A Proposed Methodology for the Ambulatory Measurement of Physiological Response to Natural Restoration in Urban Green Spaces

Honors Thesis:

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Table of Contents

FIGURES AND TABLES

ABSTRACT

It is known that natural wilderness environments can act as restorative environments for urban stress. However, it is uncertain what effect urban green spaces have on urban stress. In this study, we reviewed methodologies in natural restoration papers to determine the best method for analysing natural restoration in mobile subjects in urban green spaces. The results indicate that heart rate variability may hold the key to an ambulatory method, despite the complexities associated with analyzing data obtained via this measure.

Key Words

heart rate variability, urban stress, mental stress, mobile, environmental exposure, environmental restoration, nature, wilderness exposure

TERMINOLOGY

Green space: A natural or semi-natural environment encompassed by an urban environment. It is dominated by vegetation rather than asphalt or man-made structures. It may be highly artificial or wild by design. It can include a variety of management strategies from highly tended gardens to unmanaged reserves (urban forests).

Urban built environment: Highly developed city environments that have high traffic, high population density and no natural spaces.

Ambulatory: relating to or adapted for walking

Abbreviations

ECG: Electrocardiogram, from which heart rate variability is derived

GSR: Galvanic Skin Response, or skin conductance

HRV: Heart rate variability

OHS: Oxford Happiness Scale

POMS: Profile of Mood States

PSNS: Parasympathetic nervous system

SNS: Sympathetic nervous system

ZIPERS: Zuckerman`s Inventory of Personal Reactions

CHAPTER 1: INTRODUCTION

1.1 MOTIVATION

Cities can be highly stressful environments that have documented impacts on human health (Evans, 2003, Galea *et al.*, 2005). Psychological stressors associated with urban living can lead to a decreased quality of life and negative effects on health (Evans, 2003; van den Berg *et al.*, 2007). There is also evidence linking urban living to higher incidences of psychiatric disorders (Galea *et al.*, 2005). However, there are counterbalances to these stressful environments. Exposure to natural wilderness has been demonstrated to have a restorative effect on human mental health (Park *et al.*, 2010). Studies have demonstrated a relaxation of mental stress and greater cognitive functioning after exposure to natural environments (Berto, 2005). Due to these relaxing effects, regular exposure to natural wilderness could help to mitigate the stress of living in a psychologically distressing urban environment. Unfortunately, because natural wilderness is often removed from human development influences, it can be so far away as to be ordinarily inaccessible to urban dwellers.

Urban green spaces may provide a solution to this problem. Green spaces may exhibit the same restorative effects as natural wilderness while being located within an urban environment. However, studies of such sites are lacking. Notably absent are studies which review methodologies for measuring natural restoration in mobile

or ambulatory subjects. When this study was conceived, the author was unaware of any studies that used ambulatory subjects, which more accurately reflect the dynamic manner in which people interact with their environment. This thesis will review existing methodologies for assessing natural restoration and propose a possible method for ambulatory measurement in urban green spaces.

1.1.1 Significance

Currently, approximately half of the world's population lives in urban centres, with the percentage only expected to increase (United Nations, 2006). By 2030, more than 80% of the human population is expected to live in cities. Given that cities are growing at a rapid rate, problems associated with urban stress are predicted to grow. Since urban environments negatively affect human health, it is necessary to understand how to mitigate stressors inherent to urban living.

1.2 BACKGROUND

1.2.1 Mental Stress and Stress Physiology

Mental stress is a complex concept that is not well understood, but has known impacts on human health. Stress has been linked to numerous health conditions, such as depression and psychological distress (Evans, 2003; Jovanov *et al.*, 2003). Reducing exposure to stressors may help mitigate negative effects on health.

Environmental stressors can affect physiology via the sympathetic nervous system (SNS), which regulates involuntary visceral functions such as breathing and heart rate (Evans, 2003). When activated, this ranch of the autonomic nervous system (ANS) produces a stress response marked by changes from resting physiology (Choi & Gutierrez Osuna, 2009).

Emersion in a calming or natural environment can cause the body to relax from a stressed state (Park *et al.*, 2011). This relaxation of mental stress is associated with autonomic regulation by the parasympathetic nervous system (PSNS; Choi & Gutierrez Osuna, 2009).

1.2.2 Heart Rate Variability

Heart rate variability (HRV) is the variation in the interval between heartbeats (Malik, 1998). This measure has been used to differentiate between sympathetic and parasympathetic activation of the nervous system. SNS activity is associated with physiological responses to stressors, while PSNS activity is associated with the inhibition of the SNS as the body is relaxing from stress (Choi & Gutierrez Osuna, 2009).

Increased sympathetic activity results in increased HRV, while increased parasympathetic activity results in decreased variability (Choi & Gutierrez Osuna, 2009). The high frequency component of HRV is known to be reduced in conditions of increased stress. The activity in the high frequency component is often used as a

marker of parasympathetic activity(Choi & Gutierrez Osuna, 2009; Malik & Camm, 1993).

Given the distinguishing characteristics of sympathetic and parasympathetic influences, inferences can be drawn from HRV about changes in mental state (Dikecligil & Mujica-Parodi, 2010). These characteristics allow for HRV to act as a proxy for mental stress.

1.2.3 Natural Restoration

Natural restoration is the process of stress recovery due to exposure to a natural environment (Ulrich *et al.*, 1991). When exposed to a natural environment, mental stress tends to decrease and cognitive functioning improves (Hartig *et al.*, 2003). This natural exposure, or "forest bathing", can have positive effects on health through the process of relaxation (Matsunaga *et al.*, 2011; Park *et al.*, 2010). Urban green spaces may also have restorative properties, but currently the literature lacks evidence to support this.

1.2.4 Knowledge Gaps

There have been only a few studies that have used quantitative data such as HRV to detect mental stress from environmental exposure. One study attempted to measure natural restoration by using an EKG to detect the physiological response in geriatric women exposed to a hospital rooftop garden (Matsunaga *et al.*, 2011).

When this project was conceived, we were only aware of one study that had measured environmental stressors in subjects who were actively navigating through their environment. Hickman *et al.* (2011) had mapped police stress by neighbourhood using heart rate monitors on a patrol officer, but we were not aware of anyone who had yet applied it to the investigation of natural restoration.

Few studies have looked at the potential for urban green spaces to provide restorative effects. This is a notable omission given the global trend of urbanization; urban green spaces are the form of natural environment most likely to be utilized in city designs.

1.3 Topic of Research

By reviewing existing methodologies for measuring natural restoration, this study investigated potential methods for ambulatory measurement of natural restoration in urban green spaces. This study reviewed, analyzed and compared existing literature on methods of measuring natural restoration. Based on the results of the review, the study proposed a methodology that has the best potential to improve ambulatory measurement of natural restoration in urban green spaces.

1.3.1 Questions

The study investigates the following questions:

1. What elements of existing methodologies are transferable to the creation of an ambulatory method?
2. What are the challenges faced in designing and conducting ambulatory studies?
3. What existing methodology holds the most potential to be adapted to ambulatory monitoring of natural restoration in urban green spaces?

