

Physical Activity on Multiuse Trails and in a Novel Bike Park
within an Urban Wilderness

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DEDICATION

To my wife, Sarah Jo, and my daughter, Emma Rose, for your unwavering love and support. I am so grateful for you both and could not have done this without you.

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ABSTRACT

Research has shown that the presence of, access to, and use of parks and trails is associated with increased levels of PA. However, little research exists on nature-based, recreational multiuse trails and bike-specific amenities within parks and their impact on PA. Therefore, to explore the effect trails and bike parks have on PA, this dissertation conducted three investigations to: 1) determine the impact of trail/greenway interventions on PA, 2) investigate how seasonality and weather influence nature-based recreational trail use, and 3) develop a demographic and PA profile of bike park users.

Investigation 1 (Chapter 4) systematically reviewed the literature specific to trail/greenway interventions and their impact on PA. Findings confirmed previous recommendations that trail/greenway infrastructure interventions combined with additional interventions (e.g., enhanced accessibility, community engagement) had a positive impact on PA. Additionally, findings indicate that multiple methods of PA assessment (e.g., direct observation, trail counters, self-report questionnaires) should be considered to better understand how these interventions impact PA.

Investigation 2 (Chapter 5) assessed the impact of seasonality and weather on trail use in a nature-based recreational trail network. Hourly/daily temporal changes in trail use were consistent with prior recreational trail investigations; however, unlike previous findings, bi-modal peaks in trail use were seen throughout the year. Specific to weather, the direction of effect on trail use was similar to previous investigations; however, the magnitude of the effect varied depending on the trail surface material. Gravel trail users were more sensitive to temperature and precipitation, whereas dirt trail users were more impacted by humidity, absolute pressure, and ultra-violet radiation index.

Investigation 3 (Chapter 6) developed a demographic and PA profile of users of a novel bike park. The demographics of bike park users was significantly different than surrounding communities but was representative of mountain biking in general. The majority of bike park users (64.2%) were observed participating in moderate-to-vigorous PA. Males used the bike park more than females and participated at higher intensities. Females were more likely to use playground features while males were more likely to use cycling features. Additionally, certain amenities of the bike park experienced more use than others.

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CHAPTER 1
INTRODUCTION

The health benefits of regular physical activity (PA) have been well documented and include decreased risk of cardiovascular disease, diabetes, obesity, hypertension, and certain types of cancer.^{1,2} Despite these known health benefits of PA, 40% of adults (18+ years) and 72.0% of adolescents are insufficiently active.^{3,4} Sufficient activity being defined as the equivalent of 150 minutes or more per week of moderate-intensity PA for adults and 60 minutes or more per day of moderate-vigorous intensity PA for adolescents.⁵ In the United States, several national health objectives within Healthy People 2030 focus on increasing PA in both adults and adolescents (See Table 1.1).⁶

One potential factor that could contribute to increasing levels of PA at the community level is if the built environment, where people live and work, allows them to enjoy active living leading to better health. Built environment infrastructure designed to promote PA and active living has been associated with higher levels of leisure-time PA (LTPA) across all age groups.⁷⁻⁹ Additionally, both the Office of Disease Prevention and Health Promotion's Healthy People 2030 initiative and the World Health Organization's Global Action Plan on Physical Activity 2018-2030 include objectives and strategies focused on improving the built environment to increase population PA (See Table 1.2).¹⁰⁻¹²

One aspect of the built environment that has received particular attention are trails and parks specific to their impact on PA. Research has shown that the presence of, access to, and use of trails is associated with increased levels of PA and better perceived health compared to people who don't use trails.^{13,14} A study by Tamura and colleagues¹⁵ used accelerometer-based devices and GPS to measure PA and found trail users accumulated more PA on days when they used trails compared to non-trail use days. Likewise, research involving parks in particular has shown

Table 1.1: Healthy People 2030 objectives and current status specific to increasing PA in adults, adolescents, and children.

Healthy People 2030 Objective	Current Status
<i>Adults</i>	
Reduce the proportion of adults who do no PA in their free time.	Baseline
Increase the proportion of adults who do enough aerobic PA for substantial health benefits.	Baseline
Increase the proportion of adults who do enough aerobic PA for extensive health benefits.	Baseline
<i>Adolescents and Children</i>	
Increase the proportion of adolescents who do enough aerobic PA.	Getting worse
Increase the proportion of children who do enough aerobic PA.	Getting worse

Definitions: Baseline = No available data beyond the initial baseline. Getting worse = We are further from the target than we were at the beginning of the decade.

Table 1.2: Objectives and strategies focused on improving built environment infrastructure to increase population physical activity.

Office of Disease Prevention and Health Promotion

Increase the proportion of adults who walk or bike to get places.

Increase the proportion of adolescents who walk or bike to get places.

