real-life situations, EMA minimizes recall bias and maximizes ecological validity (Shiffman et al., 2008; Shiffman, 2009; Reis, 2011). Through linking EMA surveys with geographic coordinates, GEMA further provides rich data of individuals' real-time geographic context, and this greatly facilitates the study of individuals' health-related behaviors and outcomes (Mitchell et al., 2014; Kirchner and Shiffman, 2016; Mennis et al., 2018). Further, recent studies have aligned GEMA with activity-travel diaries and portable environmental sensors (Wel et al., 2017; Chaix, 2018). Portable environmental sensors collect high-resolution spatiotemporal data of individuals' real-time exposure to environmental pollutants. In addition, activity-travel diaries provide detailed information on activity contexts such as the type, companion, location, and time of the respondent's every activity and travel in a sequence over the 24 hours of a day (Chaix, 2018; Ellegård, 2018). Overall, these integrated approaches have great potential for more accurately assessing the relationships among individual-based real-time objective and subjective measures of environmental exposures and their impacts on individuals' psychological health while considering different activity- and travel-related contexts simultaneously (Wel et al., 2017). Yet, to our knowledge, these integrated approaches have not been used in studies on individuals' objective exposure to and subjective perception of noise, and their effects on people's psychological health.

Therefore, this chapter aims to utilize GEMA to understand both the direct and indirect relationships among individuals' momentary exposure to objectively measured noise, subjectively perceived noise, and their self-reported psychological stress. Specifically, it seeks to answer the following research questions: (1) How does momentary objectively measured noise influence a person's momentary psychological stress? (2) Is the relationship between momentary objectively measured noise and psychological stress mediated by momentary perceived noise? If so, how? (3) How does real-time context influence the relationship among momentary objectively measured noise, perceived noise, and psychological stress? The chapter attempts to enrich and deepen our knowledge of the relationships among people's spatiotemporal behaviors, environmental exposures, and psychological health. Moreover, it has practical value for urban design and planning as it can inform noise mitigation and mental health improvement strategies for achieving more livable urban environments and healthy living.

3.2 METHODS

3.2.1 CONCEPTUAL FRAMEWORK AND HYPOTHESES

The conceptual framework of this chapter focuses on the relationships among contextual effects, momentary measured noise, perceived noise, and psychological stress, after controlling for variables of demographics and neighborhood socioeconomic environments (Figure 3.1). First, based on previous studies on measured noise and psychological stress (Evans et al., 2000; Haines et al., 2001), this chapter proposes that momentary measured noise has a direct positive effect on momentary psychological stress (Hypothesis 1). Second, in line with the literature on subjectively perceived noise and its effects on psychological health (Passchier-Vermeer and Passchier, 2000; Lercher and Schulte-Fortkamp, 2003; Ma et al., 2018), the chapter proposes that momentary perceived noise plays a mediating role in the relationship between momentary measured noise and momentary psychological stress (Hypothesis 2). Specifically, momentary measured noise increases momentary psychological stress through the mediation of increasing momentary perceived noise. Third, increasing studies have advocated a contextual approach to understanding the relationship between people's noise exposure and its health effects (Lercher and Schulte-Fortkamp, 2003; Schulte-Fortkamp and Fiebig, 2006), arguing that activity-related contexts can influence people's subjective perceptions of noise and psychological stress (Bild et al., 2016; Bild et al., 2018). Further, the time-geographic approach and the activity-travel diary method provide a well-established framework for understanding the contexts of people's daily activities and travels (Schwanen and Wang, 2014; Ellegård, 2018). Based on these theoretical considerations, this chapter hypothesizes that contextual effects, involving activity and travel context, social context, and temporal context, influence people's momentary measured noise, perceived noise, and psychological stress (Hypothesis 3).

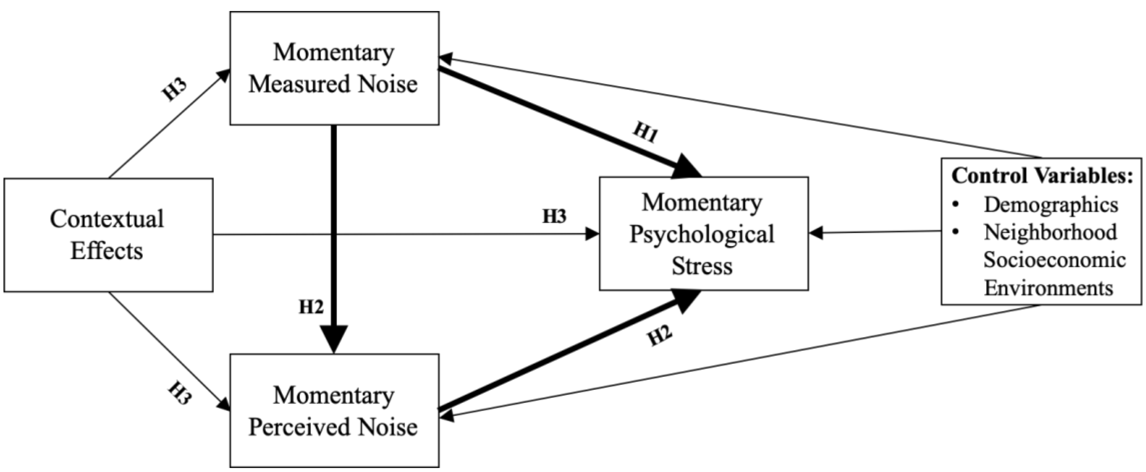


Figure 3.1 Conceptual Framework and Hypotheses

3.2.2 STUDY AREA AND DATA

The study area for this research is Beijing, the capital city of China. Beijing is a representative megacity of China since noise pollution has become a major environmental problem in Beijing with its dense population, increasing vehicles, and diverse sources of noise (Ma et al., 2018). This chapter focuses on the *Meiheyuan* community, which is located in the inner suburban area of the Fifth-Ring Road in northern Beijing (Figure 3.2). This community is a representative suburban neighborhood in Beijing because it is a mixed community with diverse housing types that include commercial housing, policy-related housing (including low-rental housing and public rental housing), and *danwei* housing (work-unit housing) that was allocated by work units to their employees at discounted prices (Shen et al., 2015). Residents in the community are from different socioeconomic backgrounds with diverse daily activity-travel behaviors, which can represent typical daily activity-travel patterns and everyday contexts of a majority of the residents in Beijing (Shen et al., 2015). Further, the community is adjacent to diverse sources of noise that include a highway, a railway, the metro, and several construction sites (Figure 3.2). Using the *Meiheyuan* community as a case study, we aim to examine the variations in individual-based noise exposure, daily activity-travel behavior, and the psychological stress of residents who live in the same residential neighborhood.

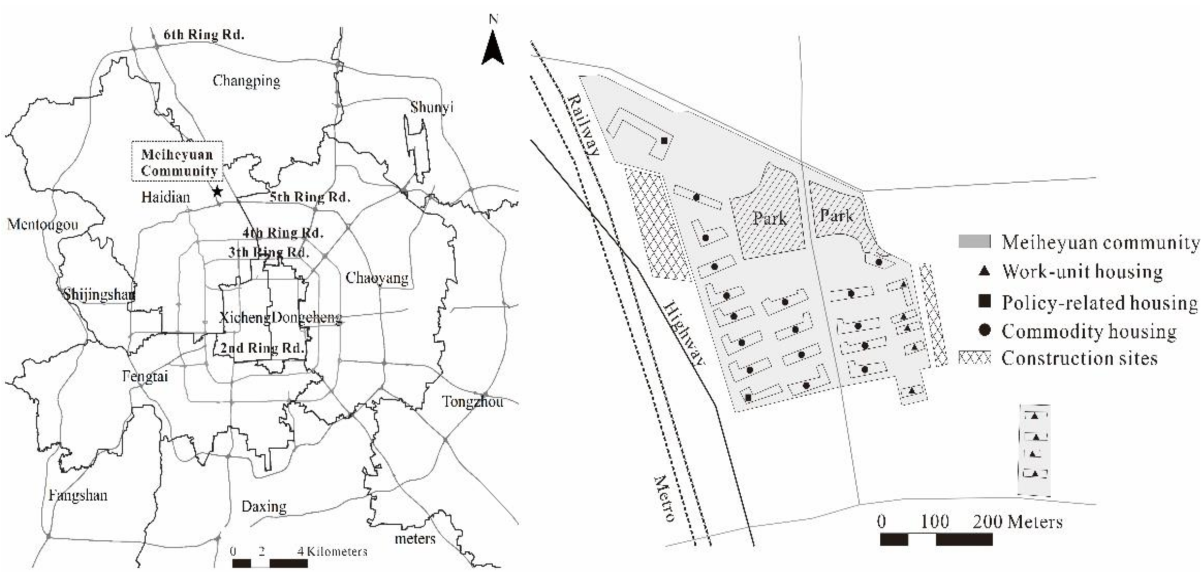


Figure 3.2 The Study Area

The data were collected in *Meiheyuan* community in Beijing from December 2017 to February 2018. Due to the limited number of instruments for measuring individual-based noise level and GPS trajectories in the study, we intended to recruit a sample of 120 participants who are 18 to 60 years old and have resided in the community for over 1 year. To ensure the representativeness of the study population, we used a stratified sampling approach, with about 2.0% of the population in each housing type of the community sampled. Specifically, according to the proportion of the number of residents in each housing type, we planned to recruit 72, 24, and 24 participants respectively from commercial housing, policy-related housing, and work-unit housing. We randomly selected the participants based on their building and apartment number, with the help of the community residential committee. If a potential participant failed to respond three times, we moved on to the next one until we reached the planned number of participants for each housing type. A total of 112 participants completed the survey, of which 101 responses were valid. The invalid responses include those with unstable signals and GPS recordings (3 participants), damages of the noise sensors (2 participants), and responses to the GEMA messages less than 6 times in the two-day survey (6 participants).

In the survey, a GPS tracking device, a portable noise sensor, a set of EMA survey questions, an activity-travel diary, and a survey questionnaire were used together to collect data on each participant's real-time measured noise, perceived noise, psychological stress, and contexts for a weekday and a weekend day (e.g., Friday and Saturday or Sunday and Monday). Specifically, each participant was asked to carry a GPS-equipped mobile phone and a portable noise sensor to collect real-time data of his/her geographic locations and objectively measured noise levels over a continuous period of 48 hours for the two survey days. The GPS-equipped mobile phone recorded participants' movement trajectories at a resolution of 1 meter or 3 seconds, whichever came first. The portable noise sensor is a data-logging sound level meter and meets the standard of IEC61672 Type 2 and ANSI S1.4 Type 2 Sound Level Meter with an accuracy of < 1.5dBA error and a measurement range from 30 to 130 dBA. The portable noise sensor logged every minute's A-weighted decibels (dBA) of participants' surrounding noise. Each noise sensor was calibrated using a CEM SC-05 Sound Level Calibrator at both C-weighted and A-weighted 94dB and 114dB to ensure accuracy before distributed to a participant.

Further, participants were also required to respond to several single-choice GEMA questions that involved their perception of the current noise problem and psychological stress using their mobile phone. This chapter used a time-based GEMA assessment (Shiffman et al., 2008), sending the GEMA messages to participants at 9 AM, 12 PM, 4 PM, and 8 PM respectively for the two survey days. The four times respectively represent the morning, noon, afternoon, and evening of a day. The rationale of selecting these four times is to cover the diversity of individuals' spatiotemporal behaviors, contextual effects, objective and subjective noise exposures, and psychological stress levels at different times across a day. There are 709 GEMA responses received from the 101 valid respondents. With inconsistent protocols of defining the valid GEMA responses in existing studies (Beute et al., 2018; Mennis et al., 2018), only those GEMA responses that were answered within an hour of each prompt were included in our analysis to better compare among individuals at similar times of a day. In total, 680 valid GEMA responses from the 101 respondents were included in the analysis. For each respondent, they responded to the GEMA questions for 6-8 times, with an average of 6.7 times, during the two survey days.

Besides, participants also recorded activity-travel diaries that included the start time, type, companion, and location of activities and travels according to the temporal sequence in which they were undertaken during the 48 hours of the two survey days (Kwan, 1999). The detailed information about each activity and travel was recorded using single-choice questions with a wide range of choices, together with an option for participants to fill in their answers if no choices applied. The diverse choices were based on the time-geographic diary method, which has a well-developed activity and travel categorization scheme that is rooted in individuals' everyday lives (Ellegård, 2018). In addition, participants also completed a questionnaire that collected their demographic information and self-reported health status. Participants were trained in briefing sessions before data collection to ensure that they fully understand all the procedures of the entire survey. Each participant signed an informed consent form before the survey.

After the data were collected, the data of each participant's activity-travel diaries were cross-validated and corrected based on the precise spatiotemporal information from his/her GPS trajectories to ensure the accuracy of the input of their activity-travel diaries. Further, based on a unique identifier of each participant and the precise time of each EMA response, we integrated the data collected from the EMA survey questions, GPS trajectories, portable noise sensors, and activity diaries. Specifically, the integrated data included information on participant ID, a specific time, geographic coordinates, momentary measured noise, momentary perceived noise, momentary psychological stress, real-time contexts, and demographic and neighborhood socioeconomic attributes.