1.3.2 Hypotheses

It is predicted that (1.) much of the fundamentals of the methods will be transferable from existing methodologies to the development of a new ambulatory method. However, it is anticipated that (2.) ambulatory measurements will provide additional complications to existing methodologies. It is expected that (3.) a physiological analysis of heart rate variability will provide the most potential as a methodology for ambulatory monitoring of natural restoration.

1.3.3 Scope

This study reviewed10 papers which contain detailed descriptions of methodologies used for analyzing natural restoration. The study was limited to 10 papers because of time constraints, database limitations[1] and difficulty in finding papers with

[1] During the literature search for papers, Dalhousie University let its subscription to the Scopus database lapse. The Scopus database had been the major source for finding nature restoration papers for this study.

substantive differentiation in methodology for review. Due to the limited number of papers reviewed, and the fact the papers are selected by significance (based on number of citations), the sample is unlikely to represent an exhaustive overview of all methodologies. Rather it will cover only the most significant or popular methods currently used. As such, some methods which may hold promise for ambulatory measurements in urban green spaces may have been missed.

1.3.4 Contribution

This study provides a methodology for how to investigate if exposure to green spaces can provide stress relief in an urban environment. If the methodology works, it may help support the hypothesis of a link between green spaces and stress relief (van den Berg *et al.*, 2007; Hartig, 2008; Swanswick *et al.*, 2003). This is significant because in addition to aesthetic values, green spaces may then have a critical role in the functioning of healthy cities. They could provide oases for restoration of mental stress. Effective use of urban green spaces in urban planning could lead to healthier cities.

CHAPTER 2: LITERATURE REVIEW

2.1 LITERATURE REVIEW METHOD

The literature review was conducted using a formal search method through the Dalhousie University library catalogues and databases. The formal search method was adopted to ensure that the review was replicable and comprehensive. The method consisted of identifying critical databases[2] and appropriate keywords for each database. The keywords were then systematically entered in logical combinations to each database. The resulting abstracts were then compared against suitability criteria, suitable articles were selected. Selected articles contributed to a snowball sampling approach, where they were parsed for relevant articles by reference links.

Search parameters

This review spans several disciplines, it was therefore important to use a variety of databases to reflect the interdisciplinary nature of the inquiry. The databases were selected as follows: PubMed for article on stress physiology; PsycINFO for articles on the links between environment and stress; Avery Index of Architectural Periodicals for literature on urban stress and urban green spaces; Environmental

[2] Thank you to Michelle Paon, a Dalhousie University librarian specializing in environmental topics, for her help with identifying suitable databases for this review.

Science and Pollution Management for articles on environmental stress and natural restoration; and Web of Science and Scopus as general databases for all topics.

The variety and specific focus of the databases required search words to be tailored for each search. Search terms for PubMed were “mental stress”, “physiolog*”, “heart rate variability”, “galvanic skin response,” and “nervous stimulation” or “nervous system activation”. For PsychINFO the terms used were “mental stress”, “environment*”, “physiolog*”, “environmental stress”, “urban stress”, “natural restoration” and “environmental exposure”. The Avery Index of Architectural Periodicals used “urban stress” and “urban green space” or “open space”. Environmental Science and Pollution Management used the terms “urban green space” or “open space”, “natural restoration”, “environmental stress”, “urban stress” and mental stress. The meta-databases used logical combinations of all of the above terms.

Relevant articles were selected from results based on the content of the abstract. The description of the article as presented in the abstract was compared against a list of criteria that were used to determine relevance. If one or more of the criteria were present, then the article was considered for selection. The criteria for relevant content were: an urban focus, the use of GPS or GIS mapping, the application of active HRV monitoring, or the terms “natural restoration”, “heart rate variability”, “mental stress”, “urban green spaces”, “mental health” or “urban stress”. Presence of one criterion alone was not grounds for automatic inclusion, and articles with more than one criterion were more likely to be selected.

Limits

Where the search terms returned large numbers of results, the parameters were filtered. Only English-language results were considered. Only peer-reviewed articles were accepted. Since the topic is a relatively novel field of study, results were limited to those articles published since the 1950's.

The databases searched were limited to those available through Dalhousie University's library network. The databases searched were also restricted by time constraints to those most likely to have relevant articles to the topic.

2.2 The Influence of Environment on Health

In the last three decades, researchers have begun to scientifically investigate the effects of the natural environment on human health (Velarde *et al.*, 2007). A sizeable body of literature has been the result, which has established links between environment types and health outcomes. In a recent comprehensive review, Cooper & Boyko (2010) have concluded that exposure to nature has a significant effect on mental wellbeing. The effects can be classified into three different types: accelerated recovery from illness, long-term improvements in health outcomes, and short-term stress recovery (Velarde *et al.*, 2007). This review will focus on the later, and specifically how natural environment exposure can mitigate the stress of the urban environment.

2.2.1 Urban Stress

The urban, or built, environment is a diverse and complex landscape that still requires much investigation, but a growing volume of literature is pointing towards the built environment having an effect on health (Lin & Lai, 1995; Srinivasalu *et al.*, 2003). Literature has concluded that exposure to urban environments is detrimental to mental health and stress (Evans, 2003; Galea *et al.*, 2005; Srinivasalu *et al.*, 2003; Velarde *et al.*, 2007). Research has begun to propose that health issues, such as depression, are the result of factors associated with the stress inherent in urban environments (Galea *et al.*, 2005; Lin & Lai, 1995).

In a review, Evans (2003) discussed direct and indirect factors of the urban environment that affect mental health. His review found that mental restoration was more effective in natural environments compared to urban settings. However, he stopped short of concluding that urban surroundings hamper cognitive functioning. Given the volume of research suggesting that urban environments are stressful and not optimal for long-term health, some researchers are now beginning to call on urban planning to incorporate natural elements into the built environment (Cooper, 2010).

2.2.2 Natural Restoration

The movement for incorporating natural elements into urban settings grows out of research suggesting that the natural environment has an inherent ability to provide

restoration to mental functioning (Hartig *et al.*, 1991). The concepts of the restorative effects of natural wilderness have evolved from Ulrich's (1984, 1999) "Stress Recovery Theory" and Kaplan & Kaplan's (1989) "Attention Restoration Theory" (Velarde *et al.*, 2007). These theories have formed the basis of natural restoration. Natural restoration proposes that emersion in wilderness settings enhances the recovery of the mind (Hartig, 1996; Hartig *et al.*, 1991; van den Berg *et al.*, 2007). Since the early work of Ulrich (1984, 1999) and Kaplan & Kaplan (1989), there have been many papers linking exposure to natural environments with stress reduction and positive health outcomes (Alvarsson *et al.*, 2010; Berto, 2005; de Vries *et al.*, 2003; Evans, 2003; Hartig *et al.*, 1991; Hartig *et al.*, 2003; Park *et al.*, 2010; Velarde *et al.*, 2007). However, one of the most exciting prospects for the application of natural restoration is that the "wilderness" environment may not need to be very isolated or solitary to still achieve a measure of restoration (Cole & Hall, 2010; Evans, 2003). This could allow for the principles of natural restoration to be integrated into urban design. However, this area has not yet been well explored and needs further investigation.

