COVID-19 Risk Perception in Urban and Architectural Environments

by

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A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Doctor of Philosophy

in

Psychology

Waterloo, Ontario, Canada, 2023

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

David Borkenhagen was the sole author for Chapters I, II, III, and IV which were written under the supervision of Dr. Colin Ellard.

This thesis consists of three manuscripts written for publication.

The findings from Chapter II and Chapter IV were presented at the Moving Boundaries Conference 2022 in Guadalajara, Mexico.

The findings from Chapter II were submitted to *Cities & Health* and as of June, 2023, are currently under review.

The findings from Chapter V were published in *Cities & Health*. Citation:

Borkenhagen, D., Grant, E., Mazumder, R., Negami, H. R., Srikantharajah, J., & Ellard, C. (2021). The effect of COVID-19 on parks and greenspace use during the first three months of the pandemic–a survey study. Cities & health, 1-10.

Exceptions to sole authorship of material are as follows:

Research presented in Chapter V:

Hanna Negami, Jatheesh Srikantharajah, Emily Grant, Robin Mazumder, and Colin Ellard were co-authors on the publication relating to this work. The authors are current members and recent alumni of the Urban Realities Laboratory of the Department of Psychology at the University of Waterloo in Waterloo, Ontario, Canada.

Abstract

The COVID-19 pandemic presented a profound challenge for cities. Cities are designed to maximize the benefits of density, yet this same density becomes a liability during an outbreak of a socially communicable infection. How did members of the general public perceive COVID-19 transmission risk in the urban and architectural environments they live in? And what effect do these perceptions have on pandemic-safe behaviours? The aim of this dissertation was to answer these questions using the methodologies of research psychology. Across five experiments, it was demonstrated that members of the general public hold complex perceptions of COVID-19 risk in urban and architectural environments, and utilize different visible and non-visible features to render judgments about risk. Moreover, risk perception consistently held a significant positive relationship with the likelihood to engage in pandemic-safe behaviours. These results provide insight on the subjective experience of citizens during the COVID-19 pandemic, and offer designers and policymakers information about human behaviour and psychology during this time of crisis. The results from these investigations are summarized in the form of design and policy insights so that designers can create spaces that are perceived as safe, and so that public policymakers can create more nuanced public health policy interventions that leverage the intrinsic motivation of citizens to protect themselves against the risk of infection. Given the inevitability of future pathogen outbreaks, the results from this dissertation stand to make a meaningful contribution to the fight to keep citizens safe during these times of crisis.

Acknowledgments

I would like to thank my family and my friends. Without their support, none of this would have been possible. I also extend a special thank you to my father, whose humour, pacifism, passion, and ethic I carry with me every day.

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Dissertation Outline

In **Chapter I**, I outline the primary aim of my dissertation, which is to investigate the characteristics of COVID-19 transmission risk perception in urban and architectural environments. I summarize relevant literature from the disciplines of architecture, psychology, and neuroscience, and synthesize this information and explain how it frames my subsequent studies. In **Chapter II**, I apply Brunswik's Lens Model to guide a study investigating the visual cues members of the general public associate with perceived pathogen transmission risk in urban and architectural environments, and I compare these associations with those of Infection Control Practitioners. In **Chapter III**, I investigate how perceived COVID-19 transmission risk differentiates as a function of knowledge about different urban and architectural environments, as well as how risk differentiates as a function of knowledge about the formal and functional characteristics of those environments. In **Chapter IV**, I conduct an image-based experimental study where I manipulate visible features of the urban and architectural environment and measure the effect on perceptions of transmission risk and likelihood to engage in the cautionary behaviour of mask wearing. Finally, In **Chapter V**, I analyze data from an applied context, investigating whether people self-regulated their behaviour in absence of mandatory stay-at-home policies during the first year of the pandemic.

Chapter I

COVID-19 Risk Perception in Urban and Architectural Environments

Introduction

The COVID-19 virus radically altered our relationship with the surrounding built environment. Over the course of the pandemic, all shared urban and architectural spaces became potential sites of infection. Moreover, the specific characteristics of these spaces acted as the mechanisms through which the virus spread. Spaces that are crowded, encourage close-contact, and are confined were quickly identified by health agencies as posing a high risk of transmission because the virus spreads through contaminated respiratory droplets (World Health Organization, 2021). Because of the role shared public spaces play in regulating the spread of COVID-19, restricting visits to these environments became a key policy tool used to counteract the spread of the virus. By the spring of 2020, only a couple months after the first COVID-19 cases were reported in Wuhan, governments around the world implemented stay-at-home policies designed to keep people at home and away from shared urban spaces that posed a high transmission risk. The scope of these behavioural restrictions was unprecedented: an estimated 3.9 billion people–half of all humanity–in 90 countries experienced some form of lockdown during the spring of 2020 (Sandford, 2020). Epidemiological research has produced evidence demonstrating public lockdowns were largely effective at reducing the spread of COVID-19 (Bendavid et al., 2021; Bjørnskov, 2021; Perra, 2021).

Yet, what remained largely unconsidered by governments—as well as by the research literature—was how members of the general public, as opposed to public health experts and government officials, conceptualized COVID-19 transmission risk in urban and architectural environments over the course of the pandemic. In times of crises such as pandemics, governments often centralize decision-making to increase decision-making efficiency (Hart, Rosenthal, Kouzmin 1993). In the context of the COVID-19 pandemic, this governance strategy manifested as a reliance on “top-down” policy initiatives such as city-wide mandatory lock-down and stay-at-home orders, as opposed to more “bottom-up” policy approaches that leveraged the decision-making of individual citizens (Allen, 2022). While efficient, this strategy may underutilize the intrinsic motivation of individuals to protect themselves against health risks. A reliable effect from the health-psychology literature is that individuals are motivated to adopt self-regulatory behaviours against threats in the world that are perceived to pose a health risk (Brewer et al., 2007). In the context of the COVID-19 pandemic, this would lead to the prediction that members of the general public would be intrinsically motivated (i.e., independent of state-enforced lockdowns) to adopt self-regulatory behaviours against the threat of COVID-19 infection, including but not limited to avoiding public spaces and mask-wearing. This predicted effect is important to study because the city-wide mandatory lock-down and stay-at-home orders were widely criticized as being “too blunt” of a policy tool that had unintended costs, including disruptions to children’s education (Allen, 2022). For this reason, it is important to study how members of the general public conceptualized COVID-19 transmission risk in urban and architectural environments over the course of the pandemic as it offers a policy makers insight into whether they engage in pandemic safe behaviours independent of state-enforced lockdowns.

In fact, a handful of studies have yielded some evidence suggesting that members of the general public self-regulated their behaviour in public spaces as a function of risk perception and independent of state-enforced lockdowns. For example, Goolsbee and Syverson (2021) used cell phone mobility data to track visits to more than 2.25 million individual businesses across multiple U.S. counties with differing COVID-19 lockdown policies. The researchers found that members of the general public refrained from visiting shared public spaces *prior to* the implementation of mandatory stay-at-home policies by local health agencies, but right after reports of increases in local infection rates. In other words, this temporal analysis suggests it is *perceived infection risk*, rather than mandatory stay-at-home policies that motivate people to refrain from visiting shared public spaces. The researchers also found that visits dramatically decreased across counties independent of whether those counties had stay-at-home policies or not. The stay-at-home policies only accounted for about 7 percentage points of an overall foot traffic decease of more than 60 percentage point. Rather than legal restrictions, it was the number of local COVID-19 deaths that predicted the drop in visits, again suggesting that perceived transmission risk drove the public to avoid the shared spaces. Given this finding, it is worthwhile to investigate the origins of the psychological construct of perceived COVID-19 transmission risk, as well as quantify its effects on self-regulatory behaviors so that policymakers can fully capitalize on individuals' motivation to protect themselves against external threats, including the threat posed by pathogens in the diverse urban and architectural environments they occupy.

The Role of Architecture in Regulating the Spread of COVID-19

This dissertation focuses on how COVID-19 transmission risk perception is conceptualized in urban and architectural environments. This is because contact with infected others is a primary mode of transmission for socially communicable pathogens like COVID-19; therefore architecture, which is responsible for the formal configuring and functional programming of both public and private spaces, is inextricably linked to regulating the spread of pathogens. Scientists have noted the link between architecture and pathogen spread for some time now. In 1854, a physician named John Snow famously traced a cholera outbreak in London's Soho district to a contaminated water supply collected from the Broad St. pump (Figure 1). Snow's finding proved profound on two fronts. First, it disconfirmed the then-accepted theory that cholera spread through miasma, or contaminated air. Second, it demonstrated that architecture–in this case the pump that provided the community's water supply–was the vector that caused the neighbourhood's outbreak. Using his finding, Snow was able to persuade local officials to remove the handle of the Broad St. pump, quelling the outbreak. Eventually, the city of London undertook massive upgrades to its water and sanitation infrastructure with the understanding that clean water promoted health among citizens. Today, safe sanitation infrastructure practices are codified in urban planning policy, ensuring citizens of cities around the world have safe drinking water. While these policies are considered normal today, the fact that they emerged in response to a public health crisis–the cholera pandemic–demonstrates the role architecture plays in regulating the spread of pathogens in cities.

Figure 1. John Snow's map of cholera cases in Soho (1855).

Since early on in the COVID-19 pandemic, a large body of research has focused on understanding which features of architecture regulated the spread of COVID-19. Because contaminated respiratory droplets expelled one to two metres in front of the infected individual are the primary mechanism through which COVID-19 spread, transmission was claimed to occur most easily in the “three C’s”: crowded places, close contact settings, and confined and enclosed spaces (Lewis, 2021; World Health Organization, 2021). Three C spaces offer multiple opportunities for the virus to spread from an infected individual to another person through a cough, a sneeze, touching, or simply breathing in the close vicinity of an uninfected individual. Because they are often crowded, the likelihood of transmission is high. Moreover, because they are enclosed and lack access to fresh air, droplets contaminated with the virus can linger in the air. For these reasons, super spreader events often occurred in three C spaces like cruise ships, classrooms, and churches (Majra et al., 2021). Further, the confinement of airplanes and the high turnover of international travellers in airports allowed COVID-19 to rapidly spread around the world (Sun et al., 2021).

In addition to the three Cs, the ventilation quality has also been demonstrated to play a role in regulating the spread of COVID-19. Although the highest concertation of virus-containing respiratory droplets occurs within three to six feet of the infected person, these same droplets can remain suspended in the air for hours in the form of an aerosol and move from one end a room to the other, infecting people metres away (Biswas et al., 2022; Lednicky et al, 2020; Li et al., 2021; de Oliveira et al., 2021). Therefore, proper ventilation, where potentially contaminated air from inside is replaced with fresh air from outside, is an effective design intervention against airborne spread. Air can also be passed through filters that remove virus-containing particles (Mousavi et al., 2020). Similarly, the risk of transmission in outdoor spaces has been demonstrated to be low due to an abundance of recycled air and the likelihood of the virus dissipating into the atmosphere (Weed & Foad, 2020).

Although less prominent than other modes of transmission, fomites also acted as a physical medium through which COVID-19 spread (Mittal & Rajat, 2020). Fomites are defined as any inanimate object, such as sink faucets, or handrails, on which the virus can lay dormant and transmit to a new host. A person can become infected with COVID-19 by touching the fomite on which the virus was deposited, which can persist for up to 9 days, and then touching their mouth, nose, or eyes (Kampf et al., 2020). However, the virus is less likely to persist on porous surfaces such as concrete or wood, or surfaces that are exposed to high temperatures, humidity, and ultraviolet radiation (sunlight) (Harvey et al., 2020). Together, fomite transmission is thought to account for only a small fraction of total infections compared to airborne transmission (Goldman 2020). Nonetheless, the potential for fomite transmission caused many organizations to drastically increase the frequency and stringency of cleaning protocols, where disinfecting agents are applied to surfaces to kill the virus (Wilson et al., 2021).

The urban realm itself has also been demonstrated to regulate the spread of COVID-19. The high population densities that cities accommodate maximize the benefits of human collaboration and competition. Yet, it is this same density that makes cities dangerous in the context of socially communicable pandemics such as the COVID-19 pandemic. Somewhat surprisingly, empirical science has yielded mixed results regarding the relationship between urban density and infection rates. An investigation by researchers at the Johns Hopkins Bloomberg School of Public Health found no significant association between density and infection rates across 913 U.S. metropolitan counties (Hamidi, Sabouri & Ewin 2020). The authors reason that, while dense areas increase the likelihood of face-to-face contact, they also tend to have better availability of health care services and adherence to social distancing measures compared to less dense areas, offsetting the downsides of increased face-to-face contact. However, in countries like India where density isn't always associated with better availability of health care services, a positive relationship between density and COVID-19 spread has been documented (Bhadra, Mukherjee & Sarkar 2021). Further, lower income neighbourhoods around the world were hardest hit by the pandemic, achieving the highest case rates (Baena-Diaz et al., 2020; Cohen et al., 2022; Jannot et al., 2021; Jay et al., 2020), suggesting it is not density *per se* that drives COVID-19 infection rates in cities, but a combination of density coupled with poor access to healthcare and overall lack of resources.

Together, these features of architecture were empirically demonstrated to regulate the spread of COVID-19 in urban and architectural environments. However, they are not necessarily the same as subjective assessments (i.e., perceptions) of COVID-19 transmission risk among the general public. Many of the summarized findings on objective transmission risk were derived from studies that utilized sophisticated measuring devices, such as optical and electrochemical biosensors, which reach far beyond the assessment capabilities of the average human. For this reason, objective assessments of COVID-19 transmission risk should not be assumed as equal to subjective assessments. In fact, a large body of research on the psychological construct of *risk perception*, summarized in the next section, has produced evidence demonstrating multiple instances in which subjective assessments of risk significantly differ from objective assessments.

The Psychology of Risk Perception

Risk perception is defined as a likelihood estimation that harm or hazard will occur (Paek & Hove, 2017). They are generated in relation to a specified threat, such as the threat of a car accident, the threat of a robbery, or the threat of global warming. In this way, risk perceptions are assessments of a state in the world. They are prompted by uncertainty about a threat such as whether it will occur and the severity of its consequences. They can be computed from a variety of informational sources, including emotions, such as how much dread a threat makes you feel (Slovic & Peters, 2006), heuristics, such as simple rules of thumb that trigger risk judgments (Maldonato & Dell'Orco, 2011), or past experiences with the threat at hand (Demuth et al., 2016), among other sources. In this dissertation, it will be investigated how risk perceptions are generated from sensory information (i.e., visual cues) as well as from prior knowledge (i.e., mental representations) about threats. An example of a risk perception generated from sensory information can be illustrated by a kayaker paddling down a river who sees large rapids ahead and perceives this section of the river to pose a high risk of capsizing. In contrast, another kayaker may possess the prior knowledge that that section of the river poses a high risk of capsizing. In both scenarios, the kayakers perceive the rapids ahead as posing a high risk, but the sources of information they used to render those judgments differ.

Regardless of the exact informational sources used in their computations, the psychological construct of risk perception is a meaningful construct to study because it holds significant power when explaining and predicting behaviours in relation to the assessed threat. The discipline of health psychology was developed to model and measure the role of human psychology in the adoption (or non-adoption) of healthy behaviours, like healthy eating, smoking cessation, and safe alcohol consumption (Gurung, 2018). Central to many of these models and measurements is the psychological construct of risk perception. For example, the Health Belief Model (HBM) (Champion & Skinner, 2008), positions healthy behaviour as a consequence of peoples' beliefs about health problems, including the perceived severity and susceptibility of the threat, as well as the perceived benefits and barriers of action against the threat. The Social

Cognitive Theory of Healthy Behaviour (SCTHB) expands on the HBM (Bandura, 1998), by incorporating the role of social norms in promoting healthy behaviour. Because the primary aim of this dissertation is to understand how risk perception changes as a function of urban and architectural environments, Protection Motivation Theory (PMT) (Rogers, 1975) was selected to model the relationship between human psychology (i.e., perceived risk) and precautionary behaviours. According to PMT, people are motivated to protect themselves against perceived risks in the world. Moreover, the relationship between motivation and risk perception has been demonstrated to follow a mathematical function; that is, in general, the higher one perceives a risk, the more likely they are to self-regulate their behaviour in the form of averting the risk (Brewer et al., 2007). For example, the kayaker who perceived the risk of capsizing from the rapids as “high” is more likely to be motivated to portage around the rapids compared to another kayaker who perceives the risk as “low”. The benefit of using PMT in this dissertation is that it primarily focuses on of the psychological construct of risk perception in predicting healthy behaviours, which allows for more tractable experiments on urban and architectural environments given PMT emphasizes one psychological construct (i.e., risk perception) as opposed to several, as observed in HBM and SCTHB. Importantly, in this regard, greater explanatory power on the adoption of healthy behaviours during the COVID-19 pandemic can likely be achieved in future studies utilizing either HBM or SCTHB, however, PMT is more amenable for tractable experimentation on urban and architectural environments and is therefore favoured for this dissertation.

This relationship between perceived risk and precautionary behaviours, as modelled by PMT, also holds for long-term health risks such as lung cancer or cardiovascular disease. In these cases, in general, the riskier one perceives the threat of lung cancer the more they will be motivated to adopt behaviours that protect them against that risk. However, the risk-management process for health risks doesn't always involve a proactive behaviour (e.g., portaging around rapids), but instead may require abstinence from specific behaviours. The psychological mechanism responsible for controlling abstinent behaviours is referred to as self-regulation, which is defined as the effortful control of behaviours, thoughts, or emotions with the aim of increasing the likelihood of attaining long-term gain over short-term outcomes (Vohs & Baumeister, 2004). In the case of long-term health risks, self-regulatory behaviours such as healthy eating, smoking cessation, and safe sex practices play significant roles in the risk-management process. Self-regulatory behaviours are important to consider in the context of the COVID-19 pandemic, given that the majority of the risk-management processes involved self-regulation, such as mask-wearing, social distancing, and staying-at-home during outbreaks. One would predict, then, that individuals that perceived COVID-19 to pose a serious risk would be more motivated to wear masks, social distance, and stay at home during outbreaks compared to those that perceived the virus posed a low risk. Previous research on the H1N1 virus has yielded evidence consistent with this prediction. In one study, it was demonstrated that greater levels of perceived risk of the H1N1 influenza strain predicted adherence to self-regulatory behaviours such as avoiding public transit (Bish & Michie, 2010). Similarly, high perceptions of H1N1 risk significantly and positively predicted intent to vaccinate against the virus (Rudisill, 2013). Together, connecting risk perception to self-regulatory behaviours through PMT provides a useful theoretical paradigm through which to investigate the behaviour of the general public in the context of the COVID-19 pandemic.

If, according to PMT, people are motivated to self-regulate their behaviour as a function of risk perception, then it is crucial that those risk perceptions are *accurate*. An accurate risk perception is defined as one that reasonably aligns with expert or objective assessments of risk, whereas an inaccurate risk perception would be one that significantly differs from export or objective assessments. Identifying inaccurate risk perceptions among the public is useful from a public policy perspective, because they provide insight to possible intervention strategies, such as public knowledge translation campaigns, designed to reduce the discrepancy between subjective and objective or expert assessments of risk. An example of an inaccurate perception of risk, as well as a knowledge translation campaign, comes from studies investigating the public's response to the threat of climate change. Research has demonstrated that perceptions of the risk of climate change differ dramatically between experts and some factions of the general public (Leiserowitz, 2004). As such, these factions often demonstrate lower engagement in climate-conscious behaviours, such as recycling programs and energy-use reduction strategies. One group of researchers attempted to reduce the discrepancy in climate change risk perception between experts and factions of the general public that had low perceptions of risk by personalizing the risk of climate change by emphasizing its effect on the ecology of individuals' local area (Scannell & Gifford, 2011). This communication strategy proved effective at increasing perceptions of climate change in their sample, but more importantly, it also resulted in an increase in the likelihood that participants subsequently engaged in climate change initiatives. This example illustrates the utility of studying risk perception from an experimental psychology standpoint; not only does it offer insight into the beliefs and subjectivities of the public in relation to public health risks, it also offers insight into intervention strategies on the part of public policymakers that can help intrinsically motivate individuals to engage in the appropriate self-regulatory behaviours in response to public health risks, including for pandemics.

The Neurobiology of Risk Perception

Although not the explicit focus of this dissertation, understanding the neurobiology of risk perception grounds the psychology of risk perception in physiological mechanisms and provides a more nuanced understanding of the construct. The biological mechanisms responsible for risk perception are thought to have a long evolutionary history. This belief is founded on the observation that even single-cell organisms have a rudimentary risk perception-risk aversion system (Dexter, Prabakaran, & Gunawardena, 2019). The trumpet-shaped protozoan Stentor roesellii can detect danger in the world, such as an environmental irritant like carmine powder, and change its response to that danger the longer it persists. First, Stentor roesellii will bend its body to avoid the carmine. If the irritant persists, it will use its cilia to expel the carmine away. If this doesn't stop the irritant, the organism will contract and pull itself inward into its shell, or swim away as a last step. The researchers argue that this hierarchy of avoidance behaviours is evidence that S. roeselii possesses a biological mechanism that allows it to track the state of danger in the world and make a "decision" based on that assessment. While these biological mechanisms are far less sophisticated than those involved in the risk perception-risk avoidance loop found in humans, their function is the same: to assess the state of the world for threats in order to trigger behaviour that mitigates the consequences of those threats. In this way, risk assessment and risk aversion can be considered fundamental processes of species with physiologies as complex as humans and as "simple" as a single-cell organism. The fact that risk perception-risk aversion loops exists across a wide range of species suggests the mechanism is *evolutionarily adaptive*, in that it increases the chances of survival and reproduction (Tooby & Cosmides, 1990). The same principle applies to human risk perception and avoidance. Given many dangers in the world pose the risk of mortality, as well as the risk of failure to reproduce, accurate risk perception and aversion are also argued to be evolutionarily adaptive for humans (Tooby & Cosmides, 1990).

Although there exists a large body of cognitive psychology research investigating the dynamics of risk perception, only a handful have studied the neural mechanisms responsible for risk perception in humans. In general, these studies have found activity in the anterior cingulate cortex (ACC) when participants are asked to assess risks (Megias et al., 2018; Schmälzle et al., 2013; Yokoyama et al., 2014) The ACC is a region of the brain that is involved in the evaluation of personal significance, emotional responses, and threat appraisal (Schmitz & Johnson, 2007). It shares connections with the prefrontal cortex, the parietal cortex, as well as the motor system and the frontal eye fields, making it a locus of integration processing between top-down and bottom-up stimuli (Posner & DiGirolamo, 1998). Because of these connections, the ACC is well-situated to process threats from incoming, bottom-up, sensory information, evaluate that information against top-down mental models, and execute motor responses. Additionally, some studies also found activation in the temporal parietal junction, inferior parietal gyrus, and the medial prefrontal cortex, all of which have been implicated in probabilistic calculations and counterfactual reasoning (Van Hoeck, Watson, & Barbey, 2015), which are important cognitive operations for simulating possible outcomes in relation to an appraised threat. Further, fMRI research on clinical populations has demonstrated that ACC hyperactivity, particularly in the dorsal region, is associated with pathological threat appraisal (e.g., catastrophizing, excessive worrying/anxiety) (Kalisch & Gerlicher, 2014). While outside of the scope of the current dissertation, it should be emphasized that understanding the underlying neural substrates of risk perception opens avenues for ameliorating the prevention and treatment of mental disorders that involve pathological threat appraisals. For example, aberrant neural activity can be treated with different neurofeedback or neurostimulation tools, which can complement traditional psychotherapy programs. Indeed, around the world, levels of depression, post-traumatic stress, anxiety, and insomnia significantly increased during the pandemic (Taylor, 2022), including to the point where they satisfied their own COVID-19 specific clinical diagnosis termed COVID Stress Syndrome (Taylor et al., 2020; Lee et al., 2021). This suggests that clinical neuroscientists should consider the unique effect of pathological threat appraisal on the uptick in mental health issues during the pandemic. Again, the purpose of this dissertation is not to validate a neuroscience-based clinical intervention for COVID-19 relation anxiety, but at the very least, the summarized findings point toward a meaningful link between a public health crisis and clinical neuroscience, which together merit future scientific study.

Why is COVID-19 Transmission Risk Perception Important for Architecture?

Rather than offering clinical neuroscience-based interventions to mitigate COVID-19 risk perception, the primary purpose of this dissertation is to provide architectural-based interventions that account for the psychology of risk perception. This aim is in part inspired by the story of John Snow and the Broad St. pump, and also by the story another deadly pathogen, tuberculosis. In comparison to cholera's effect, however, the effect of tuberculosis on architecture and urban design was driven by what was *perceived* to be true as opposed to empirical science.

Tuberculosis is an infectious disease caused by the tuberculosis mycobacterium that affects the lungs. During the 18th and 19th centuries, it ravaged much of the northern hemisphere, killing as many as a quarter of the adult population in Europe (Saleem & Azher, 2013). There was no cure for tuberculosis up until the invention of streptomycin in 1943, and doctors attempted to use non-pharmaceutical interventions to cure the disease. Open-air therapy and heliotherapy (i.e., light treatment) became two prominent strategies. Open-air treatment used fresh air to “clear the lungs” of infected patients, and the ultraviolet light provided by heliotherapy was believed to kill the disease-causing pathogens. While modern medicine has disconfirmed both of these relationships (e.g., Edwards, 2011), they remained stalwart treatment plans against tuberculosis from the mid-1800s to the early 1900s, so much so that they led to the generation of a completely new type of hospital design – the sanatorium. Unlike previous hospitals, sanatoria were designed with large windows, outdoor arcades and sun-decks so that patients could be exposed to fresh air and sunlight (Figure 2).