3.2.3 MEASURES

Momentary measured noise was calculated based on an average value over a 5-minute time window before the time point of each of the participants' GEMA responses. The average noise level over the 5-minute time window was calculated using the formula of $L_{Aeq, T}$. $L_{Aeq,T}$ is the A-weighted equivalent continuous sound level (L_{Aeq}) over a period of time T (Passchier-Vermeer and Passchier, 2000). In Formula (1) for calculating $L_{Aeq,T}$ (Rana et al., 2010), L_{PA} is every-minute A-weighted sound level, which is the reading of every-minute noise levels collected using the portable noise sensors. Its value follows a logarithm function. Therefore, to calculate the averaged value over a 5-minute time window, it is necessary to transform the every-minute A-weighted sound levels through exponentiation and then compute the arithmetical average. After computing the arithmetical average, logarithm (which is the inverse function to exponentiation) is used to transform the arithmetical average to the A-weighted equivalent continuous sound levels.

$$L_{Aeq,T} = 10 \lg \left(\frac{1}{T} \int_0^T 10^{0.1 L_{PA}}\, dt\right) \quad (1)$$

Both momentary perceived noise and psychological stress were assessed through short GEMA questions. Note that momentary perceived noise and psychological stress were not continuously measured in the course of a day, but they recorded individuals' perceptions at the four times per day when participants responded to the GEMA surveys. Given that GEMA messages required participants to respond to survey questions quickly and repeatedly during the survey period, short GEMA survey questions and simple measures have been found to be more valid in capturing the fluctuations of complex phenomena (Mennis et al., 2018). Momentary perceived noise was measured by a GEMA question "Is noise a problem now?". Participants were asked to rate using a 4-point scale ranging from "not at all", "slightly", "moderately", and "extremely a problem". Instead of asking participants to rate the levels of their surrounding noise and their noise annoyance, we used this question to first examine whether people's current surrounding sound was a noise, or they did not even notice the noise while they were undertaking their daily activities and travels; further, if it was a noise, whether the noise interfered with people's daily activities and social interactions (Schulte-Fortkamp and Fiebig, 2006). In this way, participants could focus more on the experiences of their daily activities and travels (Bild et al., 2018), which also helped to minimize the attentive listening triggered by noise-specific questions (Botteldooren et al., 2016).

Following other studies (Mennis et al., 2018; Beute and De Kort, 2018), momentary psychological stress was assessed through a GEMA question “How stressed are you now?” with 1-4 responses that range from “not at all”, “slightly”, “moderately”, and “extremely stressed”.

Information about real-time contexts was collected from the activity-travel diaries. According to the specific time point of each GEMA response, the details of each participant’s activity and travel at a particular time were connected with each GEMA response. Drawing upon the time-geographic approach (Ellegård, 2018), real-time contexts were categorized into three types, including activity and travel context, social context, and temporal context. An activity and travel context refers to the specific activity and travel types. It includes eight types of activity and travel in this chapter, which were adapted for the participants’ daily lives and based on the activity and travel categorization scheme in the time-geographic approach (Ellegård, 2018). It includes work and study, rest, maintenance, recreation at home, recreation at other locations, walk, public transportation, and car (Ellegård, 2018). Rest generally means taking a nap during a day. Maintenance activities involve personal care, taking care of a child and other family members, and household. Recreation at home involves watching TV and movies, dining, online entertainment, gathering with friends and families, and online shopping. Recreation at other locations involves dining at restaurants, online entertainment, physical exercise, and shopping at malls. Walk, public transportation, and car are the travel modes used by the participants. Public transportation mainly involves the bus, metro, and shuttle bus. The car includes those who are traveling in a car or taxi, and those who use this travel mode are mainly influenced by the surrounding noise inside the vehicle. The social context was categorized into being alone, with friends, and with families (Schwanen and Wang, 2014), since social companions can influence people’s perception of whether a sound is noise and their psychological stress level (Bild et al., 2018; Mennis et al., 2018). The temporal context indicates whether the GEMA response is on a weekday or a weekend day and what time the GEMA response is recorded. This chapter divides the temporal context into eight categories, including morning, noon, afternoon, and evening times in a weekday and a weekend day respectively. The rationale for these temporal categories was due to the temporal fluctuations of people’s spatiotemporal behaviors, noise exposures, and psychological states at different times of a weekday and a weekend day (Schwanen and Wang, 2014; Bild et al., 2016). While the temporal context was derived from the temporal information recorded by the GPS, information about the activity-travel context and the social context were provided directly by the respondents in the GEMA surveys. Together, these three aspects of the real-time contexts provide rich contextualized information for understanding the relationships between individuals' noise exposure and psychological stress.

Demographics are personal characteristics, which include age, household income, gender, and *hukou* were included as control variables in the model. Age and household income were treated as continuous variables, while gender and *hukou* were treated as categorical variables. *Hukou* is a household registration system in mainland China. Note that those participants with a local Beijing *hukou* can access to more social resources such as affordable housing, healthcare, and public schools compared to those without a local Beijing *hukou*. The variable was categorized as a binary variable: local and non-local *hukou*. In addition to demographics, neighborhood socioeconomic environments were included as confounders for explaining people's noise exposure and psychological stress. Neighborhood socioeconomic environments were indicated by the ratio of graduates from universities and above, the ratio of rural-to-urban migrants, and population density. These variables have been frequently used in Chinese urban studies to indicate neighborhood socioeconomic status, and the data are available at the neighborhood level in Beijing (Zhu, 2015; Xiao et al., 2017). Further, given that people might feel noisy and stressed in crowded environments, the population density was used as a proxy for neighborhood environments. Note that the participants are from the same residential neighborhood and thus have the same residential neighborhood socioeconomic environment. For neighborhoods outside the *Meiheyuan* community, this analysis calculated the neighborhood socioeconomic environments according to the geographic location of each GEMA response.

3.2.4 STATISTICAL ANALYSIS

Structural equation modeling (SEM) was used to examine the hypothesized relationships among contexts, momentary measured noise, momentary perceived noise, and momentary psychological stress in this chapter. Structural equation modeling was employed because it allows us to test more complex relationships among a set of variables than conventional regression analysis (Bollen, 1989). It can examine the mediation effects of variables within a single model (Baron and Kenny, 1987). Further, it helps to examine the direct and indirect path relationships among variables while accounting for multiple confounders. The direct effect refers to the direct influence of variable A on variable B without involving another variable, while indirect effect refers to the indirect influence of variable A on variable B through one or more other variables. The total effect of A on B is the sum of the direct and indirect effects. Given that the GEMA survey involved repeated measures from the same individual, a normally distributed random variable with zero mean and a constant variance was introduced to take into account the within-individual variations. The rationale for this approach to controlling cluster effects was well-documented in Jayatillake et al. (2011).

This chapter estimated several structural equation models (SEMs), including the main model and several adjusted SEMs. In the main SEM model, momentary measured noise, momentary perceived noise, and momentary psychological stress were treated as endogenous variables. The exogenous variables included contextual attributes, demographics, and neighborhood socioeconomic environment confounders. In the adjusted SEMs, the interaction term between each activity-travel context and momentary measured noise was incorporated in a different model to analyze how people perceive noise and stress differently in each context. Only the interaction terms at the 0.1 significance level were reported in the Results section below. The model fit was assessed by the goodness-of-fit indices including the Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), Goodness-of-Fit Index (GFI), Non-Normed Fit Index (NNFI), and Comparative Fit Index (CFI). According to the rule of thumb (Bentler and Chou, 1987; Hoogland and Boomsma, 1998), the number of 680 GEMA responses meets the requirements of SEM fitting. The SEMs were estimated using Mplus 8.3.

3.3 RESULTS

3.3.1 DESCRIPTIVE ANALYSIS

The characteristics of the participants and the percentage of the GEMA responses in each demographic category are presented in Table 3.1. Note that males and females are equally represented in the participants, with 47.5% male and 52.5% female. Over sixty percent of the participants are in the age range of 30-49, while about twenty percent are in the age range of 50-60. Most of the participants have high-school or higher levels of education. About seventy percent of the participants have a monthly household income above 5000 *yuan* (around US $708). About eighty percent of the participants have local Beijing *hukou*, which means that they have relatively good access to local resources such as healthcare, education, and affordable housing. The percentage of the GEMA responses are relatively similar to the percentage of participants in each demographic category, indicating that there is no bias in the GEMA responses.

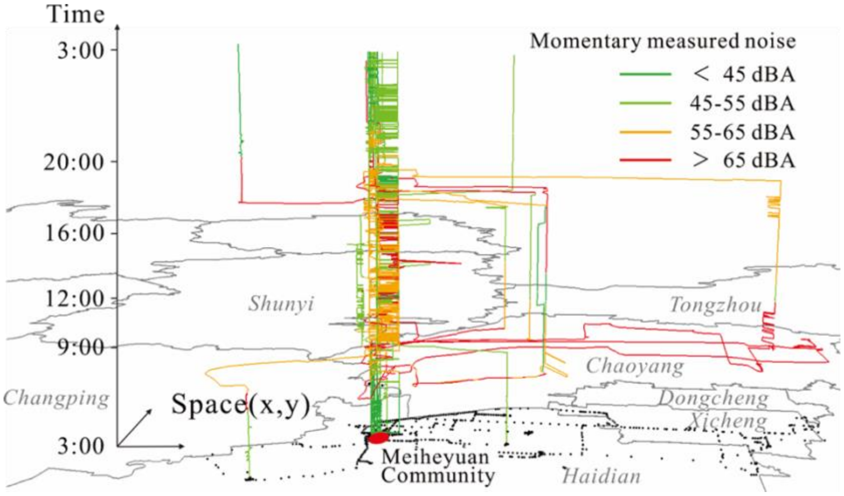
Table 3.1 Descriptive Analysis of Demographic Information (N=101)

Variable	**Category**	**Number of Participants**	**Percentage (%)**	**Number of GEMA responses**	**Percentage (%)**
Gender	Male	48	47.5	319	46.9
	Female	53	52.5	361	53.1
Age	18-30	17	16.8	147	21.6
	30-49	63	62.4	392	57.6
	50-60	21	20.8	141	20.8
Education	Middle school and below	10	9.9	47	6.9
	High school	49	48.6	332	48.8
	University and above	42	41.5	301	44.3
Hukou	Local	80	79.2	540	79.4
	Non-local	21	20.8	140	20.6
Housing type	Work-unit housing	21	20.8	150	22.0
	Policy-related housing	21	20.8	147	21.6
	Commercial housing	59	58.4	383	56.4
Monthly household income (RMB)	Below 2,000	11	10.9	47	6.9
	2,000-5,000	18	17.8	134	19.7
	5,000-10,000	21	20.8	236	34.7
	10,000-15,000	17	16.8	99	14.6
	Above 15,000	34	33.7	164	24.1

Figure 3.3 shows the spatiotemporal patterns of participants' momentary measured noise over the 24 hours in a typical weekday and a weekend day. In the weekday, people tend to travel to their workplace around 9AM, with high levels of momentary measured noise. At 12PM, they go back home if it is nearby their workplace or stay at their workplace for a rest, with relatively low levels of momentary measured noise. At 4PM, people remain in their workplace or start to travel back home from work or school, with relatively high levels of momentary measured noise. At around 8PM, people tend to have finished a busy weekday, and after dinner, they conduct recreational activities with their friends and families near their communities, with high measured noise levels.

In the weekend, people tend to stay at home with relatively low levels of measured noise or travel to recreational places such as shopping malls and parks. Again, when traveling, they are exposed to relatively high measured noise levels.

A Weekday



A Weekend Day

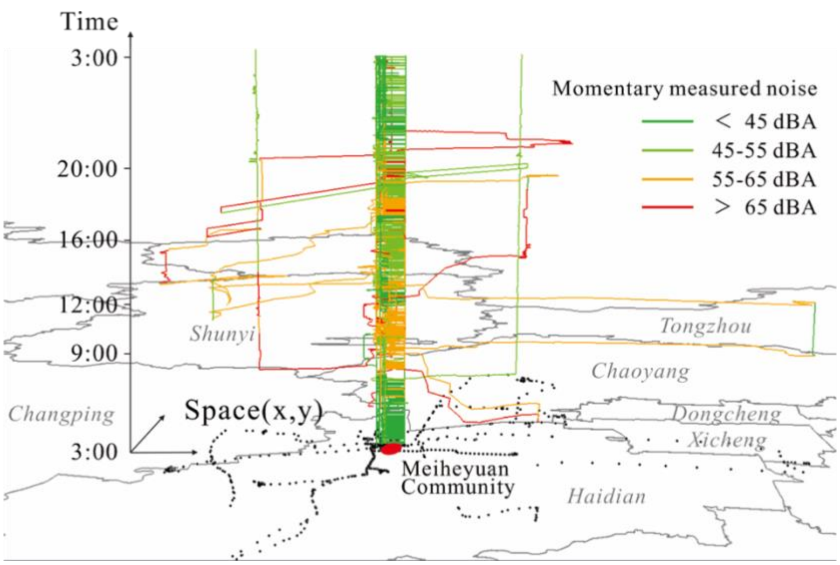


Figure 3.3 Geo-Visualization of Participants' GPS Trajectories and Momentary Measured Noise in a Weekday and a Weekend day

The averaged momentary measured noise with its standard deviation, together with the proportion of self-reported moderate and serious levels regarding momentary perceived noise and psychological stress in each contextual category, is shown in Figure 3.4-3.6, with the count of GEMA responses in each category reported in the brackets. Note that taking a rest (41.7 dBA) is the activity with the least measured noise level, while out-of-home recreational activities (49.9 dBA) are activities with relatively high levels of averaged measured noise. However, when undertaking out-of-home recreational activities, only 25% of the participants reported their perceived noise and 16% reported their psychological stress as moderate or serious. Public transport (57.2 dBA) is the travel mode with the highest levels of measured noise. When taking public transport, about 70% of the participants consider noise as “moderately or extremely a problem,” but merely 35% of the participants who used public transport feel “moderately or extremely stressed.” Activities with friends have the highest levels of averaged measured noise (47.6 dBA), but few of the participants rate their moods when undertaking these activities as “moderately or extremely stressed” (19%). The measured noise levels in both weekdays (54.4dBA) and weekend days (52.8dBA) are the highest at around 8PM, but the proportion of participants who felt “moderately or extremely stressed” is relatively low. The measured noise levels at 9AM in weekdays are relatively high, with 36% of participants rating their perceived noise as “moderately or extremely a problem.” Note that the proportion of participants who reported momentary perceived noise and psychological stress levels as “not at all” and “slightly” is always higher than the proportion of participants who reported momentary perceived noise and psychological stress levels as “moderately” and “slightly” in all contextual categories, with an exception (the momentary perceived noise of public transportation). However, this does not mean that there are no noise problems, but people might just not perceive the noise problem as they undertake their daily activities and travels in most of these contexts.