2.2.3 Green Space Restoration

Health

Green spaces in urban areas are beginning to receive attention for their ability to positively impact health. In an overview of research conducted through the Landscape Department of Sheffield University, Swanwick *et al.* (2003) found that

research confirms that green spaces play a role in positive health outcomes for urban areas. Their conclusion linking green space and health has since been supported by numerous studies by other researchers (de Vries *et al.*, 2003; Maas *et al.*, 2006; Hartig, 2008; Mitchell & Popham, 2008). In a large study of more than 250,000 people, Maas *et al.* (2006) investigated the relationship between living environment and health. They concluded that those people who lived within three kilometres of green spaces had significantly better general health than those who did not. However, these studies did not provide any detail to the types of green spaces (urban or wilderness; tended or natural; etc.) in the studies and whether type or quality of green space had any effect on health. More detailed descriptions of green space in studies are needed to investigate any differentiation of effects due to the type of green space.

Restoration

In a commentary on a study by Mitchell & Popham (2008) into health inequalities and green space, Hartig (2008) postulates that the health benefits might be a function of stress restoration. He proposes that green spaces may be exhibiting the natural restorative effects of wilderness environments, which could be positively impacting health through this vector. This argument is supported by the work of Grahn & Stigsdotter (2010) who found that urban green spaces could provide the sensory elements necessary for stress restoration. However, they concede that this area needs more study before positively concluding that urban green spaces can provide stress restoration.

Limits to knowledge

One of the major limitations to current knowledge is the detail present in the environmental descriptions included with studies (Velarde *et al.*, 2007). Many articles only define environmental characteristics at very coarse resolution, simply designating sites as urban or natural. There needs to be more detailed investigation into environmental differentiation of stress recovery with a finer resolution to landscape sub-types, especially for urban green spaces. In the case of urban green spaces there is little literature that differentiates between gardens, parks, urban forests, and other green space types. Having descriptions to distinguish between green space types could reveal common elements that enhance stress recovery.

Complicating factors

The investigation into the links between green space and health is further complicated by the effect of physical activity. Physical activity has a proven association with positive health outcomes; (REF). Since green spaces are often used for active recreation, the effects of the restorative functions of green spaces on health are hard to isolate (Hartig, 2008; Mitchell & Popham, 2008).

2.3 MENTAL STRESS

Investigations into environmental influences on health are aided by the understanding of the processes of mental stress. When people are subject to or released from psychological stressors there are predictable physiological reactions

(Lin *et al.*, 2011; Viamontes & Nemeroff, 2009). These reactions have been reliably used as a proxy to measure mental stress (Choi *et al.*, 2012; Lee *et al.*, 2005; Lin *et al.*, 2011).

2.3.1 Stress Physiology

Environmental emersion can have effects on the physiology of the body (Laumann *et al.*, 2003). Present or absence of psychological stressors in the environment activates either the sympathetic or parasympathetic systems of the autonomic nervous system (Viamontes & Nemeroff, 2009). Together these two systems regulate physiological functions of the body. The sympathetic nervous system (SNS) creates a stress response when stimulated, while the parasympathetic nervous system (PSNS) governs the body in relaxation and recovery.

Measuring Nervous System Activation

As emotional state and stress change the level of activation of the nervous system, several physiological processes also change (Lee *et al.*, 2005). These changes can be used as a proxy to differentiate between SNS and PSNS activation and measure mental stress (Choi *et al.*, 2012). Among other indicators such as galvanic skin response and respiratory rate, several studies have used heart rate variability (HRV) extensively as an indicator for determining the level of nervous system activation (Choi & Gutierrez Osuna, 2009; Choi *et al.*, 2012; Lee *et al.*, 2005; Lin *et al.*, 2011).

This preference is due in part because heart rate variability is easily measured with unobtrusive and non-invasive equipment (Choi & Gutierrez Osuna, 2009).

Heart Rate Variability

Heart rate variability (HRV) can be used as a measure of mental load, which allows for an indirect assessment of stress or relaxation (Taelman *et al.*, 2011). It is a measure of the beat-to-beat interval of the heart over time, and is more sensitive to identifying inputs from the nervous system that mean heart rate (Acharya *et al.*, 2006; Choi & Gutierrez Osuna, 2009). Comprehensive reviews of relevant studies by Acharya *et al.* (2006) and Stein *et al.* (1999) have concluded HRV is a reliable representation of nervous stimulation and mental stress.

Despite heart rate variability's touted reliability, using HRV measures correctly can be difficult due to the complexity of the analysis process. This complexity and the potential for error led to the formation of a task force to investigate and develop standard methods for measuring and assessing data from HRV (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). One of the findings of the Task Force was the association of specific frequencies with activity in either the SNS or PSNS. These frequencies are the very low frequency (VLF; 0.00 Hz), low frequency (LF; 0.10Hz) and high frequency (HF; 0.27Hz; (Malliani *et al.*, 1991; Montano *et al.*, 2009). The low frequency component is regulated by both the SNS and PSNS, while the high

frequency component is solely regulated by the PSNS (Choi & Gutierrez Osuna, 2009).

The input of the SNS on the very low frequency component has been a source of discussion. In a carefully designed study, de Paur (2012) compared HRV in tetraplegic participants against able-bodied participants under stressful conditions. Due to their injuries, the tetraplegic participants should not have a VLF component if it is controlled by the SNS. The results of his study showed that tetraplegics did have a VLF component. This argues against SNS influence on the VLF component. Instead, the VLF is regulated by the PSNS.

Complications and Limitations

Using the distinguishing frequencies, HRV can be used to differentiate between the levels of nervous system activation. However, some studies have proposed complications and limitations of HRV measures. In a study involving HRV measures during exercise, Perini & Veicsteinas (2003) found HRV varied greatly between body positions. They even found that the LF component exhibited unexpected trends in the supine position. Sample populations can also influence and complicate HRV findings. One study suggests that although HRV is applicable across age and gender, subpopulations have different responses to and recovery patterns from stressors (Kudielka *et al.*, 2004). In a separate study, researchers looked at the effect of chronotype on HRV. Although their results failed to reach the level of significance, they showed some relationship between testing time and chronotype on HRV

(Roeser *et al.*, 2012). HRV is a well-explored topic with few knowledge gaps remaining to be investigated. With adequate consideration of its limitations, HRV well-documented characteristics make it a reliable tool for differentiating between sympathetic and parasympathetic nervous regulation.

CHAPTER 3: METHODOLOGY

3.1 OVERVIEW

This study performed a review of methodologies in papers on nature restoration to gather a number of journal articles that would inform the design of an ambulatory methodology for urban green spaces. In the review, the study focused on extracting data from the papers' methodology within several categories, such as study design and nature types assessed. The study evaluated these papers within the categories based on preset criteria and performed a comparison of the strengths and weaknesses of methodologies between papers. The evaluation and comparison of methods were used to inform the design of a new ambulatory method for assessing natural restoration in an urban green space.