Enhance access to places for physical activity including trails, parks, and playgrounds.

World Health Organization

Strengthen public access to green open spaces and recreational spaces for all people, of all ages and diverse abilities.

Strengthen policies and regulations surrounding the promotion of public amenities including sports and recreation facilities.

that they can play a significant role in providing opportunities for increased PA. Liu et al.¹⁶ reported higher levels of moderate and vigorous PA in park users compared to park non-users. Evenson and colleagues¹⁷ also found that on days when a park was visited, overall minutes of moderate-to-vigorous PA (MVPA) was higher compared to days when a park was not visited.

Furthermore, in July 2021, the Community Preventive Services Task Force (CPSTF) released the results of a systematic review that included 38 studies examining the impact park, trail, and greenway built environment interventions have on PA.¹⁸ This review reported insufficient evidence regarding the effectiveness of park, trail, or greenway infrastructure changes (i.e., infrastructure improvements to parks, trails, or greenways) when implemented alone for increasing PA. However, when these built environment changes were combined with other interventions (e.g., community engagement, media campaigns, programs offering structured opportunities for PA), they found sufficient evidence of increased PA. This led to the CPSTF recommending a dual approach intervention (i.e., combining park, trail, and greenway infrastructure improvements with promotional programming) to aid in increasing PA within a community.

Moreover, incorporating parks and trails in nature-based wilderness areas may provide additional physical and mental health benefits. A systematic review and meta-analysis found those who spent time in a nature setting experienced reduced systolic and diastolic blood pressure, improved depression and anxiety scores, and increases in daily step counts.¹⁹ Other studies have concluded that the presence of nature and scenery surrounding trails was an important incentive for people to acquire more LTPA.^{14,20} With 80% of the United States population living in urban areas,²¹ it may be beneficial to provide accessible nature-based trails

and parks that allow urban dwellers the opportunities to improve their physical and mental health.

Knoxville's Urban Wilderness (KUW), located in Knoxville, TN, is a 1,500-acre outdoor adventure area that provides an ideal place for people to experience nature and be physically active.²² Housed within the KUW are over 50 miles (80.5 km) of natural surface multiuse trails, a novel bike park, lakes for swimming, a nature center, adventure playgrounds for children, and more. Activities such as biking, climbing, fishing, hiking, running, swimming, and more can all be enjoyed within the KUW. The trail network has 14 trailheads with numerous secondary access points located within residential neighborhoods that border the urban wilderness making it easily accessible to the community and visitors. A unique aspect of this nature-based recreation area is that the majority of the KUW lies within city limits and is less than 3 miles from downtown Knoxville, TN.

The KUW is made possible through a collaborative effort of numerous local organizations including the City of Knoxville and Knox County governments, the non-profit Legacy Parks Foundation, the state Tennessee Wildlife Resource Agency, the Appalachian Mountain Bike Club (AMBC), and Ijams Nature Center to name a few.²² Additionally, the KUW encompasses various land parcels owned by private landowners, non-profit organizations, and city, county, and state governments.

Through tourism and recreation, areas similar to the KUW have the potential to not only benefit the mental and physical health of its users, but also provide economic benefits to the local economy.²³ Being within minutes of downtown Knoxville, TN, the KUW is positioned in close proximity to lodging, retail, and entertainment which may suggest an even greater economic benefit to the local economy.

In 2015, the Howard H. Baker Center for Public Policy at the University of Tennessee, Knoxville (UTK) estimated that the KUW contributed an estimated \$14.7 million dollars to the local economy.²⁴ The primary limitations of this estimate were not knowing the actual number of people using the KUW trail system and if the KUW qualified as a ‘regional’ or ‘national’ destination. To address these limitations, a collaborative research effort focusing on the KUW between the Howard H. Baker Center for Public Policy, the UTK Department of Kinesiology, Recreation, and Sport Studies, and the various KUW partners began in 2020. This led to a first-of-its-kind study to analyze the health and economic impact of an urban-proximate nature-based trail system and bike park within the KUW. One aim of this study was to measure the number of trail users to allow for an estimation of the economic impact of the KUW. Furthermore, this study aimed to provide a demographic profile of trail and bike park users while also collecting PA and health-related data from trail user surveys.

As part of this KUW health and economic impact study, during 2021, mean daily trail counts were compiled from 11 strategically placed infrared trail counters throughout the KUW in order to calculate a yearly estimate of trail users. In total, it was estimated that 303,782 individual trips were made to the KUW trails for PA in 2021.²⁵ Additionally, using a modified walking/jogging path protocol from the System for Observing Play and Recreation in Communities (SOPARC),²⁶ UTK researchers directly observed KUW trail users that passed through the infrared trail counters. This enabled researchers to categorize trail users into broad demographic groups. Fitzhugh and colleagues²⁵ reported that KUW trail users were primarily male (69.5%), adults (83.7%), and white (95.0%). Regarding the type of PA performed by trail users, mountain biking was observed most frequently (51.0%), while walking was the second most popular activity observed (38.4%). An interesting finding regarding trail use by gender and

type of PA was that males were primarily observed mountain biking (64.6%), while females were primarily observed walking (60.6%).