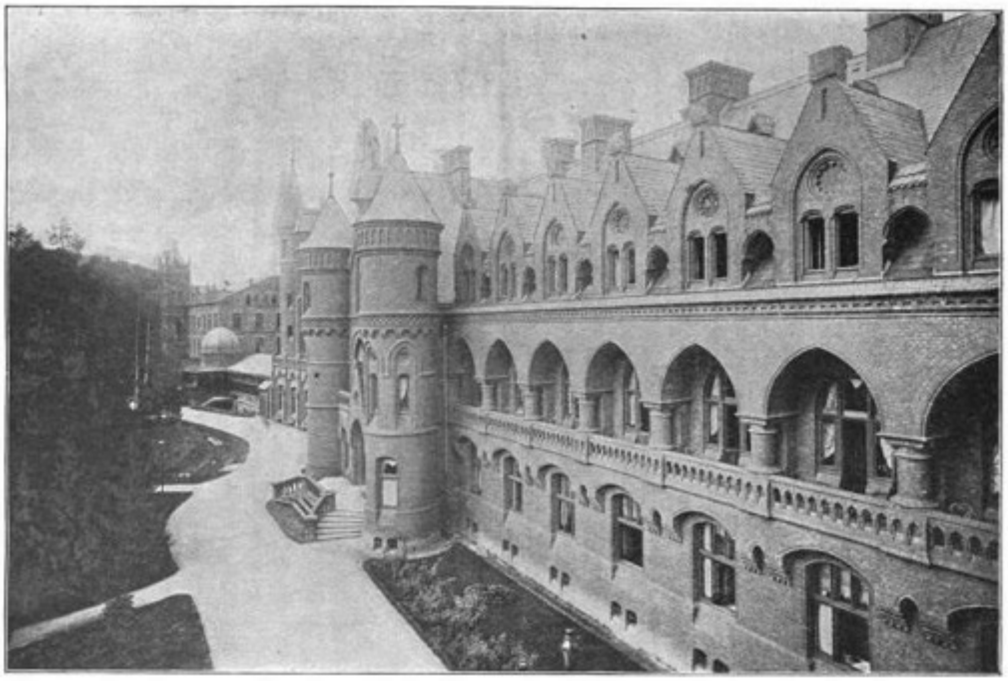

Figure 2. Brehmer sanatorium (1904). (WikiCommons, 2022)

Because tuberculosis affected a large proportion of the European population, sanatoria became common throughout the continent from the late-19th century onward, and other architects began improving on the original designs. A notable example comes from the Finish architect Alvar Aalto, who built the Paimio Sanatorium in 1933 (Figure 3). Aalto expanded on the idea that architecture itself could be used as a tool to fight against the spread of pathogens by removing ornamentation from the building to prevent dust collecting and simplifying the cleaning process, by painting the walls white to provide a stark background against which dust and dirt would be more visible, and by implementing large windows so that sunlight and fresh air could enter the room (Campbell 2005; Colomina 2019). Importantly, unlike the design changes to London's sanitation systems derived from John Snow's scientific findings on cholera, the design changes implemented in sanatoria were largely speculative and based on what was *perceived* to be true about how to treat and fight against tuberculosis. Empirical science has demonstrated that tuberculosis does not transmit through dust, and sunlight and fresh air only have a small and short-term effect on recovery, with many patients worsening or dying a few years after their discharge from sanatoriums (Grzybowski & Enarson 1978).

Regardless of the validity of the speculated associations between the design interventions implemented in Aalto's Paimio Sanatorium and the recovery of tuberculosis patients, the idea of using architecture for health proved fertile. By the 1930s, most new hospitals replicated the designs trialled at Paimio, including its lack of ornamentation, white walls, and large windows. Today this design paradigm is known as the "clinical aesthetic". Moreover, architects like Le Corbusier began experimenting with the clinical aesthetic in non-clinical spaces. Le Corbusier recognized that Aalto's aesthetic achieved psychological benefits in addition to its speculated health benefits, and replicated the style in numerous residential spaces, such as Unité d'habitation and Villa Savoye (Figure 4). This design aesthetic spread across Europe, ultimately igniting the new architectural trend known as Modernism. By the 1960s Modernism was the dominant design trend, and Modernist designs were no longer exclusive to health or residential spaces but were now deployed in every type of urban and architectural environment all while maintaining a clinical aesthetic (Figure 4). The invention of streptomycin in the 1940s neutralized the health threat posed by tuberculosis, but the pathogen's effect on urban and architectural environments proved profound. By this time, building designs inspired by tuberculosis–Modernist designs–were standing all across the world, and remain standing in our cities today.

Figure 3. Paimio Sanatorium (1933), Paimio, Finland; building and sundeck.

Figure 4. Clockwise from top left; Villa Savoye (1931), Poissy, France, Le Corbusier (Wikipedia, 2008); Saltzman House (1969), East Hamptons, USA, Richard Meier (Palmer, 2013); The Getty Center (1997), Los Angeles, USA, Richard Meier (Lulko, 2016); National Congress Brazil (1960), Brasilia, Oscar Niemeyer (Renatloky, n.d.)

Sourcing contemporary urban sanitation standards to cholera and the Modernist architectural design movement to tuberculosis raises an important question about COVID-19. As was the case with cholera and tuberculosis, urban and architectural environments are the mechanisms through which COVID-19 spreads. Moreover, COVID-19 is also invisible to the human eye, making its estimations of its risk perceptual in nature. For these reasons, asking how people perceive COVID-19 transmission in urban and architectural environments is an important question, as its answer helps predict design responses to COVID-19. Finally, given the massive effect cholera and tuberculosis achieved on urban and architectural designs around the world, it is reasonable to predict a similar effect from COVID-19, albeit one that is contextualized in the needs and demands of contemporary society.

Psychological Research in Architectural Environments

The primary purpose of this dissertation is to investigate how members of the general public conceptualize COVID-19 transmission risk in urban and architectural environments. In this way, this dissertation acts as a bridge between two disciplines–research psychology and architecture–by leveraging the concepts and methodologies of research psychology to produce meaningful insight about human psychology and behaviour in urban and architectural environments that can be actioned by designers and policymakers. This approach has achieved some success before. An example comes from work conducted on Broken Windows Theory. Broken Windows Theory, a prominent theory from criminology, claims that signs of disorder increase the likelihood of other types of disorderly behaviour (Wilson & Kelling, 1982). For example, poor lighting, signs of disorder (e.g., graffiti, litter), and an overall absence of public visibility on a street can all directly increase the viability of a successful criminal event, in that each cue indicates a lower probability of being caught by law enforcement or by the public. In other words, these cues serve a *psychological* function, in that they make crime appear more viable to would-be criminals, and also make neighbourhoods appear more like the sites of crime to average citizens. Because Broken Windows Theory places a psychological construct between perception and behaviour, it was research psychologists who were called on the validate the claims made by this theory. In general, empirical studies conducted by research psychologists on Broken Windows Theory have largely confirmed its main claims (e.g., Eck et al., 2005, Welsh & Farrington, 2008). That is, there is a significant and positive association between signs of disorder and crime levels, as well as between signs of disorder and psychological estimations that crime is more viable in those neighbourhoods. Many of these studies adopted a research paradigm that is of interest to the current dissertation. In this paradigm, the researchers systematically quantify the objective features of urban environments (e.g., lighting conditions, graffiti, litter, etc.), and then correlate those features with data indicative of citizens' perceptions of crime risk in those space. Through this method, the researchers are able to validate whether the urban and architectural features, including any broken windows, predict the perception of crime scores. What is also of relevance to this dissertation is the fact that the empirically-verified relationship between visual signs of disorder and neighbourhood crime rates caught the attention of policymakers, and in the 1990s was used as a scientific justification to implement public-space clean up campaigns in cities across the country, including in New York City, where then-mayor Rudy Giuliani also used the theory to justify public space clean up campaigns as well as strict law on low-level crimes such as public drinking, public urination, and graffiti. The idea behind these campaigns was that by cleaning up the public realm (i.e., reducing the number of broken windows and other signs of visual disorder) would-be criminals would be dissuaded to commit crimes. Moreover, the general public including tourists, would perceive the city as safer. While New York City did see a significant decline in crime across the 1990s, new research has put into question the causal link between signs of disorder and crime levels, suggesting instead that the trend observed in New York City was part a nationwide decrease in crime, and that major crime incidents such as murder, rape, robbery, or grand theft auto did not decrease (Harcourt & Ludwig, 2006; Sullivan & O'Keeffe, 2017). Nonetheless, Broken Windows Theory is important to mention in the context of this dissertation because it provides a theoretical justification for investigating the visual cues of urban and architectural environments as they relate to a latent psychological construct, and demonstrates a precedent for linking psychological theory and research in architectural environments to public policy.

Dissertation Contributions

The literature summarized to this point provides several empirical, theoretical, and historical pieces of information that help frame the approach this dissertation will use to study pathogen risk perception in urban and architectural environments. Based on this information, and stated in broad terms, it is predicted that members of the general public use visible cues in urban and architectural environments to generate perceptions of COVID-19 transmission risk. It is also broadly predicted that members of the general public hold complex mental representations of COVID-19 transmission risk in urban and architectural environments, and that these perceptions of transmission risk significantly predict the likelihood to engage in pandemic-safe behaviours, such as avoiding public spaces and mask wearing. Each of these predictions will be tested in the ensuing chapters.

This dissertation makes meaningful theoretical contributions to the discipline of health psychology, as well as meaningful methodological contributions to the discipline of environmental psychology. Regarding health psychologists, several studies in this dissertation provide evidence on the urban and architectural factors associated with a key health threat–COVID-19 infection. The results of these studies can inform future health psychology research on other urban threats, such as air and noise pollution. Regarding environmental psychologists, several studies in this dissertation utilize novel experimental methods for conducting psychological research on the effects of urban and architectural design, including digitally manipulating aspects of images between groups of participants and measuring the ensuing effect on psychological variables. This research paradigm offers environmental psychologists an efficient and effective method for conducting research on the built environment without having to control for the myriad of confounds present in real-world settings.

This dissertation also holds practical relevance for two groups of professionals. The first group of professionals this dissertation holds practical relevance for is architects and interior designers. This group stands to benefit from understanding which visual cues in urban and architectural environments are used by members of the general public to render judgments about pathogen transmission risk. With this knowledge, architects and interior designers can configure spaces so that they are perceived as posing a low transmission risk, or identify spaces a priori that are likely to be perceived as posing a high transmission risk. For example, in the same way Modernist architectural design addressed the perceived concerns about tuberculosis transmission, the results from this dissertation can be used to inform the design of spaces that address the perceived concerns of COVID-19 transmission. The second group of professionals are municipal, provincial, and federal health policymakers responsible for coordinating governmental responses to the COVID-19 pandemic, as well as future pathogen outbreaks. This group stands to benefit from understanding how members of the general public conceptualize pathogen transmission risk within the urban and architectural environments they inhabit. These conceptualizations can be assessed for their validity in relation to objective metrics of pathogen transmission risk, and tailored risk communication strategies can be adopted for observed discrepancies. Moreover, any observed significant relationship between perceived pathogen transmission risk and self-regulatory behaviours, such as mask wearing or avoiding shared public spaces, can inform the creation of more nuanced lockdown policies that integrate the intrinsic motivation of the individual to protect themselves against the threat of pathogens. Taken together, this dissertation provides meaningful insight about human psychology and behaviour during an unprecedented global crisis–the COVID-19 pandemic.

Chapter II

Investigating Expert and Lay Judgments of Pathogen Transmission Risk in Urban and Architectural Environments

Abstract

The health consequences posed by the COVID-19 virus forced members of the general public to use the visible cues within urban and architectural environments as a “lens” through which pathogen transmission risk could be inferred. This study presents a model that quantifies associations between (1) the visible cues of urban and architectural environments and lay ratings of pathogen transmission risk, (2) the same relationship for experts (i.e., Infection Control Practitioners), and (3) the association between the lay ratings and the expert ratings. To accomplish this, a series of urban and architectural environments were rated on twenty visible cues, and also rated for their perceived pathogen transmission risk by lay and expert raters. Correlational analyses between the two groups revealed considerable consensus between risk ratings, as well as between which cues were significantly associated with risk ratings, which included the space's crowdedness, the potential for crowds, and cleanliness. Expert risk ratings were also significantly associated with corridor size, and marginally significantly associated with the number of touchable surfaces, the number of furniture/seating, and access to fresh air. In this way, expert cue utilization is more complex than lay assessments. Insights for public health policymakers and designers of the built environment are discussed.

Introduction

What visible cues in urban and architectural environments do members of the general public associate with perceived COVID-19 transmission risk? Although numerous studies investigated the dynamics of COVID-19 risk perception (e.g., Cori et al., 2020; Dryhurst et al. 2020; Barrios & Hochberg, 2020), including how it differed between different individuals and the sources used for its generation, no study to the authors' knowledge investigated which visual cues in urban and architectural environments are associated with perceived transmission risk. As such, the purpose of this research project is to systematically investigate the visual cues in urban and architectural environments that correlate with lay assessments of pathogen transmission risk.

The idea that the built environment played a role in regulating the spread of the virus was central to the vast majority public health policy responses; that is, it was shared public spaces that governments mandated citizens to avoid as opposed to other areas, such as private residential spaces or secluded greenspaces (World Health Organization, 2020). These qualifications were notably broad, and elided more nuanced associations between the built environment and the spread of COVID-19. They also overlooked how members of the general public perceived COVID-19 transmission risk in urban and architectural environments, including when they visually analyzed those environments. There are two reasons to believe the public did so. First, a study conducted in the spring of 2020, near the beginning of the pandemic, found that citizens around the world did hold perceptions of COVID-19 transmission risk, and that these perceptions were generally high (Dryhurst et al., 2020). And second, previous research from the environmental psychology literature has demonstrated that people will readily use visible cues in urban and architectural environments as a means to infer the presence of latent variables. For example, according to Broken Windows Theory (Wilson & Kelling, 1982), visible cues of disorder in a neighbourhood (e.g., litter, graffiti, broken windows, etc.) are used by observers to infer latent invisible constructs, such as permissive social norms around disorderly behaviour. Similarly, visible cues in bedrooms and office spaces, such as cleanliness or the presence of prized personal items, can be used to infer the personality traits of the occupants (Gosling et al., 2002). Estimating the transmission risk of pathogens within an urban or architectural environment is suggested to operate under a similar inferential mechanism, whereby cues such as open windows, crowdedness, and number of touchable surfaces may be used to infer the likelihood of coming into contact with a pathogen. Moreover, because urban and architectural environments are compositionally diverse and varied, in their totality they serve as rich repositories of information from which observers can draw inferences about pathogen transmission risk. Given the frequency with which the general public was informed about the transmission risks posed by shared public spaces over the course of the pandemic, it is reasonably predicted that they will hold complex conceptualizations of which visible cues in those environments are associated with transmission risk.

In this study, I investigate which visual cues in urban and architectural environments are associated with lay perceptions of pathogen transmission risk. The secondary aim of this study is to investigate whether the visible cues associated with lay perceptions of pathogen transmission risk differ from those associated with expert perceptions of risk. Previous research on risk perception has demonstrated that members of the general public and experts often deviate in their estimations of risk (Sjöberg, 1998). In the context of COVID-19, healthcare professionals had higher perceptions of risk than members of the general public (Peres et al., 2020). This difference can be caused by a number of factors, such as different first-hand experiences with the virus, different knowledge about its effects, or different sources of information about its prevalence in the community. To the authors' knowledge, no study has investigated if there are differences between lay and expert raters for *visual* assessments of pathogen transmission risk in urban and architectural environments. This study intends to address this gap in the literature. Moreover, intervention strategies such as public communication campaigns can be designed based off instances where the cues used by lay raters dissociate from those used by expert raters.

The links between lay raters' estimations about pathogen transmission risk in urban and architectural environments and expert estimations are conceptualized in terms of Brunswik's (1956) lens model (Figure 5). Brunswik's lens model, which has a basis in social judgment theory, offers a systematic breakdown of critical links in the process of using visible elements in an environment as a kind of lens through which latent constructs are inferred. In this model, *cue utilization* refers to the link between the observable cue (e.g., spaciousness, sunlight) and lay raters' judgment (e.g., of pathogen transmission risk). The link between the observable cue and the expert's rating of pathogen transmission risk is referred to as *cue validity*, given the expert assessments are considered valid. If similar cues are used in a similar manner (i.e., similar correlation coefficients) by the lay raters and experts, then judgments should converge, and judgments of lay raters can be considered accurate (a.k.a., functional achievement).

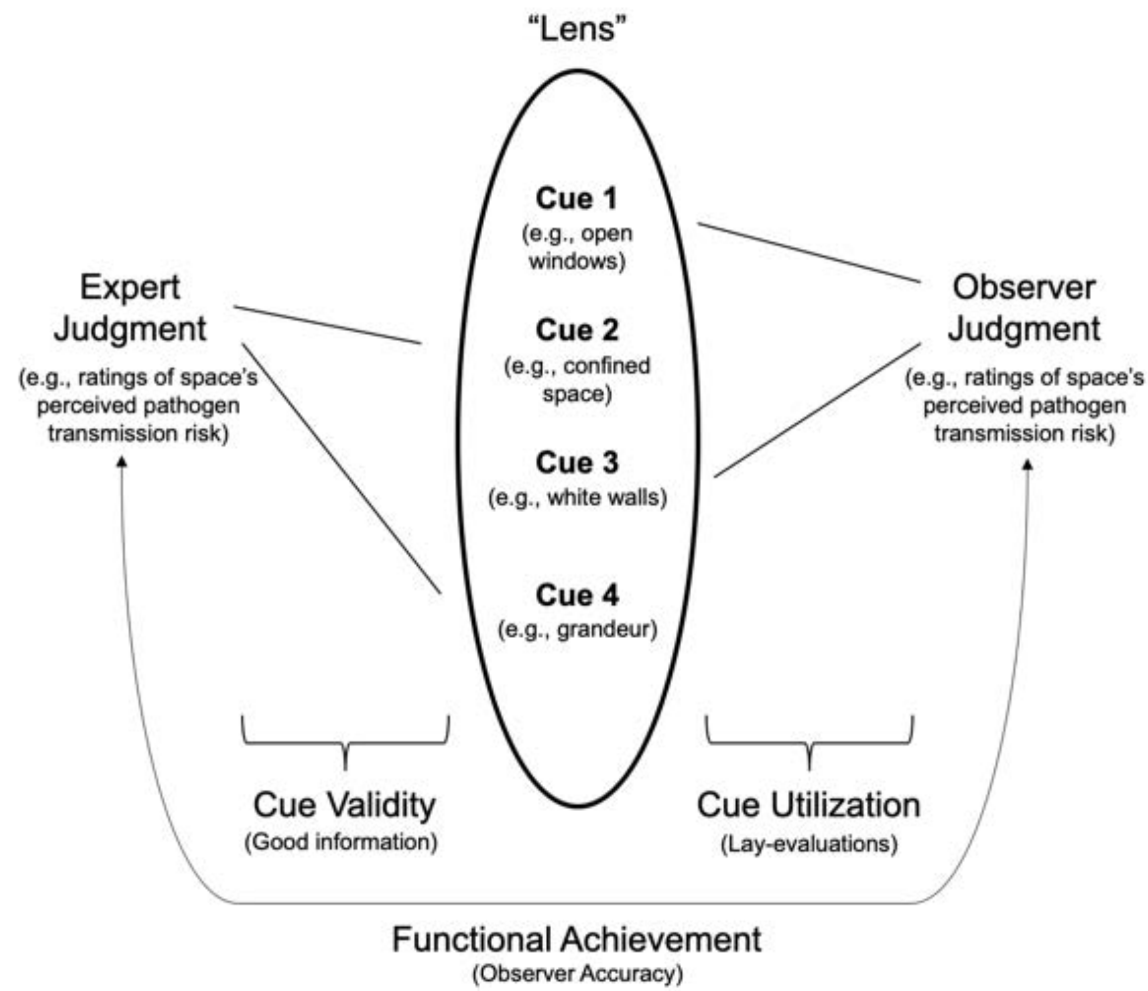

Figure 5. Modified Brunswik (1956) lens model.

Research Questions

The purpose of the present experiment was to document evidence in urban and architectural environments of cue utilization (links between visual cues and lay raters' ratings of risk), cue validity (links between visual cues and expert ratings of risk), and functional achievement (the link between lay raters and expert ratings). Prior to specifying these model links, a correlation between lay and expert perceptions of pathogen transmission risk will be conducted to assess risk consensus between groups.

Question 1. Intergroup Consensus: Are Lay and Expert Perceptions of Pathogen Transmission Risk on the Basis of Images of Urban and Architectural Environments Correlated?

It is hypothesized that lay and expert perceptions of pathogen transmission risk will be significantly correlated. This hypothesis is borne out of the observation that the transmission dynamics of COVID-19 were regularly reported during the pandemic and that the same, or similar, mental models of pathogen transmission risk are likely to exist within lay raters.

Question 2. Cue Utilization and Cue Validity: Which Cues Do Observers Use to Form Their Impressions, and Which Cues Are Valid?

It is hypothesized that a selection of reasonable cues (e.g., confined spaces, poor ventilation) will be correlated with risk perceptions by lay raters. Again, this hypothesis is borne out of the assumption that lay raters hold reasonable conceptualizations of pathogen risk. The same analysis will be conducted for the correlations calculated from the expert raters, which will demonstrate which visible cues are to be considered valid.

Question 3. Functional Achievement: Are Observers' Impressions Consistent with Experts?

Urban and architectural environments are considered to hold many legitimate cues about pathogen transmission risk (Lewis, 2021), yet, observers can make both good and bad judgments using those cues. Good judgments occur when observers use valid cues and when they ignore invalid cues. Poor judgment occurs when they ignore valid cues or use invalid cues. Given the high degree of familiarity lay raters are expected to hold with pathogen transmission risk, significant correlations are expected between cue utilization and cue validity metrics.

Methods

The above three questions were examined in images of urban and architectural environments, which are settings that are often interacted with and that posed a risk of pathogen transmission. Images of urban and architectural environments sourced from Flickr (licenced as creative commons) were used and included a diversity of urban and architectural environments available in cities, such as health care spaces, educational institutions, public transportation spaces, recreational spaces, private businesses, and grocery settings, among others. Images were selected by members of the research team. The criteria used to select images was that they show variability in usage type, as well as variability on the three C's of crowdedness, close-contact conditions, and confinement. Although it was not predict that these three aspects of urban and architectural environment would be the only factors associated with perceived pathogen transmission risk, it was predicted that–across 60 images–the diversity of spaces selected would offer variability on the other measures of environmental features such as access to fresh air and lighting conditions. Each step of this study was reviewed and received ethics clearance by the University of Waterloo's Research Ethics Board. All analyses and visualizations were completed using Python version 3.8.1 using the SciPy 1.10.0, Matplotlib 3.4.2, and Seaborn 0.11.1 modules.

Environmental Features

Three experts in urban and architectural design were recruited to provide assessments of the degree to which each urban and architectural environment was characterized by 20 cues. The experts were either Master's students in an Architectural program or professionals with Architecture degrees working in a design profession. The experts were recruited through professional networks using snowball sampling. Experts were provided with a digital link to the study and completed the study remotely. After providing consent, they were asked to provide a

1- 5 rating for each of the 20 cues for each of the 60 images. The list of cues used in this experiment was derived from previous empirical and theoretical work on the perception of cleanliness (Vos et al., 2019) and the perception of tuberculosis risk (Campbell, 2005) in urban and architectural environments. The full list of items is provided in Appendix 1. 60 images were chosen based on a sample size calculation for significance testing of moderate correlations of r = .35, β = .2, and α = .05, which yielded a sample size of 62, which was rounded down to 60 images. Boxplots with of how each cue was rated across all 60 images is provided in Appendix 2. An analysis of these boxplots demonstrates a considerable variance for each of the 20 cues across all 60 images, indicating the selected images did capture a diversity of features present in urban and architectural environments.

Lay Ratings

A total of 52 participants were recruited from the University of Waterloo's undergraduate population. A sample of at least 35 is recommended to surpass the central limit theorem threshold, and a 50% oversample was applied as a cautionary method against missing/poor-quality data. Participants were recruited through the University's student research participation system, in which students who are registered in psychology courses can receive additional credits for participating in research studies. Students were rewarded 0.5 class credits for participating in this research study which took approximately 30 minutes to complete. After removing implausible data (i.e., non-responses to all questions), the total sample size was 46 participants.

Participants were provided with a definition of the key measure of interest, "pathogen transmission risk", prior to beginning the experiment. Pathogen transmission risk was defined as the likelihood you will come into contact with a pathogen (e.g., a cold virus, a flu virus, the COVID-19 virus). Perceived pathogen transmission risk does not include the likelihood of falling sick from the pathogen. It only refers to the likelihood of coming into contact with a pathogen. Participants were asked to rate the perceived pathogen transmission risk of the 60 urban and architectural environments on a 0-10 slider scale, with 0 indicating no risk and 10 indicating an extremely high risk.