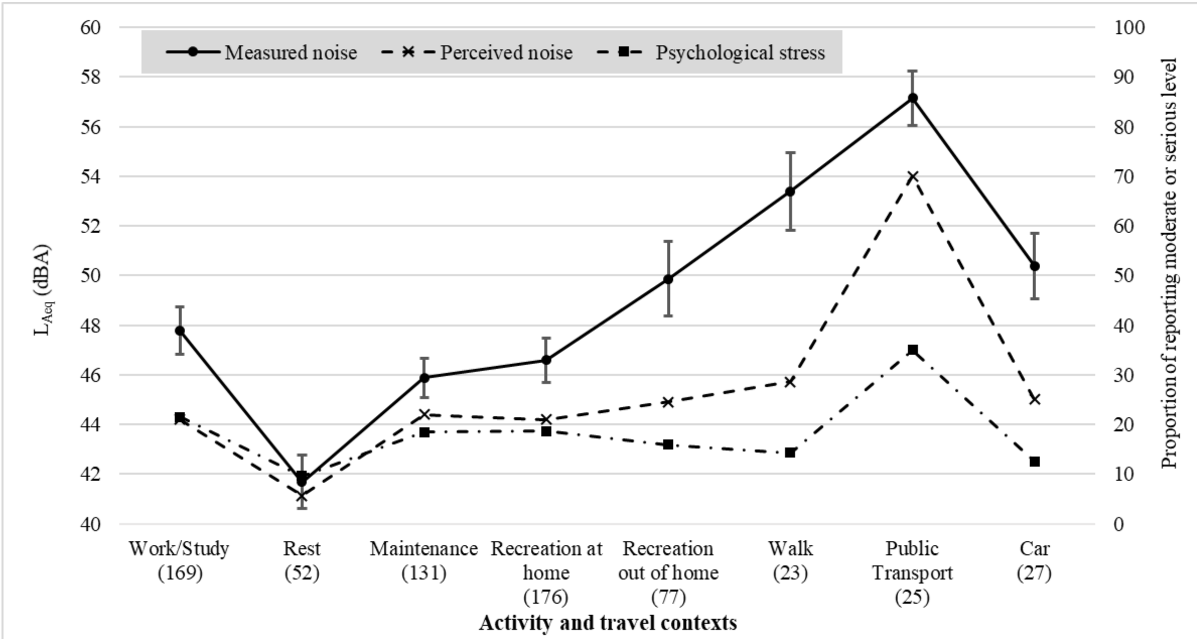


Figure 3.4 Activity and Travel Context, Momentary Measured Noise, Perceived Noise, and Psychological Stress

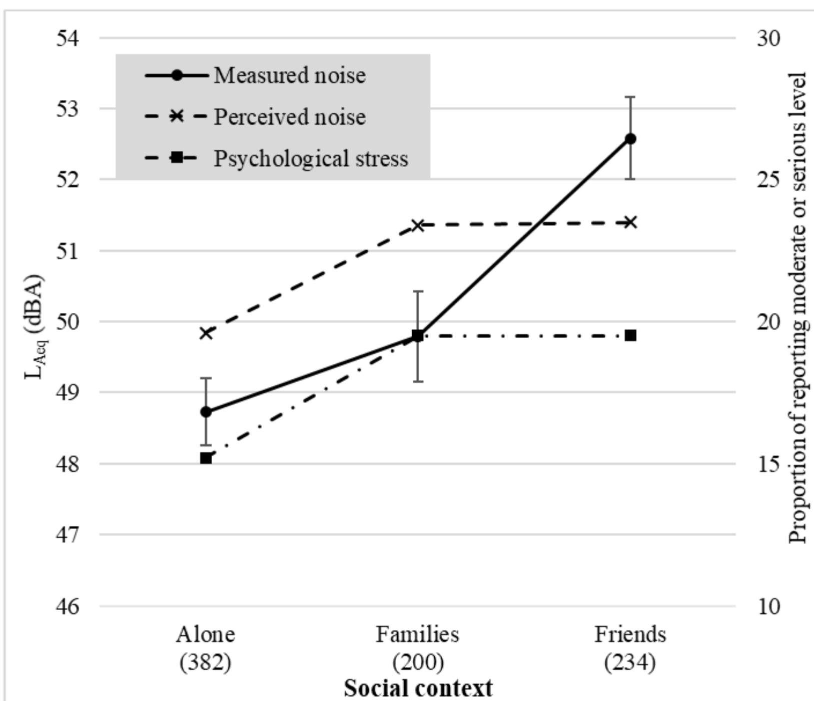


Figure 3.5 Social Context, Momentary Measured Noise, Perceived Noise, and Psychological Stress

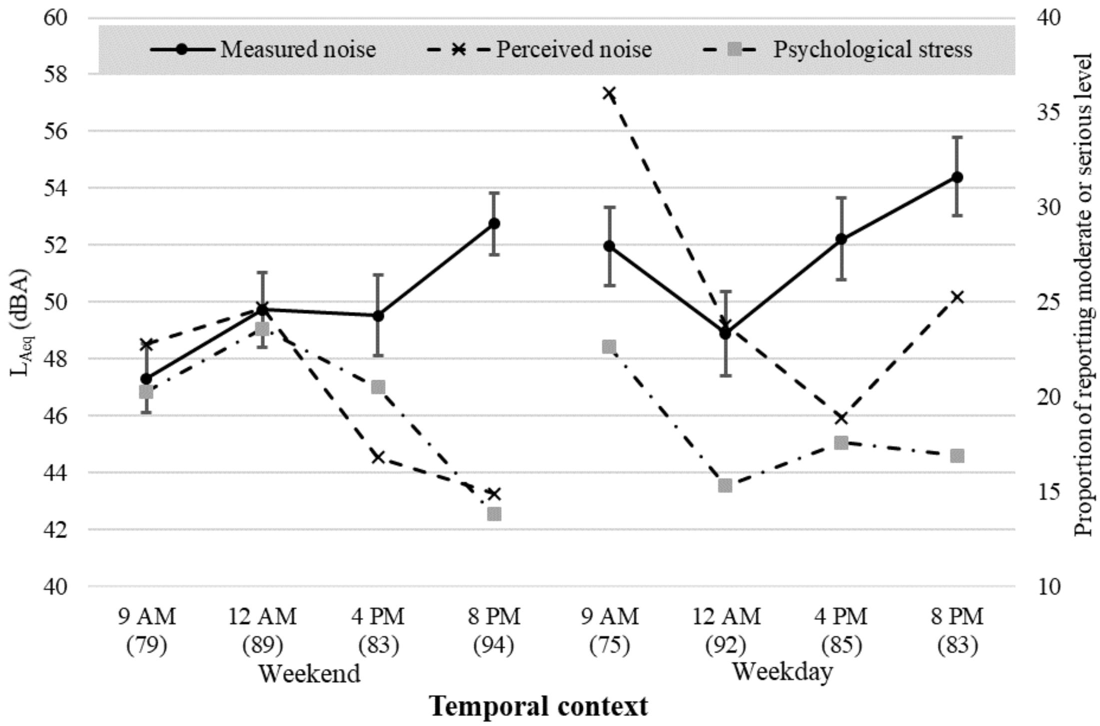


Figure 3.6 Temporal Context, Momentary Measured Noise, Perceived Noise, and Psychological Stress

3.3.2 STRUCTURAL EQUATION MODELING RESULTS

The structural equation modeling results are shown in Figure 3.7, Table 3.2, and Table 3.3. Overall, the results of the model's paths suggest that Hypothesis 2 and Hypothesis 3 are retained, but Hypothesis 1 is not statistically significant. Specifically, momentary measured noise does not directly influence momentary psychological stress. Instead, momentary measured noise increases momentary psychological stress through the mediating effect of increasing momentary perceived noise. Contextual effects (which include the effects of the activity and travel context, social context, and temporal context) significantly influence people's momentary measured noise, perceived noise, and psychological stress. The specific paths and relationships regarding the hypotheses are discussed in the following sections.

3.3.2.1 THE MEDIATING ROLE OF PERCEIVED NOISE

The mediating effect of momentary perceived noise is illustrated in Figure 3.7, with a dashed line indicating non-significant paths and a solid line indicating significant paths at the $p<0.05$ level. Momentary measured noise does not directly influence momentary psychological stress, which indicates that Hypothesis 1 is not retained. Instead, momentary measured noise indirectly influences momentary psychological stress through the mediating effects of momentary perceived noise, as Hypothesis 2 is statistically significant. Momentary measured noise has a direct positive effect on momentary perceived noise, which in turn positively influenced momentary psychological stress. The impact of momentary perceived noise on momentary psychological stress (0.318) is stronger than the impact of momentary measured noise on momentary perceived noise (0.142). The standardized indirect effect of momentary measured noise on momentary psychological stress is 0.0452 (which is equal to 0.318×0.142), indicating that a standard deviation increase (that is 10.06 dB(A) in the unstandardized natural scale) in measured noise will lead to a 4.52% increase in momentary psychological stress through momentary perceived noise.

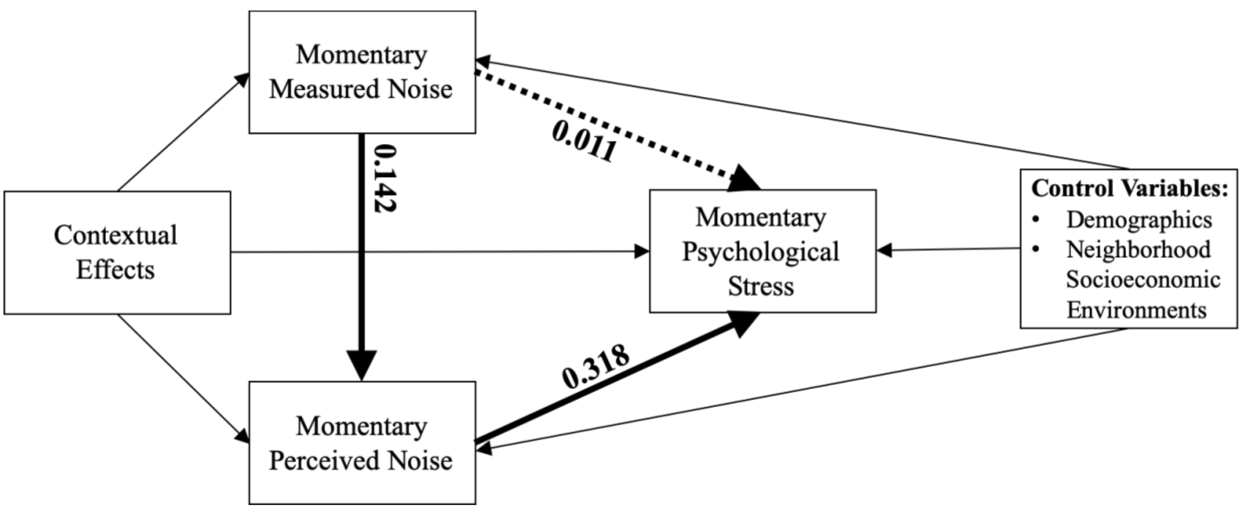


Figure 3.7 The Mediating Effect of Momentary Perceived Noise

(Notes: The dashed line indicates insignificant effect.)

3.3.2.2 THE EFFECTS OF CONTEXTS

The unstandardized path coefficients of the direct effects among the variables of the main SEM are summarized in Table 3.2. All path coefficients are unstandardized to make it easy for interpreting the results on the natural scale. As shown in the table, the context variables play important roles in influencing individuals' momentary measured noise, perceived noise, and psychological stress after controlling for participants' demographic attributes. Certain contexts including taking a rest, conducting out-of-home recreational activities, conducting activities with friends, or undertaking activities around 8 PM on a weekday can reduce people's momentary psychological stress. Noticeably, taking a rest during a day is significantly associated with lower levels of momentary measured noise ($\beta = -5.933$, $p < 0.01$), momentary perceived noise ($\beta = -0.033$, $p < 0.05$), and momentary psychological stress ($\beta = -0.302$, $p < 0.05$), compared to when people are working and studying.