More research is warranted to get a better understanding of the impact nature-based recreation areas similar to the KUW may have on PA. For example, specific to the multiuse trail network, understanding the temporal trends and how weather conditions impact trail use could help managers adapt their trail planning and design (i.e., surface treatment, type of trail, and overall user experience), maintenance, and funding for various trail projects. Previous research has reported recreational trail use to be highest in warmer months (e.g., May-September) and lowest in cooler months (e.g., December-February).^{27,28} Regarding weather variables, prior research has reported a curvilinear relationship between temperature and trail use with the maximum temperature deflection point ranging from 76°F to 91.6°F.²⁸⁻³³ Precipitation consistently results in a negative relationship with trail use.^{27-29,31,34,35} Other weather variables including wind speed^{27,28,35-37} and humidity^{29,31,32,34} have also been shown to be associated with trail use. Each of these studies, with the exception of two,^{27,33} were conducted solely on paved surfaces including urban greenways, rail trails, and bike lanes. The study by Zajchowski and colleagues³³ was the only study to involve a trail with a natural surface material (dirt), but was limited to only 32 days over summer months. It is clear that a gap in the research exists regarding the temporal trends and impact weather conditions may have on trail use within a multiuse trail network with varying natural surface materials (i.e., gravel and dirt).

Additionally, a unique feature of the KUW is Baker Creek Bike Park. This park is designed to incorporate features specific to mountain biking and pump track cycling that allow people to learn and practice bike-related skills. These bike parks may also be referred to as bike hubs, bike skills parks, or pump tracks and they have been gaining popularity all over the

world.³⁸ However, only one investigation focusing on bike parks, using direct observation, has assessed the use and PA levels of users.³⁹ The researchers reported that the bike parks attracted primarily male children and teens, with 63% of users being physically active. With the popularity of this park design growing across the world, more research is needed to gain a better understanding of who uses these bike parks and how their various features promote PA.

Definitions

Below are definitions and commonly used terms discussed in the following research investigations.

1. Active living: A way of life where physical activity is valued and incorporated into the daily routine of all people.⁴⁰
2. Pump track: A continuous series of rollers (i.e., bumps or small hills in the track) and berms (i.e., corners of the track) that can be ridden continuously. This feature of a bike park allows riders to propel themselves around the track by a pushing-down and pulling-up action on a bike (i.e., “pumping”).⁴¹
3. Pump and jump track: Similar to the design features of a pump track, this track also includes steeper drops and turns with ramps to enable the rider to become airborne. These features may also have a start and finish point.
4. Asphalt jump line: A single lane feature (asphalt surface material) with a series of steep drops, turns, and jumps (i.e., ramps) that enable a rider to increase speed and become airborne. This feature also has a start and finish point.
5. Stone line: A single lane feature (gravel/stone surface material) with a series of steep drops and jumps. This feature has a start and finish point.

6. Steep or rolled lips: This refers to the transition point when going over a roller (i.e., bumps or small hills in the track). A steep lip is a sharp transition from the upslope to a flat surface and then the downslope. A rolled lip is a smoother, more rounded transition from the upslope to the downslope. This feature is often seen on pump tracks and pump and jump tracks.
7. Rock navigation course: Cycling skill-building feature that allows cyclists to maneuver on and around large rocks and boulders.
8. Wall features: Wooden structure that extends above the surface of the pump track that allows a rider to maneuver the bike so they are parallel to the wall.
9. Linear cycling skill features: Linear cycling skill-building features made of a metal frame and wooden riding surface ~ one foot wide. Various features include a table-top (i.e., cycle up a small incline, then along a flat surface, and back down to the ground), rolling hills, and zig-zag design.

Statement of the Problem

A preponderance of evidence exists that supports the benefits urban trails, parks, and nature have on physical and mental health. However, few urban metropolitan areas have access to nature-based recreational trail systems and bike parks within their city limits and in close proximity to population-dense downtown areas. Hence, little to no research exists on trail systems or bike parks similar to the KUW in Knoxville, TN. Most of what we find specific to similar trail systems are user reports^{25,42} and economic impact studies.^{43,44} The following investigations begin to examine the relationship of an urban-proximate, nature-based recreation area with the PA of its users. This research could help influence future built environment interventions to consider adding nature-based trail networks and bike parks as an accompanying

amenity to aid in increasing population level PA. First, a systematic review of peer-reviewed studies investigating the impact trail/greenway built environment interventions had on PA was conducted. Second, an investigation was conducted to analyze the temporal variations and the relationship of varying weather conditions with the use of natural surface trails for PA in an urban, nature-based recreation setting. Finally, an investigation was conducted to create a demographic profile of bike park users (gender, age group, race/ethnicity), assess how the bike park is used for PA, and determine the intensity of PA among park users. The specific research questions addressed across these investigations are specified below.