3.1.1 Justification of methodology

The search methodology used by this study is similar to that employed by other literature reviews in the scientific field (Stein & Klieger, 1999; Bowler *et al.*, 2010). The rationale for employing the review methodology is that since many studies have already developed methods for measuring natural restoration, these studies would contribute to the development of a new method for ambulatory measurement.

The second part of the analysis is the evaluation of selected papers. The evaluation is necessary because the critical analysis will identify which methodologies hold the

most potential for an ambulatory study method. The analysis is similar in substance to many other literature reviews conducted in the scientific realm (Evans, 2003; Bowler *et al.*, 2010).

3.3 RESEARCH DESIGN

3.3.1 Search Method

The literature review used a formal method to provide a comprehensive search with repeatable results. The search was performed through Dalhousie University`s library catalogues and databases. The target of the research was to find significant articles in natural restoration literature; so, after searching the databases with keywords, the articles that were highly cited were identified as candidates (more than 25 citations). The rationale for discriminating for highly cited articles was that these articles were more likely to provide reliable and proven methods than those articles which were lightly cited. Articles that contained relevant methods and were highly cited were selected. This process was continued until 10 papers[3] were selected, with a preference given for papers containing methods novel to the review, so as to represent a variety of methods for measuring natural restoration.

[3] See the section on limits on p.27

Search Parameters

The review was conducted using the PsycINFO database as it was the most useful database indentified during the literature review. The keywords were systematically entered into the database to obtain results. The keywords used in the search were combinations of "natur*", restoration, "environment*", "natural restoration", "urban green space" and "environmental exposure" together with the terms "mental stress", "physiolog*", "environmental stress" and "urban stress". The papers were selected on the basis of containing the keywords, having relevant methods, and employing methods that were not already duplicated by a previously selected article. Snowball sampling was also employed.

Limits

Due to constraints on the project, the study was limited to reviewing only 10 papers. Time, database access limitations and small population of relevant papers all played a role in the small sample size. Due to the small number of papers reviewed, the study did not provide an exhaustive review of all methodologies for measuring natural restoration. While significant methodologies for the field were reviewed, it is likely that other methodologies were missed in the review. Also, the review only selected to be significant in the field, as judged based on high numbers of citations. This form of selection biases against new papers in the field and new methodologies may have been overlooked.

3.3.2 Data Extraction

From the selected papers, data were extracted which allowed the papers to be evaluated. The three main components of evaluation were: the validity of the study design, the applicability of the study methodology to developing an ambulatory method for urban green spaces, and the ability of the study design to achieve meaningful results.

To achieve this evaluation within the three components, the data was summarized according to the following attributes: sample population (sample size, percentage male, and age); study design; use of an ambulatory method; types of exposure environments (e.g. natural, urban); experimental variables measured (e.g. HRV, blood pressure, questionnaires); results; and strength of evidence (an inference made from study design, methods, validity, and results).

The data was extracted by first reading the entirety of the study, and then the methods and results were summarized according to the various attributes.

In evaluating the strength of evidence, the papers were placed into one of four categories: strong, moderate, weak or insufficient. Studies with strong evidence were characterized by good study design and significant results that were able to give evidence of natural restoration. Studies with moderate evidence were those with fair study design and significant results that showed some evidence of natural restoration. Weak studies were those with poor study design, some equivocal or

contradictory results or little evidence of effects of natural restoration. Studies deemed to have insufficient evidence lacked significant results. Measuring the papers in this category required judgment on the part of the researcher to place the paper in the category which best describes the evidence presented.

Once the data was extracted and the evidence was evaulated, all of the summaries were entered into a table and sorted by reference and country of study origin.

3.4.1 Analysis

The selected papers were subjected to a qualitative analysis based on the data extracted to determine the method(s) with the most potential to measure nature restoration in an ambulatory study of urban green space. Studies that achieved well in all three components (validity, applicability, and ability to achieve results) were investigated as potential methods for an ambulatory study.

The validity of the study was the first component of the evaluation. Validity refers to the ability of a study to give meaningful results based on its design and execution (REF). In this study, papers were evaluated on both internal and external validity. The internal validity was critiqued based on the experimental design adhering to accepted scientific methods for experimental trials (observational or treatment; blind, randomized, etc.), with repeatable and controlled experiments being preferred. The ability of the study design to assess the role of nature restoration in the sample group was key to the evaluation.

External validity refers to the ability of the study results to be generalized to other populations or settings (REF). The suitability of the study population and sample representativeness plays a factor in the external validity. For the purposes of this study, sample groups judged as good were those that accurately reflected diversity of the general Canadian population. Sample populations which were composed of special groups (e.g. cardiac patients, geriatrics) were not discounted, but were not preferred. Ecological validity also had a role in the evaluation. Ecological validity refers to the ability of the study to represent real-word conditions (REF). Where the studies are trying to replicate and measure the affects of nature, this is an important factor. The studies judged to have high experimental validity had high internal and external validity.

The applicability of the study methodology to ambulatory methods in urban green spaces was the next category of evaluation. Studies with methods and study areas which closely mimiced the desired scenario (i.e. ambulatory methods in an urban green space measured against a city environment) were shown preference. Furthermore, studies which used techniques or equipment that were easily adapted to mobile use were also shown preference in the analysis. Since the ability to adapt a method to ambulatory use was a key requirement of this study, unsuitable techniques were eliminated as a potential method.

Finally, studies with methodologies that demonstrated the ability to achieve statistically significant results were also preferred. However, due to the many complicating factors that can plague experiments, studies with insignificant results

were not discounted, as the type of environmental exposure may have had a significant impact: For example, the difference in restoration in an urban park after exposure to suburban neighbourhood would be less compared to that of a natural old-growth forest after exposure to a downtown street. For these reasons, while significance of results was considered, it was not a main criterion.

To identify the best methods, the studies were ranked against one another. Each study was given a rank from 1-10 in the evaluation categories: validity, applicability and ability to achieve results. Each rank was conducted blindly without the author names attached,. The ranking were based on the criteria described above for each category of evaluation. For validity, the ranking was based on data from the design, sample and environment (considering only real-world or simulated settings) categories. For applicability, the ranking was based on data in the ambulatory environment (considering details of settings) and methods categories. For ability to achieve results, the ranking was based solely on the results and evidence categories. The rankings in the categories were summed to create a total score for each paper (the best possible score was 3, and the worst was 30). The rankings were then complied with the author names to provide a ranking of potential for studies to provide a possible ambulatory method.

3.4.2 Limitations and Assumptions

One of the limitations of the analysis was that many articles did not publish detailed descriptions of their methodologies. The lack of detail limited the accuracy and

insight of the analysis of methods. In some cases, there was not enough detail in the methods description to provide a summary under each attribute. Other details which may affect the applicability may have also been excluded, but it is impossible to know.

Another limitation is the limited number of studies reviewed. It may not be possible to provide the best potential study. With such a limited review, it is only possible to propose a potential study given what methodologies came to light during the brief review. Other more suitable methodologies may have been overlooked.