The focus of this research project is pathogen transmission risk as opposed to exclusively COVID-19 transmission risk. At the time this study was conducted, COVID-19 no longer posed a unique threat to the majority of the general population because of mass vaccination campaigns, with the exception of unvaccinated individuals (Dyer, 2021), and individuals who are immunocompromised (Fung & Babik, 2021). To control for the possibility that participants would mistakenly indicate that COVID-19 poses no risk whatsoever, a broader conceptualization of risk was adopted for this experiment by asking participants to rate the perceived *pathogen* transmission risk of urban and architectural environments (as opposed to specifically about COVID-19). This approach also allows findings to be generalized to all types of pathogens that have transmission dynamics similar to COVID-19.

Expert Ratings

The expert sample was drawn from a population of Infection Control Practitioners (ICP) currently working in healthcare settings. ICPs are responsible for the development, implementation, and evaluation of policies, procedures, and practices that impact the prevention of infections caused by pathogens. They receive extensive training on healthcare standards for pathogen prevention (for review, see Zingg et al., 2015), including COVID-19 (Islam, 2020). A total of three experts were recruited. Although small, the basis for this sample size was findings from a research study that used the Delphi method to show a high degree of consensus among ICP experts for how to manage COVID-19 in healthcare settings, including how to manage healthcare worker safety, visiting policies, personal protective equipment use, patients and procedures, disinfection, and sterilization procedures (Nasa et al., 2022). Given this finding, it was predicted that there would be an acceptable agreement and validity within our expert sample. Still, it is recognized that results from the ICP experts should be interpreted with caution given the small sample size, and that future research should strive for a larger sample of experts to ensure generalizability. ICP experts were recruited via email through existing professional networks. As was the case with the lay participants, experts were asked to rate the perceived pathogen transmission risk of the same 60 urban and architectural environments.

Results

Question 1: Intergroup Consensus

A Pearson's correlation was calculated between lay and expert perceived pathogen transmission risk scores across all 60 images (Table 1, intergroup consensus). Across all images, Pearson's correlation coefficient was positive, strong, and significant ($r = .77$, $p < .05$; Figure 6).

Table 1

Judgments of Pathogen Transmission Risk.

	Q1: Intergroup Consensus	Q3: Functional Achievement
Perceived risk	.77*	.95*

*$p < .05$, two-tailed.

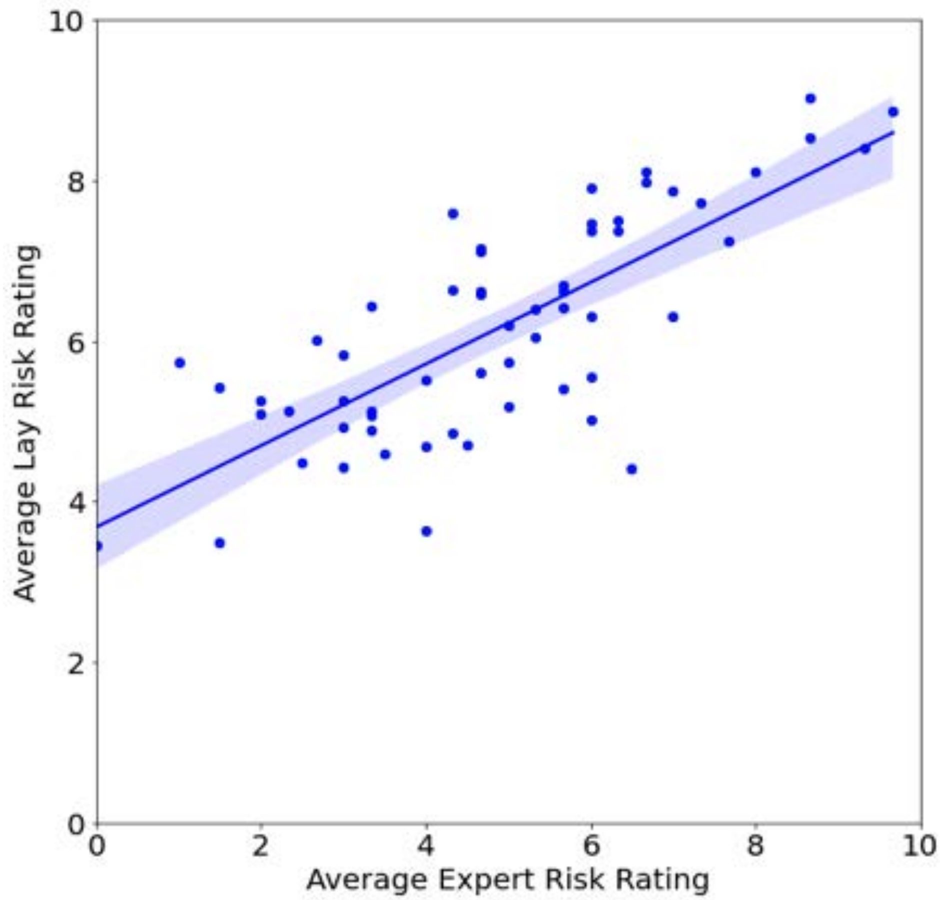

Figure 6. Lay versus Expert Risk Ratings Across All Images.

Questions 2: Cue-Utilization and Cue-Validity

Risk ratings were averaged across all participants for each image and correlated with feature assessment ratings to determine which cues were used to make judgments about pathogen transmission risk, also known as cue utilization (Table 2, first column). The same calculation was completed using the expert ratings to ascertain cue validity (Table 2, third column). To account for multiple comparisons across 40 instances, an adjusted p values of 0.00125 was used (0.05/40). Because of the exploratory nature of this study, marginally significant p values equal to or below 0.0025 (0.00125*2) are also reported.

Table 2

Cue-Validity and Cue-Utilization Correlations.

Cue-validity	Environmental cue	Cue-utilization
-0.32	Dark (vs. well-lit) [natural light]	-0.23
0.23	Dark (vs. well-lit) [artificial light]	0.23
0.05	Small (vs. large) square footage	0.09
-0.42*	Small (vs. large) corridors	-0.34
0.03	Low (vs. high) ceilings	-0.01
0.40†	No (vs. a lot of) pieces of furniture/seating	0.29
0.39†	No (vs. a lot of) touchable surfaces	0.31
-0.25	Dark (vs. light) colouration	-0.03
-0.39†	Very little (vs. a lot) of access to fresh air	-0.30
-0.02	Unlikely (vs. likely) good ventilation	0.12
-0.44*	Unclean (vs. clean)	-0.46*
-0.33	Poorly maintained (vs. well-maintained)	-0.34
-0.23	Difficult (vs. easy) to clean	-0.35
0.23	Unlikely (vs. likely) to be cleaned frequently	0.18
0.47*	Vacant (vs. crowded)	0.70*
0.07	Single (vs. multiple) functional uses	0.16
0.51*	Unlikely (vs. likely) to be crowded	0.69*
0.18	Unlikely (vs. likely) to be occupied by sick people	0.29
-0.32	Unlikely (vs. likely) to be occupied by elderly people	-0.26
-0.15	Unlikely (vs. likely) to be occupied by children	0.016

*$p < .00125$, two-tailed, adjusted alpha of .05/40 used to accommodate for multiple comparisons.
†$p < .0025$, marginally significant.

For lay raters, cleanliness, crowdedness, and potential for crowds were significantly associated with perceived risk. The two highest and two lowest-scoring images for each of these three visible cues is provided in Figure 7. The cleaner a space was the less risky it was perceived to be. The more crowded, and the greater likelihood a space has for crowds, the riskier it was perceived to be. No evidence was found indicating any other cues were significantly associated with perceived risk for lay raters. For example, no evidence was found that artificial or natural light was significantly associated, nor was colour or cleanability. Similarly, no evidence was found that the potential presence of sick, elderly or children was associated with risk perception.

For expert raters, the same three correlations were found. Additionally, corridor size was significantly associated with perceived risk, where the larger the corridors were the less risky the space was perceived. Three marginally significant ($p < .0025$) associations were also found. These were the number of furniture/seating, the number of touchable surfaces, and access to fresh air. The more furniture/seating and touchable surfaces that were in a space, the more it was perceived as risky. The more access to fresh air a space had, the less it was perceived as risky.

Figure 7. Example Images for Significant Visible Cues for Lay Raters.

Question 3: Functional Achievement

A correlation between cue-utilization values and cue-validity correlation coefficients was conducted to assess the accuracy of judgments (Table 1, functional achievement) of the lay raters. Across all cues, Pearson's correlation coefficient was positive, very strong, and significant ($r = .95$, $p < .05$; Figure 8).

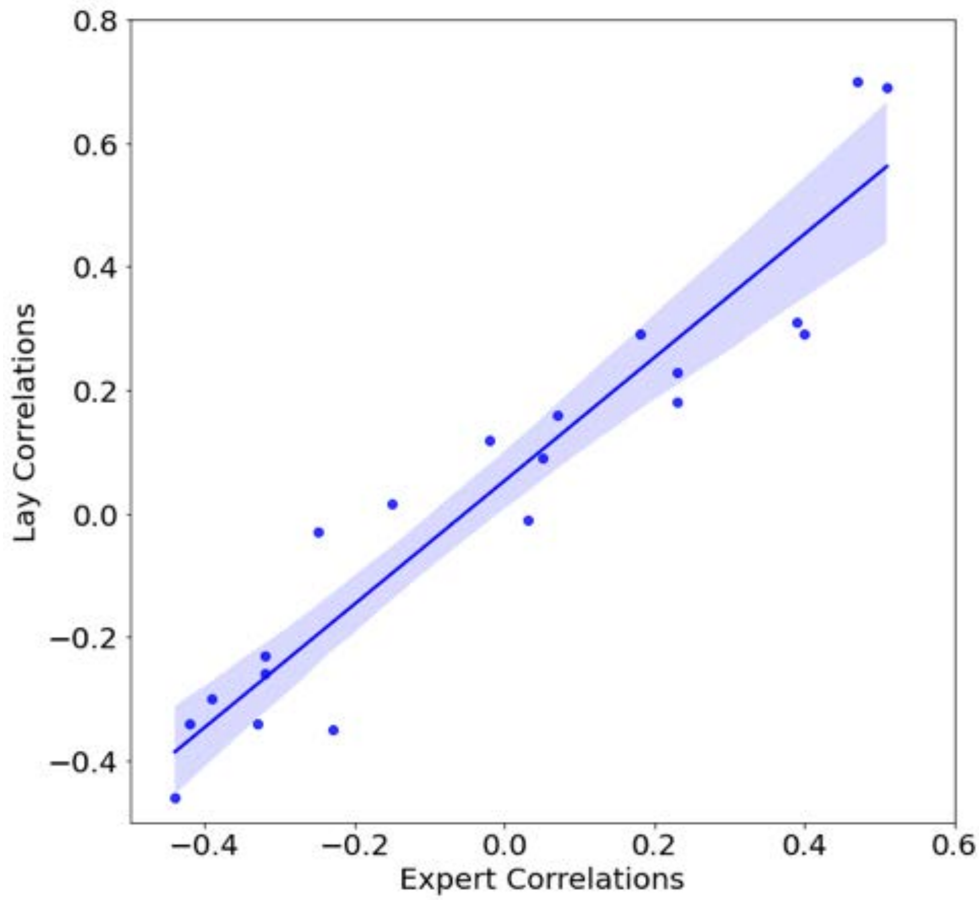

Figure 8. Lay versus Expert Cue Correlation Coefficient.

Discussion

According to the results, lay raters associated pathogen transmission risk with how clean the spaces was, how crowded the space was, and the potential for crowds the space has. Two of these cues—crowdedness and potential for crowds—are consistent with two of the three Cs (i.e., crowdedness and close contact settings) architectural conditions identified by the WHO that pose a high COVID-19 transmission risk. Notably, no evidence of associations between pathogen risk perception and cues of sick people, the elderly, or children were found, suggesting that it is the crowds of people, rather than individual people or even the composition of the crowds, that is most salient to lay raters when assessing pathogen transmission risk. Importantly, although the “crowds” cue is straightforward to operationalize (i.e., it is characterized by many people in a confined space) the “potential for crowds” cue is somewhat more ambiguous. According to a visual analysis of the spaces that ranked lowest on highest on this metric, the potential for crowds cue considers the space’s *function*; namely, whether it is a private or semi-private space or not. Both the spaces that ranked lowest on this metric (i.e., had the lowest potential for crowds) were private or semi-private spaces (i.e., a hotel room and a swimming pool with lane dividers). This suggests that lay raters look for cues that indicate that a space limits the amount of people that can enter at any one time that, given the role crowds play in spreading pathogens, is a viable strategy to use to infer pathogen transmission risk.

What was not predicted *a priori* was the significant association between cleanliness and pathogen transmission risk. Although not a part of the three C’s, keeping spaces clean was routinely emphasized by public health authorities as an important strategy to mitigate the spread of COVID-19 during the pandemic (Wilson et al., 2021). However, the communication around cleanliness focused on using antiseptics to kill pathogens lying dormant on surfaces like handrails and tables. In this way, *cleanliness,* as it relates to COVID-19 risk has a specific definition. In contrast, in this study, the spaces rated as the lowest cleanliness had a diversity of forms and functions, including a sandy beach and an office with papers strewn on desks (Figure 7). Certainly, these spaces are both *unclean,* but they are unclean in different ways–one with sand particles and the other with general workplace disorganization. Moreover, neither is unclean with organic waste, such as spoiled food in a kitchen or a dirty bathroom. For this reason, it appears that general scene disorder is driving the cleanliness rating and that general scene disorder in and of itself is associated with pathogen transmission risk.

It is also important to mention the cues for which no evidence was found indicating a significant association with pathogen transmission risk for lay raters. Several meaningful cues appear on this list, including formal variables such as ceiling height, colouration, and lighting conditions, as well as functional variables such as cleaning frequency or maintenance level. At the very least, the face that no evidence of associations was yielded for any of these cues suggests that it is *people*—and namely crowds—that is the most salient factor for lay raters when assessing pathogen transmission risk in urban and architecture environments, as opposed to any one formal characteristic.

The three cues that were significantly associated with perceived pathogen transmission risk for lay raters–cleanliness, crowdedness, and potential for crowds–were also significantly associated with perceived pathogen transmission risk for expert raters. This finding is encouraging and suggests that lay raters are utilizing similar visible cues as expert raters as lenses through which to infer the pathogen transmission risk. However, there were also differences between the cue utilization and cue validity coefficients. The expert raters also significantly associated corridor size with pathogen transmission risk, as well as marginally significantly associated the number of touchable surfaces, the number of furniture/seating, and access to fresh air with risk. This additional significant association, as well as the three additional marginally significant associations, suggest that the expert raters held more complex mental models of pathogen transmission than the lay raters. Moreover, they demonstrate a more nuanced understanding of the transmission mechanisms of pathogens. For example, the corridor size cue demonstrates they consider the spatial configurations of the environment where transmission can occur, noting it is more likely to occur in confined spaces. They also consider the role fomite transmission (i.e., number of touchable surfaces, the number of furniture/seating) as well as aerosol transmission (i.e., access to fresh air). Regarding fomites, although their overall effect on infection rates was speculated to be small (Cheng et al., 2022; Goldman 2020; Rocha et al., 2021), COVID-19 can transmit through fomites, and fomites are a key transmission route for some pathogens, such as rhinovirus and norovirus (Kraay et al., 2018). Therefore, fomites are important to consider when assessing pathogen transmission risk. Perhaps most surprising is the fact that the data yielded no significant association between ventilation or access to fresh air and pathogen transmission risk for the lay raters, but did achieve a marginally significant association for access to fresh air for the expert raters. Indeed, there is ample evidence demonstrating a positive effect of fresh air on the reduction of airborne particles containing COVID-19 and other pathogens (Morawska et al., 2020). The discrepancies in visual cues uncovered in this study can be used as the foundation for public health communication intervention strategies; namely, members of the general public can be reminded of the role fomites and contaminated airborne particles play in pathogen transmission.

Notwithstanding the discrepancy of risk associations with corridor size, fomites, and access to fresh air, the correlation between cues used by the two groups (i.e., functional achievement) was significant and very strong, indicating lay raters are likely using the same cues in environments as expert raters to render judgments about pathogen transmission risk. This finding is encouraging from a public health perspective. During the COVID-19 pandemic, misinformation about COVID-19 was prevalent and proliferated rapidly across social media (Frenkel, Alba, & Zhong, 2020). In some cases, the misinformation was harmless, such as that groceries needed to be individually washed after returning from the grocery store (Shamim et al., 2021). In other cases, there were extremely harmful potential consequences associated with some pieces of misinformation, such as that the COVID-19 virus was a governmental conspiracy that posed no real health threat (Romer & Jamieson, 2020). The fact that lay and expert risk scores were strongly associated suggests our sample of lay raters had relatively accurate information about the transmission dynamics of pathogens. Overall, this study provides evidence that there is considerable consensus between lay and expert raters regarding pathogen transmission risk in urban and architectural environments, with the exception that expert raters have slightly more complex cues associated with their ratings which take into account the potential for dormant pathogens on surfaces.

Policy and Design Insights

The data demonstrated a high degree of functional achievement between lay raters and expert raters with regard to the cues associated with the perception of pathogen transmission risk in urban and architectural environments. Tentatively speaking, this finding supports the suggestion that lay raters have accurate perceptions of pathogen transmission risk as it occurs in urban and architectural environments. What would be important to demonstrate next would be if these risk assessments also predict pathogen-safe behaviour, such as mask wearing and social distancing. Future research should strive to replicate the strong correlation between expert and lay raters, as well as generalize the results outside of a university sample, to determine its reliability. Also, future research should strive to replicate these findings following exposure to real world environments as opposed to digital images. Following these empirical studies, this body of research can inform public health policy making for future pathogen outbreaks by offering an additional tool to slow the spread of pathogens in urban and architectural environments; namely, self-regulatory behaviour initiated by individual citizens and mediated by conceptualizations of pathogen transmission risk.

The findings from this research project also hold implications for architectural designers, who are motivated to consider how architecture should function in a post-pandemic world. Architectural theorists have speculated that post-COVID-19 pandemic design will reflect the emerging desire for residents to feel safe against possible pathogen transmission risk (Eltarabily & Elgheznawy, 2020). The findings from this research project can be used by designers to design spaces with visible cues associated with "low" perceived pathogen transmission risk. According to the results, these spaces should be mostly clean, vacant, and have a low potential for crowds. These types of design configurations can be implemented in spaces where objective safety against transmission risk is also ensured. For example, vaccination clinics that offer influenza vaccinations can be assessed for their safety from an objective perspective by IPC experts, but then also configured so that they are perceived as safe by the public. This type of space should be configured so that they are perceived as clean, which includes the perception of overall cues of disorderliness, that there are few people in the space at any one time (low on crowdedness), and that the amount of people in the space is overtly regulated (low on potential for crowds). Conversely, spaces that are unclean, crowded, and have a high potential for crowds will be perceived as posing a high pathogen transmission risk.

Importantly, there are trade-offs to designing architectural spaces so that they are perceived as mostly clean, vacant, and have a low potential for crowds, particularly in consideration of the fact that some architectural spaces are specifically designed to accommodate large crowds of people. For example, public transit stations like metro stops or entertainment complexes like sports stadiums often accommodate hundreds or even thousands of people at any one time. For this reason, it is not necessarily feasible to design these spaces as "vacant". In these instances, designers are encouraged to think creatively about how to implement *programmatic* interventions to control crowds in these spaces to achieve some crowd control despite overall high numbers of people. For example, transit stations can implement frequent trains so that crowds flow through the space at high rates, and sports stadiums can stage entry and exit times for different seating sections so that the entrances and exits are not overwhelmed with people at any one time. Although these programmatic interventions will not reduce the overall number of people that occupy the space at any one time, they will help promote crowd flow and reduce the potential for emergent crowds.

This study had four limitations that are important to mention. First, the types of correlational analyses implemented in this study must be interpreted cautiously for three reasons. First, correlation does not equal causation. All significant and marginally significant associations yielded by the analyses can be interpreted to mean that observers' judgments were associated with the presence of certain cues, however, the correlations did not show conclusively that the observers actually used these cues to make their judgments. Second, the present analysis lacked the power to conduct a multiple regression analysis, which would have demonstrated the extent to which different cues were used independently of one another. Third, despite previous research indicating broad consensus on infection control measures for COVID-19 (Nasa et al., 2021), future research should strive for a larger sample of experts to ensure generalizability. For this reason, *cue validity* scores should be interpreted cautiously. Nonetheless, I consider these assessments are considered to be more valid than lay ratings. Finally, the lay ratings were derived from a sample of undergraduate students and should not be considered representative of the general population. Previous research on age-based differences in COVID-19 risk perception has demonstrated that younger individuals had *higher* perceptions of COVID-19 infection risk compared to older adults, although lower perceptions of the health consequences of infection (de

Bruin 2021). In the context of the present results, this would lead to the prediction that a sample that included older adults would show weaker associations and/or less cue diversity than what was observed in the present sample. Future research should strive to replicate the present findings using a sample with an age spread representative of the general population.

Conclusion

This research project aimed to understand which visible cues of urban and architectural environments were associated with lay and expert perceptions of pathogen transmission risk. Overall, lay and expert raters had similar perceptions of the riskiness of different environments and had similar cues associated with their perceptions, which included the cleanliness, crowdedness, and potential for crowds of the environment. However, expert raters had a slightly more diverse set of cues associated with perceived risk, including cues for areas where pathogens can lay dormant. These findings legitimize the risk conceptualizations of lay individuals by demonstrating they are broadly consistent with those of experts, a fact that can be leveraged by public health policy makers intent on shifting the self-regulatory onus onto members of the public during future pathogenic outbreaks. Finally, the cues associated with perceived risk can be used by designers to design post-COVID-19-pandemic spaces that account for the emergent need for occupants to feel safe against the risk of pathogen transmission.

Chapter III

Investigating Mental Representations of COVID-19 Risk Perception of Urban and Architectural Environments

Abstract

Throughout the COVID-19 pandemic, urban and architectural environments became the media through which the virus spread. But not at random; certain spaces, such as those that were crowded, close contact, and confined were riskier than others for coming into contact with the virus. How did people think about COVID-19 transmission risk when asked to think about different urban and architectural environments? In this study, two experiments were conducted to investigate the mental representations of COVID-19 transmission risk as it differs as a function of urban and architectural environments in a sample of undergraduate students. In the first experiment, participants were asked to rate 82 different spaces on their perceived risk, as well as the extent to which they changed visitation to those spaces as a result of perceived risk. In the second experiment, participants were asked to rate the perceived risk of 20 spaces as well as how those spaces rated on 12 formal and functional architectural characteristics. Results showed that participants' mental representations of risk are broadly consistent with what was communicated about risk during the pandemic; that is, that spaces that are crowded, close contact, and confined pose a high risk. However, results also showed that participants consider the *function* of the space, including whether it is a private space, for socialization, or for healthcare when generating perceptions of risk. A secondary regression analysis also revealed the relationship between risk perception and change in visitations was significant, albeit moderate. Together, these results provide evidence of how COVID-19 transmission risk was represented mentally and offer designers and policymakers insight into strategies to mitigate perceived COVID-19 transmission risk in urban and architectural environments.

Introduction

In Chapter II, it was demonstrated that members of the general public associate different visual cues in urban and architectural environments with COVID-19 transmission risk. The purpose of Chapter III is to investigate how COVID-19 transmission risk in urban and architectural environments is mentally represented. In other words, how do people think about transmission risk in cities independent of being in any of those spaces? Because the COVID-19 virus is invisible to the unaided human eye, members of the general public were forced to adopt strategies to reduce the likelihood of coming into contact with COVID-19 in cities. One such strategy was to develop mental representations of the areas in cities that posed a high transmission risk, similar to how crime risk across a city can be mentally represented (Pain 2000). Public health institutions, community leaders, and the media played a large role in developing these mental representations. The World Health Organization quickly identified "three C spaces"–crowded places, close contact settings, and confined and enclosed spaces–as posing a high risk of transmission (World Health Organization, 2021). While these qualifications were useful in informing the public about the types of spaces that posed a risk during the pandemic, they are notably broad and do not directly specify the *types* of urban and architectural environments–of which there are many–that are risky. This study addresses this gap by asking members of the general public to rate the perceived COVID-19 transmission risk of a wide range of urban and architectural environments, as well as to rate the extent their visitations to those spaces changed as a function of transmission risk. In addition, a secondary analysis was completed to isolate the effect of specific formal and functional characteristics of urban and architectural environments on risk perception scores.