Research Questions

1. How do trail/greenway built environment interventions impact physical activity?
2. How does seasonality and various weather conditions and trail surface material (gravel vs. dirt) relate to trail use at the KUW?
3. What are the demographics (gender, age group, race/ethnicity) of users at the Baker Creek Bike Park?
4. At the Baker Creek Bike Park, what features are most used for physical activity and at what intensity?

Significance

The purpose of the following investigations was to determine the impact trail/greenway built environment interventions have on PA, analyze the relationship between seasonality and varying weather conditions and use of multiuse trails, as well as to create a profile of users in a novel bike park for PA. This was the first study to analyze how seasonality and weather relates to the use of natural surface trails in an urban, nature-based recreation setting and the first study in the United States to assess who and how bike parks are used for PA. The results of these

investigations can help guide future research that examines urban-proximate, nature-based recreation settings containing multiuse trail systems and bike parks. Additionally, results of these studies can inform future built environment interventions to consider non-traditional trails/greenways (i.e., paved, linear-based routes) such as nature-based, multiuse trail networks. Future built environment interventions may also want to consider installing a bike park as a trailside amenity. Finally, results of these investigations may provide evidence that encourages other communities to incorporate nature-based trail systems and parks in close proximity to their residents.

Limitations

The current investigations have several limitations inherent within their design and the instruments/protocols used; therefore, the findings in these investigations should be interpreted with caution. The limitations of these investigations are described below.

1. The heterogeneity in study and intervention designs, population demographics, PA outcome measures, and measurement tools used across studies in the systematic review (Investigation 1, Chapter 4) limits our capacity to draw conclusions or conduct a more rigorous meta-analysis.
2. The generalizability of the findings from the systematic review (Investigation 1, Chapter 4) are limited due to the vast majority of studies occurring in middle-to-high income, majority white, urban/suburban neighborhoods.
3. The generalizability of Investigations 1 and 2 (Chapters 5 and 6) is limited to 1) climate regions similar to East Tennessee, 2) nature-based multiuse urban trail networks similar to the KUW, and 3) bicycle parks with similar features and amenities as those at the KUW Baker Creek Bike Park.

4. The study design of Investigation 2 (Chapter 5) limits the inferences that can be made regarding how weather variables relate to trail use due to the inability of infrared counters to identify trail user characteristics (i.e., gender, age, race/ethnicity, socioeconomic status, etc.).
5. Trail user counts for Investigation 2 (Chapter 5) were measured using an infrared trail counter that cannot distinguish whether an individual passes the counter more than once, is unable to identify trail user characteristics (i.e., gender, age, race/ethnicity, etc.), and cannot detect mode or intensity of activity.
6. The SOPARC protocol used for Investigation 3 (Chapter 6) only provides park use and physical activity information for a moment in time. For example, an individual who was active for the majority of their park visit may have sat down at the time of the scan observation and would have been coded as sedentary.
7. The SOPARC data collected for Investigation 3 (Chapter 6) was completed on a quarterly basis and therefore limits the inferences that can be made for months where direct observations did not occur.
8. Data collected using the SOPARC protocol in Investigation 3 (Chapter 6) was organized by gender for the categories of age, race/ethnicity, and physical activity. Therefore, data could only be analyzed by gender, not by age group or ethnicity.

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CHAPTER 2
REVIEW OF LITERATURE

Introduction

Physical activity (PA) is a modifiable behavior that has been associated with reduced risk of cardiovascular disease, hypertension, obesity, diabetes, and increase quality of life and well-being.¹⁻³ The built environment where people live and work could be a contributing factor that has either a positive or negative impact on someone's PA level. Previous research has identified a positive association between built environment infrastructure that promotes PA and higher levels of PA.⁴⁻⁶ In particular, trails and greenways have received increasing attention for their potential influence on PA at the population level. The idea being that trails/greenways within close proximity to residents within a community would provide substantial opportunity for participating in PA.

Cross-sectional based studies have consistently shown the presence of, access to, and use of trails/greenways is associated with increased levels of PA and better perceived health compared to those who don't use trails.⁷⁻⁹ However, to better determine the impact trails/greenways have on PA, intervention studies with pre- and post-measurements of PA levels are crucial. Inevitably, the method of PA measurement in these studies will impact the strength of the relationship between trails/greenways and their effect on PA. Oftentimes, there is a trade-off between the feasibility of a PA measurement technique and its validity (See Figure 2.1). For example, self-report questionnaires are one of the most frequently used methods of collecting PA-related data (i.e., high feasibility); however, self-report measures are synonymous with having low levels of validity. On the other hand, direct observation methods of assessing PA can be more time intensive and deemed less feasible but results in much higher validity of PA measurement.