CHAPTER 4: RESULTS

4.1 OVERVIEW

The search resulted in 10 articles being selected. All ten articles focused on measuring the effects of restoration through exposure to natural environmental stimuli. The articles encompassed a variety of approaches to investigating restoration effects, including a mixture of qualitative and quantitative measures, environmental exposures, and study designs. The papers also had an international distribution: five studies were from the United States of America, three from Europe, and two from Japan.

The selected papers were: Cole & Hall (2010); Hartig, *et al.* (1991); Hartig, *et al*. (1996); Hartig, *et al*. (2003); Laumann *et al*. (2003); Martens *et al*. (2011); Matsunaga *et al*. (2011); Park, *et al*. (2009); Parsons *et al*. (1998); and Ulrich *et al*. (1991).

4.2 DATA EXTRACTION

All ten papers were summarized into a data table (Appendix 1) consisting of seven categories: sample population, study design, use of an ambulatory method, types of

exposure environments, experimental variables measured, results, and strength of evidence.

4.2.1 Sample Populations

In the summary table, the sample populations were recorded according to three characteristics: sample size, percentage male, and median or mean age (as reported in the study). Most of the study populations had large sample populations (n>100). Only three studies had less than forty subjects (Hartig *et al.*, 1991; Laumann *et al.*, 2003; and Matsunaga *et al.*, 2011).

Most studies tended to have an even gender distribution. Only three studies differed substantially from normal gender distributions: Park *et al.* (2009) had an all male sample; and Laumann *et al.* (2003) and Matsunaga *et al.* (2011) had all female samples.

The ages of the sample reflected the populations from which the study participants were drawn. Many of the studies relied heavily on recruiting college or university students (Hartig *et al.,* 1996; Hartig *et al.,* 2003; Laumann *et al.* 2003; Park *et al.*, 2009; Parsons *et al.,* 1998; Ulrich *et al.,* 1991). Despite relying on recruiting from a university, Martens *et al.* (2011) had a sample population with a relative older median age (M=37.6). Cole & Hall (2010) also had a higher median age (med=40), due in part to the fact that they did not specifically target university students but rather active wilderness hikers. The eldest population was in a study by Matsunaga

et al. (2011), which targeted a geriatric female population in hospitals. (M=81.7) Ulrich *et al.* (1991) did not give a mean or median age or range, stating only that they selected a sample from undergraduate students.

4.2.2 Study Methods

Study Designs

All of the selected papers were evaluated for their study design. Of the papers, all but Cole & Hall (2010) used a controlled experiment. The majority used unblinded treatments in randomized trials. The only exception, Cole & Hall (2010) is a large observational study.

Testing Environment

The selected papers included studies with both clinical and real-world testing environments. Studies using a laboratory environment simulated environmental exposures through pictures or videos. There were four studies which used this method: Hartig *et al.,* 1996; Laumann *et al.* 2003; Parsons *et al.,* 1998; and Ulrich *et al.,* 1991.

The other studies used real-world testing environments. Some of the studies lacked any detail in their environmental descriptions, other than the distinction of "natural" or "urban" (Hartig *et al.* 1991; Park *et al.*, 2009). The environments used for testing varied between studies. Natural environments ranged from remote wilderness (Cole

& Hall, 2010) to roof-top gardens (Matsunaga *et al.,* 2011); urban environments ranged from urban forests (Martens *et al.*, 2011) to developed cities (Hartig *et al.*, 2003; Matsunaga *et al.*, 2011).

Most studies provided a comparison between natural wilderness and urban city environments, but there were some exceptions. Martens *et al.* (2011) compared two forest types: one natural and one tended-urban forest. Matsunaga *et al.* (2011) compared two urban settings: roof-top garden as a natural green space against a car park as an urban stressor. In their observational study, Cole & Hall (2010) only looked at a wilderness environment.

Ambulatory

All of the papers were classified by the amount of freedom of mobility under which the subjects were tested. The methods were classified as fully, semi-, pseudo-, or non- ambulatory in the studies.

To achieve a designation of fully ambulatory, the study had to achieve continuous monitoring while the subject was walking. Only one study was able to meet this standard. In that study, Park *et al.* (2009) used multiple techniques that were specifically adapted to ambulatory subjects.

Semi-ambulatory were those studies that had measurements at discrete intervals while mobile, or requiring brief pauses for measurements in otherwise continuous and free mobility. Only one study met these criteria: Hartig *et al.* (1991) had

participants walk a course with periodic stops for blood pressure measurements, and skin conductance as a secondary measure continuously throughout.

Pseudo-ambulatory studies were those that did not monitor during the period of mobility, but allowed subjects to be ambulatory in the period between pre- and post-tests. Three studies were in this category: Hartig *et al.* (2003), Cole & Hall (2010), and Martens *et al.* (2011).

For a study to be designated non-ambulatory, the design must not allow for the subject to be freely mobile during the course of the experiment. The remaining five studies met this criterion: Hartig, *et al*. (1996); Laumann *et al*. (2003); Matsunaga *et al*. (2011); Parsons *et al*. (1998); and Ulrich *et al*. (1991).

Experimental variables

The selected studies utilized a variety of experimental measures, with five of the ten studies incorporating more than one measure into their methodology. The most common methodology employed in the papers was a questionnaire, which was used in five studies (Figure 1; Appendix 1). The second most common variable measured was HRV (sometimes as a component of ECG as in Parsons *et al.*, 1998 and Laumann *et al.* 2003). Other common measures were blood pressure (n=3) and skin conductance (n=3). The least common measure was pulse transit time, used only in the study by Ulrich *et al.* (1991).

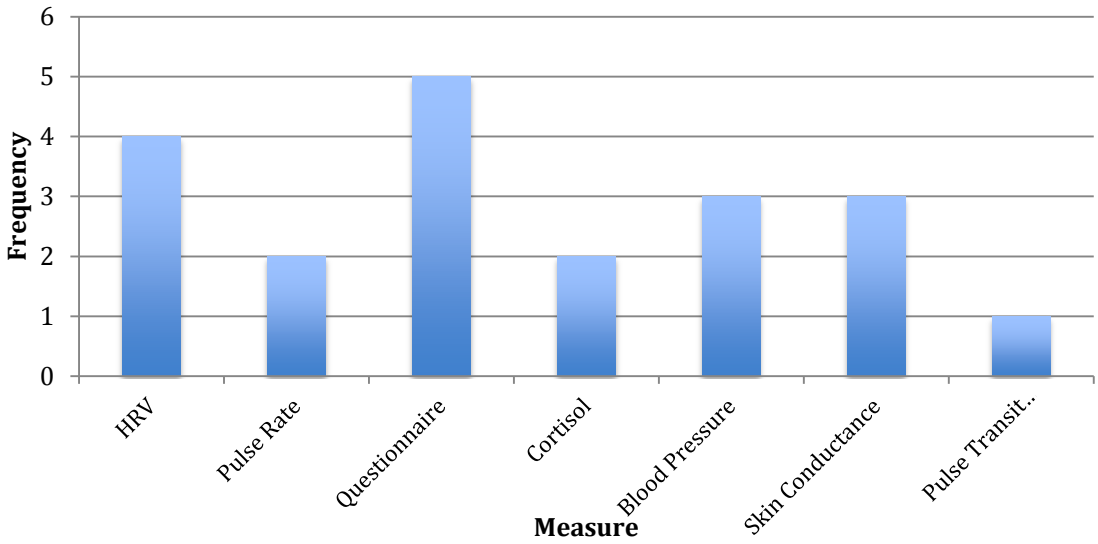

Figure 1: Experimental measures by frequency for natural restoration studies.