Interestingly, when participants were conducting out-of-home recreational activities, they were exposed to higher levels of momentary measured noise ($\beta = 2.204$, $p < 0.05$) when compared to participants who were working and studying. However, they did not perceive the noise as a problem. Instead, they experienced a decrease in their momentary psychological stress ($\beta = -0.188$, $p < 0.05$). Similarly, when the participants were undertaking activities with their friends, they were exposed to significantly higher levels of momentary measured noise compared with the moment when they were alone ($\beta = 1.538$, $p < 0.05$). Although they did not notice that noise is a problem, they experienced a significant decrease in their momentary psychological stress level ($\beta = -0.050$, $p < 0.05$). In addition, when people were undertaking activities around 8 PM at weekdays, although they were exposed to considerably higher levels of measured noise compared to that at 9 AM in weekend days ($\beta = 6.078$, $p < 0.01$), people did not necessarily consider the noise as a problem and they had significantly lower levels of momentary psychological stress ($\beta = -0.266$, $p < 0.05$). This is probably because, conducting out-of-home recreational activities, undertaking activities with friends, or at around 8PM, were the contexts where people enjoyed a moment of relaxation through positive activities and interactions. In these contexts, they were not bothered by the high measured noise levels and experienced less psychological stress.

Noticeably, in some particular contexts, although people's momentary measured noise is significantly higher, it does not necessarily influence people's momentary perceived noise and psychological stress directly. Specifically, when the participants were walking, traveling to work at 9AM in weekdays, or returning from work at 4PM in weekdays, although they experienced significantly higher levels of momentary measured noise, they did not notice the noise as a problem or experienced increased psychological stress. Besides, when the participants were taking public transportation, they tended to be exposed to considerably higher levels of momentary measured noise and they perceived the problem of higher noise levels, but it did not significantly influence their psychological stress. This is probably because people tend to get accustomed to and become more tolerant of certain sources of noise that they habitually encountered in their daily life.

With regard to demographic attributes, the older participants tended to more easily perceive noise as a problem when they were exposed to a similar level of objectively measured noise when compared to younger participants, but it did not significantly increase their momentary psychological stress. Note that those participants with a local Beijing *hukou* tended to have significantly lower levels of momentary measured noise compared to those without a local *hukou*. However, there are no significant differences in terms of momentary perceived noise and psychological stress between these two groups. In terms of neighborhood socioeconomic environments, when people were undertaking activities or travels in neighborhoods with higher ratios of rural-to-urban migrants, they had a higher tendency of considering noise as a problem. However, the perceived noise relieved people's momentary psychological stress. This could be because it is popular to have outdoor markets and commercial activities in neighborhoods with higher ratios of rural-to-urban migrants in Beijing, and the lively commercial activities and interactions relieve people's psychological stress. In addition, when people were undertaking their activities in neighborhoods with higher population density, they tended to have higher momentary measured noise. However, this did not significantly increase their momentary perceived noise and psychological stress.

Table 3.2 Unstandardized Path Coefficients of the Direct Effects Among Variables

Variables		Momentary Measured Noise		Momentary Perceived Noise		Momentary Psychological Stress	
		Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.
Momentary Measured Noise				0.011***	0.003	0.001	0.003
Momentary Perceived Noise						0.349***	0.035
Activity and Travel Context	Work/Study	Reference					
	Rest	-5.933**	1.851	-0.033*	0.148	-0.312*	0.136
	Maintenance	-1.799	1.145	-0.099	0.091	-0.059	0.083
	Recreation at home	1.672	1.208	-0.070	0.096	-0.084	0.088
	Recreation at other locations	2.204*	1.019	0.137	0.129	-0.188*	0.086
	Walk	6.534*	2.628	0.042	0.209	-0.278	0.191
	Public Transport	12.165***	2.712	0.941***	0.218	-0.212	0.202
	Car	1.614	2.979	0.269	0.236	-0.411*	0.210
Social Context	Alone	Reference					
	Families	2.679*	1.137	0.179*	0.091	0.035	0.083
	Friends	1.538*	0.735	0.028	0.094	-0.050*	0.024
Temporal Context	Weekend 9 AM	Reference					
	Weekend 12 PM	2.343	1.776	-0.043	0.141	0.079	0.129
	Weekend 4 PM	1.864	1.797	-0.311*	0.143	-0.036	0.131
	Weekend 8 PM	4.695**	1.798	-0.445**	0.143	-0.199	0.132
	Weekday 9 AM	3.287*	1.553	0.249	0.150	-0.055	0.137
	Weekday 12 PM	1.198	1.800	-0.131	0.143	-0.021	0.130
	Weekday 4 PM	3.672*	1.817	-0.191	0.145	-0.003	0.132
	Weekday 8 PM	6.078**	1.847	-0.215	0.148	-0.266*	0.135
Demographics	Male	-0.769	0.896	-0.108	0.071	0.069	0.065
	Female	Reference					
	Age	0.020	0.052	0.008*	0.004	-0.008*	0.004
	Locals	-2.683*	1.163	0.004	0.093	0.120	0.085
	Non-locals	Reference					
	Income	0.001	0.001	0.001	0.001	0.001	0.001
Neighborhood Socioeconomic Environments	Ratio of graduates from universities and above	-1.503	3.557	-0.455	0.282	-0.271	0.258
	Ratio of rural-to-urban migrants	-7.239	13.317	4.816***	1.056	-3.462***	0.979
	Population density	0.026*	0.014	0.001	0.001	0.000	0.001
Goodness-of-fit Indices	RMSEA 0.024 SRMR 0.003 GFI 0.994 NNFI 0.933 CFI 0.997						

*P<0.05, **P<0.01, ***P<0.001

In addition to the main SEM, this chapter also examines the moderating effects of activity and travel contexts in influencing the effect of momentary measured noise on perceived noise and psychological stress. Table 3.3 includes the significant interaction terms of different contexts and momentary measured noise. There are three significant interaction effects. First, the context of car significantly modifies the relationship between momentary measured noise and psychological stress. Specifically, when people were traveling in a car, it mitigated the positive relationship between momentary measured noise and psychological stress (-0.049 =-0.051+0.02). This can be due to that people may have positive conversations or listen to music when traveling in a car, which helps to reduce their psychological stress. Second, when people were undertaking recreational activities at locations other than their home, it intensified the positive relationship between their momentary measured noise and perceived noise (0.032=0.008+0.024). However, this did not necessarily increase their momentary psychological stress. Finally, when people were undertaking recreational activities at home, given the same levels of momentary measured noise as that in the main model, it further increased people's momentary perceived noise by 0.045 (=0.018+0.024) and psychological stress by 0.012 (=-0.004+0.016). The extent of increase in momentary perceived noise is larger than that in psychological stress considering the same level of momentary measured noise. This could be explained by the positive effects generated by recreational activities themselves.

Table 3.3 Models with Significant Interaction Terms Regarding Contextual Effects

Variables	**Model2**		**Model3**		**Model4**	
	Unstandardized Coefficient		Unstandardized Coefficient		Unstandardized Coefficient	
	Momentary perceived noise	Momentary psychological stress	Momentary perceived noise	Momentary psychological stress	Momentary perceived noise	Momentary psychological stress
Momentary measured noise	.	0.002	0.008*	.	0.018***	-0.004
Car	.	-0.372*				
Momentary measured noise×Car	.	-0.051*				
Recreation at other locations			-1.120*	.		
Momentary measured noise ×Recreation at other locations			0.024**	.		
Recreation at home					1.256***	-0.897**
Momentary measured noise ×Recreation at home					0.027***	0.016**
Model Goodness-of-fit Indices						
RMSEA	0.021		0.023		0.023	0.022
SRMR	0.005		0.003		0.003	0.006
GFI	0.990		0.995		0.994	0.991
NNFI	0.919		0.936		0.937	0.924
CFI	0.999		0.997		0.993	0.998

*P<0.05, **P<0.01, ***P<0.001

3.4 DISCUSSION

To the best of our knowledge, this analysis is the first study that investigates individuals' noise exposure and psychological stress using GEMA along with activity-travel diaries and portable noise sensors. This integrated approach takes advantage of real-time environmental sensing and geospatial technologies. It seeks to contribute to advancing studies on individuals' environmental exposures and their health effects.

This analysis makes methodological contributions to research on noise exposure and psychological stress in three aspects. First, compared to previous studies that focused on individuals' chronic noise exposure to a specific source of noise at a particular geographic location (Evans et al., 2000; Basner et al., 2014; Klompmaker et al., 2019), the present chapter provides more accurate exposure assessment through collecting and using data on individual-based daily movement and person-specific noise exposures. It considers individuals' exposure to different sources of noise at multiple geographic locations and during people's travels between these locations. Second, this chapter uses GEMA to record real-time data of people's self-reported noise perception and psychological stress and to examine contextual effects on noise exposure and psychological stress. Compared to previous studies that used retrospective questionnaires to collect people's responses (Evans et al., 2000; Haines et al., 2001), the integrated approach provides more accurate assessments and reduces the recall bias compared to retrospective assessments. It also provides rich contextualized information about how noise exposure is related to psychological stress. Finally, the analysis simultaneously considers both objective and subjective measurements of noise and their effects on people's psychological stress, which provide a more holistic understanding of how environmental exposures influence psychological health.

Using this integrated approach, this chapter also makes conceptual contributions. First, it advances our knowledge of the effects of objectively measured and subjectively perceived noise on psychological stress. It observes that exposure to higher decibel levels of noise increases psychological stress through the mediating effects of increasing perceived noise. This finding aligns well with previous studies that revealed that noise annoyance acts as a mediator between noise exposure and psychological stress (Babisch, 2002; Van Kamp and Davies, 2008; Riedel et al., 2015; Klompmaker et al., 2019). However, this chapter extends previous studies by using "subjective noise" to focus on whether the surrounding sound is noise and whether the noise interferes with people's daily activities and travels, which more holistically understand people's subjectively perception and evaluation of noise in real-life situations. Further, similar to previous studies (Stansfeld et al., 2005; Clark et al., 2013), this analysis revealed that the direct association between momentary measured noise and psychological stress was insignificant. However, this analysis showed that momentary measured noise significantly influenced psychological stress indirectly through the mediating effects of momentary perceived noise. In other words, the effects of noise on psychological stress mainly depend on whether people notice the noise and are disturbed by it. One possible explanation of this is that people's psychological stress depends on psychological mechanisms that are influenced by how individuals subjectively evaluate their objective physical surroundings (Heft, 2010; Marselle et al., 2015).

Another conceptual contribution of this chapter is that it provides a contextual approach to understanding people's exposure to noise and its effects on their psychological stress. Building upon the time-geographic approach, the study provides a framework for examining people's noise exposure and its health impacts in relation to their real-life contexts as they occur, which include the activity and travel context, the social context, and the temporal context. This chapter shows that the context in which an individual is situated at a particular moment influences their momentary measured noise, perceived noise, and psychological stress. As observed in this chapter, conducting certain types of daily activities, certain types of social interactions, or activities at particular periods during a day (especially the activity of rest, out-of-home recreational activities, activities with friends, and activities after work) helps to reduce people's perceived noise and psychological stress. This could be explained by the relaxing characteristics of these contexts, which directly relieve people's psychological stress and indirectly influence it through reducing people's objective exposure to noise and the disturbance by the noise they subjectively experienced.

Further, this chapter also revealed that when people are undertaking some daily activities with high levels of momentary measured noise, these contexts do not necessarily increase their levels of perceived noise and psychological stress. This was observed in several specific contexts, especially when people are traveling on public transportation such as the bus and metro, when people are walking, or when people are traveling during peak time at weekdays. This perhaps can be explained by the habituation effect of noise (Kjellberg, 1990), which refers to the phenomenon that people get used to and become less bothered by certain sources of noise when exposed to the noise habitually and regularly over time. On the one hand, the finding suggests that these contexts reduce the impact of measured noise by decreasing people's noise perception and psychological stress. However, on the other hand, considering the health risks such as noise-induced hearing loss, cardiovascular diseases, and cognitive performance impairment associated with exposures to high levels of noise (Basner et al., 2014), it is still necessary to identify these contexts and encourage individuals to adopt appropriate strategies to recognize and avoid the noise in these contexts.

We acknowledge several limitations of this analysis, which are promising venues for future studies. First, the sample size is small in this analysis. However, we believe that the study to some extent can represent the daily activity and travel patterns, noise exposures, and psychological stress of residents from suburban Beijing. Future studies can use the methods proposed in this chapter to validate the findings. Second, this chapter has mainly focused on self-reported psychological stress without considering physiological stress and other stress-related health outcomes. With the development of wearable sensors to measure individuals' real-time stress levels, these technologies can further be applied to understand more complex relationships among objective and subjective measurements of noise, stress, and other stress-related symptoms. Third, this chapter mainly focuses on the relationships among real-time measured noise, perceived noise, and psychological stress. However, the impacts of noise on people's psychological stress may accumulate over time (cumulative effect) or become apparent after a certain period of exposure (time-lagged effect). Future studies should further explore the relationships between individuals' noise exposure and psychological health at different temporal scales. Future studies can also take seasonal variations of individuals' noise exposure into consideration. Last, while the structural equation modeling enables us to understand the direct and indirect pathways among contextual variables, momentary measured noise, perceived noise and psychological stress, a more in-depth understanding of the psychological processes and mechanisms of how individuals interact with their sonic environments are needed. Qualitative methods can be used to investigate how individuals experience various sonic environments and the associated influences on their psychological well-being in their everyday life.

3.5 CONCLUSION

To conclude, this chapter contributes to the growing literature concerning individual-based environmental exposures and psychological health effects using a novel GEMA approach. It has found that people's momentary noise exposure adversely affects their psychological stress not in a direct way but instead through the mediating effect of momentary perceived noise. It also shows that the effects of activity and travel, social, and temporal contexts on individuals' momentary measured noise, perceived noise, and psychological stress are complex. In particular, at the moment when people are taking a rest, undertaking an out-of-home recreational activity, conducting their activity with their friends, or undertaking their activity at around 8 PM on a weekday, regardless of whether they are exposed to lower or higher levels of momentary measured noise, they tend to experience significantly lower levels of perceived noise and psychological stress.