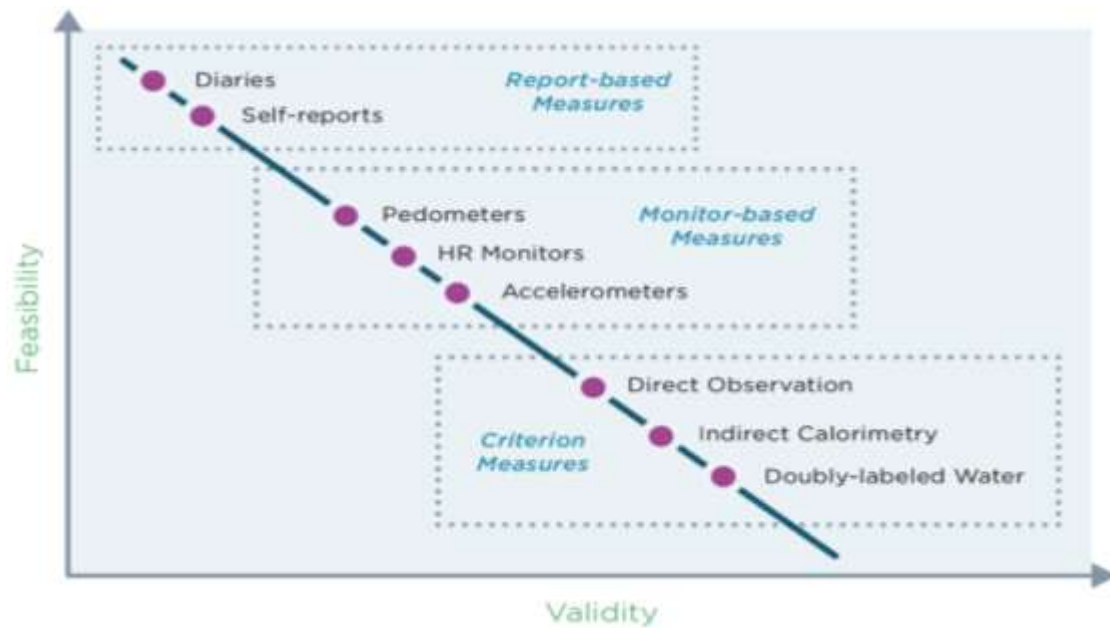


Figure 2.1: Physical activity assessment tools and their relative positions on the feasibility/validity continuum. From “Measures Registry User Guide: Individual Physical Activity,” by G. Welk, J. Morrow, and P. Saint-Maurice. National Collaborative of Childhood Obesity Research (p. 28), January 2017.

A recent systematic review (Chapter 4) identified 25 peer-reviewed studies that investigated the impact of trail/greenway built environment interventions on PA. These studies used a variety of methods including direct observation (n=8), electronic trail counters (n=5), and self-report questionnaires (n=14) to assess if changes in PA occurred after improving trail/greenway infrastructure. Therefore, the following review of literature will: 1) review studies using direct observation to examine the impact of trail/greenway interventions on PA, 2) review studies using electronic trail counters to examine the impact of trail/greenway interventions on PA, and 3) review studies using self-report questionnaires to examine the impact of trail/greenway interventions on PA. Studies within each section will be presented by PA measurement tool and chronologically.

Direct Observation to Assess the Impact of Trail/Greenway Interventions

The impact trail/greenway interventions have on PA has been assessed using a variety of PA measurement tools. In particular, direct observation of individuals in the trail/greenway infrastructure location has been used to assess changes in PA after an intervention occurred. In addition to counting individuals using the infrastructure, certain direct observation protocols can also identify the type and intensity of PA performed. For example, a study by Gustat et al.¹⁰ used the System for Observing Play and Recreation in Communities (SOPARC)¹¹ to assess changes in observed moderate-to-vigorous PA (MVPA) after the installation of an 8-foot wide walking path that spanned 6-blocks in a low-income, primarily African American neighborhood in New Orleans, LA, USA. SOPARC is a reliable¹¹ and valid¹² tool that uses a momentary time sampling technique of direct observations that provides data regarding the number of trail users, gender, age group, race/ethnicity, activity type and PA level. Investigators reported a significant increase in the percentage of people observed in the neighborhood performing MVPA from baseline

(36.7%) to follow-up (41.0%, $p < 0.001$), while the control neighborhoods had a decrease in the percentage of persons observed in MVPA. Auchincloss et al.¹³ also used SOPARC to investigate changes in PA following the construction of a 1.5-mile (2.4-km) urban greenway in Philadelphia, PA, USA. They reported an increase in persons observed per hour using the trail (pre: 100 persons/hr, post: 116 persons/hr) and an increase in the proportion of users participating in MVPA (+2%). However, neither of these outcomes were significantly different than the increases in PA observed in the control area.