The questionnaires were not only the most common method, but also came in several different versions. The most prevalent type of questionnaire was the Zuckerman Inventory of Personal Reactions (ZIPERS) that was used in two studies as the primary tool for investigation (Hartig *et al.* 1996). Other standardized types included the Oxford Happiness Scale (OHS) and the Profile of Mood States (POMS). Also used were a variation of a scale by Abele-Brehm & Brehm (1986) in the Martens *et al.* (2011) study and a unique scale designed by Cole & Hall (2010) specifically for their study.

4.2.3 Results and Analysis of Evidence

Results

Most of the selected papers had significant results to support a relationship between restoration and exposure to natural environments. However, Hartig *et al.* (1991) had equivocal results in quantitative physiological measures (i.e., blood pressure,

pulse, and skin conductance), but significant results in the qualitative measures (ZIPERS and OHS questionnaires). Only Hartig *et al.* (2003) did not have significant results.

Strength of evidence

Given the significance of the results and the study design, each study was evaluated and given a rating for the strength of the evidence it presented. The ratings resulted in two papers being rated as having strong evidence, three as having moderate evidence, four as weak evidence, and one was rated as having insufficient evidence.

Papers awarded a rating of having strong evidence demonstrated good study design and sufficient evidence to support the conclusions of the papers. Only two studies met these criteria: Park *et al.* (2009), which used multiple measures to test for natural restoration over several trials groups; and Matsunaga *et al.* (2011), which used a sensitive method to investigate natural restoration in a carefully controlled, small-scale trial in real-world settings.

Papers awarded a rating of having moderate evidence demonstrated fair study design, reliable measures, and sufficient evidence to support results. These studies took place in clinical settings with simulated environmental exposures, which limited the ecological validity of their results and thus lowered the strength of their evidence supporting natural restoration. The three studies awarded this rating were Laumann *et al.* (2003), Parsons *et al.* (1998), and Ulrich *et al.* (1991).

A rating of weak evidence was given to papers demonstrating poor study design, a few contradictory or equivocal results, or unreliable or inferior measures of investigation. Four studies were place in this category: Martens *et al.* (2011) and Hartig *et al.* (1996), both of which relied mostly on questionnaires for results; Hartig *et al.* (1991), which had insignificant results on physiological measures that contradicted the results of their questionnaires; and Cole & Hall (2010), who were unable to draw a inference about any relationship between nature exposure and restoration because of the study design, and furthermore relied solely on a questionnaire unique to their experiment.

In a special case, a rating of insufficient was given to one study whose results failed to achieve significant levels. Hartig *et al.* (2003) was rated as insufficient. In this papers the authors acknowledged that a significant relationship likely existed in their results, but because of the large gaps in their sampling intervals and lack of sensitivity in measurements, there results were insufficient to show this relationship.

4.3 RANKINGS

4.3.1 Overview

Using the data summaries in the table (Appendix 1) as well as the analysis of strength of the evidence presented, the papers were ranked in three categories (Table 1): Validity, Applicability, and Ability to provide significant results. These

rankings were then summed and a total score was given for each paper which reflected its ranking across all three categories: low total scores indicate papers which generally had more potential as an ambulatory method, while higher scores reflect papers which were less suited to ambulatory use.

Table 1: **Natural Restoration Papers by Rankings in Validity, Applicability, Ability of Results and Overall Score (Total).**

Paper	Validity	Applicability	Ability of Results	Total (3-30)
Cole & Hall, 2010	6	5	9	20
Hartig, et al. 1991	3	2	7	12
Hartig, et al. 1996	10	8	6	24
Hartig, et al. 2003	2	3	10	15
Laumann et al. 2003	7	10	5	22
Martens et al. 2011	1	4	8	13
Matsunaga et al. 2011	5	6	2	13
Park, et al. 2009	4	1	1	6
Parsons et al. 1998	8	9	3	20
Ulrich et al. 1991	9	7	4	20

4.3.2 Rankings in Validity

Ranking highest in the validity section was Martens *et al*. (2011; Table 1), which had a good study design, a good sample population and good external validity (due in part to a real-world testing environment). Other high ranking studies were Hartig *et al.* (2003) and Hartig *et al.* (1991). Ranking lowest was Hartig *et al.* (1996), which sacrificed the ability to compare natural against urban environments in its methodology (Hartig *et al.*).

4.3.3 Rankings in Applicability

The highest ranking paper in the applicability category was Park *et al.* (2009; Table 1). This paper had a fully ambulatory method and used varied environmental types (forest vs. city) which were similar to the desired types (green space vs. city). Since the paper already used fully ambulatory subjects, the methods did not need adapting.

Other high ranking papers were Hartig *et al.* (1991) and Hartig *et al.* (2003). Both papers used semi- or pseudo-ambulatory subjects. Hartig *et al.* (1991) had more experimental measures – many of which are easily adapted to ambulatory use – which gave it a slight edge over Hartig *et al.* (2003), which had only one measure which would not as easily adapted for an ambulatory study.

The lowest ranking papers in the category of applicability were Laumann *et al.* (2003) and Parsons *et al.* (1998). Both used simulated environments and non-ambulatory methods.

4.3.4 Rankings in Ability of Results

The highest ranking papers in the category of ability to provide significant results were Park *et al.* (2009) and Matsunaga *et al.* (2011; Table 1). They had significant results and were rated as having strong evidence. Another highly ranked paper was Parsons *et al.* (1998), which had significant results over multiple measures and a rating of moderate evidence.

The lowest ranking paper was Hartig *et al.* (2003), which had insignificant results in its only measure and was rated as having insufficient evidence.

4.3.5 Overall Scores

The highest overall score was given to Park *et al.* (2009; Table 1). This paper scored highly across all three categories: first in applicability and ability of results and fourth in validity for a total score of six.

Four other papers scored highly: Hartig *et al.* (1991) scored twelve; Martens *et al.* (2011) and Matsunaga *et al.* (2011) both scored thirteen; and Hartig *et al.* (2003) scored fifteen. Hartig *et al.* (1991), Martens *et al.* (2011), and Hartig *et al.* (2003) all had low scores in the ability of results category (scoring seven, eight, and ten, respectively). Matsunaga, however, had mid-range or high scores in all categories (including a ranking of second in ability of results).

The lowest scoring paper was Hartig *et al.* (1996), which ranked very poorly in two of the three categories (ten and eight in validity and applicability, respectively). Also scoring low was Laumann *et al.* (2003), which was ranked lowest in the applicability category.

CHAPTER 5: DISCUSSION

5.1 OVERVIEW

The literature search resulted in the selection of 10 papers that encompassed a variety of study designs and methodologies. These studies were evaluated and ranked as part of the analysis. The purpose of the analysis was to identify methods that held the most potential for being adapted to an ambulatory study.