The findings of this analysis have important implications. First, considering the important role of noise perceptions, it is important to focus on not just urban residents' objective exposures to noise but also their subjective evaluations of noise in order to improve their psychological health and well-being. Second, a contextual approach should be adopted to understand how the specific contexts in urban residents' daily life influence their noise exposures, noise perceptions, and psychological stress. Such an approach would shed light on the appropriate interventions for mitigating noise problems, preserving noisy but livable urban life surroundings, and achieving healthy urban environments.

CHAPTER 4: LISTENING TO URBAN SOUNDS: UNDERSTANDING THE EFFECTS OF HUMAN MOBILITY ON INDIVIDUAL SOUND EXPOSURE AND PSYCHOLOGICAL RESPONSES

4.1 INTRODUCTION

Urbanization generates diverse sources of sound due to human activities. Exposure to high levels of sound can negatively influence human health, resulting in annoyance, sleep disturbance, hearing loss, psychological stress, and cardiovascular diseases (World Health Organization, 2011). How urban residents are exposed to sound, how they perceive sound, and why some people are constrained in their attempts to avoid the high levels of sound in their everyday lives have become critical questions that influence urban residents' socio-psychological health and quality of life. In addition, urban residents may have different daily movement patterns. How urban residents' daily mobilities further influence the process of people's sound exposure, sound perceptions, and psychological health remains unclear and calls for further investigation.

Therefore, the objective of this chapter is to better understand the role of human mobility in influencing people's exposure to environmental sound and psychological health. Specifically, this chapter intends to investigate the following research questions. First, how are people exposed to urban sound and how do they perceive the sound during their daily movements? Second, how do people's daily sound exposures and perceptions influence their perceived psychological annoyance and stress? Third, how do people's space-time constraints influence their sound exposure, psychological responses, and coping strategies against loud sound? To answer these research questions, this chapter adopts a mixed-method approach, which involves qualitative methods (in-depth interviews), quantitative methods (portable sound sensors and GPS trackers), and geo-narrative analysis.

The chapter is organized as follows. It first reviews existing literature on sound exposure and psychological health and summarizes research gaps. Then, it reflects upon recent theoretical and methodological advancements to better understand the role of human mobility in influencing individual-based sound exposure and psychological health. The methodology section describes the study area, data collection, and data analysis. The results section first reveals how individual-based objective sound exposure and socio-cultural meanings associated with the sound in different geographic contexts during people's daily movements influence people's psychological responses. Further, the results section shows how space-time constraints influence people's sound exposures, psychological responses, and coping strategies against loud sound. This is followed by a discussion of the effects of human mobility, which is considered as both actual movements and potentials for movements, on individual-based sound exposure and psychological responses. Finally, it concludes with major findings, theoretical contributions, and practical implications for mobilizing constraints and facilitating better urban sonic environments for socially vulnerable and susceptible individuals and groups.

4.2 LITERATURE REVIEW

4.2.1 SOUND EXPOSURE AND ITS EFFECTS ON PSYCHOLOGICAL HEALTH

Studies have been widely conducted on noise exposure and its health effects that involve noise annoyance, sleep disturbance, physiological and psychological stress, cognitive performance impairment, cardiovascular diseases, and mental disorders (e.g., Field, 1993; Lercher, 1996; Passchier-Vermeer and Passchier, 2000; Stansfeld and Matheson, 2003; Basner et al., 2014; Ma et al., 2018). These studies considered sound as environmental noise and focused on people's exposure to actual sound levels from a specific source (e.g., road, railway, and aircraft traffic) at a particular geographic location (e.g., residential location, workplace, or school) (Evans and Johnson, 2000; Evans and English, 2002). Using quantitative measures and statistical analysis, these studies further examined the associations between people's exposure to actual sound levels and specific symptoms of health outcomes (Evans and Johnson, 2000; Haines et al., 2002; Basner et al., 2014). Studies have shown that noise-induced psychological annoyance and stress are not just primary health effects associated with high levels of sound exposure but also key modifiers to further increase cardiovascular disease risks and cause mental health problems (Job, 1996; Babisch, 2002; Babisch et al., 2013).

Recent studies have advocated the soundscape approach, arguing that people's exposure to urban sound should not be oversimplified as an environmental pollutant (Raimbault and Dubois, 2005; Oldoni et al., 2015; Aletta et al., 2016). Sound influences people's psychological responses (e.g., annoyance, stress, distress, and pleasure) not only through the physical aspects of sound such as actual sound levels (Lercher and Schulte-Fortkamp, 2003; Schulte-Fortkamp and Fiebig, 2006) but also through the socio-psychological aspects of sound that can be understood as socio-cultural meanings associated with the sound and are subjectively perceived and experienced by individuals (Saldanha, 2009; Bild et al., 2016; Doughty et al., 2016). Therefore, increasing studies have utilized mixed methods that combine both quantitative and qualitative methods to collect actual sound levels using sound level meters and socio-psychological aspects of sound using survey questionnaires and in-depth interviews (Ge et al., 2009; Herranz et al., 2017). Furthermore, these studies have considered people's exposure to sound from various sources (e.g., mechanical, natural, and human-made sound) (Lercher and Schulte-Fortkamp, 2003) and at particular urban spaces (e.g., urban parks, squares, and restaurants) (Cain et al., 2013; Lindborg, 2015; Kang et al., 2016).

In addition, studies have also shown that individuals are not passive receivers of sound, but they can actively respond to sound (Jeon et al., 2011; Kogan et al., 2017). How people perceive and experience the surrounding sound involves five stages (Schulte-Fortkamp and Fiebig, 2006; Jeon et al., 2011; International Organization for Standardization, 2014): (a) the acoustic environment, which involves the physical properties of sound and sources of sound; (b) auditory sensation, which is a biological process of producing auditory signals and allows people to detect acoustic environments; (c) interpretation of auditory sensation, which is a process of creating useful information for the auditory signals. In this process, individuals perceive and experience the acoustic environment, which is shaped by their personal experiences and socio-cultural backgrounds; (d) psychological reactions and responses (e.g., annoyance, pleasure, and stress); and (e) coping strategies and behavioral responses to sound that involve staying and ignoring, changing and avoiding, improving the conditions. As a result, it influences people's health and quality of life. Based on these stages of people's experience of sound, this chapter will examine people's objective exposure to (involving the first and second stages above), subjective perceptions of sound, psychological responses, and coping strategies of urban sound.

Although progress has been made towards better understanding people's sound exposure and their psychological responses, there are still two research gaps. First, past studies have primarily focused on people's exposure to sound at some particular geographic locations (people's home location, workplace, school, urban spaces) (Evans and Johnson, 2000; Evans and English, 2002; Cain et al., 2013; Lindborg, 2015; Kang et al., 2016; Herranz et al., 2016; Bild et al., 2016). However, as individuals move around to undertake their daily activities and social interactions in their everyday lives, they are exposed to diverse sources of sound at multiple geographic locations and contexts (e.g., work, gym, a grocery store, walk, in a bus or car) (Kwan, 2009, 2013). The neglect of people's daily movements and the spatiotemporal dynamics of the sonic environment during their movements can lead to the uncertain geographic context problem (UGCoP) and the neighborhood effect averaging problem (NEAP) (Kwan, 2012a,b; Kwan, 2018a). Both the UGCoP and the NEAP can modify relationships between individual environmental exposure and its health effects and thus may lead to erroneous assessments of the effects of environmental risk factors on human health (Park and Kwan, 2017; Kou et al., 2020; J. Ma et al., 2020; X. Ma et al., 2020; Kim and Kwan, 2020). To mitigate the UGCoP and the NEAP, individuals' actual movements and spatio-temporal variations of urban sound should be considered when assessing individual-based sound exposures and their effects on people's psychological health (Yoo et al., 2015; Park and Kwan, 2017; Helbich, 2018).

Second, studies that explored the dynamic processes of people's experience of sound exposure and psychological responses have assumed that people can actively respond to sound without constraints (Schulte-Fortkamp and Fiebig, 2006; Jeon et al., 2011). However, Jerrett et al. (2010) have identified the health risks of environmental exposures as the overlap of exposure, susceptibility, and adaptation. In addition to people's exposure to environmental risk factors, individuals' different extents of susceptibility in specific geographic locations and times, their perceptions of the risk factors, and their capabilities and constraints of changing their behaviors also influence their socio-psychological health (Jerrett and Finkelstein, 2005; Jerrett et al., 2010; Elliot, 2010). For instance, studies have shown that in addition to high levels of sound exposure, socially vulnerable and susceptible groups such as low-income populations and older people can be exposed to multiple stressors environmentally and socially, and they are less mobile and often stuck in the situations that they could not change (Evans and English, 2002; Van Kamp and Davies, 2013; Basner et al., 2014). Therefore, the role of people's different daily mobility patterns and space-time constraints in influencing their sound exposures, sound perceptions, psychological responses, and coping strategies in their everyday lives require further investigation.

4.2.2 THEORETICAL AND METHODOLOGICAL ADVANCEMENTS

Recent theoretical and methodological advancements provide considerable potential for bridging these research gaps. Theoretically, human mobility can be conceptualized as both actual movements and potentials for movements (Kwan and Schwanen, 2016). Based on Hägerstrand's (1970) time-geographic framework, actual movements can be understood in terms of space-time paths. It represents an individual's daily activities at different geographic locations and trips in temporal sequence (Hägerstrand, 1970; Ellegård, 2018). Further, potentials for movements can be understood by space-time constraints, which is a key time-geographic concept. Individuals encounter a varying mix of capability, coupling, and authority constraints, which together impose space-time constraints on individuals' actual daily movements and define their potentials for movements (Hägerstrand, 1970; Schwanen et al., 2008; Ellegård, 2018). Capability constraints refer to the constraints generated by biological necessity (e.g., sleeping, eating) and limited capabilities, skills, and resources. Coupling constraints define where, when, and for how long an individual has to join other individuals or tools to undertake certain daily activities and trips, such as picking up children from school at a certain time. Authority constraints are related to restrictions imposed by rules, regulations, and social norms. While some studies have utilized measures of the degree of spatial, temporal, and spatiotemporal fixity of individuals' daily activities and trips (Kwan, 1999; 2000; Ta et al., 2016) to examine space-time constraints, other studies have utilized qualitative space-time approaches to understanding individuals' subjective narratives of space-time constraints on their everyday mobilities (e.g., Wong, 2018). This chapter adopts a mixed-method approach to understanding the space-time constraints of different individuals.

Individuals encounter different space-time constraints, which lead to inequality in their actual movements and potentials for movements (Kwan and Schwanen, 2016). For instance, women tend to have more space-time constraints imposed by their gender roles and household responsibilities, especially for women with young children (Kwan, 1999; 2000). Low-income people also have space-time constraints imposed by fixed schedules and work environments with a lack of economic resources to mitigate them (Ellegård, 2018; X. Ma et al., 2020). Disabled people, very older people, and infants tend to have capability constraints and be less mobile (Wong, 2018; Ellegård, 2018). Additionally, a majority of people encounter space-time constraints due to their sleeping and eating needs (Hägerstrand, 1970). The time-geographic framework of people's actual movements and mobility constraints helps to provide insights on how human mobility influences people's sound exposure and psychological responses.

Methodological advancements also contribute to the understanding of people's sound exposure and psychological responses. First, the recent development of portable real-time environmental sensing and geospatial tracking technologies enables researchers to capture individual-based and person-specific sound exposures during their daily movements at high spatiotemporal resolutions (Kang et al., 2013; Liu et al., 2013). This helps to capture people's exposures to sound in not just their residential neighborhoods but also non-residential contexts. Further, drawing upon the time-geographic approach, activity-travel diaries provide a powerful space-time perspective for understanding individuals' arrangements of their daily activities and trips at different spaces and times, which provide rich contextualized information for individual-based sound exposures. In addition, works on critical GIS have advocated gaining contextualized understanding and situated knowledge of data collected by geospatial technologies (Kwan, 2007, 2008; Kwan and Ding, 2008). They argue that human individuals should not just be represented as dots and values on maps but also different bodies with thoughts, feelings, and emotions (McLafferty, 2005; Kwan, 2007; Kwan and Ding, 2008). Therefore, drawing on these advanced theoretical and methodological trends, this chapter aims to further understand how individuals with different actual movement patterns and potentials for movements are exposed to and influenced by urban sound in their everyday lives.

4.3 METHODS

Beijing, the capital city of China, is the study area for this research. Beijing is a representative megacity with diverse sources of urban sound. With its increasing population and number of vehicles, Beijing is confronted with increasing noise problems from traffic, construction, and neighborhood activities. Coping with noise problems and improving residents' well-being through their everyday engagement with sonic environments has become a critical issue. This chapter focuses on the suburban residents in a mixed-housing community, the *Meiheyuan* community, to investigate the variations in people's daily mobility patterns, sound exposures, and well-being experiences. The *Meiheyuan* community is located in the inner suburban area of the Fifth-Ring Road in northern Beijing. This community well represents the different types of housing and suburban residents from diverse socio-economic backgrounds in Beijing. It includes commercial housing, policy-related housing (including low-rental housing and public rental housing), and *danwei* housing (work-unit housing) that was allocated by work units to employees at discounted prices (Shen et al., 2015). Additionally, residents from different socio-economic backgrounds in the community exhibit diverse daily mobility patterns and activity-travel behaviors.