Studying the mental representations of risk is important because how people mentally represent risk plays a large role in regulating judgments and behaviour in relation to those risks. For example, mental representations about climate change risk affect the interpretation of extreme weather events in terms of climate change. In one study, researchers asked members of the general public who were affected by a 2010 heatwave whether they reported experiencing a warmer-than-normal summer, as well as whether they perceived climate change to pose a risk (Howe & Leiserowitz, 2013). Those who were "doubtful" or "dismissive" about climate change (i.e., had low mental representations of risk) were also 27% less likely to report experiencing a warmer-than-normal summer, even though there was a heatwave. Mental representations of risk also affect our behaviour in the world. Regarding climate change, people who perceive climate change as posing a high risk are more likely to engage in environmentally conscious behaviour (for meta-analysis, see Hornsey et al., 2016). Similar effects had been found in the context of the COVID-19 pandemic. Because fighting the COVID-19 pandemic was contingent on the public participating in a wide range of self-regulatory behaviours, such as mask-wearing and social distancing, a large body of research investigated the role mental representations (a.k.a. beliefs) about COVID-19 risk, including conspiratorial beliefs, played in motivating these behaviours. At the extreme end of the spectrum, research demonstrated that conspiracy beliefs about COVID-19, such as that the virus was manufactured as a way to implant microchips into the public, significantly predicted a lack of participation in crucial pandemic-safe behaviours, such as willingness to social distance or wear masks in public (de Bruin & Bennett, 2020; Mulukom et al., 2022; Wise et al., 2020), as well as the willingness to receive the COVID-19 vaccine (Sallam et al., 2021). A provocative example comes from Rozenkrantz et al. (2022), who demonstrated that individuals who believed COVID-19 posed a significant health risk experienced worse symptoms when infected with the virus compared to demographic-matched individuals who did not share that perception. These studies highlight the importance of assessing mental representations of risks as a way of predicting behaviour in relation to those risks. This relationship is important to consider in times of public health crises, such as pandemics, because it allows for predictions to be generated about who and how strongly they will engage in precautionary behaviour, such as adherence to stay-at-home or social distancing policies.

There is reason to predict that the mental representations of COVID-19 transmission risk in urban and architectural environments would be nuanced. This prediction is borne out of the observations that the urban realm offers a rich diversity of concepts, each with their own associations to different formal and functional characteristics. Terms like library, school, hospital, as well as many more, refer to spaces in cities with specific formal and functional characteristics. When invoked mentally, they activate a network of content relevant to the term at hand, supplying the term with meaning (Siew et al., 2019). In the case of terms that refer to urban and architectural environments, these semantic networks could include associations to information about how these spaces tend to look, who tends to occupy them, where they tend to be located in cities, and how safe they are. For example, when invoked, the term of "rural" tends to elicit associations of lower socio-economic statuses compared to cities, whether that association is an accurate reflection of reality or not (Halfacree, 1993). These associations can be so potent that they guide behaviour in cities. For example, in one study, researchers demonstrated that the *perceived* (i.e., mentally represented) quality of greenspaces in a city is a better predictor of visitation to greenspaces rather than objective assessments of the quality of those same greenspaces (Chen et al., 2020). Another, more extreme, example comes from combining social psychology content with urban environments. Here, research has demonstrated that it is not only people who can be the targets of racial bias, but also physical spaces. Bonam et al. (2016) demonstrated participants describe neighbourhoods that are predominantly composed of African American populations as physically degraded, unpleasant, unsafe and lacking in resources. These stereotype-laden mental representations also affected subsequent behaviour. Participants rated themselves as less likely to purchase the same house if the listing included a photo of a black family compared to if the listing included a photo of a white family. Follow-up analysis revealed that this difference in decision was mediated by assumptions of the surrounding neighbourhood. When the photo of the black family was present, participants were more likely to assume the property had lower maintenance, there were lower-quality schools and municipal services, less access to shopping and financial institutions, and lower safety. This study highlights the importance of understanding the network of associations the mental representations of different urban and architectural environments are connected to, as they can have significant effects on resulting judgments of and behaviour toward those spaces. In some instances, the associations of urban locations can be changed. In 2001, Rotterdam staged a “Cultural Capital of Europe” event that aimed to market the city as a cultural destination. Longitudinal surveys of residents, non-residents, policy-makers and cultural managers demonstrated the city’s image as a cultural destination did improve, despite remaining the same “city” in objective terms (Richards & Wilson, 2004). This example suggests that other associations, such as the racial makeup of an area or even perceptions of COVID-transmission risk, can be changed following public communication campaigns.

How has the COVID-19 virus changed the public’s perception of the city? Because cities are designed to foster human collaboration, competition, and cohabitation during normal times, they are the ideal arena for the spread of a socially transmitted disease like COVID-19. In the context of COVID-19, this susceptibility has proven true, as approximately 90% of the world's confirmed COVID-19 cases occurred in urban areas, despite only about 56% of the world's population lives in cities (UN, 2020). Yet, despite the role urban and architectural environments played in the spread of COVID-19, only a handful of studies investigated how members of the general public mentally represented COVID-19 transmission risk in these spaces. For example, Sadique et al. (2007) asked members of the general public to indicate the perceived transmission risk of the influenza virus for six different types of urban and architectural environments. Results showed that, in order, public transportation, hospitals, shops, workplaces, and schools were perceived as the riskiest places, and homes were deemed as the least risky places. Another study out of Korea investigated this question by asking members of the general public to report their change in visitation to fourteen different urban spaces, which the researchers classified as either a space for mandatory activity (e.g., work, school, etc.), a maintenance activity (e.g., shopping, banking, etc.), or a discretionary activity (e.g., leisure, entertainment, etc.). This study found, in order, spaces for mandatory activities, maintenance activities, and discretionary activities all decreased in visits during the pandemic, and that perceived COVID-19 risk was a significant predictor in all three cases. In other words, the theorized relation between risk perception and cautionary behaviours was uncovered in the context of behaviour in urban and architectural environments. While informative, this study collapsed the fourteen different urban spaces prior to conducting any analyses, thereby limiting the specificity of the conclusions regarding behaviour in urban and architectural environments.

The present study extends this literature by expanding the set of urban spaces included in the experiment. To accomplish this, participants were asked to provide perceived COVID-19 transmission risk ratings for eighty-two (82) urban and architectural environments. Results were analyzed to uncover urban and architectural themes associated with risk. Participants were also asked to rate the extent to which their frequency of visitations changed over the course of the pandemic, which allowed for an analysis of the relationship between risk perception and behaviour. Finally, participants were asked to rate the extent to which a series of spaces differed on twelve formal and functional characteristics, which allowed for an analysis of the relationship between specific architectural features and risk perception scores. A positive relationship between risk ratings and change scores was predicted. It was also predicted that the spaces and characteristics of those spaces associated with risk would be broadly consistent with the WHO's position that spaces that are crowded, close contact, and confined pose the greatest COVID-19 transmission risk.

Methods – Experiment 1

Four-hundred (N = 420) University of Waterloo undergraduates were recruited for this descriptive, cross-sectional study. Data collection occurred between March 3rd and April 5th, 2022. At that time, capacity limits mandated by local governing bodies on all indoor public settings were lifted in the province on Ontario, and about 80% of the population was vaccinated against COVID-19 (PHAC, 2023). Sample size was calculated using Slovin's formula (Slovin, 1960), with a population sample set to 1,000,000 (one-million), and a confidence level set to 95%. The population was limited one million given the practical impossibility of obtaining a sample large enough to capture the opinion of the entire Canadian population, but is also large enough to still produce meaningful results.

$$n = \frac{N}{1 + Ne^2}$$

With values inserted.

$$n = \frac{1000000}{1 + (1000000)(0.05)^2}$$

$$n = 399.84$$

A 5% oversample was applied to prospectively account for missing data and/or outliers. Participants with more than 50% missing data were excluded from the analysis due to egregious non-compliance with experiment instructions, reducing the total participant count to N = 393. Three different scales of urban and architectural environments were tested: regional scale (e.g., urban, rural, suburb, etc.), urban scale (e.g., library, hospital, private residence, etc.), the architectural scale (e.g., doorknobs, public benches, hallways, etc.). For the experiment, participants were presented with eighty-two (82) urban and architectural environments. Seven (7) of which were drawn from a regional scale, sixty-five (65) of which were drawn from the urban scale, and ten (10) of which were drawn from the architectural scale. A full list of environments is provided in Appendix 3. The list of environments was derived from a Wikipedia page that outlined different types of urban and architectural environments (“List of building types,” 2022). The environments provided by this page were deemed by the researcher to be sufficiently diverse for the purposes of this study. For each environment, participants were asked to: (1) rate the perceived COVID-19 transmission risk of this element in comparison to other urban environments and architectural elements, with 0 indicating “much less risky”, 5 indicating “average risk”, and 10 indicating “much more risky”. Additional phrasing was provided in experiment instructions to clarify that participants are not being asked to indicate the risk each item poses getting infected by the virus, but rather the risk each item poses to coming in contact with the virus. And to (2) rate the extent to which your visits to this element have changed due to perceived COVID-19 transmission risk, with 0 indicating “much fewer visitations”, 5 indicating “neither more nor less”, and 10 indicating “much more visitations”. Terms within the three scale categories, as well as the three scale categories themselves, were randomized between participants. This study was reviewed and received ethics clearance by the University of Waterloo's Office of Research Ethics Board (REB # 44145).

Analysis – Experiment 1

Environments corresponding to the first and fourth quartiles for perceived COVID-19 transmission risk ratings and change in visitation scores were isolated. These lists document which items were perceived as riskiest, least risky, witnessed the greatest change in visitations, and witnessed the lowest change in visitations. A regression between perceived risk and change in visitation was run in an attempt to replicate the previously demonstrated positive relationship between those variables.

Regression Equation:

$$Change_i = \beta_0 + \beta_1 Risk_i + \varepsilon_i$$

Next, a high-risk high-change index was calculated in order to identify items that were perceived as having high COVID-19 transmission risk and received many fewer visits as a result of COVID-19 transmission risk. Items that achieve high scores on this index offer designers and policymakers opportunities to implement design interventions that mitigate perceived risk, which would be predicted to increase visits. The high-risk high-change index was calculated by mirroring ($MirroredChange_i = 10 - Change_i$) the change in visitations variable so that greater values indicate greater change, and multiplying this value by perceived COVID-19 transmission risk scores. Spaces that are ranked high on perceived risk and high change scores are spaces for which the pandemic was the most disruptive. Conversely, spaces with a low design intervention index were relatively undisrupted during the pandemic. Lists and figures were generated using Excel and the regression analysis was completed in Python version 3.8.1 using the SciPy 1.10.0 module.

Results – Experiment 1

Risk scores for the list of items ranged from 2.82 (your private residence) to 8.03 (hospitals) with a mean risk score of 5.81 and a standard deviation of 1.18. A histogram of the distribution of risk scores is provided in Figure 9. According to a visual analysis of this histogram, the risk scores across all 82 spaces appear to have achieved a Gaussian distribution, suggesting the 82 selected spaces were appropriately diverse in terms of riskiness. Table 3 and Table 4 list the items for the first and fourth quartiles for perceived COVID-19 transmission risk scores and change in visitation scores, respectively. Regarding spaces perceived as posing a low COVID-19 transmission risk, participants' own private residences scored the lowest risk, followed by a series of outdoor spaces (golf courses, parks, sidewalks). The thematic cluster of "low-density living regions" came next, and included items such as rural regions and small towns in rural settings. Small private businesses were also found on this list, such as small art galleries and small retail businesses.

Regarding spaces perceived as posing a high COVID-19 transmission risk, hospitals ranked the highest. Next were spaces that were either dense and large (e.g., downtowns, large cities) or dense and confined (e.g., concert venues, pubs/bars, airplanes, metros and buses). All types of schools – kindergartens, elementary and high schools – were rated as posing a high transmission risk except for, notably, post-secondary institutions.

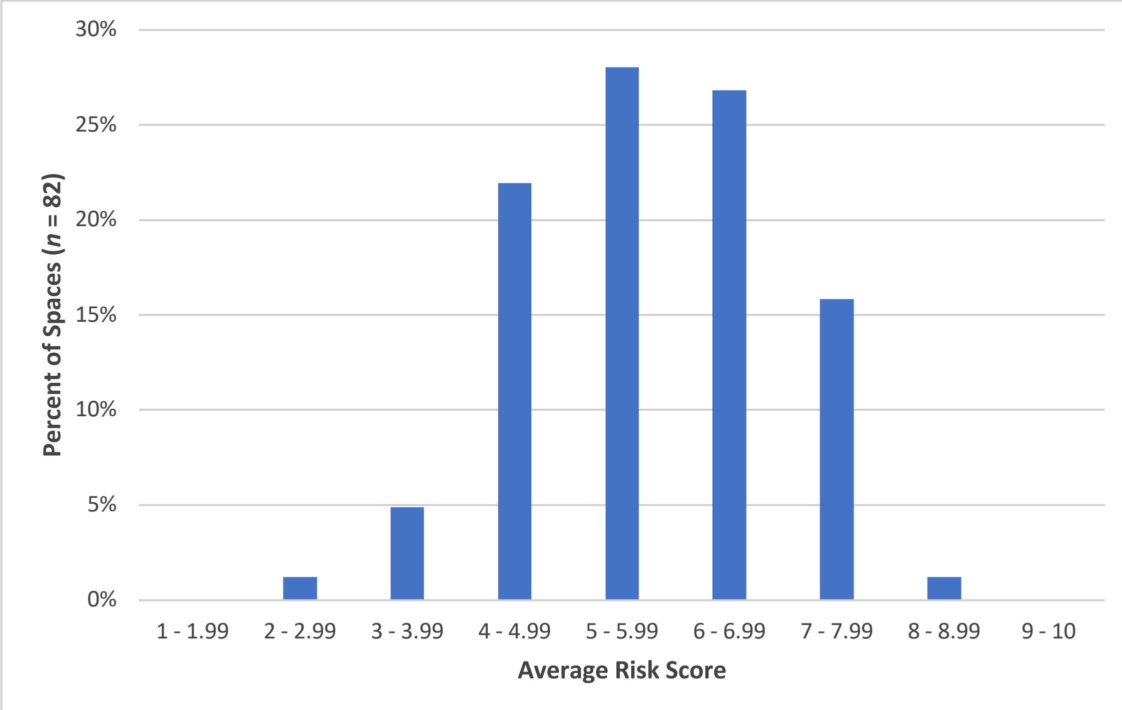

Figure 9. Histogram of percent of spaces binned by risk score.

Table 3.

Perceived Risk Scores.

First Quartile		Fourth Quartile	
Item (ascending order)	Perceived Risk	Item (descending order)	Perceived Risk
1. Your private residence	2.82	1. Hospitals	8.03
2. Golf courses	3.52	2. Concert venues	7.88
3. Parks/Greenspaces	3.57	3. Downtowns of large cities (> 1,000,000 people)	7.76
4. Suburban sidewalks	3.59	4. Pubs/bars	7.6
5. Rural regions	3.61	5. Large cities (e.g., 1,000,000 people or more)	7.54
6. Small towns in rural settings (e.g., less than 20,000 people)	4.0	6. Airplanes	7.47
7. Park benches	4.07	7. Public swimming pools	7.44
8. Urban parks	4.15	8. Schools – elementary (grades 1 - 8)	7.33
9. The private residence of an acquaintance	4.32	9. Airports	7.31
10. Small art galleries	4.34	10. Schools – high schools (grades 9 – 12)	7.2
11. Auto dealerships	4.38	11. Schools – kindergartens	7.19
12. Residential apartments with less than 10 units	4.51	12. Major metropolitan regions	7.13
13. Stairwells	4.55	13. Retirement/nursing homes	7.11
14. Post offices	4.59	14. Public transit buses (interior)	7.02
15. Downtown sidewalks	4.67	15. Public washrooms	6.92
16. Small retail businesses	4.75	16. Casinos	6.88

17. Hallways	4.82	17. Metros (e.g., underground subways) or streetcars	6.87
18. Ski resorts	4.83	18. Fitness centres	6.85
19. Farmers Markets	4.86	19. Door handles	6.85
20. Courthouses	4.88	20. Prisons	6.82

Note: 0 indicated ‘much less risky’, '5' indicated 'average risk', and 10 indicated ‘much more risky’.

Change in visitations scores for this list of items ranged from 3.54 (airplanes) to 5.9 (your private residence) with a mean change score of 4.27 and a standard deviation of 0.40. A histogram of the distribution of change in visitation scores is provided in Figure 10. According to a visual analysis of this histogram, the change in visitation scores across all 82 spaces achieved a distribution where the plurality of spaces (i.e., 72%) scored within the 4 – 4.99 range, and no scores were lower than 3 or greater than 6.

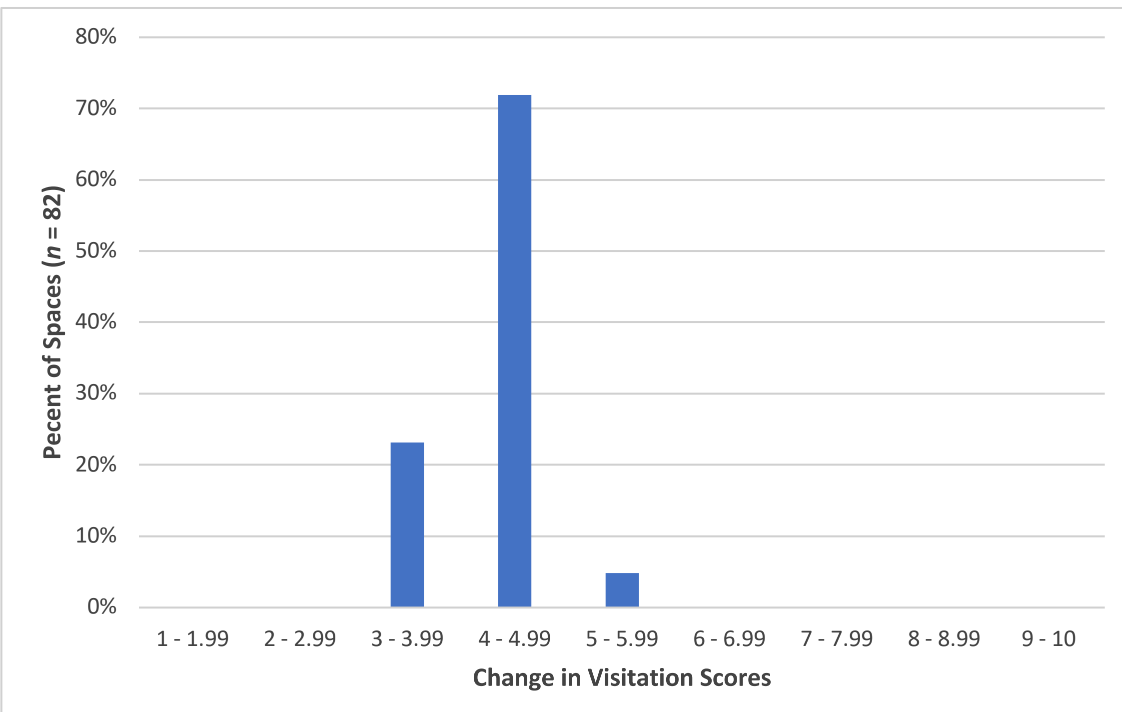

Figure 10. Histogram of percent of spaces binned by the change in visitation score.

Regarding spaces rated as receiving more visitations, participants’ private residences, parks & greenspaces, door handles, and post-secondary institutions all received more visits during the pandemic. However, none of these spaces scored more than a 6 on the 10-point scale, with a score of 5 indicating "neither more nor less" and a score of 10 indicated "much more visitations". On the other end of the spectrum, the spaces that were rated as receiving the greatest reductions in visitations were all related to travel, leisure, and sports. Regarding travel, airplanes, resort hotels, airports, motels and hotels were all spaces deemed to have been visited less. Regarding public leisure, movie theatres, live theatre venues, concert venues, museums, and exhibition/fair grounds. And regarding sporting, public swimming pools, sports arena (e.g., for hockey, basketball, etc.), bowling alleys, and recreational sport clubs. In general, each of these spaces from the three categories are ones in which contact with others is highly probable and are also spaces where non-mandatory activities occur. Importantly, these were also spaces that were targeted by mandatory lockdowns. While the effect of mandatory lockdowns on this study's measure of change in visitations could be argued to have a confounding effect on this measurement, it is important to highlight that the phrasing of the question tried to control for this confound by asking participants to specifically report the effect that COVID-19 risk perception had on their change in visitations to these spaces.

Table 4

Change in Visitations Scores.

Fourth Quartile		First Quartile	
Item (descending order)	Change in visitations	Item (ascending order)	Change in visitations
1. Your private residence	5.9	1. Airplanes	3.54
2. Parks/Greenspaces	5.41	2. Movie theatres	3.61
3. Door handles	5.1	3. Public swimming pools	3.69
4. Post-secondary education institutions; universities, community colleges, etc.	5.1	4. Resort hotels	3.75
5. Suburban sidewalk	4.94	5. Live theatre venues	3.76
6. Stairwells	4.93	6. Concert venues	3.80
7. Hallways	4.92	7. Museums	3.82
8. Store checkouts/areas for processing payments	4.9	8. Sports arena (e.g., for hockey, basketball, etc.)	3.83
9. Urban parks	4.74	9. Schools – high schools (grades 9 –	3.86

		12)	
10. Fast food restaurants	4.70	10. Exhibition grounds/fair grounds	3.86
11. Elevators	4.68	11. Small art galleries	3.86
12. Suburbs of large cities	4.68	12. Airports	3.87
13. Residential apartments with 10 or more units	4.6	13. Motels	3.87
14. Multiple occupancy educational institutional residences located on or off campus	4.55	14. Bowling alleys	3.87
15. Escalators	4.52	15. Recreational sport clubs	3.92
16. Bus/subway seats	4.51	16. Retirement/nursing homes	3.97
17. Freestanding supermarkets	4.48	17. Places of worship (e.g., churches, mosques)	3.98
18. Public transit buses (interior)	4.46	18. Hotels	3.98
19. Town centres of medium sized cities (< 200,000 people)	4.46	19. Auto dealerships	3.98
20. Large cities (> 1,000,000 people)	4.44	20. The private residence of an acquaintance	4.00

Note: 0 indicated ‘much fewer visitations’, '5' indicated 'neither more nor less', and 10 indicated ‘much more visitations’.

Regressing change in visitation on risk scores yielded an $R^2 = 0.14$, which achieved an $F(1, 80) = 12.54$, and reached significance at $p < .001$ (Table 5). This relationship is visualized in Figure 11. Based on Cohen’s (1988) indices, R^2 scores between 0.13 and 0.26 are considered to be of moderate effect size.

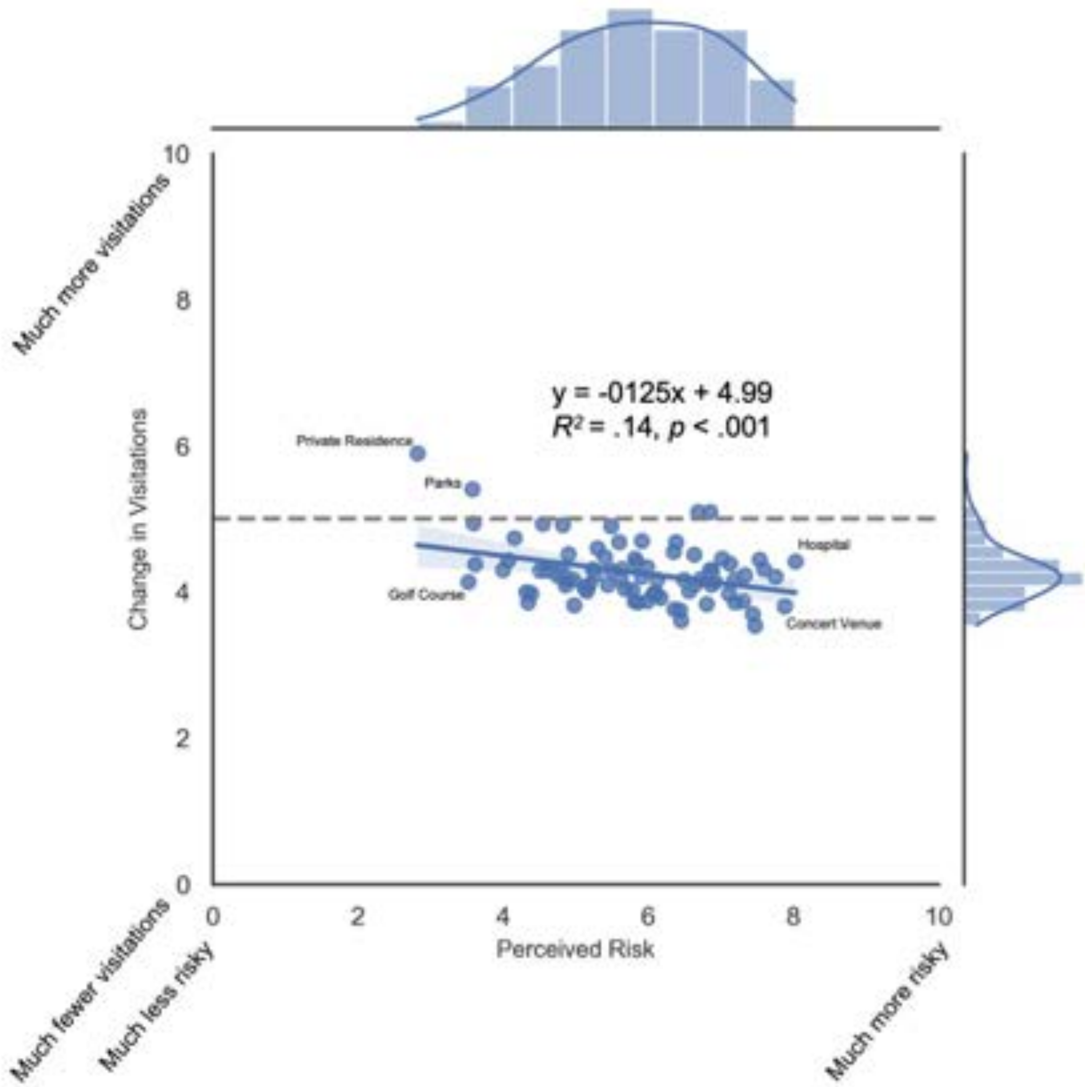

Figure 11. Change in Visitations Regressed on Risk Perception Scores.