The study that ranked highest overall was Park *et al.* (2009). This paper was identified by the analysis as having the most favourable methodology for informing the design of an ambulatory study. In the following sections, the discussion will focus on why this may be the case, and also the challenges associated with using the methodologies employed by Park *et al.* (2009).

Another important paper was Hartig *et al.* (1991), which ranked 2nd overall. It employed different approaches than Park *et al.* (2009); but in some respects, the complementary nature of their approaches could be used to inform the design of a stronger method.

5.1.1 Research Questions

In the discussion, this study will attempt to address the research questions proposed at the beginning of the paper.

1. What elements of existing methodologies are transferable to the creation of an ambulatory method?
2. What are the challenges faced in designing and conducting ambulatory studies?
3. What existing methodology holds the most potential to be adapted to ambulatory monitoring of natural restoration in urban green spaces?

The papers identified during the literature search will serve as the basis of the answers presented in the following sections.

5.2 Discussion of Results

5.2.1 Significant Papers

Top two ranked papers in the results were also the most ambulatory studies identified in the literature search. Where the system of evaluation set out to identify the best papers on which to base an ambulatory methodology, the fact that the ranking system used in the review identified the most ambulatory studies as having the most potential, was a positive sign about the validity of the evaluation method.

The first paper, Park *et al.* (2009) was a fully ambulatory study. The subjects were fitted with monitoring equipment and then allowed to freely roam and interact with the environment around them while physiological data was being continuously recorded. Park *et al.* used HRV, pulse rate, salivary cortisol and the Profile of Mood States (POMS) questionnaire. In the data gathered from the experiment, Park *et al.*

were able to show significant differences between the environments in all variables measured.

When the methods paper was initially designed, the author was unaware of any fully ambulatory studies in the literature. However, the presence of a fully ambulatory study gives a great template for future restoration investigations with dynamic subjects. Furthermore, it provides a good example of the transferability of existing technology and methods: many of the techniques used by Park *et al.* (2009) were already prevalent in non-ambulatory restoration studies (Laumann *et al.*, 2003; Hartig *et al*., 1991; Hartig *et al.*, 1996).

One of the strongest aspects of this study is that it measures both physiological and psychological components of stress. By measuring only one aspect, it limits the authors to making inference about the other aspect based on the data at hand and an understanding of the interplay between physiological and psychological components of stress. With measures on both aspects, Park *et al.* can make more definitive statements, limiting the risk of erring in an inference.

Another strong paper identified in the literature was by Hartig *et al.* (1991). This paper was semi-ambulatory; most of the primary measurements were only taken at periodic sampling intervals. While this provides data throughout the course of the experiment, it does so in a discrete fashion. The limits imposed by sampling in intervals may lead to missed events or trends that occur between sampling periods.

Also, while Hartig *et al.* used blood pressure, pulse rate and skin conductance to measure physiological stress, they only achieved equivocal results in these measures. The psychological measures, tested with the Zuckerman Inventory of Personal Reactions (ZIPERS) and Oxford Happiness Scale (OHS), did not find significant results. The lack of agreement between the two measures is a weakness of the study, but also highlights the importance of utilizing complementary methods to investigate both physiological and psychological aspects of stress.

Table 2: Park *et al.* 2009 compared against Hartig *et al.* 1991 in five categories.

	Park *et al.* 2009	**Hartig *et al.* 1991**
Ambulatory	Fully	Semi
Environment	Undef. forest/city	Undef. natural/city
Sample	Large (100% male)	Small (50% male)
Method	HRV, pulse rate, POMS, salivary cortisol	Blood pressure, pulse rate, skin conductance, ZIPERS, OHS
Results	Significant	Equivocal/Significant

While the studies are similar in many respects, including the degree of mobility for subjects and testing environments (Table 2), the major differences were in the methods used. Park *et al.* (2009) used experimental measures (such as HRV and pulse rate) which were able to provide continuous sampling and demonstrate significant differences between environment types. This is a critical difference, particularly the distinction between continuous and discrete monitoring, which makes Park *et al.* (2009) the more promising method on which to base an ambulatory study.

5.2.2 Other Papers of Interest

Matsunaga *et al* (2011) was another significant paper identified in the literature search. The environments chosen for the study were a roof-top garden at a hospital and the car park outside. It was the only selected paper to investigate restorative potential of urban green spaces. The study used HRV as its sole measure but showed significant differences between environments at a $p < 0.05$ level.

While it was a small, non-ambulatory study, it was set in real-world environments very similar to that of the desired scenario (an urban green space tested against a city environment). While our paper set out to develop an ambulatory method to measure the restorative potential of green space, we discovered that Matsunaga *et al.* have already provided proof of concept in the area of restoration in urban green space.

5.2.3 Transferability

Non-ambulatory methods have good transferability to ambulatory settings. As Park *et al.* (2009) have already demonstrated, existing methods are capable of being utilized in studies with freely mobile subjects. Matsunaga *et al.* (2011) have shown that green spaces may indeed have restorative effects and have provided proof of concept in this area.

5.3 Potential Measures

5.3.1 Heart Rate Variability

Heart rate variability is arguably the best method for measuring natural restoration in an ambulatory population. Firstly, HRV is measured with electrocardiogram equipment, which are reliable and readily mobile (Salahuddin & Kim, 2006; Choi & Gutierrez Osuna, 2012). Secondly, it is a powerful but sensitive measure with a recognized ability to distinguish between sympathetic and parasympathetic nervous system activation (Choi & Gutierrez Osuna, 2009; Malik, 1998). While there are limitations and complications to using heart rate variability, many studies have already used it successfully to measure natural restoration, including four of the ten studies selected in the literature search (Matsunaga *et al.*, 2011; Park *et al.*, 2009; Parsons *et al.*, 1998; Ulrich *et al.*, 1991).

5.3.2 Skin conductance (GSR)

Skin conductance, or galvanic skin response, was one of the most popular measures for natural restoration, after HRV (Fig. 1). While Hartig *et al.* (1991) achieved mixed results using skin conductance, other studies have successfully used it to measure natural restoration (Parsons *et al.*, 1998; Ulrich *et al.*, 1991; Appendix 1). Furthermore, since it is easily adapted for mobile use it could be used to provide additional data on nervous system activation and the physiological aspect of stress (Kuijpers *et al.,* 2012). It could be used as a secondary measure to validate the

reliability of the HRV measure throughout the study, a purpose for which has already been used by Salahuddin & Kim (2006). Having two physiological measures would add to the internal validity of study results.

5.3.3 Questionnaire

The most common method employed by the selected studies was the use of questionnaire (Fig. 1). Questionnaires can be used as tools to assess the psychological states of study participants (Bowler *et al.*, 2010; Park *et al.*, 2009; Hartig *et al.*, 2003). There are a variety of questionnaires that can be chosen: in the papers selected for this study there were seven types of questionnaires used, with some studies employing more than one type (Hartig *et al.*, 1991).