Data for this research were collected in two stages. In the first stage, data were collected using survey questionnaires, GPS tracking devices, portable sound sensors, and activity-travel diaries in Beijing from December 2017 to February 2018. Specifically, each participant completed a survey questionnaire that collected data on their demographic information and self-reported health status. Further, each participant carried a GPS-equipped mobile phone and a portable sound sensor and recorded activity-travel diaries for a weekday and a weekend day (e.g., Friday and Saturday or Sunday and Monday). The GPS-equipped mobile phone recorded the time and geographic coordinates of participants' daily trajectories. The portable sound sensor, which is a data-logging sound level meter, recorded every minute's A-weighted sound level over a continuous period of 48 hours. The activity-travel diaries collected data on the start time, type, companion, and location of participants' daily activities and travels according to the temporal sequence for the two survey days. A total of 112 participants who are 18 to 60 years old and have resided in the community for over 1 year completed the survey.

In the second stage, in-depth interviews were conducted with community organization members and representative participants in Beijing from June to July 2019. Representative participants in the first stage were selected according to the richness of their daily activity-travel patterns, exposures to sources of sound, and their experiences of well-being. Interviews with the community organization members mainly involved the histories, development, organizations, housing types, residents' background, environmental-related issues and policies, and sonic environments of the *Meiheyuan* community. Interviews with the participants mainly focused on their daily life arrangements, their perceptions and experiences of sound and well-being in specific contexts and situations during their everyday mobilities, and their coping strategies when they are confronted with different urban sounds in their everyday life. Further, the data of their activity-travel diaries and GPS trajectories were printed out before each interview. During the interviews, participants were asked to describe their lived experience regarding their perceptions of different sources of sound and the effects on their psychological health and well-being in their usual activity spaces in the *Meiheyuan* community and in the city of Beijing. With the permission of the participants, interviews were recorded and transcribed. The interviews were in Mandarin and the quotes were translated to English. Field notes were also taken in the field. In total, 32 participants and 6 community organization members were interviewed. The demographic information of the 32 participants is summarized in Table 4.1.

Geo-narrative analysis was utilized to analyze the qualitative data and understand the richness of how participants experience and cope with different sources of urban sound at specific spatiotemporal contexts during their daily movements. Geo-narrative analysis is a powerful approach to integrating both accurate spatiotemporal information and contextualized qualitative data (e.g., personal narratives, subjective perceptions, lived situations, and socio-cultural meanings) (Kwan, 2008; Kwan and Ding, 2008). By using geo-narrative analysis, this chapter can integrate spatiotemporal information of individuals' daily movements, actual sound levels, and their lived experiences of specific urban sound and psychological effects on their health in their everyday lives.

Table 4.1 Summary of demographic information of 32 participants

Gender	Female		Male	
	20		12	
Age	21-29	30-39	40-49	50-60
	5	9	9	9
hukou	Local *hukou*		Non-local *hukou*	
	25		7	
Time to move to Beijing	Born in Beijing	Move before 2010	Move after 2010	
	17	11	4	
Education	High School	College	Graduate	
	8	22	2	
Employment	Full-time	Part-time	Non-employ	Retirement
	22	4	3	3
Monthly Income (RMB)	< 2,600	2,600-5,000	5,000-10,000	>10,000
	3	5	16	8
Housing Type	Commercial	Work-unit	Public-rental	Low-rental
	23	5	2	2
Rent/Purchase Housing	Purchase		Rent	
	24		8	

4.4 RESULTS

4.4.1 EXPOSURE TO ACTUAL SOUND LEVELS

When considering people's exposure to actual sound levels, it is inadequate to only consider their actual sound exposure levels at their home location. As shown in Figure 4.1, there are variations in participants' actual sound exposure levels in diverse geographic locations that involve their homes, workplaces, other locations, and trips. The x-axis represents the sample ID and the y-axis represents the actual sound levels collected by the portable sound sensors. It shows that only considering people's sound exposure at their home might overestimate or underestimate their actual sound exposure during their daily movements in diverse geographic locations and contexts.

Diverse sources of loud sounds at different geographic locations can make people annoyed and stressful. Specifically, at home, people tend to be bothered by high levels of sound from traffic, construction (occur in the surrounding areas), renovation (occur inside a dwelling unit), neighbors' talking, and their domestic activities (e.g., cooking, cleaning, doing laundry, and washing dishes). As a participant mentioned, "*During peak time, there is always traffic congestion in the major road across the community. The sound of horning and vehicle engine is really annoying. I believe this is because our community is next to the exit of a highway, so there is a high volume of traffic, especially during the peak time* (S20)". At the workplace, participants tend to be bothered by sound from traffic, renovation activities, and neighborhood activities (e.g., music from nearby kindergarten and playing children), as well as sound from their work itself such as air conditioners and complaining costumers. At other locations, the sound depends largely on the nature of the venues or places such as restaurants, shopping malls, parks, gym, extracurricular schools, hospitals, grocery stores, and so on. Sound from traffic activities and loud talking of strangers are frequently considered as annoying and stressful at these locations. When people are traveling in a bus, metro, a car, or other transport modes, they are more easily annoyed by sound from construction and road traffic activities. As pointed out by one participant, loud and sudden traffic sound increases her perceived annoyance and stress during traveling. "*When I am walking on the street with an accelerating motorcycle passing by. You know, the sound from its engine, the hysterical sound. I can even feel my heart shrinking and my blood pressure levels rising* (S18)."

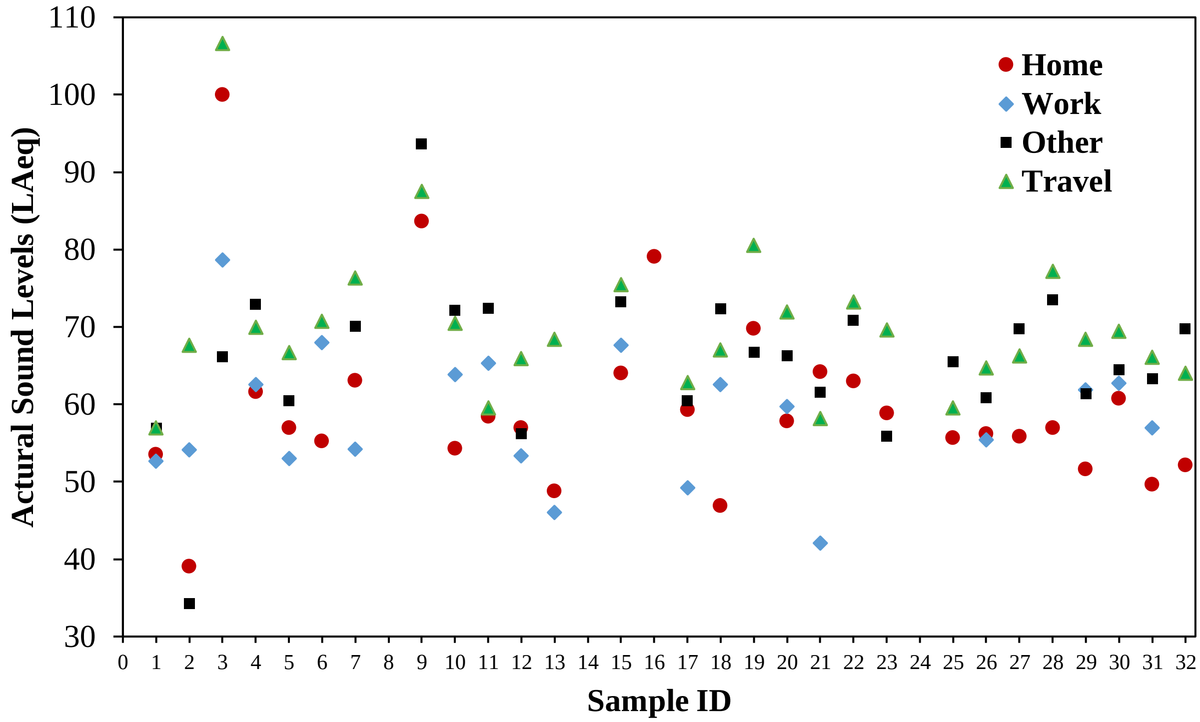


Figure 4.1 Participant's Exposure to Actual Sound Levels at Different Geographic Contexts

4.4.2 SOCIO-CULTURAL MEANINGS ASSOCIATED WITH SOUND

Whether high levels of sound can lead to annoyance and stress depends on the socio-cultural meanings associated with the sound and its source. The first is unnecessary and inconsiderately loud sound such as arguing and drunken neighbors. One participant complained about inebriated people in restaurants near his apartment, "*Every day from 8pm to midnight, the restaurants nearby opened their night markets, people get drunk and shout. I can understand the loud sound from those who have to maintain a living, like those driving taxis and constructing buildings, but I cannot understand and really hate these drunken people. They make the annoying noise and disturb our sleep* (S26)". Another participant complained about her quarreling neighbors in the upper level of her apartment, "*They just argue and fight with each other in the nighttime, especially when the surrounding environment is quiet. I am frequently awakened by the sound of their arguing, shouting, and crying. I just cannot understand and accept this kind of sound* (S31)".

The second is the loud sound that is associated with crowdedness, messy, and humid environments. One participant mentioned that she tends not to go to a food court near her workplace. "*Although there are more choices in the food court. It is loud and there is always a crowd of people and a long waiting line. I would like to order some takeaway and enjoy my lunch quietly at my workplace* (S5)".

Lastly, the loud and sudden sound can signify some unsafe and dangerous situations, which further lead to people's alertness and stress. This is especially the case among female participants who show fear of violence and attack in public spaces. One participant mentioned the barking dogs in the dark: "*Lights in our community park are turned off after 9pm, but people can still conduct their activities after that time. People still go out and walk their dogs. Some neighbors have really rough dogs. Once I walked in the park after 9pm, it was really scary that dogs barked nearby. I was just afraid that they came out from the dark…hurt me and my kid. Now we just avoid being in the park after 9pm. Once the lights are turned off, we go back home immediately* (S30)." Another participant mentioned the sound from braking vehicles: "*My workplace is close to a major street. I feel stressed when I hear the sound of sudden braking. That is an abnormal sound. I cannot stop thinking that there must be something bad like a traffic accident happened* (S18)".

4.4.3 MOBILE CONSTRAINTS AND COPING STRATEGIES REGARDING LOUD SOUND

People's space-time constraints also influence their perceptions of psychological annoyance and stress. When people are exposed to loud sound and they are constrained from changing their geographic locations during certain time periods, they tend to be more annoyed and stressed by the loud sound. Individuals face different degrees of space-time constraints, which further influence people's psychological responses and coping strategies in response to the loud sound. Three groups of spatiotemporally constrained people are considered: those facing dominantly work-related constraints, those facing mainly household-related constraints, and those with dominantly mobility capability constraints.

4.4.3.1 PEOPLE FACING DOMINANTLY WORK-RELATED CONSTRAINTS

This group of participants tends to be low-income people and have low-skilled work such as taxi drivers, security guards, maintenance workers, and customer services. They tend to be exposed to relatively high levels of sound at their workplaces, during their daily trips and at their home locations. They are highly constrained by their fixed work schedules and work environments from making any changes to avoid exposures to loud sounds.

One participant works as a taxi driver, as he mentioned, "*When I am stuck in traffic congestion, I do not like the sound of horns. But I have to work for money to feed my family and support my kid for school* (S9)". At the very beginning, their limited capability to change their loud work environments make them more annoyed and stressed. As one participant who works as a customer service described: "*My workplace faces a kindergarten. In the morning, kids do exercises with loud music. When people are just passing by, they may feel the kids are very cute. But I am there every day. Especially when I am busy at work, the loud music really makes me annoyed and stressed* (S1)". However, as time passes by, with limited capability of changing their work environments, they gradually get accustomed to their loud work environments. One participant who works as a safety guard mentioned, "*I take care of air conditioners for a building. When the air conditioners are running to cool the building, it is noisy. The buzzing sound from the air conditioners made me stressed when I first started this job. But I just got used to it, and now I feel nothing* (S7)". Another participant who is retired from a noisy cement factory and currently has a part-time job in customer service mentioned, "*It seems that I am used to the loud work environment. I cannot remember when I started to get used to it. But now I just don't notice it anymore. It is just a part of my job* (S18)".

The work-related constraints of this group of participants also influence their sound exposure during travel. Due to their long work hours and fixed work schedules, they have limited capability to avoid rush hours when commuting from their homes to their work locations and back. As one participant said, "*It takes about 20 minutes to ride my bike to my workplace. I have to be in my workplace by 8am in the morning. There is a lot of traffic and horning. Everybody is in a hurry for their work. When I am in a hurry, the loud sound makes me more annoyed* (S11)". Further, those who rely on public transportation have limited options of travel modes and routes, and the loud sound during rush hours makes them more annoyed. One participant who works as a security guard in a college students' dormitory described her experience when she was in a noisy bus, "*I have to be at my workplace from 8am to 6pm. The bus during peak hours is very crowded and noisy. Sometimes, there are passengers talking very loudly. It is really annoying, especially in the small and compact bus. I feel stuffy and stressful* (S3)". However, when participants are stuck in traffic with limited capability of changing the situations, they tend to gradually adapt to the loud sound during their travels. "*I mean, when you are stuck in the traffic, you can do nothing. When you are annoyed, it just bothers you more. I encounter it every day. I can do nothing about it. I just make myself get used to it* (S9)".