Table 5

Change in Visits by Risk Regression.

Variable	B	95% CI	*t*	R^2	*F*	*p*
Model				0.14	12.54	< .001*
Constant	4.99	[4.58 – 5.41]	23.92	--	--	< .001*
Risk	-0.13	[-0.20 – -0.06]	0.04	--	--	.001*

*Denotes significance at .05 level.

The first and fourth quartiles for the high-risk high-change index are presented in Table 6. Many of the spaces that appear on this list are three C spaces (i.e., crowded, close contact, and confined), such as concert venues, airplanes, and swimming pools were spaces that support non-mandatory activities, such as entertainment, travel, and recreation. Spaces with mandatory activities also appeared on the list, such as downtowns of large cities and hospitals.

Table 6

High-risk high-change index.

Fourth Quartile		First Quartile	
Item (descending order)	Design Int. Ind.	Item (ascending order)	Design Int. Ind.
1. Concert venues	48.86	1. Your private residence	11.56
2. Airplanes	48.26	2. Parks/Greenspaces	16.39
3. Public swimming pools	46.95	3. Suburban sidewalks	18.17
4. Downtowns of large cities (> 1,000,000 people)	44.93	4. Rural regions	20.29
5. Airport	44.81	5. Golf courses	20.63
6. Hospitals	44.81	6. Urban parks	21.83
7. Schools – high schools (grades 9 – 12)	44.21	7. Park benches	22.67
8. Pub/bars	43.24	8. Small towns in rural settings (< 20,000)	22.80
9. Retirement/nursing homes	42.87	9. Stairwells	23.07
10. Schools – elementary (grades 1 - 8)	42.29	10. Hallways	24.49
11. Sports arena (e.g., for hockey, basketball, etc.)	42.02	11. Residential apartments with less than 10 units	25.75
12. Large cities (> 1,000,000 people)	41.92	12. The private residence of an acquaintance	25.92
13. Schools – kindergartens	41.92	13. Post offices	26.21
14. Movie theatres	41.22	14. Auto-dealerships	26.37
15. Public washrooms	40.55	15. Downtown Sidewalks	26.57
16. Metros (e.g., underground subways) or streetcars	40.53	16. Small art galleries	26.65
17. Resort hotels	40.25	17. Escalators	26.85
18. Major metropolitan regions	40.00	18. Small retail businesses	27.46
19. Prisons	39.76	19. Ski resorts	27.77
20. Live theatre venues	39.69	20. Store checkouts/areas for processing payments	28.00

Discussion

The wide range of COVID-19 transmission risk perception scores across the 82 environments, as well as the Gaussian distribution of scores, suggests that risk perception is a valid psychological construct that varies as a function of different urban and architectural factors associated with each environment. Analyzing the types of spaces that ranked in the fourth quartile–those rated as riskiest–offers insight into the factors driving perceptions of risk. Three C spaces, such as concert venues, pubs/bars, airplanes, metros and buses, appear on the list. This suggests that public perceptions of risk accorded with what public health institutions were communicating. Interestingly, regional-scale items, such as downtowns, large cities, and metropolitan regions also made the list. This suggests that respondents could conceptualize transmission risk above and beyond the scale of specific architectural environments and consider urban-level factors such as regional density. Similarly, the fact that door handles made the list demonstrates that respondents were also thinking about the role smaller-scale architectural elements play in spreading COVID-19. On the other end of the spectrum, open spaces like golf courses, parks, and suburban sidewalks were all rated as posing a low transmission risk. Again, from the perspective of the three C criteria, these spaces represent the opposite of crowded, close contact, and confined, and hence rating these spaces as posing a low risk makes sense.

Notably, private residential spaces, including one's own residence, the private residence of an acquaintance, and residential apartments with less than 10 units made the list. Public health institutional messaging during the pandemic emphasized the importance of staying at home, not just to stop the spread of the virus but also to protect oneself against catching it. However, research has demonstrated that residential spaces, especially those in which multiple people live, can themselves be the sites of transmission (Cerami et al., 2021). This is due to the fact that residential spaces are close contact spaces that contain many items that are shared between people (e.g., kitchens, bathrooms). For this reason, all private residential spaces don't necessarily pose a low transmission, and the association between safety and residential spaces observed in this data set merits further investigation to uncover whether respondents are considering the number of people that may be living in those spaces and whether risk scores would increase as the number of people does.

The regression model demonstrated a significant association between risk perception scores and change in visitations, the precautionary behaviour of interest in this study. This finding is consistent with a large body of literature on risk perception (Brewer et al., 2007), including on COVID-19 (de Bruin & Bennett, 2020; Mulukom et al., 2022; Wise et al., 2020), and bodes well for public health policymakers interested in predicting the behavioural responses during pandemics. According to this study, the prediction would be that spaces with higher transmission risk perception scores would also achieve greater reported reductions in visitations. While the regression analysis in this demonstrated a significant association between risk and change in visitations, it should be noted that the effect size of this relationship ($R^2 = 0.14$) was smaller than Brewer et al's (2007) yielded ($r_{\text{pooled}} = 0.26$) from their meta-analysis. This is likely due to the fact that risk perception scores varied considerably ($SD = 1.18$) across different urban and architectural environments while change in visitation scores had a comparatively small amount of variance observed ($SD = 0.40$). It is possible that the small amount of variance in change in visitation scores was due to the fact that at the time of the study about 80% of the population was vaccinated against COVID-19 (PHAC, 2023), and that because most people were vaccinated, the risk of being hospitalized or becoming infected with COVID-19 was low. Therefore, given this context, respondents in this study may have been less likely to indicate they would regulate their behaviour in relation to perceived COVID-19 transmission risk because the consequences of becoming infected were less severe. However, crucially, according to the data, *perceptions* of COVID-19 transmission risk achieved a wide range of values, suggesting that respondents are still able to produce complex mental representations of transmission risk despite being less likely to act in relation to those mental representations. It is plausible that the relationship between risk and change in visitations would be strongest at the start of the pandemic, prior to mass vaccination campaigns and when COVID-19 risk was highly salient because of the lack of clear information and anecdotal reports about the severity of the virus. Follow-up research can investigate how the strength of the relationship between COVID-19 transmission risk and precautionary behaviours changed over the course of the pandemic.

The high-risk high-change index demonstrated that three C spaces that supported non-mandatory activities, like entertainment, travel, and recreation achieved the highest scores on this index. Examples include concert venues, airplanes, and swimming pools. This finding makes sense, given the fact that these spaces would have been objectively risky and also ones that could be omitted from daily routines during the pandemic. Some of the spaces that reached this list, however, were spaces where mandatory visits are sometimes required, such as hospitals or downtowns of large cities. In these cases, public health institutions can ensure that communication about objective risk is up to date for these spaces, so that perceptions of risk that outstrip objective measures don't dissuade citizens from making mandatory visits to these spaces. Municipal politicians and policymakers are, in part, responsible for communicating an accurate image of the city. As was demonstrated in Rotterdam in the Richards & Wilson (2004) study, politicians and policymakers do have some control over how their cities are perceived by different audiences and can engage in campaigns or communication strategies that emphasize specific narratives. Should, for example, infection rates be low in specific metropolitan areas, it is important that this information be communicated to the general public so they can update their mental representations in accordance with the data. Designers can also create design interventions that mitigate the objective COVID-19 transmission risk, such as social distancing labels and partitions, in order to ensure that those that have to visit these spaces can feel safe doing so.

Experiment 2

Experiment 1 provided data on how different urban and architectural environments were scored by lay raters on perceived COVID-19 transmission risk. While useful, this list does not provide information specific information about which aspects of those environments are associated with risk scores. Experiment 2 sought to answer this question. To do this, the ten spaces that were rated as posing the highest transmission risk along with the ten spaces that were rated as posing the lowest transmission risk were selected for a secondary analysis (Appendix 2). Items at the top and bottom ends of the spectrum were selected to ensure the items tested in this experiment would have enough variability in risk scores to determine which factors of those environments are correlated with risk scores. With regards to perceiving COVID-19 transmission risk, it is theorized that judgments are rendered as a result of a combination of different formal (i.e., how the space looks) and functional (i.e., the behaviours that take place in the space) characteristics of the architecture itself. The purpose of experiment 2 was to investigate which formal and functional characteristics of urban locations affect judgments of COVID-19 transmission risk.

To do this, participants were asked to rate the perceived COVID-19 transmission risk of different urban locations on a 0 – 10 scale, as well as rate each location on different formal and functional characteristics on a 1 – 7 Likert scale. Based off previous research on the perception of cleanliness (Vos et al., 2018) and the perception of tuberculosis (Colomina 2019), five formal and seven functional factors of urban and architectural environments were selected for the study.

Formal characteristics investigated were the extent to which each space was characterized by its access to fresh air, natural light, spacious, provides adequate space for social distancing, and is crowded. The functional characteristics investigated were the extent to which each space was accessible by the public, a private space (not accessible by general public), a space for physical activity, a space for work, a space for eating, a space for socialization, or a space for healthcare. Given this experiment was designed to develop theory, no specific predictions were forwarded, but it was broadly hypothesized that spaces that are more crowded, close contact, and enclosed will be rated higher on perceived COVID-19 transmission risk as opposed to other space. This hypothesis is borne out of public health institutions' communication about COVID-19 transmission risk.

Methods – Experiment 2

This study employed a cross-sectional correlation research design using self-reported survey data. One-hundred and fifty-five (*n* = 155) University of Waterloo undergraduates were recruited for this descriptive, cross-sectional study. Data collection occurred between March 3rd and April 5th, 2022. The Green (1991) criteria of $N > 50 + 8m$ was used to determine sample size. There were 12 independent variables (12 x 8 = 96; 50 + 96 = 146). A 5% over sample was included and rounded to 155. A total of 115 participants were recruited for this study. While this number is below the desired recruitment level, it was the maximum number of participants that opted to participate during the study period. Nonetheless, the total number recruited is within an acceptable range from the desired sample size, but findings should be interpreted with caution. Participants were asked to rate 20 urban and architectural environments on their perceived COVID-19 transmission risk, as well as the five formal and seven functional characteristics of those environments. The experiment took approximately 30 minutes to complete and participants were awarded 0.5 credits for participating. This study received clearance from the University of Waterloo Research Ethics Board (REB #44403).

Analysis – Experiment 2

Prior to submitting the data to a multiple regression equation, the variance inflation factor (VIF) was calculated for each variable to check for multicollinearity. VIF values above 10 were found for seven out of the eleven variables, meaning multicollinearity was present. Bartlett's Sphericity Test confirmed that correlations are present among the variables ($X^2 = 16820.02$, $p < .001$) and the Kaiser-Meyer-Olkin Test achieved an index score of 0.70, indicating the data is suitable for factor analysis, based on the >0.6 criteria set by Kaiser & Rice (1974). A correlation heatmap of the original set of factors is presented in Figure 12.

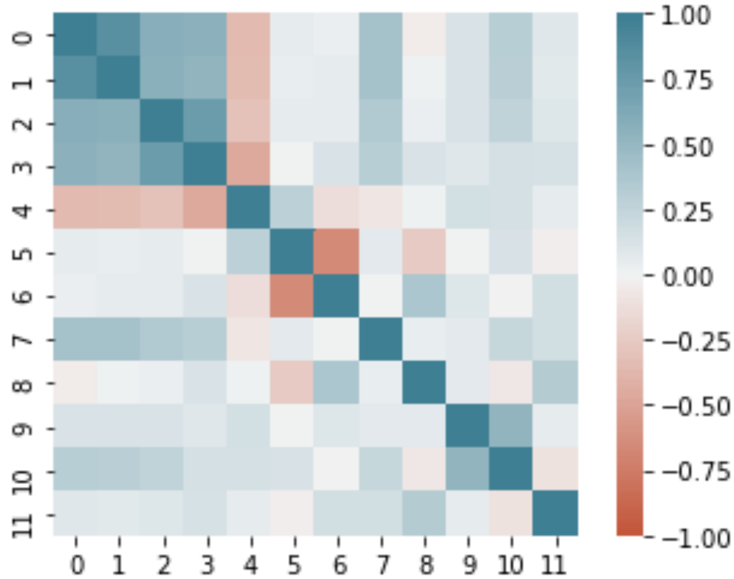

Figure 12. Correlation Heatmap for Five Formal and Seven Functional Variables.

Eigenvalues for the twelve variables were calculated and plotted on a Scree plot (Figure 13). Eigenvalues of greater than or equal to 1 were retained, which is consistent with standard practice (Girden & Kabacoff, 2001). A total of 4 factors reached this criterion. Together, these 4 factors accounted for 60% of the variance of the original 12 items.

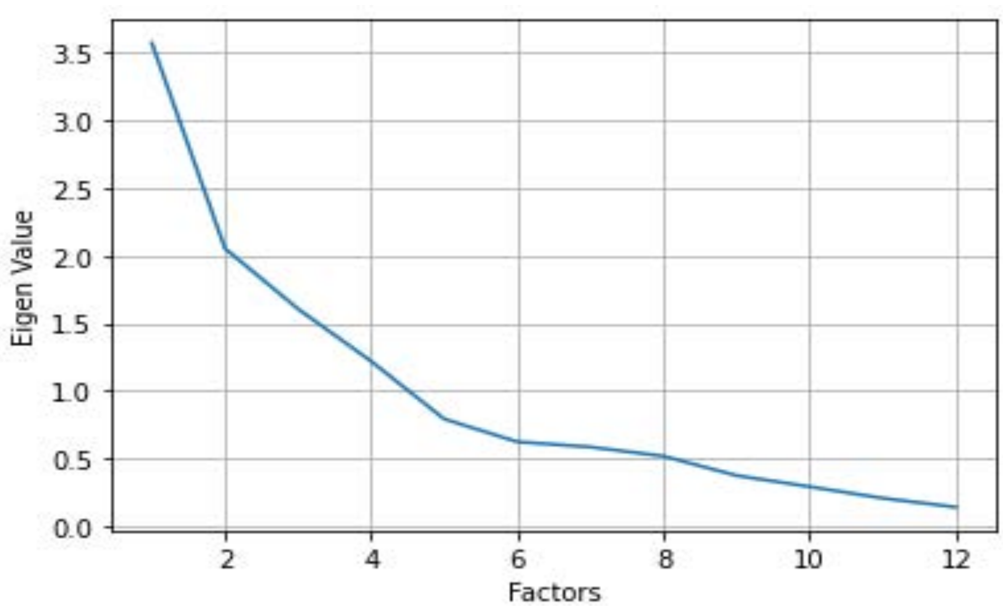

Figure 13. Factor Analysis Scree Plot.

An analysis of the factor loading scores for each variable allowed the researcher to generate names for each of the four factors. Because Factor 1 had high loading scores with access to fresh air, access to natural light, spaciousness, and ability to social distance, this factor was named "openness". Because Factor 2 had high loading scores with the private space (not accessible by the general public) rating and the accessible by the public rating, this factor was named "private/public access". Because Factor 3 had high loading scores with whether the space was for eating and whether the space was for socialization scores, this factor was named "social eating". Finally, because Factor 4 had high loading scores with whether the space was for health care and whether the space was for professional work, this factor was named "professional health care space". A follow-up VIF calculation confirmed all factors achieved acceptable VIF scores. These four factors were submitted to a regression equation with risk regressed on the four architectural factors. All analyses and visualizations were completed using Python version 3.8.1 using the SciPy 1.10.0, FactorAnalyzer 0.2.2, Matplotlib 3.4.2, and Seaborn 0.11.1 modules. Multiple regression equation:

$$Risk_i = \beta_0 + \beta_1 Op_i + \beta_2 PrPu_i + \beta_3 SoEat_i + \beta_4 PrHea_i + \varepsilon_i$$

Results – Experiment 2

The multiple regression model was significant ($p < .001$), with an $R_{adj}^2 = 0.46$. All four factors–openness, private/public, social eating, and professional healthcare–were significant predictors of perceived COVID-19 transmission risk (Table 7). The relationship was negative for openness, and positive for the three other factors. Visualizations of the relationship between each factor and perceived COVID-19 transmission risk as well as the names of the lowest and highest-ranking spaces for each factor are presented in Figure 14

Table 7

Four Factor Regression.

Variable	B	SE	*t*	$R^2_{adj.}$	*F*	*p*
Model				0.46	674.9	< .001*
Intercept	4.37	0.19	23.47	--	--	< .001*
Openness	-0.23	0.01	-42.78	--	--	< .001*
Private/public	0.16	0.01	14.16	--	--	< .001*
Social Eating	0.32	0.01	23.57	--	--	< .001*
Prof. Health	0.34	0.02	16.44	--	--	< .001*

*Denotes significance at .05 level.

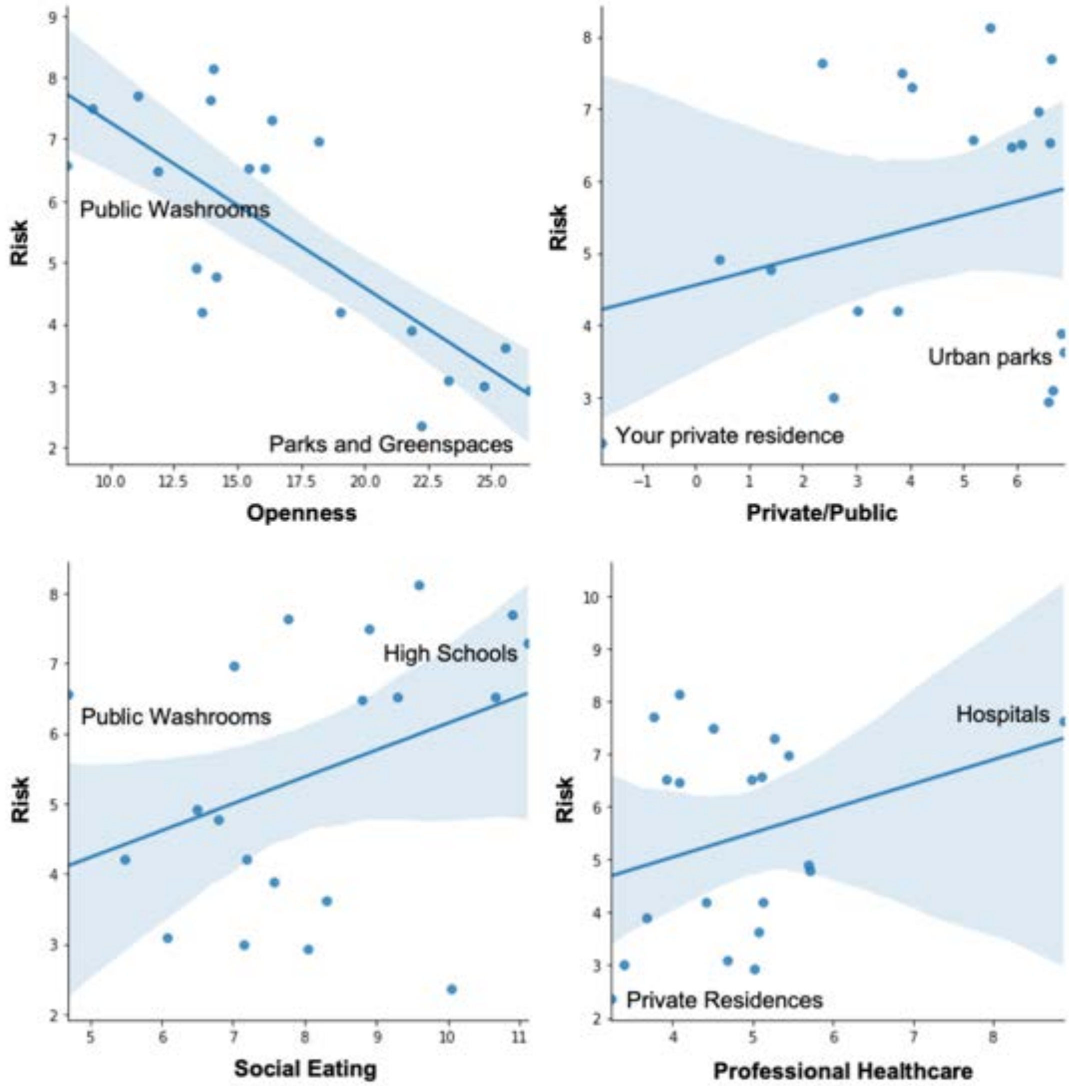

Figure 14. Average Risk Score for Each Urban and Architectural Environment by the Average Score for Openness, Private/Public, Social Eating, and Professional Healthcare Factors. Shaded Area Indicates 95% Confidence Interval.

Discussion

The fact that formal and functional aspects of urban and architectural environments significantly predicted COVID-19 transmission risk perception scores suggests that respondents do consider specific aspects of spaces to render risk judgments about those spaces. The amount of variance in risk perception scores accounted for by the model was medium to large, with a $R^2_{adj.} = 0.46$ (Cohen 1988). This means that nearly half of all the variance in risk perception scores can be predicted simply by considering a space's openness, whether it is private or allows for public access, whether it is used for socialization and eating, and whether it is a professional healthcare space. Future research can attempt to uncover which other aspects of urban and architectural environments predict risk perception scores in order to improve the model fit.

It is important to note the role that both formal and functional factors played in this association. Only one factor–openness–was composed of variables that were strictly formal (i.e., access to fresh air, access to natural light, spaciousness, and ability to social distance), while the other three factors were in part composed of *functional* variables. In other words, mental representations of COVID-19 risk are not only deduced from how a space looks but also from the types of behaviours that tend to occur in that space. This finding is important from a design intervention standpoint. It suggests that it's not enough for interventions intended to mitigate COVID-19 risk to focus only on the design of the space. Rather, they must also consider the space's function. Specifically, reducing a space's publicness, opportunities for socialization and eating, and offering of professional healthcare services are all predicted to decrease the extent to which that space would be judged as posing a high COVID-19 transmission risk. In a sense, this makes interventions more tangible, in that they do not always require architectural interventions, but can instead be programmatic. Moreover, they indicate that respondents hold more complex mental representations of the urban and architectural factors associated with COVID-19 transmission risk than the three C criteria as originally communicated by the WHO.

Still, one formal factor–openness–was a significant negative predictor of perceived COVID-19 transmission risk, and is broadly consistent with what was communicated about COVID-19 risk; that is, that risk is higher in spaces that are crowded, close contact, and confined. This association offers another intervention avenue for designers interested in mitigating perceived COVID-19 transmission risk. That is, the more a space is mentally represented as being high on openness, which is defined by its access to fresh air, access to natural light, spaciousness, and the ability for occupants to social distance, the less likely it will be perceived as posing a high COVID-19 transmission risk.

General Discussion

Across two studies, it was demonstrated that participants had complex mental representations of the urban and architectural environments, as well as their formal and functional characteristics, that are associated with COVID-19 transmission risk. This study adds to an emerging body of research, which includes the other chapters of this dissertation, that investigate the dynamics and consequences of the psychological construct of COVID-19 risk perception. Throughout the pandemic, the majority of decision-making was centralized in governments and disseminated to the public largely in a "top-down" manner (Allen, 2022), which is a common strategy for governments during times of crisis (Juhl et al., 2022). Because the mental representations of COVID-19 transmission risk in urban and architectural environments were shown to be broadly consistent, if not more nuanced, with the spaces deemed risky by public health institutions during the pandemic, the data presented in this study should be taken as an encouraging sign that members of the general public, in our case undergraduate psychology students, are thinking seriously about transmission risk in their cities. Moreover, the fact that these assessments of risk were significantly associated with change in visitations demonstrates the construct has real-world relevance, particularly in the context of controlling the outbreak of a socially communicable infection. Finally, as was summarized in each experiment's discussion section, the results provide ample insight for intervention strategies aimed at reducing perceptions of COVID-19 transmission risk in urban and architectural environments.

Specifically, policymakers can target communication strategies towards spaces deemed as risky that also require mandatory visits, such as hospitals and downtowns in urban centres. Additionally, designers can focus on making spaces high on “openness”, and space planners can alter the function of spaces, where possible, so they are less frequently used as public spaces, for socialization, and for professional healthcare.

This study had three limitations that are important to mention. First, the sample was drawn from the Canadian undergraduate psychology student population. It should not be assumed that the results from this sample generalizes perfectly to the general Canadian population. In general, teenagers and younger adults tend to rate risks associated with health-threatening activities as less severe than adults (Cohn et al., 1995). However, the opposite trend has been yielded from studies looking at the effect of age on COVID-19 risk perception. In this context, some studies have found *lower* risk perception scores among older adults compared to younger individuals. For example, de Bruin (2021) found that older adult age was associated with perceiving larger risks of dying if infected by COVID-19, but with perceiving less risk of getting COVID-19 in the first place. This finding would inform the prediction that the distribution of risk perception scores across urban and architectural environments yielded in this study would be even more varied in a sample representative of the ages of the general population. Future research should attempt to confirm this prediction using a sample drawn from the general Canadian population. Second, regression equations do not, in and of themselves, provide evidence of causality. The significant effects found in the regressions included in this study are only interpreted as correlations and are not necessarily indicative of causal relations. It is not clear whether respondents were using “openness” *per se*, or any other of the factors to render judgements about COVID-19 transmission risk. It is possible, for example, that the openness factor was related to some other unmeasured latent cue that respondents were using. However, given the diversity of independent variables included, multiple confounds are controlled for and the results of this regression are more robust than, for example, univariate regressions. Similarly, while the relationship between risk perception and change in precautionary behaviours seems intuitive, some psychologists have questioned the causal direction between these two variables (e.g., Weinstein & Nicolich, 1993). For this reason, protocols that implement experimental manipulations should be undertaken to produce stronger claims about causality. And third, the reported significant relationship between COVID-19 risk perception and change in visitation should be interpreted cautiously, given that self-report data is susceptible to error and, in this specific case, lacks ecological fidelity (Chan, 2010). Future research, including some presented in subsequent chapters in this dissertation, should strive to render this measure more objective through the use of, for example, automated and reliable mobility measuring devices.