A similar methodology to SOPARC that has been recently developed is the Method for Observing pHysical Activity and Well-being (MOHAWk).¹⁴ MOHAWk uses systematic observations to assess PA intensity (Sedentary, Walking, and Vigorous) and two well-being behaviors (Take Notice: taking notice of the environment; Connect: social interactions). Additionally, it measures gender, age group, ethnicity, the total number of people, and incivilities (e.g., broken glass, graffiti, trash). Using MOHAWk, Benton et al.¹⁵ reported increases in the number of people using new and revitalized footpaths at 7-month follow-up (IRR 1.67, 95% CI 1.44, 1.95), 12-month (IRR 2.10, 95% CI 1.79, 2.48), and 24-month follow-up (IRR 2.42, 95% CI 1.80, 3.24) in Manchester, United Kingdom. Investigators also reported significant increases in persons observed walking and performing vigorous PA.

Fitzhugh and colleagues¹⁶ used neighborhood-level direct observation¹⁷ and school-level direct observation¹⁸ protocols to assess the impact of retrofitting a neighborhood with a 2.9-mile (4.7-km) greenway that improved accessibility to retail stores, schools, and other public spaces. The neighborhood-level protocol involved three, 2-hour observations (morning, midday, and evening), on Wednesday and Saturday, where researchers documented counts of pedestrians, cyclists, and other forms of PA. The school-level observations were performed on Tuesday and

Thursday at two times (7:00 – 9:00am) and (2:30 – 4:30pm) to record the number of school-aged individuals using active transportation to school. Results of the study showed a significant increase in total PA counts (4.5 vs 13.0, $p = 0.000$) in the experimental neighborhood, while the control neighborhood experienced a significant decrease (3.0 vs 1.0, $p = 0.000$). PA counts were significantly higher in the experimental neighborhood compared to the control neighborhood specific to walking ($p = 0.002$) and cycling ($p = 0.036$). Regarding active transportation to school, no significant differences were found in the experimental or control neighborhoods.¹⁶

A number of studies have used direct observation to simply count the number of individuals using the trail/greenway before and after an infrastructure intervention occurred. For example, Matsuoka et al.¹⁹ used manual trail counts completed in the morning, noon, and evening on two weekdays and one weekend day in January and June to determine the impact of revitalizing a walking/jogging path, community-wide promotions, and PA programming on trail use. Results showed a 24% increase from January 2003 to January 2005, and a 30% increase from June 2003 to June 2005 in observed trail user counts. Similarly, Cook et al.²⁰ used manual counts to assess trail use before and after the completion of a critical link in a trail in Durham, North Carolina, USA. Researchers reported a substantial increase in trail use from 9,266 counts (pre-construction) to 21,365 counts (post-construction).

In the United Kingdom, a large investment (Connect2 program) involved upgrading or creating 84 walking and cycling routes along with improved road crossings in various locations. Researchers used manual trail counts pre- and post-construction between the hours of 7am and 7pm on 4 days. Across all sites measured, Le Gouais et al.²¹ reported an increase in trail counts from 189,250 (pre-construction) to 319,531 trail counts (post-construction). To assess the impact of improvements to bicycle infrastructure, Fields et al.²² used manual bicycle counts on

weekdays in September between the hours of 4pm and 6pm. Results showed that protected cycleways led to a faster rate of growth of cyclists (21 more riders per count period per year, $p = 0.003$). Additionally, at locations with protected bikeways, cyclist counts increased by 69% over the six-year study.²²

Summary of Direct Observation to Assess the Impact of Trail/Greenway Interventions

Of the eight studies reviewed, results consistently favored an increase in persons using the trail/greenway infrastructure and increases in persons observed in MVPA. Across studies that assessed changes in the number of people using the trail/greenway, a 16% to 188% increase in users were observed following trail/greenway infrastructure interventions. Studies using direct observation to assess changes in PA intensity reported increases in observed MVPA ranging from 2% to 200%. The observed range seen across studies may be a result of the direct observation protocol used, the number of days and hours observed, the time-of-day observations took place, and the study population.

There are several limitations associated with using direct observation protocols. First, the inability to identify trip purpose on the trail/greenway (i.e., transport or leisure-time PA) and identify additional demographic data outside of gender, age group, and race/ethnicity. Secondly, direct observation only provides trail use and PA information for a moment in time. An individual could have been jogging/running for the majority of their time on the trail and may have started walking at the time of the scan observation and would have been coded as walking/moderate-intensity instead of vigorous-intensity. Thirdly, there are limitations on the inferences that can be made for the times, days, and months where direct observations did not occur. Lastly, it can be difficult to match control areas at the neighborhood level surrounding the trails/greenways which can make it difficult to control for confounding variables.