The low-pay jobs of this group of participants also limit their capability of moving to another home location even if they are exposed to high sound levels at their home. As one participant mentioned, "*The windows of my apartment are towards the G7 highway. The speed of passing vehicles is very fast, and the sound is really loud. We have to open our windows for fresh air. When I am watching TV at home, I can't hear clearly the sound from my TV. There are always vehicles passing by. But my home is here. I can't afford to move to another place* (S11)". Their work schedules also influence their time to rest and sleep at their home. Those who work in the service industry tend to work at nighttime/weekend days and rest at daytime/weekdays, and they are more easily bothered by sound from the renovation activities in the neighborhood. "*I work for the entire week, and normally I have Tuesday as my day off. I feel really exhausted by my weekly work, and I don't want to go to any other places. I normally spend the day resting at home. Sometimes I become very unhappy when the renovation noise from neighbors disturbs my rest* (S1)". "*My work schedule is like two daytime shifts, one nighttime shift, and two days off. When I have night shifts, I go off work at 8AM and go back home for a sleep. I am frequently awakened by renovation noise* (S7)". With limited capabilities of changing their situations, these low-income participants adjust their perceptions to adapt to the loud sound. "*There are always renovation activities in this building, and there is no way to turn it off. That's understandable with the frequent transfers in the second-hand apartments in this community. Whoever buys an apartment would decorate it to their own styles. I would do it too (if I ever bought an apartment)* (S7)".

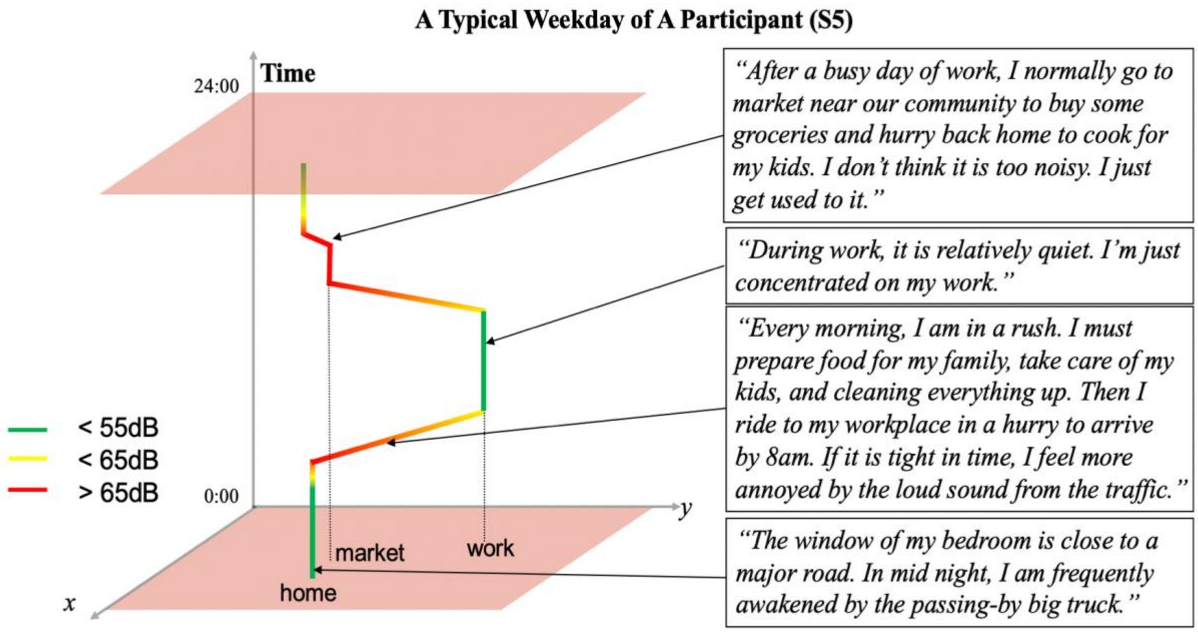
4.4.3.2 PEOPLE FACING DOMINANTLY HOUSEHOLD-RELATED CONSTRAINTS

This group of participants tends to be women who are responsible for childcare and household-related activities. They may be housewives or have a part-time job to better take care of their children, or have a full-time job struggling with home-work balance. They tend to be exposed to loud sound at their home, during travel, and at other locations where they have to accompany their children, while some also have low-skilled jobs and work in loud environments. They are constrained by their gender roles and household responsibilities from avoiding loud environments.

At home, they tend to be exposed to high levels of sound while conducting their childcare and household-related activities. However, they seem not to complain or even notice their high sound exposure levels, and they regard taking care of their families and children as a crucial part of their lives. As explained by a female participant who is exposed to high levels of sound during her cleaning activities at home: "*I like to keep my home clean all the time. I clean a lot, both weekdays and weekends… I don't think it is loud when I am cleaning. Maybe I focus more on my tasks rather than the surrounding sound itself* (S15)". Only when they feel stressed due to their household-related activities do they tend to be more easily bothered by the loud sound. "*My pressure mainly comes from taking care of my young son and my older parents. Sometimes when I am stressed out by the household work, even though it is just a little loud, like the sound from the refrigerator, washing machine, and kitchen hood, it makes me annoyed and stressed* (S22)*".*

Due to the time that they spend on childcare and household-related activities at home, they are constrained from adjusting the time of traveling to dropping off or picking up their children at school and traveling to their workplaces. These activities are frequently undertaken during rush hours and they cannot avoid being exposed to high levels of sound during their travels. Many female participants with children spend their time on household-related activities before traveling to work, and these impose temporal constraints that make it difficult for them to adjust the time of their travels to avoid rush hours. As one of them said, "*Every morning, I am in a rush. I have to prepare food for my family, take care of my kids, and clean up everything. Then I ride to my workplace in a hurry to arrive by 8am* (S5)". Further, the loud sound adds to their stress in conducting household-related activities. "*When I feel that time is tight, such as picking up my child or hurrying to work, I feel more stressed by the traffic noise* (S5)". One participant, a housewife who has to take a half-an-hour bus ride to send her son to kindergarten during peak time, mentioned: "*People all send their kids to school at that time and everybody is just stuck on the road. I am not just anxious about whether my kid can get to school on time, but also upset by the slow or halted traffic and endless honking* (S28)". However, they have limited capability of coping with the loud sound during traveling. Since they need to be alert about the traffic to protect their children and themselves, they cannot cover their ears using earphones and earplugs. As one participant described, *"I don't like to put on earphones when I am walking or riding my motorcycle. I don't like my kid to wear that either. It is dangerous, and we have to watch out for the traffic situations* (S22)". They gradually adapt to the loud sound given their limited capabilities to adjust their travel spatially and temporally. As one participant said, "*We can do nothing about the traffic. What I can do is to adjust my attitude towards the traffic noise…Before, when I paid too much attention to noise, it seemed that I was more bothered by it. Now, I just don't pay attention to it. Strangely, I feel more relaxed and less stressed* (S3)".

Their household-related responsibilities also bring about space-time constraints associated with the need to undertake activities in other locations, such as going to grocery stores for household needs and accompanying their children to hospitals and extra-curricular schools, where they are exposed to high levels of sound but have limited capabilities to change the situations. As they mentioned, after a busy working day, they have to conduct household-related activities in locations such as grocery stores with limited capabilities to adjust the time. *"I go off work at 5PM. After work, I normally take half an hour to buy some groceries at the nearby market. Then I have to hurry back home to cook for my family for supper. It is busy time at the markets, with many people* (S4)". When they are stressed, they more easily notice the loud sound. As some participants described their experience of bringing their children to hospitals and being bothered by the loud sound, "*Sometimes my kid gets sick, I bring him to the children's hospital. The sound in the hospital is really loud because there are a lot of people; they're talking, quarreling, walking, and crying. When my kid feels uncomfortable, I am anxious and irritable. The uncontrollable sounds make me more upset and stressful. I would say there is nothing worse than that experience* (S28)". However, just like their adaptation to their household-related responsibilities and activities, loud sound from most of their household-related activities have gradually become a part of their everyday lives. "*Most of the time I just do not notice the loud sound. My attention is on my kid and family* (S15)".



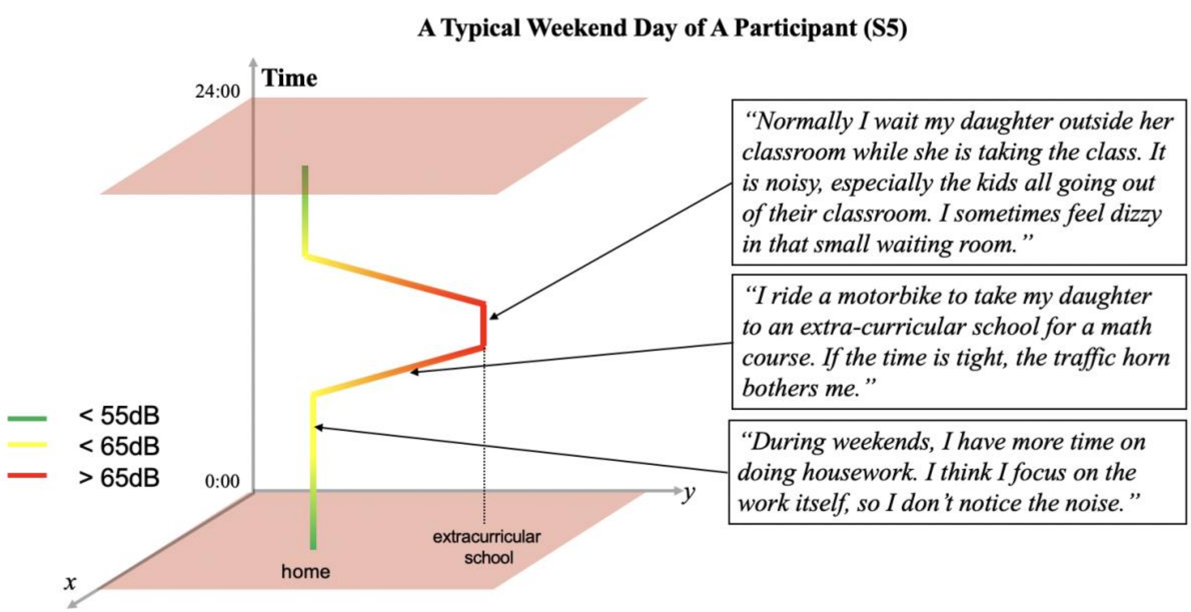


Figure 4.2 An Example of Geo-narrative Analysis for a typical Household-Related Constrained Participant

4.4.3.3 PEOPLE FACING HIGH MOBILITY CONSTRAINTS

This group of participants tends to face dominantly mobility constraints. They are less mobile and more noise-sensitive people such as disabled people, older people, and infants. They are more sensitive and susceptible to their surrounding sound. One mother described her young baby's response to the loud sound from passing trains, "*Babies are more sensitive to noise. There is a railway station near our community. When my kid was just one year old and every time when the trains passed by, she got afraid and cried* (S5)". One participant with disability in her legs and lung and has to carry portable oxygen described, "*I can't go too far away from home. Normally I just walk around the building. Maybe because of my health conditions and restricted movements, I am a bit anxious and sensitive to the surrounding environment. Even with only a little noise, I feel bothered and stressed* (S25)".

Further, due to their mobility constraints, sometimes participants in this group are passively exposed to relatively high levels of sound. They spend most of their time at home and are more easily influenced by the renovation noise from their neighbors. As reflected by a staff member from the community organization, "*Renovation activities in this community are only allowed on weekdays during 8:30-11:30am and 2:00-5:30pm. Still, sometimes we've had complaints from those families with young infants and older people. Since they stay at home all the time and there is nowhere for them to avoid the noise*". Because participants in this group can only move slowly (e.g., due to the use of wheelchairs) when compared to people without mobility constraints, they cannot avoid the loud traffic-related sound. "*I have to use an electric wheelchair to move around. Sometimes there are many people on the sidewalk, and we can only ride on the main road. My mom and I ride slowly. Many drivers are impatient, and they horn at me. I am frequently scared by the sudden and harsh sound of horns… I hope I can use the road within the park. It is quiet and the environment is good, but I can't access it because of the S-shaped entrance to prevent wheelchairs from entering* (S25)". Their limited capability to avoid high sound exposure further increases their psychological annoyance and stress. As one participant mentioned, "*With my little kid and older parents at home, we have installed double-glass windows at home. But still it doesn't help. I suggest that whenever someone needs to renovate, it is a good idea to inform everybody in the building ahead of time. Then we can arrange my kid and older parents out to travel during that time period* (S32)".

In addition to this group of mobility-constrained participants, other people can also be less mobile in specific spaces and times. It is especially the case for those who have to sleep at their home during nighttime but suffer from loud sounds during their sleep. Many participants complained about the loud sound that disturbed their sleep, but they cannot avoid the sound because they have no alternative places for their daily sleep. *"In daytime, we go out for work and kids go to school. We can escape from the traffic sound. But during nighttime, there are always big trucks passing by. Since the trucks are not allowed to travel in this area during daytime, they pass through here from midnight to early morning when my families and I need to sleep. The sound feels really loud and harsh, and sometimes we are awakened by the sound. It is really annoying* (S2)*".* Only the few who can afford to move to another location can avoid the loud sound during nighttime. One participant was often annoyed by drunken people because his apartment was close to restaurants, and during the interview, he and his family were planning to move to a community with quiet environments: *"After a busy working day, we really need a quiet environment for a good rest. The loud noise at night disturbs our sleep and normal life…I am glad that my family will soon move to a new place. When I picked the location of my new home, I deliberately chose a quiet place* (S26)". However, for a majority of the participants who cannot afford a new home location due to the rising housing price in Beijing, they are continuously annoyed by and have to gradually adapt to the loud sound during their sleep.