Conclusion

Understanding how members of the public mentally represent COVID-19 transmission risk within the cities they inhabit could be a key tool in fighting future pathogenic outbreaks, in that it offers insight into what spaces in cities people will be likely to avoid. This study demonstrated that these mental representations of risk vary widely between different urban and architectural environments, and consider factors beyond crowdedness, close contact, and confinement, such as whether the space is a private space or is used by the public, whether it is used for socialization, and whether it is for professional healthcare. These associations can be used by designers to create spaces that are perceived as having a "low" transmission risk. Moreover, the risk perception scores for the different spaces proved significantly predictive of changes in visitations to those spaces. Because of this association, public health policymakers can undertake more research that investigates the possibility of shifting some of the decision-making onus about pandemic-safe behaviours away from governments and onto individual citizens, which is an invaluable additional tool to fight the spread of the COVID-19 virus during the final stages of the pandemic, as well as any other socially communicable infection that may affect humanity in the future.

Chapter IV

Manipulating the Visual Cues of Urban and Architectural Environments to Affect Perceptions of COVID-19 Transmission Risk

Abstract

Does the perception of COVID-19 transmission risk in urban and architectural environments predict the likelihood that individuals will wear a mask in those spaces? Additionally, what effect does perceiving individuals with and without masks in those spaces have the relationship between perceived risk and likelihood to wear a mask? To answer these two questions, participants were asked to indicate the extent to which they perceived images of different urban and architectural environments as posing a transmission risk of COVID-19, as well as the likelihood they would be to wear a mask should they enter the space. The images were manipulated between three groups of participants so that one group viewed the environments without people in them, another group viewed the environments with people in them without masks, and a third group viewed the environments with people with masks. Results demonstrated that risk perception scores were a strong predictor of the likelihood to wear a mask scores across all three groups. When comparing groups, participants who viewed images with people with masks in them showed the strongest relationship between risk perception and likelihood to wear a mask scores, followed by the no people group and the people without masks group. In other words, this study found evidence of a bidirectional social effect of mask wearing. Implications for public health policy and communication strategies are discussed.

Introduction

Do certain visible cues in urban and architectural environments play a causal role in affecting perceptions of COVID-19 transmission risk? In Chapter II, it was demonstrated that specific visible cues in urban and architectural environments are significantly associated with lay perceptions of COVID-19 transmission risk. However, because of the correlational design of that study, it cannot be claimed that the observed associations are causal. In order to arrive at a causal claim about the relationship between two variables, an experimental design that manipulates the variable of interest between conditions and measure the ensuing effect on the dependent variable must be used. This study accomplishes this task by manipulating specific visible cues in urban and architectural environments theorized to be related to COVID-19 risk perception, namely, the presence of people and the presence of people with masks, and measuring the effect of those manipulations on risk perception as well as on the relationship between risk perception and a key pandemic precautionary behaviour of masking wearing.

The presence of people in urban and architectural environments is theorized to cause greater perceptions of COVID-19 transmission risk. As early as 2019, when the COVID-19 virus first gained international attention, it was widely reported that contact with an infected other is the most likely scenario through which the virus spreads (WHO, 2020). Given this information, the majority of policy and design interventions focused on maintaining distance between people (i.e., lockdowns, social-distancing) as well as preventing the discharge of contaminated aerosol from infected individuals (i.e., mask wearing). The analysis of visible cues associated with pathogen transmission risk completed in Chapter II demonstrated that cues of crowds is significantly associated with perceived risk. For these reason, it is reasonable to hypothesize that the presence of people, as well as the extent to which people are wearing masks, will causally affect perceived COVID-19 transmission risk. Specifically, spaces with people are predicted to be perceived as riskier than spaces without people, and people that are not wearing masks are predicted to be riskier than people not wearing masks.

The presence of people is also speculated to affect the motivational dynamics of precautionary behaviours. Social psychology has a long history of demonstrating individual decision-making and behaviour are highly influenced by desire to belong, claiming that group belongingness is a key motivational force for all human behaviour (Baumeister & Leary, 1995; Leary & Cox, 2008), and previous research has demonstrated effects of group belongingness on healthy behaviours. For example, psychological variables related to belongingness have been demonstrated to have positive associations with feeling of self-efficacy in exercise (Resnick et al., 2002) and levels of exercise adherence (Spink & Carron, 1992; Cooper et al., 2015). In the context of the COVID-19 pandemic, media campaigns have specifically referenced themes of altruism and group solidarity to promote adherence to precautionary behaviours (Cheng et al., 2020). Messages that reference themes of belongingness during the COVID-19 pandemic have been demonstrated to be more effective at convincing people to share health messaging on social media compared to messages that did not reference these themes (Everett et al., 2020). There have already been media reports indicating certain externally identifiable pandemic-related behaviours, such as mask wearing, have become symbols indicative of broader political affiliation (Sunstein, 2020). It is reasonable, therefore, to hypothesize that perceiving masks themselves can act as symbols for group belongingness, and thereby encouraging more mask-wearing among observers.

To test these predictions, a series of images of urban and architectural environments with no people in them were presented to a group of participants who were asked to indicate the perceived COVID-19 transmission risk of those spaces as well as the likelihood they would wear a mask should they enter the space. From a methodological perspective, using digitally edited images of urban and architectural environments allows environmental psychologists to move beyond correlation study designs and into causational designs. Historically, the bulk of environmental psychology research involves exposing participants to a specific type of environment in the real world and measuring subjective and physiological reactions. For example, many studies have investigated the effect of exposure to nature on stress reduction and attention restoration, and have broadly demonstrated that exposure to nature is associated with improvements on multiple indices of psychological and physiological well-being (Ochiai et al., 2015; Song et al., 2017). Although useful, these research paradigms are often cross-sectional or rely on pre-post experimental that use crude definitions of their independent variables (e.g., “exposed” vs. “not exposed” to nature) that say little about causal. To overcome this limitation, researchers have begun to use digitally rendered images of urban and architectural environments to manipulate specific features in the environments to achieve better explanations about the causal associations between architectural elements and psychological variables. Digital technologies like Photoshop and virtual reality (VR) help on this front. With photoshopped images and VR environments, researchers are able to control for key parameters of the nature experience, such as how long participants are exposed to the stimuli, their vantage point, the light conditions, the weather, the colouration, the density of foliage, the time of day, as well as other variables that may play a role in causing changes to stress recovery and attention restoration following exposure to nature. For example, Li et al. (2020), who used VR to systematically manipulate the natural light levels in a forest environment and measured the effect of these manipulations on stress recovery. The researchers found that the light manipulation did indeed cause changes in stress recovery, whereby bright sunlight conditions in virtual forests reduce stress more effectively compared to dark night lighting conditions. What is most important to highlight is this paradigm is that, because all other variables are controlled for, the cause of the effect of stress recovery can be linked to the manipulated variable with greater confidence than in correlational designs. Moreover, if there is an intention to translate the research findings into some type of design intervention strategy, the researchers can specify what feature specifically in the urban and architectural environment is causing the psychological or behavioural effect of interest. For example, in one study, researchers used VR environments to manipulate the amount of light generated by street lights along four narrow streets and measured the effect on perceptions of crime (Son et al., 2023). Results demonstrated that perceptions of crime can be reduced by enhancing overall luminance levels as well as by improving the uniformity of luminance levels. This finding—which is highly specified—can then be leveraged by local policymakers to inform a design intervention strategy that enhances overall luminance levels and improves the uniformity of luminance levels in urban streets as a method to reduce fear of crime. These examples highlight the utility of conducting environmental psychology research using digitally edited images, particularly in applied research context.

The purpose of this study is to manipulate two specific aspects of urban and architectural environments and measure the effect of the manipulations on perceived COVID-19 transmission risk, as well as on the relationship between perceived COVID-19 transmission risk and a key precautionary behaviour in the pandemic: mask-wearing. In the first manipulation, one group of participants was exposed to the same images of urban and architectural environments but with people with no masks in them. In the second manipulation, another group of participants was exposed to the same images but with people with masks in them. This experimental paradigm allowed for a quantification of the interaction effect of people and people with masks on the relationship between risk scores and the likelihood to wear a mask scores. The results from these two experiments will be useful for designers of the built environments (i.e., architects and urban planners), as well as stakeholders who set policies that guide behaviour in urban contexts (i.e., federal, provincial and municipal politicians, business owners). Regarding designers, the results can be used to guide the design of spaces that are perceived to hold "low" COVID-19 transmission risk, as well as to predict which spaces that currently exist are likely to be perceived to hold "high" COVID-19 transmission risk. Regarding policy makers, the results can guide a more nuanced approach to policy design in the context of pandemics, wherein perceived COVID-19 transmission risk is construed as a psychological construct that plays a significant role in moderating pandemic-safe behaviours within the built-environment.

Methods

In North America, the American and Canadian federal governments recommended citizens wear masks in public to reduce the transmission of COVID-19 in the spring of 2020 (Jingnan, 2020). As of fall 2021, masks were required on conveyances, transportation hubs, and in all indoor settings (e.g., restaurants, businesses, educational institutions) in both the U.S. and Canada (Centred for Disease Control and Prevention, 2021; Public Health Agency of Canada, 2021). However, the majority of outdoor spaces were not subject to mask mandates. In these spaces, individuals may rely on a risk judgment to decide whether or not they should wear a mask. For this reason, only images of outdoor urban and architectural environments were used.

One-hundred and 73 University undergraduate students (131 female, 32 male, 2 non-binary, 3 undisclosed) were recruited from the undergraduate research participation pool and participated in this three-condition (stimuli: no people condition, N = 57, vs. people without masks condition, N = 58, vs. people with masks condition, N = 58) between-participants experiment. The sample size was determined using sample size calculator for a between-participants ANOVA with a medium effect size, statistical test power of 0.80, and alpha of 0.05. This sample size calculation produced a sample size of 158, on top of which was added a 10% oversample to deal with the potential for missing data. However, it should be noted that a multiple regression was ultimately chosen as the analysis method, for which our sample size was large enough to detect significant effects for each beta coefficient. Participants were compensated with 0.5 credits that could be counted towards a psychology course that they were currently enrolled in. Informed consent was obtained at the start of the study. Participants completed the study on their personal computers Qualtrics software. Ten images of outdoor urban environments were collected from Creative Commons (www.creativecommons.org) and were marked as being in the public domain. Images were selected by the research team, and to reflect the diversity of urban environments (e.g., sidewalks, outdoor plazas, parks, etc.) that the general public interacts with during their daily activities, including during the pandemic. The spaces in the images selected were also evaluated by the research team on their degree of "openness" (i.e., full exposure to outdoors, moderate exposure to outdoors, enclosed space, etc.), with the final set of spaces achieving a range of openness. This selection strategy increased the likelihood of producing a range of risk perception scores for the different spaces, given that openness is commonly associated with reduced potential of viral transmission (Dietz et al., 2020). Images were either used "as is" (no people condition), or were edited using Adobe Photoshop. Edited images had human figures inserted (people no masks condition) or human figures with masks (people with masks condition) (for examples, see Figure 15). All figures were sourced from Skalgubbar (www.skalgubbar.se), a collection of vector images of figures free to use by the public. This study was reviewed and received ethics clearance by the University of Waterloo's Research Ethics Board (REB #43747). Data was collected between October 5th and November 12th, 2021.

Participants first received instructions that they would be presented a series of 10 images of various outdoor urban environments and that they would rate each scene on a 0-10 scale the perceived COVID-19 transmission risk posed to them by the space, and rate on a 7-point scales how likely they would be to wear a mask in the space. To control for participants who were vaccinated, perceived COVID-19 transmission risk was further operationalized as "the perceived risk of coming in contact with the COVID-19 virus, regardless of your vaccination status." To control for participants basing their mask wearing likelihood rating on mandatory mandates, the instructions indicated "All spaces are public/outdoors and are not subject to mandatory mask wearing mandates. Mask wearing is done so at the discretion of the individual." Next, they were randomly assigned by the Qualtrics system to one of the three conditions and presented 10 images in randomized order. Below the image, text was presented that asked "What is the perceived COVID-19 transmission risk this space poses to you? (0 - no risk; 10 - extremely high risk)" with a slider scale response option, and below that was a 7-point semantic differential scale anchored by the options *very unlikely* and *very likely* preceded by the text "How likely would you be to wear a mask in this space should you enter?" Participants had unlimited time to complete the survey.

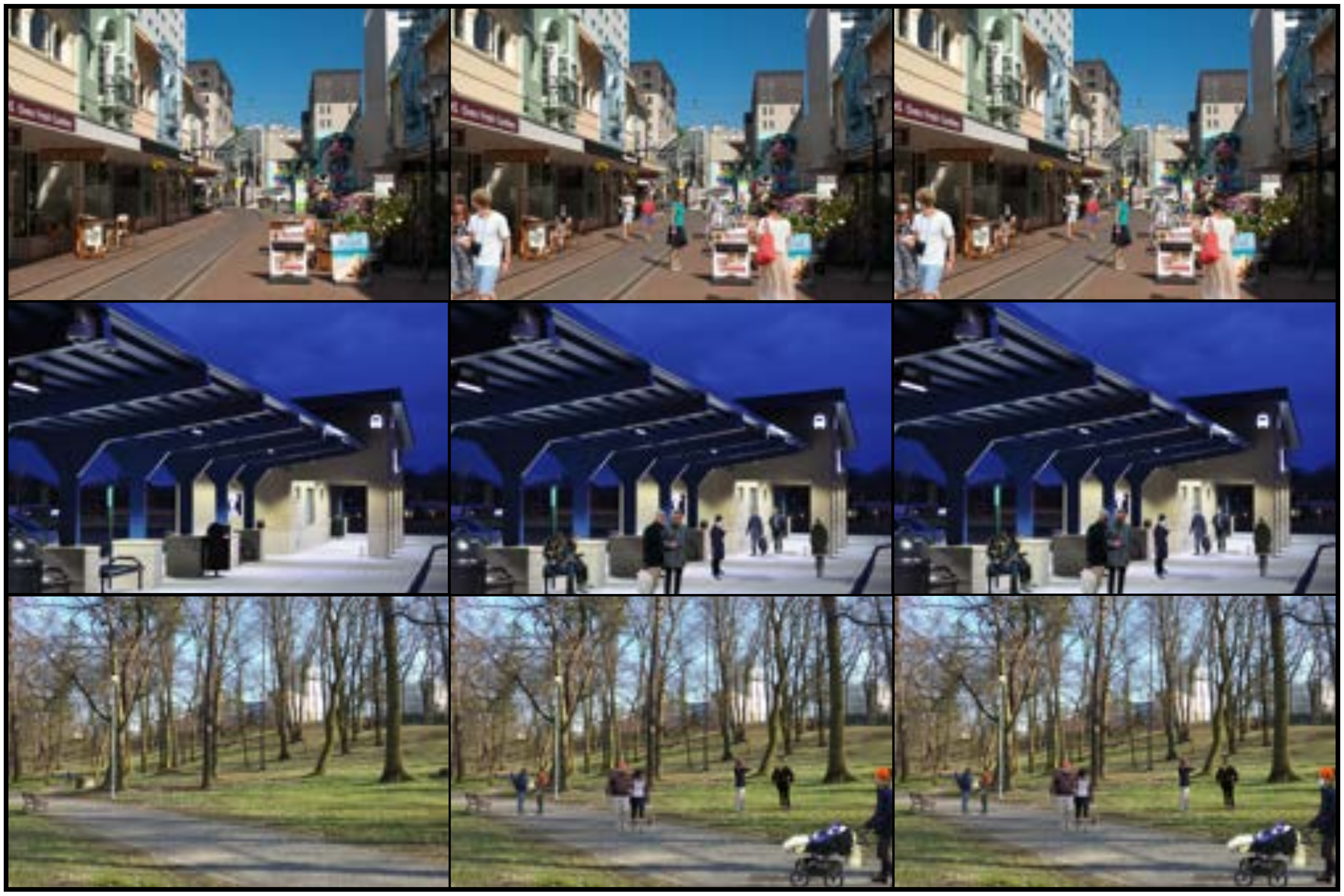

Figure 15. Three Stimuli Examples from Each of the Three Conditions of Experiment 2.

Analysis

Prior to conducting the regression analysis, images were rank ordered for each group based on risk scores, and rank orders were compared between groups using Friedman's test to determine whether the manipulations significantly affected the order of images between groups. Next, the average risk scores for each group were compared using a between-participants ANOVA. Then, a two-step hierarchical multiple linear regression analysis in which likelihood to wear a mask scores were regressed on perceived COVID-19 transmission risk scores for step one, with condition added as a dummy variable for step two was conducted. A two-step hierarchical model allowed for a dissociation between the relationship between perceived risk and mask wearing in general (step one), and between this relationship based on condition (step two), which provides data towards the question of a social effect of mask wearing. All analyses and visualizations were completed in Python version 3.8.1 using the SciPy 1.10.0, Matplotlib 3.4.2, and Seaborn 0.11.1 modules.

Results

The Friedman's test did not yield a statistically significant result, $\chi^2(2) = 0.48$, $p = 0.79$, meaning there is no evidence suggesting the rank orders between the three groups significantly differed from one another. The fact that there was no significant difference in the risk rank order of the images between the three groups suggests that there was no meaningful interaction between the content of the images (i.e., the urban and architectural characteristics) and the manipulated variables (i.e., presence of people without masks, presence of people with masks). For that reason, a figure depicting all 10 images used in this experiment is presented in Figure 16, and the images are ordered in terms of risk magnitude for the no people group. It can be assumed that the order of the images presented in Figure 16 one would be ordered the same, within an acceptable range of variance, had they been from either of the other two groups. A visual analysis of the content of these images reveals predictable trends. Images that were rated as posing a low COVID-19 transmission risk include a public park, an urban plaza, and a community garden, while spaces with many fomites, such as an outdoor café and public transit station were rated as posing a high risk. Mean perceived risk and likelihood to wear a mask scores are presented in Table 8. The people no masks condition produced the highest mean risk rating ($M = 4.38$) followed by the people with masks condition ($M = 3.85$), while the no people condition produced the lowest risk rating ($M = 3.73$). The people with masks condition produced the highest mean likelihood to wear a mask rating ($M = 4.71$) followed by the people no masks condition ($M = 4.10$), while the no people condition produced the lowest risk rating ($M = 3.92$).

Figure 16. No People Images Used as Stimuli Rank Ordered by Risk.

The between-participants ANOVA for risk scores yielded a significant omnibus, $F(2, 1602) = 10.74$, $p < .001$, with an effect size of $\eta^2 = 0.01$, indicating a small effect. Tukey's HSD posthoc showed that no people group scored lower than the people without masks group ($p < .001$), and the people without masks group scored high than the people with masks group ($p = 0.001$). For the hierarchical regression model, step one found that just over half of the variance across conditions was explained by risk perception scores, $R^2_{adj} = .52$, which was significant at the $p < .001$ level (Table 9). The beta coefficient indicated a .62 increase in likelihood to wear a mask score for every 1-point increase in perceived risk. Step two of the hierarchical regression model accounted for a small but significant ($\Delta R^2_{adj} = .04$, $p < .001$) amount of variance in likelihood to wear a mask scores. Both the people without masks condition and the people with masks condition were significantly different than the reference group, the no people condition. However, the differences for these two groups went in opposing directions. Participants in the people without masks conditions rated themselves as less likely to wear a mask compared to participants in the no people condition ($B = -0.23$, $SE = -0.06$, $p < .001$), while participants in the people with masks conditions rated themselves as more likely to wear a mask compared to participants in the no people condition ($B = .72$, $SE = .89$, $p < .001$). A scatterplot with regression lines for the average mean likelihood to wear a mask scores by perceived risk scores for each image for each of the three conditions are presented in Figure 17.

Table 8

Mean Risk and Likelihood Ratings by Condition.

Condition	Risk *M (SD)*	Likelihood *M (SD)*
No People	3.73 (2.42)	3.92 (2.07)
People no masks	4.38 (2.52)	4.10 (2.11)
People with masks	3.85 (2.39)	4.71 (2.06)

Table 9

Risk Perception and Condition Predicting Likelihood Ratings.

Predictor	*B*	95% CI for *B*		*SE B*	β	R^2_{adj}	ΔR^2_{adj}
		LL	*UL*				
Step 1	--	--	--	--	--	.52	.52***
Constant	1.78***	1.64	1.92	.07	--	--	--
Perceived Risk	.62***	.59	.65	.01	.72	--	--
Step 2	--	--	--	--	--	.56	.04***
Constant	1.58***	.08	1.42	1.74	--	--	--
Perceived Risk	.63***	.01	.60	.66	.73	--	--
No people†	--	--	--	--	--	--	--
People no masks	-.23**	.09	-.40	-.06	-.05	--	--
People with masks	.72***	.09	.55	.89	.16	--	--

CI = confidence interval; *LL* = lower limit; *UL* = upper limit; †Reference group. **p* < .05. ***p* < .01. ****p* < .001.

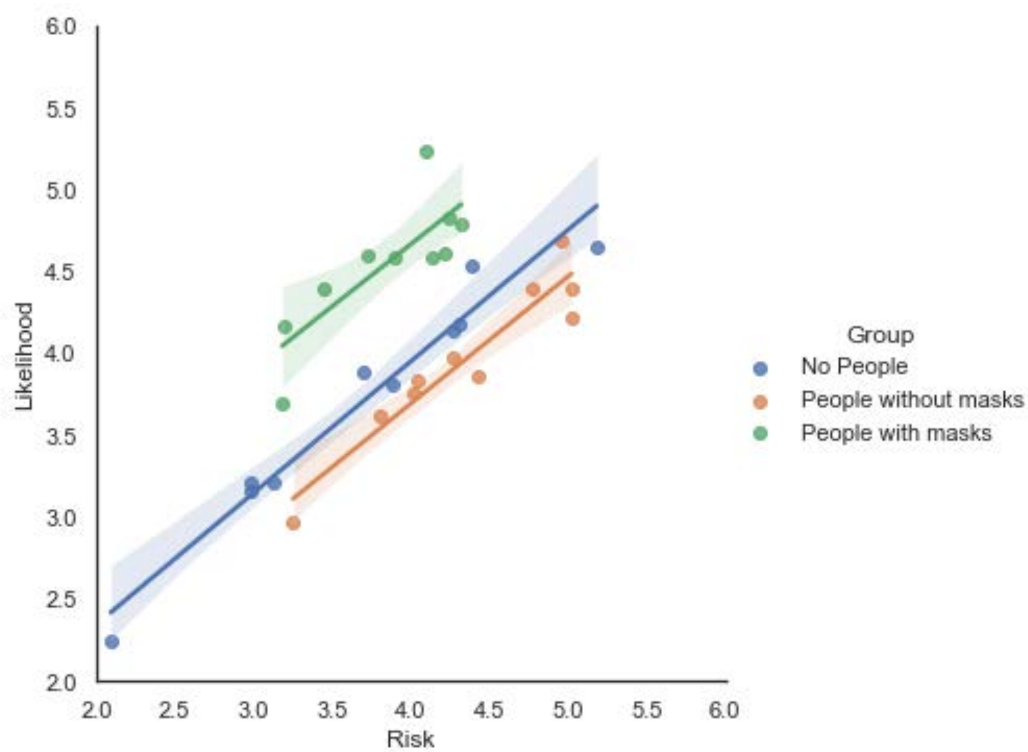

Figure 17. Average Likelihood by Risk Ratings per Image for Three Groups.

Discussion

This experiment set out to answer two key questions. First, is there a significant relationship between perceived COVID-19 transmission risk in outdoor urban environments and the likelihood to wear a mask in those environments? Second, what effect do people-free environments, people not wearing masks, and people wearing masks, have on the relationship between perceived risk and mask wearing? The experiment showed that perceived COVID-19 transmission risk is a strong predictor of self-reported likelihood to wear a mask. Additionally, it was demonstrated that when risk perception is controlled for, participants were most likely to report wearing a mask in the condition where others were also wearing masks, and least likely to report wearing a mask in the condition where others were not wearing masks. These findings confirm the original predictions, as well as show a new, unpredicted effect; that is, it was not predicted that there would be a social effect of *not* wearing a mask.