Electronic Trail Counters to Assess the Impact of Trail/Greenway Interventions

Although the impact of trail/greenway infrastructure interventions has been demonstrated using various direct observation methods, interpretation of the results is limited to the timeframe and/or season in which the observations occur. In contrast, electronic trail counters have the ability to measure trail/greenway use at all times of the day and throughout various seasons. These counters can work via infrared technology or electromagnetic conduction loops. Infrared trail counters sense and detect the infrared wavelength emitted by people. When a person passes through the infrared beam the device records a precise timestamp of that user event (e.g., persons walking, running, cycling). Electromagnetic conduction loops detect the metal in bicycle frames as they pass over the conduction loop. These devices are specific to counting cycling activity and are unable to detect walkers/runners.

In Sydney, Australia, cycling counts were monitored before, during, and after the completion of a 16.5-km (10.3-mile) cycleway using electronic bicycle counters. Researchers reported increased mean daily cycling counts post-construction in Cabramatta (weekdays: 11.4 to 14.7 counts; weekend days: 17.6 to 24.0 counts) and in Guilford (weekdays: 16.8 to 19.8 counts; weekend days: 24.2 to 26.2 counts).²³ Another study in Sydney used electronic bicycle counters that measured the number of cyclists during peak morning (6-9am) and evening hours (4-7pm) on one weekday two times per year. In this study, Crane et al.²⁴ analyzed bicycle counts before and after the construction of a 2.4-km (1.5-mile) protected cycleway that included traffic calming measures, improved crossings, and increased tree coverage. Results showed an increase in bicycle counts (812 to 886 per day) at one counter location (Site A) and from 237 to 450 cyclists per day at Site B.

Clark et al.^{25,26} collected trail use data in Las Vegas, NV, USA at three periods of seven days in October 2011, April 2012, and October 2012 using TRAFx Infrared Trail Counters.²⁷ The intervention included a media campaign promoting trail use, along with wayfinding and distance markers being installed on trails. A significant increase in mean trail users per day pre- and post-intervention was found for both the intervention trails (pre: 79 counts vs. post: 107 counts; $p < 0.001$) and the control trails (pre: 112 counts vs. post: 147 counts; $p = 0.039$). The authors stated the non-random nature of selecting the control trails and that the marketing campaign impacted all trails made it difficult to compare the intervention and control trails.²⁵

Grunseit et al.²⁸ used time series analyses of trail user counts before and after the completion of a multiuse, off-road, 8.5-km (5.3-mile) walking and cycling loop trail in Sydney, Australia. Researchers used Eco-Counter²⁹ infrared counters and reported a statistically significant increase in bicycle counts (ranging from 1391 to 1899 per week) and pedestrian counts (ranging from 756 to 1149 per week).²⁸ In Manitoba, Canada, researchers assessed the impact a seasonal 10-km (6.2-mile) frozen waterway trail had on trail user counts using an Eco-Counter PYRO-Box.²⁹ The trail is typically open for 8-10 weeks (January-April). Trail user counts were collected for 20-30 days prior to the trail opening, during the entire time the trail was open, and for 30-40 days following the closure of the frozen waterway trail. Daily trail counts significantly increased ($p < 0.001$) two-to-four-fold during the time in which the frozen trail was open in 2017/2018 (2449 to 4515 counts per day) and in 2018/2019 (405 to 1813 counts per day).³⁰

Summary of Electronic Trail Counters to Assess the Impact of Trail/Greenway Interventions

Each of the five studies reviewed reported increases in trail users detected by the electronic counters pre- and post-intervention ranging from 7.5% to 347.7%. The large variation

in the observed range could be due to study design, study populations, electronic trail counter brand used, and the number of hours of data collected. For example, across these five studies, the data collection time frame ranged from six hours of trail counts pre- and post-intervention (12 total hours) to 984 days of trail count data (monitored 24 hours per day).

While the results of these studies consistently reported positive changes in trail user counts, there are several limitations that need to be considered when using electronic trail counters. Specifically, there are several issues that can impact the number of counts registered by these devices. For example, wildlife or wind-blown vegetation that crosses the infrared beam could be recorded. These devices are unable to discern if an individual passes the trail counter more than once (i.e., going into the trail vs coming out from the trail). Additionally, if individuals pass the counter side-by-side or in large groups, the counter may not be able to accurately detect all users that passed. Some brands of electronic trail counters cannot detect the mode of PA (i.e., pedestrian versus cyclist). Furthermore, the generalizability of the data is limited due to the inability of electronic trail counters identifying trail user characteristics (i.e., gender, age, race/ethnicity, socioeconomic status, etc.).