4.5 DISCUSSION

This chapter incorporates human mobility into understanding people's sound exposure and health effects. Human mobility is considered as not just people's actual daily movements in diverse geographic locations (e.g., home, workplace, other locations, and travel) but also their potentials for movements.

People's potentials for movements are shaped by their space-time constraints, which further influence people's sound exposures, psychological responses, and coping strategies of sound in their everyday lives. More specifically, due to the space-time constraints, some individuals are exposed to high levels of sound in certain environments. Work-related constrained individuals are constrained by high sound exposure levels at their workplaces, during travel, and during their stay at home. Household-related constrained individuals are exposed to high sound levels when they conduct household-related activities at their homes, during their travel, and at other activity locations. High mobility constrained individuals are exposed to high levels of sound at home location and during their travel.

Further, the space-time constraints of the participants influence their psychological responses to and coping strategies against loud sounds. Only a few individuals with fewer space-time constraints can flexibly adjust their geographic locations at particular time periods to avoid the loud sound. These include those who are retired with fewer space-time constraints from work, whose children have grown up, and people who can adjust their travel time to avoid rush hour on a daily basis, afford to move to a new home location, or change to another workplace with better environments.

However, in contrast, a majority of the participants in this chapter to some extent are constrained spatially and temporally and they can only adopt alternative coping strategies such as wearing earplugs and earphones, installing soundproofing (e.g., double-glass) windows, and closing their windows at home. However, these coping strategies are not necessarily effective in mitigating the loud sound. For instance, to be aware of the traffic, people do not prefer to wear earphones while they are walking or riding a bike. Further, they cannot wear earplugs in some workplaces such as being customer services and security guards. Additionally, some people may prefer to open their windows for fresh air despite the loud sound.

Nevertheless, when their coping strategies fail to protect themselves from the loud sound, people have limited capability to change the situations. In the beginning, their space-time constraints make them more annoyed and stressed by the loud sound. However, in the long run, people gradually but passively get used to the loud sound in cities. The work-related constrained and household-related constrained individuals adjust their perceptions of sound, consider the loud sound as part of their social roles and urban lives, and become more tolerable for the loud sound in their everyday lives. However, their exposure to loud sounds can still cause negative effects on their physiological health, but they become unaware of the loud sound. Moreover, the situation can be worse for those high mobility constrained individuals given that they are not just highly constrained spatially and temporally but also more susceptible to the surrounding sound. Accordingly, they tend to be continuously annoyed and stressed by the loud sound that they have limited capability to make changes, which can compound negative effects on their psychological health.

4.6 CONCLUSION

Different individuals can be constrained by specific situations where they are forced to be exposed to high levels of sound in their everyday lives. Further, they have limited capabilities to avoid loud sounds due to their space-time constraints. In addition, they have to adjust their sound perceptions and passively adapt to the loud sound. Therefore, their limited capabilities to move and exposure to high levels of sound act as multiple stressors that continuously influence their psychological health.

This chapter reveals that merely considering people's exposure to sound at their home location is inadequate. Instead, people's exposure to sound from diverse sources in multiple geographic contexts can provide more accurate assessments of individuals' sound exposure. Further, in addition to actual sound levels, socio-cultural meanings associated the sound can add to people's psychological annoyance and stress. Additionally, when people are constrained spatially and temporally and exposed to high levels of sound in the short run, they experience an increase of psychological annoyance and stress. However, in the long run, work-related and household-related mobility constrained individuals tend to adjust their perceptions of loud sound and passively adapt to the loud sound, and thus, the effects of loud sound on their psychological annoyance and stress decrease. Noticeably, those who are highly mobility-constrained and noise-sensitive tend to be continuously annoyed and stressed by loud sounds. Their exposure to loud sound and their sensitivity to their surrounding environments generate tensions in their everyday lives, and their high mobility constraints further add to their susceptibility of exposure to high levels of sound.

This chapter advances knowledge of the effects of human mobility on people's sound exposure and psychological health. Human mobility is understood as both people's actual movements and their potentials for movements. In terms of people's actual movements, using innovative methods that combine portable sound sensors, GPS trackers, activity-travel diaries, and in-depth interviews, this chapter assesses people's objective exposures to and subjective perceptions of sound during their daily movements. Compared with previous studies that focused on people's sound exposure at some particular geographic locations (Evans and Johnson, 2000; Evans and English, 2002; Cain et al., 2013; Lindborg, 2015; Bild et al., 2016), this research gains a more accurate and in-depth understanding of people's experiences of different sources of sound during their movements in different geographic locations and contexts. Further, this chapter shows that people's potentials for movements are largely shaped by their space-time constraints in their everyday lives, which further influence their sound exposures and psychological responses. Compared with previous studies that assumed that people can actively react to loud sounds that generate psychological annoyance and stress without constraints (Schulte-Fortkamp and Fiebig, 2006; Jeon et al., 2011), this chapter shows that people's reactions to loud sound are restricted by their space-time constraints. More generally, this analysis contributes to the literature on assessing environmental health risks (Jerrett and Finkelstein, 2005; Jerrett et al., 2010; Elliot, 2010) by demonstrating how individuals' exposure, adaptation, and susceptibility related to environmental risk factors can be influenced by their actual movements and potentials for movements.

This chapter has practical implications for protecting those socially vulnerable and susceptible individuals and groups from high levels of sound. First, it is important to create and maintain quiet surrounding environments for urban residents especially when they are constrained spatially and temporally, such as creating quiet residential and working environments, public transportation spaces, childcare facilities, and nighttime hours for sleep. Second, it is also necessary to increase the awareness of those work-related and household-related mobility constrained individuals related to their loud sound exposure and potential physiological health effects. Third, it is necessary to increase mobility capabilities of work-related constrained individuals through providing more flexible work schedule and better work environments to avoid their high exposure to sound, and similarly for those household-related constrained individuals, through releasing the constraints of their gender roles and engaging more family members in household-related activities. Last, particular attention should be given to those socially susceptible and highly mobility constrained individuals such as disabled people, older people, and infants. It is essential to protect them from loud sound through providing them with quiet residential environments, ensuring restricted time of construction and renovation activities in their residential neighborhoods, and improving their access to quiet and safe traveling environments.

CHAPTER 5: CONCLUSIONS AND FUTURE DIRECTIONS

5.1 SUMMARY OF CONTRIBUTIONS

This dissertation advances the knowledge of individuals' sound exposure and its psychological health effects through a sonic perspective and a contextualized understanding of noise pollution in cities. More broadly, this dissertation contributes to the literature on people's environmental exposures and their effects on human health by highlighting the role of human mobility, contextual effects, and subjective perceptions of environmental risk factors.

This dissertation also utilizes innovative methods that can also be applied to future studies on environmental exposure and health effects. In terms of data collection, it integrates the methods including a survey questionnaire, real-time GPS trackers, portable sound sensors, activity-travel diaries for a weekday and a weekend day, together with observations and in-depth interviews. Data collected from various sources allow for cross-validation and triangulation among different approaches. More importantly, the integrated methods also address the uncertain geographic context problem (UGCoP) (Kwan,2012a,b). By collecting high-resolution spatiotemporal data on individuals' daily movements, sound exposures, and psychological health, it allows for more accurate assessments of individual-based sound exposures and health outcomes. In terms of data analysis, this dissertation uses a mixed-method approach that combines both quantitative and qualitative analysis. The quantitative analysis provides an understanding of the relationships between individuals' sound exposure and health outcomes, and the qualitative analysis captures the richness and complexity of people's experience of daily mobility, urban sound, and psychological health in their everyday lives. Together, using the integrated methods, it contributes to a more holistic understanding of human-environment interactions and their effects on human health from a sonic perspective.

Specifically, the first study (Chapter 2) develops a conceptual understanding of activity-related contexts and their effects on individuals' subjective evaluations of sound. The use of the activity-based approach and multilevel modeling can be applied to future studies on the exploration of contextual effects on individuals' environmental exposure and health effects. The activity-based approach provides a powerful space-time perspective for understanding individuals' sound exposure and perception at the level of their daily activities. Multilevel modeling provides an analytical tool to integrate individual-level and activity-level data, which provides a more contextualized understanding of how people's daily activities and trips can make a difference in their environmental exposure and health effects.

The second study (Chapter 3) further adds a dimension of psychological stress. This chapter advances the knowledge of people's sound exposure and health effects by highlighting the role of contextual effects and subjective perceptions of sound. By using structural equation modeling, this chapter reveals the complex relationships among contextual effects, objective exposures to sound, subjective perceptions of sound, and psychological health effects. Further, the use of geographic ecological momentary assessment (GEMA) analysis in this chapter can be applied to future studies on understanding individuals' environmental exposure to risk factors and their psychological health effects at high spatiotemporal resolutions.

The third study (Chapter 4) advances the situated knowledge of how people experience urban sound and psychological stress as they perform their activities and trips at diverse geographic locations and contexts in their everyday lives. The use of geo-narrative analysis contributes to the integration of data collected from various sources. These include spatiotemporal information collected by GPS trackers and activity-travel diaries, actual sound levels collected by portable sound sensors, and qualitative data on subjective perceptions of sound and psychological responses. Using the integrated data, this work provides new insights on human mobility, which is not just understood as individuals' daily movements but also their potentials for movements. Further, individuals with different degrees of mobility constraints were identified. This analysis enriches the understanding of how human mobility can play a role in influencing the entire process of people's objective sound exposure, subjective sound perception, psychological responses, and coping strategies.

In addition to theoretical and methodological contributions, this dissertation also makes practical contributions. First, unlike conventional vision-dominated urban planning processes, this research advocates for incorporating a sonic perspective to urban planning practices and promoting residents' urban experiences from a sonic perspective. Second, this dissertation provides an alternative approach to managing noise pollution in cities. In addition to the noise mitigation and control approach, a human-centric and context-aware urban development agenda can be encouraged. By understanding by whom and in what spatiotemporal situations a sound generates socio-psychological stress, it provides valuable guidance for diversifying ways to improve urban sonic environments, promote the psychological health of urban residents, and construct livable and healthy cities. Third, this dissertation also has social implications for protecting mobility constrained and susceptible populations in cities and promoting environmental justice. This research identifies the socially vulnerable and susceptible populations not only as those who are segregated and stuck in noisy residential locations but also as those who are exposed to high levels of sound during their daily movements and encounter mobility constraints to make changes. It provides policy implications for mobilizing mobility constraints of these socially vulnerable individuals and improving sonic environments in specific situations in order to protect these constrained individuals from being exposed to high levels of sound.

5.2 FUTURE STUDIES

This dissertation can be expanded in several future directions through subsequent studies. First, one future direction is undertaking comparative studies in cities with different socio-cultural backgrounds and urbanization stages (e.g., cities in the U.S. and China). Specifically, how socially vulnerable individuals in both cities are objectively exposed to, and how they subjectively respond to and cope with sound can be further compared. Further, how different urban forms and socio-cultural backgrounds influence urban residents' space-time behaviors, daily sound exposures, and psychological health outcomes is another important topic to explore through comparative studies. The comparative framework will advance theories in different urban contexts and help to better understand the environmental challenges for global cities.

Second, another future direction is exploring the neighborhood effect averaging problem (NEAP) (Kwan, 2018b). The current study has only focused on variations in individuals' actual sound exposure levels during their daily movements. Future studies can be conducted to compare the differences between individuals' actual sound exposure levels at their home locations (residence-based assessment) and during their daily movements (mobility-dependent assessment). Further studies can explore how the differences between these two measures of assessment are influenced by people's different socio-demographic backgrounds. In this way, how people's daily movements influence their daily environmental exposure levels and who can be better off (e.g., with lower levels of daily exposure to environmental risk factors) through their daily movements can be understood.

The third potential direction for future studies is to advance knowledge of the therapeutic soundscape by exploring how urban sound in people's everyday lives can be therapeutic for individuals. This dissertation has focused on people's psychological stress as a key health outcome related to their sound exposure. Future studies can further explore in what situations and to what extent people's daily exposure to urban sound and sonic environments can improve their social and mental well-being. Future studies can also explore how individuals' life histories and senses of places shape their experiences of urban sound and well-being. Methods such as participant observation, mobile interview, and video-recording can be utilized to complement existing methods and approaches used in this dissertation.

Finally, this dissertation has collected and analyzed individual-based sound exposure and psychological health effects at different temporal scales (e.g., momentary, daily, weekly, and long-term). Future studies can be conducted to investigate the role of temporality in influencing the relationships between individual-based sound exposure and psychological health effects. For instance, future studies can further explore the relationships between individual-based momentary noise exposure and levels of their momentary, daily, and long-term psychological stress. Future studies can also investigate whether there are accumulative effects of their short-term psychological stress on their long-term psychological health. Additionally, each individual's environmental health risks that are associated with his/her exposure, adaptation, and vulnerability can change over time. This dissertation mainly used cross-sectional data to examine associations, and future studies can collect longitudinal data to investigate potential casual relationships.

More broadly, future research can explore individual-based exposures to other environmental risk factors (e.g., air pollution, crime, sense of safety, and crowdedness) using the approaches and conceptual frameworks that have been developed in this dissertation. Further studies can be undertaken on how people from different socio-demographic backgrounds are influenced by the compound effects of multiple environmental risk factors in their everyday lives. Future studies can also be conducted on socially vulnerable groups and individuals and how they cope with multiple environmental stressors. This direction of studies can considerably contribute to the literature on environmental justice and mobility justice.

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