The strong association between perceived risk and likelihood to wear a mask is consistent with previous research demonstrating perceived risk to be a key factor motivating the likelihood to engage in precautionary behaviours, including in relation to the threat of infection from COVID-19 (Dryhurst et al., 2020; Wise et al. 2020). This is encouraging from a public health policy perspective. According to the findings, in outdoor spaces where there were no mandatory mask-wearing mandates in place, participants still rated themselves as likely to engage in a key COVID-19 precautionary behaviour, mask wearing. Moreover, this effect was reliably predictable as a function of perceptions of COVID-19 transmission risk in those spaces. This means that policymakers can conduct more research that investigates the potential of leveraging the intrinsic motivation of individuals to protect themselves against the threat of COVID-19 infection in their policies, by shifting some of the decision-making onus away from mandatory legislation and on to the individual citizen, for whom, according to this data, 50% of their mask-wearing behaviour could be predicted by their perceptions of risk. Crucially, these types of policies should only be crafted if the observed effect could be replicated, including in an applied context, and also only if perceptions of risk by lay individuals correlated with expert perceptions or objective assessments. At the very least, this suggestion offers policymakers an intriguing line of research that can yield insight into how to slow the spread of a socially communicable infection through policy interventions that place minimal behavioural constraints on citizens, which is an increasingly attractive option in light of new evidence demonstrating the negative effects of stringent lockdowns on mental health (Kim & Bhullar, 2020, Pancani et al., 2021, Sinha et al., 2020), physical activity (McDougall et al., 2020), and financial gain more difficult (Coibion, Gorodnichenko & Weber, 2020).

However, it should be noted that perceived risk was not perfectly predictive of likelihood to wear a mask. According to the regression, about 50% of the variance in mask-wearing scores was unaccounted for by risk perception scores. This indicates that some other factor, or collection of factors, beyond risk perception motivated (or unmotivated) individuals in this study to indicate they would wear a mask. Three possible explanations are offered. First, some participants may have automated the decision to wear a mask into an "if-then" heuristic, whereby if the individual were to enter a shared public space then they would wear a mask regardless of whether or not people were present. Some psychologists specifically argued that the psychology of habit formation can be leveraged by public health experts to achieve higher compliance with COVID-19 prevention behaviours (Harvey et al., 2021). In the context of this experiment, such a heuristic would result in likelihood to wear a mask scores that outpace perceived risk scores and are high regardless of the risk rating. Another possible explanation would be that some participants were unmotivated to wear a mask regardless of risk rating. Throughout the pandemic, researchers and public officials alike lamented the fact that certain segments of the general population showed poor adherence to COVID-19 prevention behaviours. For example, previous research demonstrated that demographic factors such as whether someone an individual was politically conservative (Barrios & Hochberg, 2020), was younger, or showed a lack of trust in healthcare professionals (Mallinas, Maner & Plant 2021) predicted anti-mask beliefs and behaviour. It's possible that certain segments of this study's sample held beliefs about COVID-19 that made them unlikely to indicate they would wear a mask in the different urban and architectural environments, regardless of how risky they perceived the space to be. And third, in October 2021 at the time of our study, about 70% of the Canadian population had received at least one dose of the COVID-19 vaccine (PHAC, 2023). Although mask wearing in shared public spaces was still common practice at that time, it is possible that some respondents began not wearing masks in these spaces because they believed COVID-19 no longer posed a significant health risk. If this effect were present, it would not have been captured by the risk measure because participants were asked to rate "the perceived risk of coming in contact with the COVID-19 virus, regardless of your vaccination status" and only would have revealed itself on a measure of precautionary behaviour against that risk. Taken together, future experiments can investigate the multiple motivational factors driving (or preventing) participation in COVID-19 prevention behaviours, including mask-wearing, independent of perceptions of transmission risk.

The fact that risk perception was a stronger predictor of likelihood to wear a mask scores in the people with masks group is in line with previous research demonstrating a positive effect of feelings of group belongingness on adherence to healthy behaviours (Spink & Carron, 1992; Cooper et al., 2015). This effect should not be taken lightly. In one study, researchers polled

367,109 individuals in 29 countries about their mask wearing behaviour, and found that people in more collectivistic (versus individualistic) regions were more likely to wear masks during the pandemic (Lu, Jin & English, 2021). Moreover, the researchers argue that these difference in adherence to COVID-19 prevention behaviours between cultures was in part responsible for wide disparities in infection and mortality rates between different regions of the world. This finding highlights the monumental role the psychology of group belonging can play in slowing the spread of COVID-19. According to data from this study, this effect can be triggered simply by perceiving the COVID-19 prevention behaviours of others. It is also important to mention that, in addition to group belongingness, social leaning may have been the mechanism through which the social effect of mask-wearing occurred. Social learning occurs when we learn new behaviours by observing and imitating the behaviours of others (Reed et al., 2010). In the context of this experiment, participants could *learn* that the space poses a high or low transmission risk based on whether other people were wearing masks in the space. A social learning mechanism does not require that observers feel like members of a group, or desire to want to belong to a group, in order to participate in the group's behaviour. Follow-up investigations using mediational analyses can be conducted to clarify the cognitive mechanism responsible for the observed social effect of mask-wearing.

Notably, according to the data from this study, the social effect of mask-wearing appears to be a double-edged sword. That is, participants who viewed people *not* wearing masks were themselves less likely to indicate they would wear a mask compared to the other groups. Previous research on health behaviours has yielded a similar effect. For example, observing the negative eating habits of other peers often has a negative effect on healthy eating behaviour for children and adolescents (Rageliené & Grønhøj 2020). For this reason, public officials and visible members of organizations must remain vigilant when practicing publicly visible COVID-19 and pandemic-safe behaviours, understanding that not practicing these behaviours, including not wearing a mask, may not be perceived as "neutral". Moreover, public health agencies can leverage collectivist ideals in their communication strategies that emphasize themes of group belongingness (e.g., Marinthe et al., 2021), given the positive effect perceiving others wearing masks had on participants rating themselves as likely to wear a mask.

This study had two limitations that are important to mention. First, this use of images as opposed to real environments. As outlined in the introduction, digital media like VR and images offer researchers the control necessary to conduct experimental research on the psychological effects of urban and architectural environments. However, these same images lack important phenomenological experiences present in real-world environments, such as the ability to act, and hence are limited in the extent to which findings produced using images are generalizable to real-world contexts. Nonetheless, they are considered an adequate proxy for real-world environments, and are frequently used in research studies. Efforts should be made to replicate these studies using virtual reality and real-world studies. A second limitation is the fact that the sample was drawn from an undergraduate student population. This population is not identical to the general Canadian population and caution should be used when generalizing results to the latter group. Previous research investigating the effect of age COVID-19 risk perception has found that younger individuals tend to have *higher* perceptions of the risk of catching the virus compared to older adults, although lower perceptions of the health risks posed by the virus once infected (de Bruin 2021). Moreover, susceptibility to peer behaviour shifts across age ranges, with one study demonstrating that the lowest susceptibility rates are achieved around 18 years of age, around the age of our sample, while the highest are achieved in early adolescence (Steinberg & Monahan, 2007). Based on this finding, this would suggest that the present sample would be some of the least likely individuals to be affected by the behaviour of their peers, especially those judged as belonging to a shared political identity, and that the relationship between risk perception and mask wearing in the people with masks condition would be predicted to be greater in an adult (25 years and older sample). Future research should strive to replicate the findings observed in this study in a sample from the general population, especially one that includes a larger age range of participants.

Conclusion

In this study, it was demonstrated that perceived COVID-19 transmission risk in urban and architectural environments is a strong predictor of self-reported likelihood to wear a mask, and that when risk perception is controlled for, participants were most likely to report wearing a mask the condition where others were also wearing masks, and least likely to report wearing a mask in the condition where others were not wearing masks. These findings are consistent with previous evidence about self-protective behaviours; that is, people are more motivated to protect themselves against threats that are perceived to pose a high risk and that motivation can be enhanced by social cues. Together, these results offer policymakers two overlooked psychological dispositions that can be leveraged to help slow the spread of COVID-19 in cities, as well as other socially communicable infections in the future.

Chapter V

The Effect of COVID-19 on Parks and Greenspaces Use During the First Three Months of the Pandemic – a Survey Study

Abstract

In Chapters II, III, and IV, it was demonstrated that people hold robust and complex mental representations of COVID-19 transmission risk and are able to assess risk using visible cues in urban and architectural environments. Moreover, these investigations demonstrated that risk perception is a significant predictor of precautionary behaviours. The purpose of this study is to investigate COVID-19 precautionary behaviours in an applied context. In this study, data was reviewed from a survey asking citizens of a region in Southwestern Ontario how the COVID-19 pandemic has affected their use patterns of parks and greenspaces by comparing visitation frequency three months into the pandemic against the same time last year. Additionally, ordinal regression modelling was completed to investigate whether different demographic and contextual variables interact with pandemic use patterns. Because parks and greenspaces offer stress restoration benefits during times of crisis, it was predicted that the results would show an increase in visitation during the time of the study. However, results indicated a significant decrease in park and greenspace use three months into the pandemic, despite no governmental restrictions preventing them from doing so. Change in the frequency of park and greenspace visitation was significantly predicted by gender, reason for visitation, number of people in the household, and income. Regarding these effects, it is reasoned that COVID-19 transmission risk perception overrides the perceived stress restoration benefits of parks and greenspaces.

Introduction

The COVID-19 pandemic led to the emergence of an unprecedented paradox for urban dwellers. Because the virus spreads through direct and indirect contact with an infected person (WHO, 2020a), all shared public spaces can act as potential sites of transmission. Yet, some of these same urban spaces, such as parks and greenspaces, are uniquely valuable during times of crises because they offer opportunities for stress reduction and attention restoration. How did members of the general public behave in parks and greenspaces during the COVID-19 pandemic in light of this paradox? Answering this question will yield insight into whether the motivation to protect oneself against the risk of coming into contact with the virus was greater than the motivation to experience the stress reduction and attention restoration benefits of parks and greenspaces.

There is a large body of research demonstrating the positive effects of exposure to nature on various indicators of physical health and psychological well-being (for review, see Jimenez et al., 2021). This body of research has also demonstrated that natural environments can attenuate negative health effects caused by acute stress events (Antonelli et al., 2019; Bratman, Daily, Levy, Gross, 2015; van den Berg et al., 2010; Hansmann et al., 2007; Hartig et al., 2003; Kaplan & Kaplan, 1989; Kuo, 2001; Tsunetsugu, Park, Miyazaki, 2009; Ulrich et al., 1991). For example, Ulrich et al. (1991) induced stress in participants using a stressful movie and then measured the extent to which physiological markers of stress improved as a function of exposure to one of six different natural and urban settings. The researchers found that recovery from the stressful video was faster and more complete when subjects were exposed to natural rather than urban environments. In a real-world context, Kuo (2001) found that residents of apartment blocks with views of trees were better able to manage stressful life events, and reported less mental fatigue compared to those that did not have views of nature. Parks and greenspaces also afford physical activity, which itself is strongly associated with positive health outcomes, including improved mood and stress reduction (U.S. Department of Health and Human Services, 1996; Hardman & Stensel, 2003). These results suggest that parks and greenspaces present a unique restorative environment that not only help people cope with stressful life events, but also reduce negative health outcomes, and relieve stress faster and to a greater extent than other urban environments. For this reason, practicing architects design natural landscapes in their architectural designs, including in health care settings, specifically for the purposes of physical and psychological wellbeing (Marcus & Barnes, 1999). Given COVID-19 has been tied to stressors such as physical and social isolation, economic instability, fear of infection, future uncertainty, as well as anxiety and insomnia (Ellis, Dumas, & Forbes, 2020; Hartt, 2020; Kalita et al., 2020), parks and greenspaces could provide a valuable resource in the stress associated with the pandemic, which suggests they would be heavily utilized during the pandemic to help mitigate stress and stress-related disorders.

However, these same spaces may act as sites of viral transmission and therefore pose a risk to visitors. At the time of the study, perceptions of COVID-19 risk among the global public were considerably high (Dryhurst et al., 2020). Not only that, but the nature of the risk was highly ambiguous. It was a time when little was known about the virus. Global infections had yet to pass 300,000, and no vaccine had been developed (Nature, 2020). Human-to-human transmission had just been established in January 2020 (WHO, 2020b), and scientists were still investigating the complete symptomology of the virus. In Canada, the first death from COVID-19 was reported only two months prior (Miller, 2020). Whereas it is now well-reported that COVID-19 is far more transmissible in crowded, confined and closed spaces compared to open spaces (Belosi et al., 2021; WHO, 2020c), this information was just starting to circulate among the general public at the time of the study, resulting in more ambiguity around the virus. A reliable finding from the risk perception literature is that risk perception tends to be greater for ambiguous risks compared to concrete risks (Viscusi, Magat & Huber, 1991). This makes the psychological construct of risk perception all the more salient at the start of the pandemic—which was when this study took place—when the threats posed by the virus were ambiguous.

In most circumstances, the fact that COVID-19 risk perceptions were high at the time of study could be used generate a prediction about behaviour in shared public space. As has been discussed in previous Chapters, risk perception is a reliable and significant predictor of motivation to engage in precautionary behaviours (Brewer et al., 2004; Sheeran et al., 2014), including in relation to the risk of COVID-19 infection (Wise et al. 2020). This effect was empirically demonstrated in Chapter III and Chapter IV of this dissertation. Given risk perceptions were high at the time of the present study, it would be predicted that there would be a decrease in visitations to parks and greenspaces. However, this effect is confounded by the fact that parks and greenspaces also afford stress restoration benefits, which may motivate greater visits to parks and greenspaces during the COVID-19 pandemic, a stressful health crisis. Therefore, In the context of the present study, it is unclear whether the general public would visit parks during the pandemic more or less often than before the pandemic.

Research on the topic has yielded mixed results. In one study out of New Jersey, the researchers compared geotagged social media data of park space use from before the pandemic began versus after the onset of the pandemic and found park visitations *increased* by 63.4% (Volenec et al., 2021). Similar effects were found in a global analysis of Google's Community Mobility Reports (Geng et al., 2020), as well as from an analysis of a sample of the general population from Norway (Venter et al., 2020), which also showed that the magnitude of visitation increases was positively associated with trail remoteness, suggesting respondents specifically sought greenspaces that afforded distance from people. However, not all research has demonstrated park visitation increases during the pandemic. Several, more recent projects, have found park visitation *decreases* when the window of analysis is shortened to comparing the time window just before stay-at-home orders to the time window just after those orders, even when those orders don't prevent visits to parks and greenspaces (Curtis et al., 2022; Ding et al., 2022). For this reason, it is important that researchers strictly specify their time periods of study, so that effects that may have decreased parks and greenspaces visitations, such as policy initiatives or perceived transmission risk, can be revealed.

This study sought to investigate whether parks and greenspaces visitation decreased or increased in a time window that occurred during the first three months of the pandemic and within the context of a region in Southwestern Ontario. At this study location, as well as in many other cities in North America, parks and greenspaces were open for public use (although social distancing policies prevented the use of physical infrastructure, such as benches and play structures). This study explored whether the frequency of, as well as reason for, visiting parks or greenspace was self-reported as to have changed as a result of the pandemic. This study also investigated whether demographic and contextual variables predicted change in park and greenspace use. The demographic variables of age, gender, income, and education were selected for analysis based on previous work demonstrating associations between these demographic variables and parkspace use or COVID-19 risk perception (Foster et al., 2004; Richardson & Mitchell, 2010; O'Brien, 2005; Dryhurst et al., 2020; Joseph & Maddock, 2016; Dowd et al., 2020; Capolongo et al. 2020; Schipperijn et al., 2009; Molinari et al., 1998; van den Berg et al., 2010). Regarding contextual variables, this study examined the effects of household density (i.e., the number of people participants share housing with), household type (detached vs. undetached) and city (township) of residence. It was predicted that the data would demonstrate a significant increase in self-reported park visitation compared to the same time last year. This prediction was borne out of the fact that, despite COVID-19 risk perception being high at the time of the study, citizens were speculated to perceive parks and greenspaces as posing a low risk given their openness and access to fresh air. Moreover, it was speculated that citizens would be motivated to seek exposure to natural environments in times of stress, as stress reduction and attention restoration theories would predict (Kaplan & Kaplan, 1989). Despite the literature demonstrating significant effects of COVID-19 risk perception by age, gender, income, and education, this study remained exploratory (i.e., prediction neutral) regarding the effect of any demographic or contextual variable on parks and greenspaces visitation given the dependent variable of this study is similar, but not identical, to the dependent variable in those studies (perceived COVID-19 transmission risk).

Methods

Location and Context

Waterloo Region is a collection of cities and townships in Southwestern Ontario with a population of approximately 617,870 and an area of 1,369 km^2 (Region of Waterloo Planning, Development and Legislative Services, 2020). 154 new cases of COVID-19 were reported in the Waterloo Region during the time window of the study (May 14th – June 2nd, 2020), with an average daily active case count of 8.3, and cumulative case count of 1,141 by June 2nd (Region of Waterloo, 2020). This represents an average active daily case count of 1.34 per 100,000 people. Toronto, a nearby major metropolitan area, had 3,364 new reported cases of covid-19 between

May 14 – June 2, which represents an average daily case count of 5.74 per 100,000 people (City of Toronto, 2021). The province of Ontario was under emergency orders under the Emergency Management and Civil Protection Act for the entire duration of the data collection period (Nielsen, 2020a). Emergency orders included the closure of shared physical infrastructure within parks and greenspaces, such as benches, playgrounds, play structures and equipment, public swimming pools, and outdoor water facilities, while parks and greenspaces themselves remained open and free to visit by citizens. Images of these spaces are presented in Figure 18.

Figure 18. Images of Waterloo Parks and Greenspaces.

Materials and Participants

Data was collected by email as part of a wider online survey regarding perspectives on COVID-19 in Waterloo Region conducted by the Survey Research Centre (SRC) of the University of Waterloo in Waterloo, Ontario, Canada. Participants were recruited by email and were previous respondents to the SRC's annual Waterloo Region Matters survey, which recruited participants in the Waterloo Region using a random-digit dialed telephone sampling system. Out of an initial 821 invitations, 317 participants 18 years of age or older (181 women, 135 men; Age M = 55.65, SD = 15.99; see Table 10 for full demographic information) completed the online survey between May 14 and June 2, 2020.

Design and Procedure

This study employed a cross-sectional correlation research design using self-reported survey data. To assess how the COVID-19 pandemic affected participants' frequency of parks or greenspace use, participants were asked, "In the past month, how frequently did you visit parks and greenspaces, compared to the same time last year?" with responses from (1) *much less frequently* to (5) *much more frequently*, with an additional option of (6) *I don't use parks/greenspace.* Unless participants indicated that they do not use parks/greenspace, they indicated their reason for using parks and greenspaces through the following question: "Thinking of the park/greenspace that you have frequented the most in the past month, what was the main reason for going?" Participants chose one of the following options: (1) *to escape to nature*, (2) *to socialize*, (3) *physical activity*, (4) *to be alone*, and (5) *to pass through to get to another destination*. In addition to the main measures of interest, demographic and contextual variables were also examined, such as age, gender, education level, and residence type (see Table 10 for full list). This study was reviewed and received ethics clearance by the University of Waterloo's Office of Research Ethics. Analyses were performed in SPSS version 27.0.1.0.

Table 10

Sample Descriptive Statistics.

Demographic variable	Categories	Percentage	Mean (SD)
Age in years			54.50 (14.99)
Gender	Female	55.1%	
	Male	44.9%	
	Other[a]	<1%	
Education (highest level completed)	University	48.5%	
	College/Trade apprenticeship	33.5%	
	Grade school or high school	18.0%	
Income level	$100,000 or more	39.8%	
	$80,000 - $100,000	14.7%	
	$50,000 - $80,000	28.2%	
	Less than $50,000[b]	17.4%	
Employment status	Employed[b]	49.4%	
	Not Working[b]	39.1%	
	Other	11.4%	
Marital status	Married[b]	74.1%	
	Unmarried	25.9%	
City	Kitchener	46.3%	
	Waterloo	25.0%	
	Cambridge	19.5%	
	Other[b]	9.2%	
Residence	Detached house	71.6%	
	Other[b]	28.4%	
Household size (number of people participants live with, not including themselves)			2.02 (1.42)

Note. Percentages calculated based on full sample of 272 and do not include missing responses. [a]For gender, the other category allowed participants to indicate several options; one participant indicated identifying as genderqueer/gender nonconforming. [b]These categories have been condensed for greater power: For income level, "less than $20,000" and "$20,000 - $50,000" have been combined. For employment status, "Employed" comprises options "Full time" and "Part time", and "Not working" comprises options "Retired", "Unemployed", "Student" and "Homemaker", and "Other" comprises text input answers that ranged from "Self-employed" to "Temporarily laid off". For marital status, "Married" comprises options "Married" and "Living with partner/common-law"; Unmarried" comprises options "Widowed," "Divorced or separated," and "Never married." For city, "Other" comprises townships North Dumfries, Wellesley, Wilmot, and Wollwich. For residence, "Other" comprises options "Semi-detached house," "High-rise apartment," "Duplex or fourplex apartment," "Low-rise apartment," and "Room."

Results

Participants who selected response (6) *I don't use parks/greenspace* (n = 45) were omitted from the analysis because the primary research question was about how the pandemic affected parks and greenspaces use for parks and greenspaces users. The response (6) *I don't use parks/greenspace* was interpreted as a pandemic-independent statement, while response (1) *much* *less frequently* was interpreted as including those who used park space before but use it much less frequently—if at all—during the pandemic. A histogram of the total responses for each item is provided in Figure 19. Park visitation frequency, the criterion variable, was treated as ordinal due to the subjective nature of the difference between items in the scale (i.e., 'much less' vs 'much more'). Additionally, for comparative purposes, the analysis was designed to be consistent with those of Burnett et al. (2021) who, like this study, examined self-reported change in park space use as a result of the pandemic, and treated their criterion variable as ordinal, using an Ordinal Regression Model.

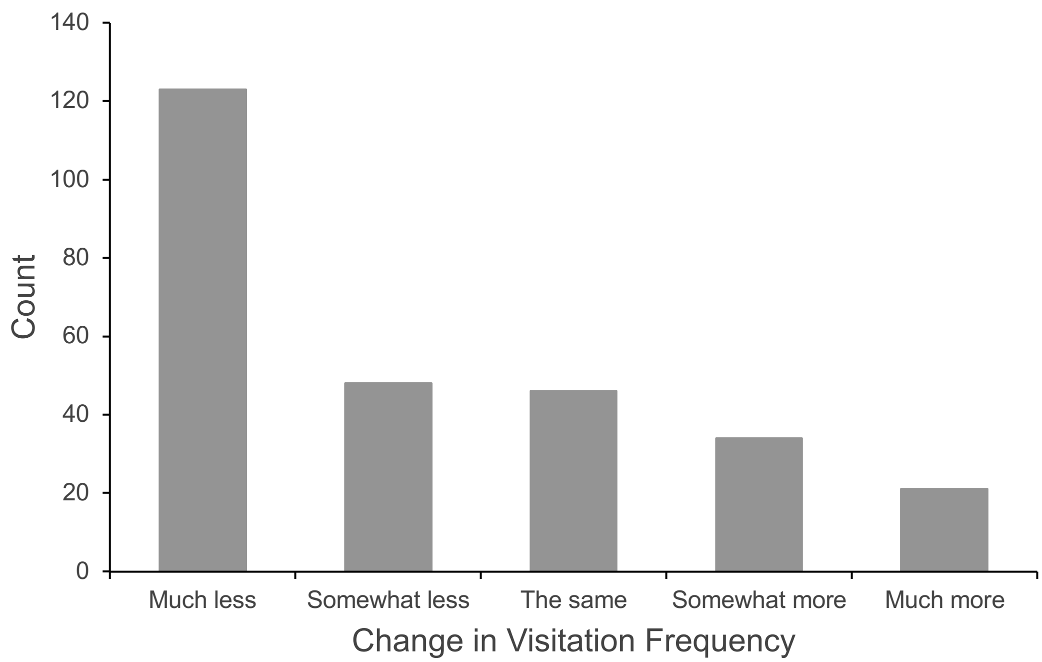

Figure 19. Change in Park Visitation Frequency Compared to the Same Time Last Year.

The first research question was whether there was a significant change in visits to parks and greenspace. To assess whether the self-reported change in visitation frequency was significant from the null, a chi-squared test was conducted, where the observed values were compared to a researcher-generated sample (N = 272) of expected values should the null hypothesis (no significant change) be true. Specifically, a sample was generated in which all respondents selected ‘3’, indicating they used parks and greenspaces with “the same frequency” compared to this time last year. The chi-squared test was significant, $x^2(4, N = 272) = 187.78, p < .001$, indicating the sample reported visiting park space significantly less frequently than the null distribution. A histogram of observed responses is presented in Figure 19, and a breakdown of responses for categorical predictor variables is presented in Table 11.

Table 11

Parks and Greenspaces Visitation Change Breakdown for Categorical Predictors.