For the creation of a comprehensive ambulatory methodology, the POMS test would complement the physiological measures well. The POMS test is widely used and is an recognized tool for measuring psychological state and stress (Park *et al.*, 2009; Bowler *et al.*, 2010). Furthermore, it incorporates Cronbach`s alpha, a measure of internal validity, into its design.

While the ZIPERS test was the most common questionnaire used in the selected studies, the sample is biased by the high inclusion rate of papers associated with Terry Hartig. Hartig`s papers tend to favour the ZIPERS scale. While the ZIPERS test does have its supporters, it lacks a measure of internal consistency such as Cronbach`s alpha, making it an inferior test (Bowler *et al.*, 2010).

5.3.4 Other Measures

Other measures from the results were excluded on several grounds, including lack of resolution, lack of sensitivity, or lack of acceptance or recognition.

Measures lacking resolution included blood pressure, with which continuous measurement is not practical. The discrete data samples it provides were considered to be inferior to the continuous data records of HRV or GSR. Cortisol also fell into this category because of its lag time and discrete data samples (Hartig *et al.*, 1996). Measures lacking sensitivity include pulse rate. Although it is related to HRV, it does not have the sensitivity of the latter measure (Constant *et al.*, 1999; Schafer & Vagedes, 2012). In light of the literature review, pulse transit time was excluded because it appears to be a relatively unknown and untested method in natural restoration studies.

5.3.5 Proposed Methodology

Based on the results of the analysis, the best potential method would be a measure of HRV, validated by skin conductance, and complemented by a questionnaire. This method would address both physiological and psychological aspects of stress and restoration.

5.4 Complications and Limiting Factors

The use of heart rate variability and other measures are not without their challenges. Particularly, ambulatory subjects bring new challenges that would not otherwise be present in studies of non-ambulatory subjects, particularly with respect to controlling for the effects of breathing. Also, measuring multiple variables presents challenges for small studies.

5.4.1 HRV Analysis

Heart rate variability can be very difficult to analyze. The analysis of the frequency components requires the use of advanced statistics (Malik, 1998). The wave forms generated by the ECG need to undergo a spectral analysis to test for differences between environments. This is not an easy process: the author had to abandon an earlier project after encountering overwhelming difficulties in the analysis stage of HRV data. Matsunaga *et al.*(2011) made use of two experts in their HRV analysis, including one author whose main contribution to the paper was teaching the other authors how the statistical analysis worked.

Heart rate variability also has another important consideration to be addressed in the case of ambulatory studies. Respiration is known to have a large effect on heart rate variability (Bernardi *et al.*, 2000). Where the subjects are more physically active than during a non-ambulatory study, the effects of respiration are now a larger consideration. However, subtraction of respiratory influences from HRV signals is

possible, but requires simultaneous recording of breathing rate (Choi & Gutierrez-Osuna, 2011; Bernardi *et al*., 2000).

While a proper analysis can be a complex process, the opportunities presented by heart rate variability outweigh the challenges.

5.4.2 Resources

Another limitation to the proposed methodology is that to employ both physiological and psychological measures in a study could require substantial resources; certainly more than using one measure alone. The two types of measures require distinct data collections and analyses, which provide additional burdens on studies. Small studies may not have the time or resources to record both types of data. However, not performing both limits the extent of the conclusions that the study would be able to draw.

5.4.3 Further Investigation

With ambulatory populations, the terrain and slope of the environment may have an effect on the physiological variables measured, particularly heart rate variability. Some studies have shown in trials that a relationship exists between gradient and physiological responses, but in freely-mobile subjects this relationship may differ (Sagiv *et al.*, 2000). This is an area that requires further investigation.

5.5 Results and Significance

5.5.1 Addressing the Research Questions

Through the results presented in this paper, we have shown:

1. Much of the existing methodologies are transferable. Park *et al.* 2009 is a fully ambulatory study that used no unique experimental measures or techniques. All of the measures used were present in earlier non-ambulatory studies.
2. Conducting ambulatory studies does hold unique challenges. The effect of respiration on heart rate variability may become a larger factor in ambulatory studies, and must be addressed through the analysis. Also, ambulatory studies may face new challenges with yet unknown consequences, such as the effect of slope on the physiological variables being measured.
3. As a result of the literature search and evaluation, it was determined that heart rate variability complemented by a questionnaire would provide the best methodology. Skin conductance could be used as a secondary measure to help ensure reliability of data. Using this method, both physiological and psychological aspects of stress would be measured.

5.5.2 Implications and Significance

Given this ambulatory method, the potential is there to investigate urban green spaces in a dynamic way for evidence of natural restoration. Hopefully, using this

method will help to create a large understanding of the services that green space can provide to cities and perhaps lead to better urban design practices in the future.

CHAPTER 6: CONCLUSION

6.1 IMPORTANCE, TOPIC, AND RESEARCH QUESTIONS

Where urban stress is a growing problem in cities, urban green spaces may provide oases of relief to the stress of city life. However, the scientific literature lacked a method to measure the restoration effects of green spaces, which contributed to the lack of knowledge on green space benefits. Furthermore, the literature lacked an ambulatory method that would better reflect the dynamic manner in which people interact with the environment around them. For these reasons, this study attempted to investigate a new methodology for ambulatory measurement of natural restoration in urban green spaces through the following questions:

1. What elements of existing methodologies are transferable to the creation of an ambulatory method?
2. What are the challenges faced in designing and conducting ambulatory studies?
3. What existing methodology holds the most potential to be adapted to ambulatory monitoring of natural restoration in urban green spaces?

6.2 FINDINGS

An ambulatory method has already been successfully used by Park *et al*. (2009) to measure natural restoration in freely mobile subjects. This study provides a

template for future research to move forward into the investigation of ambulatory effects of green space . Matsunaga *et al*. (2011) also provided an example of using HRV to measure restoration in green spaces in urban locations. Based on the results from these studies and others, we determined that the best methods would consist of HRV monitoring and questionnaires so as to incorporate both physiological and psychological measures of stress and relaxation.

6.3 Limitations, Implications, Areas for Further Research

Using HRV as a measure not only provides many opportunities, but also some challenges. While it is a very sensitive measure of nervous system activation, it can be very difficult to analyze, as it requires the use of advance statistics. Making the measure ambulatory also presents challenges in the form of respiratory effects. Breathing rate can have a significant effect on HRV, and its effects on HRV must be considered. Furthermore, using both physiological and psychological measures requires significantly more resources. This may exceed the resources of small studies.

Using this method could lead to further research studies investigating natural restoration in urban green spaces. However, further investigation should be performed into the effect of slope on HRV in regards to natural restoration, as it is possible that slope could have some confounding effects on HRV especially in freely mobile subjects.

6.4 CONCLUSION

With respect to the research questions and given the results of our study, we found that 1) much of the existing methodologies are transferable to a new ambulatory method, as evidenced by the existing ambulatory studies; 2) the challenges faced by ambulatory methods include controlling for respiration and difficult analyses; and 3) HRV complemented by a questionnaire would provide the best method for ambulatory studies. Hopefully this research can contribute to knowledge on the restoration potential of urban green spaces, and eventually to the design of healthy cities.

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