Demographic variable	Categories	1	2	3	4	5
Gender	Female	52.0	17.3	12.7	11.3	6.7
	Male	36.9	18.0	22.1	13.9	9.0
Education (highest level completed)	University	34.1	21.2	19.7	16.7	8.3
	College/Trade apprenticeship	58.2	12.1	11.0	7.7	11.0
	Grade school or high school	51.0	18.4	20.4	10.2	0
Income level	\$100,000 or more	35.0	20.4	21.4	13.6	9.7
	\$80,000 - \$100,000	47.4	15.8	10.5	15.8	10.5
	\$50,000 - \$80,000	56.2	12.3	16.4	9.6	5.5
	Less than \$50,000[b]	44.4	24.4	15.6	8.9	6.7
Employment status	Employed[b]	42.5	20.1	17.9	10.4	9.0
	Not Working[b]	44.3	17.0	17.0	14.2	7.5
	Other	61.3	9.7	12.9	12.9	3.2
Marital status	Married[b]	43.5	17.5	18.5	12.5	8.0
	Unmarried	50.0	18.6	12.9	11.4	7.1
City	Kitchener	45.2	18.3	19.0	13.5	4.0
	Waterloo	38.2	16.2	22.1	8.8	14.7
	Cambridge	56.6	17.0	7.5	11.3	7.5
	Other[b]	40.0	20.0	12.0	20.0	8.0
Residence	Detached house	42.8	16.5	20.6	12.4	7.7
	Other[b]	51.9	20.8	7.8	11.7	7.8
Visitation Reason	To escape to nature	60.6	21.2	6.1	9.1	3.0
	To socialize	33.3	33.3	0	33.3	0
	Physical activity	34.7	16.2	22.8	15.6	10.8
	To be alone	100	0	0	0	0
	To pass through	66.7	16.7	13.3	0	3.3

All values percentages. Responses were (1) much less frequently, (2) somewhat less frequently, (3) the same frequency, (4) somewhat more frequently, and (5) much more frequently.

The second aim was to examine how demographic and contextual variables predict change in parks and greenspaces usage. The data were submitted to an Ordinal Linear Regression Model (OLM), where the criterion variable, park visitation frequency, was regressed on the categorical predictor variables gender, education, income, residence type, employment status, township, and visitation reason, as well as the quantitative predictor variables of age and number of people in household. Given the exploratory nature of this study, both significant ($p <$ .05) and marginally significant ($p = < .10$) effects are reported, with the understanding that any marginally significant effects should be subjected to more rigorous, follow-up evaluations. A model with all the predictor variables accounted for a significant amount of the variance of the criterion variable, Wald $\chi^2(19) = 56.62$, $p < .001$; however, the demographic variables of education, employment status, and marital status, as well as the contextual variable of household type did not yield significant ($p < .05$) or marginally significant ($p < .10$) effects for any of their items and were therefore removed to create a new model 2. Model 2 was composed of the criterion variable, park visitation frequency, regressed on the categorical predictor variables of gender, income, township, and visitation reason, as well as the quantitative predictor variables of age and number of people in household. Model 2 accounted for 18.2% (Nagelkerke R^2) of the variance of the criterion variable, which was significant, Wald $\chi^2(13) = 47.94$, $p < .001$, and all terms in the model had items that yielded significant or marginally significant effects (i.e., the demographic variables of gender, income, and visitation reason, and the contextual variable of township). Model 2 also satisfied the assumption of proportional odds, $x^2(39) = 18.96$, $p = .997$. A full summary of the results of model 2 can be found in Table 12.

Table 12

Parks and Greenspaces Visitation Frequency Ordinal Regression Model

Variable	Category	OR [95% CI]	Sig.
Age	--	.98 [.96 – 1.00]	0.056*
Number of people	--	.81 [.67 –.99]	0.039**
Gender	Female (ref.)	--	--
	Male	1.70 [1.04 – 2.76]	0.033**
Parkspace reason	To pass through (ref.)	--	--

	To escape to nature	1.54 [.59 – 3.99]	0.378
	To socialize	2.13 [.33 – 13.74]	0.426
	Physical activity	5.03 [2.13 – 11.87]	< .001**
	To be alone[a]	0[a]	--
Township	Waterloo (ref.)	--	--
	Cambridge	.54 [.26 – 1.12]	0.095*
	Kitchener	.96 [.54 – 1.70]	0.882
	Other	1.23 [.50 – 3.00]	0.651
Income	100k or more (ref.)	--	--
	Less than 50k	.50 [.25 – 1.02]	0.056*
	50k to 80k	.49 [.27 –.90]	0.021**
	80k to 100k	.74 [.37 – 1.51]	0.412

Ref. indicates reference group. * indicates $p < .1$, ** indicates $p < .05$. [a]No p-value calculated due to limited item power (n = 1)

Discussion

The results from this study demonstrated a significant decrease in parks and greenspaces use three months into the pandemic compared to the same time last year. This was the opposite effect than what was predicted. It was predicted that visits to parks and greenspaces would see an increase at the time of the study. This finding suggests that the stress reduction and attention restoration benefits of parks and greenspaces were not sought out during this time of crisis, at the start of the pandemic. Not only were they not sought out, but according to the data parks and greenspaces were actively avoided during the time of study. The most reasonable explanation for this effect is the role perceived COVID-19 transmission risk plays in motivating pandemic-safe behaviours, including avoiding shared public spaces. It is highly plausible that the respondents in our sample perceived the risk associated with COVID-19 as “high”, and were therefore motivated to protect themselves against the threat of infection by avoiding shared public spaces, despite being free to do so; i.e., the Provincial Emergency Orders did not prohibit visiting municipal parks and greenspaces, only the shared physical infrastructure within parks (e.g., play structures and equipment, swimming pools, etc.). This explanation accords with previous research on risk perception demonstrating a reliable and significant positive relationship between perceptions of risk and motivation to engage in precautionary behaviours (Brewer et al., 2004; Sheeran et al., 2014), including in relation to the risk of COVID-19 infection (Wise et al. 2020), which was empirically demonstrated in Chapter III and Chapter IV of this dissertation. Importantly, given the limitations of the survey apparatus, the survey did not provide an opportunity for respondents to provide their motivations for accessing parkspace less frequently than before the pandemic; therefore, the proposed explanation is speculative, albeit grounded in previous scientific findings.

The analyses also showed that change in patterns of park and greenspace usage was significantly associated with certain demographic and contextual variables. Identifying as female, being older, or having a low income were associated (significantly and marginally significantly) with fewer visitations to park spaces. Regarding the effect of gender, it has been found that women experience higher perceptions of COVID-19 risk than men (Dryhurst et al., 2020), which is consistent with data from the analysis indicating men had 1.7 times greater odds of visiting parks and greenspaces more frequently than during the study period, compared to the same time the previous year. It is therefore plausible that the observed gender differences are informed by feelings of safety. Similarly, there was also a marginally significant effect of age, where older age was associated with lower odds of visiting parks and greenspaces. The pandemic presented a uniquely difficult circumstance for older adults. Older adults were more likely to die from the virus than younger adults (Dowd et al., 2020), and in the region from where the sample was collected 82% (93/113) of reported COVID-19 deaths came from residents of long-term care or retirement homes (Bueckert, 2020) indicating the imminent risk. It is speculated that older adults experience a heightened vigilance with regard to COVID-19 in comparison to younger demographics, which dissuaded them from visiting parks and greenspaces at the time of the survey. Follow-up qualitative investigations should be conducted to investigate whether the marginally significant effect of age is corroborated by subjective reports of motivational differences between age-groups, giving specific attention to older adults. Income was also a significant predictor of visitation frequency, with those that made less money (less than 80k) being less likely to visit parks and greenspaces compared to those that made 100k or more. Such an effect could be driven by differences in the quantity and quality of parks and greenspaces between neighbourhoods with different median incomes, given that more affluent communities tend to have better parks (Jenkins et al., 2015). This survey did not specifically ascertain data about parks and greenspaces quality or quantity; therefore, future research should investigate the extent to which these variables influence park visitation during the pandemic.

To that end, the two contextual variables that were analyzed—number of people in household and township—were significant and marginally significant, respectively. With regard to number of people in household, larger households were associated with a significant decrease in odds of visiting parks or greenspace. With regard to township, respondents that resided in Cambridge had lower odds of visiting parks and greenspaces compared to those that lived in Waterloo, which was a marginally significant difference (p = .10). Regarding the effect of the number of people in household, research has confirmed that household transmission was a prominent route the disease spread during times of quarantine (Shen et al., 2020). It is possible that respondents in our sample living in high-density households had greater vigilance towards viral exposure in dense households, as the virus is more likely to spread in these conditions. Future qualitative work can examine risk-perception differences as they manifest within households of differing densities. The effect of township lacks a clear explanation. Both Cambridge and Waterloo have comparable quality and quantity of park space. The fact that respondents living in Cambridge reported fewer visitations compared to respondents living in Waterloo could be confounded by other variables not included in the regression, such as time availability or family composition. Future research should attempt to replicate and explain this effect.

Notably, visiting parks and greenspaces for physical activity was associated with significantly higher odds of more frequent visits. This finding is encouraging, given previous research demonstrating the positive effects of physical activity on indices of mental health (Clow & Edmunds, 2014). It is probable that this effect is also enhanced by the fact that all major indoor recreational facilities and fitness centres were closed at the time of data collection. Public health authorities and municipal governments should be aware of the public's desire to use parks and greenspaces for physical activity during the pandemic because it offers a low-cost and effective method for stress reduction during a time of crisis. Public health authorities and municipal governments can find ways to facilitate and encourage this type of behaviour provided the appropriate physical-distancing guidelines are made explicit.

The study had two limitations that are important to mention. First, the sample did not accurately reflect the demographic characteristics of the population of study. Only 3.2% of the sample consisted of adults aged 18–25, which is far lower than the equivalent in the Waterloo

Region population (12.67%), while 41.9% of the sample consisted of adults aged 65+, which is far greater than the equivalent in the Waterloo Region population (30.6%; Statistics Canada, 2017). The survey also over-represented people who have a university education (46.4% in sample, 25% in population; Statistics Canada, 2017). Follow-up studies should strive to achieve a sample that is representative of the population under study. And second, while data were collected on gender and age, the survey was unable to collect data on these other important demographic variables, such as race or disability status. Again, visible minorities in particular are critical groups to collect pandemic-related data from, as research at the national level has already indicated that COVID-19 mortality rates are approximately two times higher in neighbourhoods with higher proportions of their population groups designated as visible minorities (Statistics Canada, 2020). Differences in neighborhood structure, including provision of and access to quality park space, has been proposed as a possible mechanism that in part accounts for the observed racial/ethnic differences in COVID-19 infection and mortality statistics (Berkowitz et al., 2020). For that reason, policymakers should consider the role of urban design in shaping unequal urban experiences, particularly as they relate to stress restoration behaviours in the context of a public health crisis such as COVID-19.

General Discussion

The primary aim of this dissertation was to provide insight into the dynamics of the psychological construct of COVID-19 risk perception in urban and architectural environments, as well as to explain some of its effects on pandemic-safe behaviours. This aim was inspired by three precedents from architectural theory, environmental psychology, and health psychology. Specifically, the effect the tuberculosis pandemic achieved on Modernist architectural designs, the way the public will analyze visual cues in urban and architectural environments to render estimations of crime risk, and the reliable effect risk perception achieves on motivation to protect oneself against those risks. Together, these precedents set the stage for the empirical investigations completed in this dissertation on the topic of COVID-19 risk perception in urban and architectural environments.

This dissertation began with an investigation into the visible cues of urban and architectural environments that were associated with lay and expert perceptions of pathogen transmission risk. According to this analysis, the cleanliness, crowdedness, and potential for crowds in an environment were all significantly associated with COVID-19 transmission risk perception scores for lay raters. No evidence was found indicating lay raters associate the lighting conditions, access to fresh air, colour, or the cleanability of the space. Similarly, no evidence was found that the potential presence of sick, elderly or children was associated with risk perception for lay raters. Expert raters also the cues of cleanliness, crowdedness, and potential for crowds with pathogen risk perception, and also associated fomites and access to fresh air with pathogen risk.

Following this study, an investigation of the mental representations of COVID-19 risk perception in urban and architectural environments found that risk perception varies widely between different urban and architectural environments, and consider factors beyond crowdedness, close contact, and confinement, such as whether the space is a private space or is used by the public, whether it is used for socialization, and whether it is for professional healthcare. Moreover, the risk perception scores for the different spaces proved significantly predictive of changes in visitations to those spaces.

Next, the presence of people and whether they were wearing masks was manipulated in images of urban and architectural environments. In this study, it was demonstrated that perceived COVID-19 transmission risk in urban and architectural environments is a strong predictor of self-reported likelihood to wear a mask, and that when risk perception is controlled for, participants were most likely to report wearing a mask the condition where others were also wearing masks, and least likely to report wearing a mask in the condition where others were not wearing masks.

Finally, in an applied context, it was demonstrated that citizens of a mid-sized North American city reported visiting parks and greenspaces less frequently during the period of May 14th – June 2nd, 2020, approximately three months into the pandemic, compared to the same time last year, despite the fact that no restrictions were in place preventing citizens from visiting parks and greenspaces. Based off earlier findings, it is theorized that pandemic-related stress and perceived COVID-19 transmission risk, particularly at a time when little was known about the virus, dissuaded citizens from visiting parks.

These findings are compiled and presented as design insights and insights for policymakers. Design insights are ones that can be actioned by designers of the built environments, including urban planners, architects, interior designers, and space planners. Importantly, these design insights offer strategies for designers to mitigate *perceived* COVID-19 transmission risk, but have not been validated in relation to objective measures of COVID-19 transmission. For this reason, designers should only implement these insights if they have also ensured that the resulting designs are *objectively* safe with regard to COVID-19 transmission. The insights for policy provide information about the psychological and behavioural responses to urban and architectural environments that policymakers may find useful when designing policies that guide the public's behaviour during pathogen outbreaks. They do not, in and of themselves, provide specific phrasing for policies, but rather offer policymakers a more nuanced understanding of members of the general public's responses to the COVID-19 pandemic.

Design insights:

- Designing spaces that are perceived as clean, have small crowds, and have low potential for crowds are likely to be perceived as posing a low COVID-19 transmission risk.
- There is no evidence indicating changing a space's colour or lighting condition will change the perception of COVID-19 transmission risk in that space.
- Designing spaces that are mentally represented as high on openness, as a private space, as a space that hosts few socialization or eating opportunities, and are not a professional healthcare space are likely to be perceived as posing a low COVID-19 transmission risk.
- Designing spaces that feature visual cues of people wearing masks in them reduces estimations of perceived COVID-19 transmission risk in those spaces compared to the same space featuring people in them without masks.

Insights for Policymakers:

- The visual cues associated with perceived COVID-19 transmission used by members of the general public are significantly and strongly correlated with those used by expert raters. Policymakers should be aware of the fact that there is a high correlation between these two groups.

- Risk perceptions vary considerably across different urban and architectural environments, and these perceptions significantly predict the likelihood people will avoid those spaces during the pandemic. Policymakers should be aware that there is considerable discrepancy of risk perceptions scores between the different environments, and that these perceptions can be leveraged in policy decisions that intent to motivate people to stay away from risky spaces in cities.
- People consider different functional and formal characteristics of urban and architectural environments when rendering estimations about risk, including how open the space is, whether it is a public or private space, if the space is used for eating or for socialization, and whether the space is a professional health care space. Policymakers should be aware of the fact that these considerations are more complex and nuanced than simply considering whether the space is crowded, close contact, and confined.
- Other people wearing masks in shared public spaces increases the likelihood an individual will wear a mask in that space, while other people not wearing masks decreases the likelihood. Policymakers should be aware of the social effect of participation in precautionary behaviours.
- People will avoid parks and greenspaces at the start of the pandemic even when those spaces are available to access and provide stress reduction attention restoration benefits during times of crises. Policymakers should be aware of the strong motivational effect perceived COVID-19 risk perception is speculated to have on precautionary behaviours.

- Respondents were most likely to visit parks and greenspaces during the first three months of the pandemic for physical activity, compared to all other measured reasons. Policymakers should be aware that members of the general public are motivated to participate in physical activity in parks and greenspaces during the pandemic, and should facilitate ways to do so provided it meets COVID-19 safety standards.

Conclusion

The COVID-19 pandemic was a global health crisis that placed unprecedented demands on the public as well as on the governments and public health agencies responsible for protecting citizens. While many researchers around the world investigated numerous questions about the virus and its effects, few focused on how the public conceptualized COVID-19 transmission risk in urban and architectural environments. The purpose of this dissertation was to address this gap in the literature by leveraging the research methodologies of experimental psychology.

Across five experiments, it was demonstrated that members of the general public hold complex and nuanced perceptions of COVID-19 transmission risk in urban and architectural environments. Moreover, perceived COVID-19 risk perception was demonstrated to be a significant predictor of self-reported likelihood to engage in precautionary behaviours against the threat posed by the virus. Taken together, the findings from this dissertation offer meaningful insight for health psychologists, public health policymakers, and designers of the built environment, all of whom are interested in understanding and predicting the behavioural and psychological responses people had against the COVID-19 virus. Given the inevitability of future outbreaks, the findings stand to remain relevant for as long as pathogens pose a threat to human health and well-being the world over.

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Appendices

Appendix 1.

Some questions, such as ceiling height (Q5), only need to be answered for indoor spaces.

Some questions, such as ventilation (Q11), should be "best guesses". You do not need to explain the method through which you arrive at a rating.

Some questions, such as general use characteristics, should be "best guesses" as to how the space is used *in general* (i.e., not just how the space is being used in the image).

All items are presented as 1-5 Likert scales.

Lighting (consider only in terms of how the space appears in the image).

1. Dark (vs. well-lit) [natural light]

2. Dark (vs. well-lit) [artificial light]

Physical Characteristics

3. Small (vs. large) [in terms of the space's square footage]

4. Very small (vs. very large) corridors for movements [referring to physical characteristics only, independent of the number of people currently in space]

5. Low (vs. high) ceilings [answer for indoor spaces only]

6. No (vs. a lot of) pieces of furniture/seating

7. No (vs. a lot of) touchable surfaces [includes, but is not limited to, table surfaces, desk surfaces, etc.]

Colour

8. Dark (vs. light) colouration

Ventilation

9. Very little (vs. a lot) of access to fresh air

10. Unlikely (vs. likely) of having a good ventilation system [answer for indoor spaces only]

Appearance of cleanliness

11. Unclean (vs. clean) [refers to the general amount of waste, dirt, and overall disorder currently visible in the space]

12. Poorly maintained (vs. well-maintained) [refers to the general upkeep of the space, such as whether the space looks new or heavily used]

13. Difficult (vs. easy) to clean [refers to the complexity of the cleaning process, which is influenced by things like the amount and ornamentation of surfaces]

14. Unlikely (vs. likely) to be cleaned frequently [use your best guess; “frequently” is defined as once every couple of hours]

People

15. Vacant (vs. crowded) [In terms of how the space currently appears in the image]

General usage (consider how the space is used in general, not just how it is being used in the image).

16. Single (vs. multiple) functional uses [refers to the number of unique functions a space can have, such as using a gym for basketball as well as for dancing (i.e., multiple uses)]

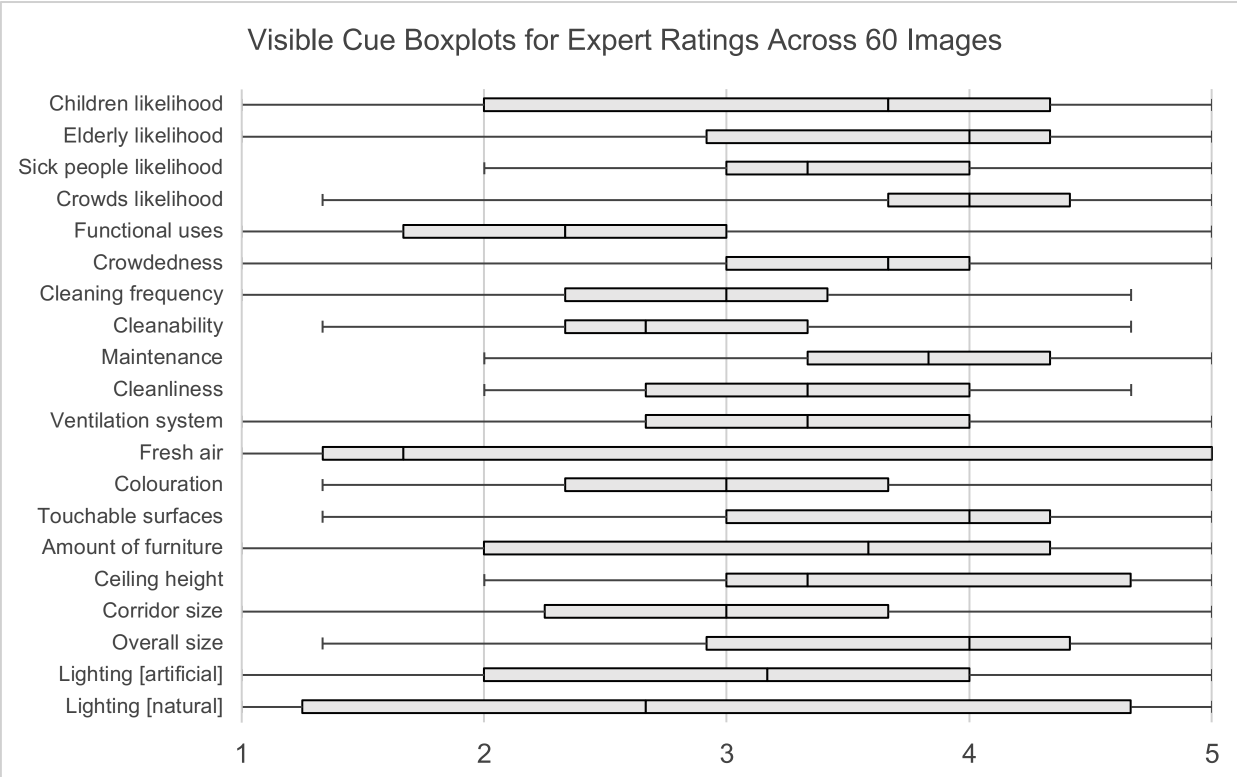
17. Unlikely (vs. likely) to be crowded

18. Unlikely (vs. likely) to be occupied by sick people

19. Unlikely (vs. likely) to be occupied by elderly people

20. Unlikely (vs. likely) to be occupied by children

Appendix 2.



Appendix 3.

Urban scale items.

1. Your private residence
2. The private residence of an acquaintance
3. Residential apartments with 10 or more units
4. Residential apartments with less than 10 units
5. Low-rise office buildings (less than 7 stories)
6. Mid-rise office buildings (7–25 stories)
7. High-rise office buildings (more than 25 stories), including skyscrapers (over 40 stories)
8. Dental offices
9. Restaurants
10. Fast food restaurants
11. Pubs/bars
12. Small retail businesses
13. Auto dealerships
14. Community shopping centre (e.g., 125,000–400,000 sqft; provides general merchandise and commodities, e.g., supermarket, discount department store)
15. Regional shopping centres (e.g., enclosed space; 400,000–800,000 sqft; 1–5 anchor stores with other tenants that sell a large variety of goods).
16. Strip malls (open space; less than 30,000 sqft; located along suburban roads)

17. Main streets (e.g., with pedestrian circulation in core and vehicular circulation along perimeter; upscale national chain specialty stores, dining or entertainment)
18. Big box shopping centres (e.g., the Brick, Best Buy, etc.)
19. Freestanding supermarkets
20. Farmers markets
21. Full-service hotels
22. Motels
23. Resort hotels
24. Concert venues
25. Live theatre venues
26. Movie theatres
27. Golf courses
28. Ski resorts
29. Places of worship (e.g., churches, mosques)
30. Recreational sport clubs
31. Bowling alleys
32. Casinos
33. Sports arena (e.g., for hockey, basketball, etc.)
34. Fitness centres
35. Public swimming pools
36. Exhibition grounds/fair grounds
37. Museums
38. Small art galleries
39. Public libraries
40. Community halls
41. Post-secondary education institutions – universities, community colleges, etc.
42. Multiple occupancy educational institutional residences located on or off campus
43. Schools – kindergartens
44. Schools – elementary (grades 1 – 8)
45. Schools – high schools (grades 9 – 12)
46. Hospitals
47. Retirement/nursing homes
48. Airports
49. Airplanes
50. Prisons
51. City halls
52. Courthouses
53. Police stations
54. Post offices
55. Bus stations
56. Public transit buses (interior)
57. Metros (e.g., underground subways) or streetcars
58. Metro station (e.g., underground subway stations) or streetcar stations
59. Regional rail way stations
60. Parks/Greenspaces
61. Urban parks
62. Public square in urban setting
63. Downtown sidewalks
64. Suburban sidewalks
65. Coffee shops

Regional scale items.

1. Small towns in rural settings (e.g., less than 20,000 people)
2. Large cities (e.g., 1,000,000 people or more)
3. Suburbs of large cities

4. Town centres of medium sized cities (e.g., 200,000 people or less)
5. Downtowns of large cities (e.g., 1,000,000 people or more)
6. Rural regions
7. Major metropolitan regions

Architectural scale items.

1. Park benches
2. Door handles
3. Bus/subway seats
4. Store checkouts/areas for processing payments
5. Public washrooms
6. Elevators
7. Escalators
8. Stairwells
9. Hallways
10. Dining tables in restaurants/coffee shops

Appendix 4.

1. High schools
2. Public washrooms
3. Restaurants
4. Community shopping centres
5. Movie theatres
6. Golf courses
7. Auto-dealerships
8. Small art galleries
9. Courthouses
10. Police stations
11. Your private residence
12. Parks and greenspaces
13. Suburban sidewalks
14. Park benches
15. Urban parks
16. Hospitals
17. Concert venues
18. Pubs/bars
19. Airplanes
20. Public swimming pools