Self-Report Questionnaires to Assess the Impact of Trail/Greenway Interventions

Overall, the use of direct observation and electronic counters have shown a positive impact on PA being performed in the trail/greenway locations. However, one of the primary limitations when using direct observation or electronic counters is that changes in PA levels at the individual level cannot be assessed. Self-report questionnaires are a method of PA measurement that can be used to detect changes in PA levels as a result of a trail/greenway intervention. For example, the Behavioral Risk Factor Surveillance System (BRFSS) uses telephone surveys to collect state level data regarding health-related behaviors, use of preventive

services, and chronic health conditions about U.S. residents.³¹ Researchers consistently use questions from the various iterations of the BRFSS to assess several outcomes in smaller investigations.

Evenson et al.³² assessed changes in leisure activity, walking and bicycling, MVPA, and transportation activity (walking or bicycling) before and after the completion of a 4.8-mile (7.7-km) rails-to-trails conversion. Leisure activity was assessed using a telephone-based interview that asked the following question from the 1984-2000 BRFSS: “During the past month, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?” Changes in walking/bicycling and MVPA were assessed using questions from the 2001 BRFSS iteration. Specific to walking/bicycling, participants were asked, “In a usual week, do you walk (bike) for at least 10 minutes at a time for recreation, exercise, while at work, to get to and from places, or for any other reason?” If a participant answered “Yes” to any of the above questions, they were then asked to provide information on the frequency, duration, and/or type of activities performed. Regarding transportation activity, participants were asked, “In the past month, how many times did you walk (bike) for transportation, such as to and from work or shopping,” and “In the past month, when you walked (biked) for transportation, how many minutes or hours did you usually do this at a time?” Results of this study showed no significant changes in median time spent in leisure activity, MVPA, walking and bicycling, or transportation activity. Furthermore, Harding and colleagues³³ used an ecological study design to assess changes in leisure-time PA (LTPA) after the construction of a 1.4-mile (2.3-km) paved mixed used path in Oahu, HI, USA. Pre-construction LTPA data came from the 2009 BRFSS survey, while post-construction data was from the 2012 BRFSS survey (both BRFSS survey data was collected via telephone-based interviews). Results showed a 5%

increase in the proportion of individuals participating in LTPA and a 6.2% increase in the proportion of individuals reporting being active (150-300 minutes/week or moderate PA or 75-150 minutes/week of vigorous PA) after the path was constructed.

Another self-report survey instrument, the International Physical Activity Questionnaire (IPAQ), has been shown to be a reliable and valid tool for measuring physical activity.³⁴ Questions from this survey are specific to vigorous-intensity PA, “During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling,” and moderate-intensity PA, “During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis?” Participants are instructed to think about those activities that lasted at least 10 minutes. If participants answer 1+ days to either of the above questions, they are then asked how much time they usually spend doing moderate or vigorous physical activities on one of those days. The IPAQ also contains questions specific to time spent walking over the last 7 days and the amount of time spent sitting during the last 7 days.

Frank et al.³⁵ used a self-administered IPAQ short form to assess changes in MVPA and sedentary behavior following the retrofitting of a 2-km (1.2-mile) urban greenway and improved streetscape in Vancouver, Canada. Researchers reported that the experimental group (those living within 300 meters of the greenway) experienced a non-significant increase in MVPA (51.9 vs 62.9 minutes/week) and a non-significant increase in the proportion of participants who met the recommended MVPA guidelines (67.6% vs 69.4%). The control group (those living farther than 300 meters from the greenway) reported a non-significant decrease in both minutes/week of MVPA and the proportion of participants who met the recommended MVPA guidelines. In Wuhan, China, a 102-km (63.4-mile) motorized vehicle road was converted to a traffic-free

greenway with service facilities. Participants were interviewed and asked questions specific to walking and MVPA from the IPAQ, investigators found those living within 5-km significantly increased walking minutes per week (+31.2 minutes, $p < 0.001$).³⁶ Additionally, those living within 2-km significantly increased their amount of MVPA per week (+62.7 minutes, $p < 0.001$) and MET-minutes per week (+448.9 MET-minutes, $p < 0.001$).^{37,38}

The Active Australian Survey (AAS)³⁹ is a widely used survey in Australia to measure PA and has been shown to be a reliable^{40,41} and valid⁴² measurement tool in various populations. It is similar in nature to the IPAQ in that it uses a 7-day recall asking questions specific to walking, vigorous gardening, moderate PA, and vigorous PA. For example, participants are first asked, “In the last week, how many times did you do any vigorous physical activity which made breathe harder or puff and pant? (e.g. jogging, cycling, aerobics, competitive tennis)”. They are then asked, “What do you estimate was the total time you spent doing this vigorous physical activity in the last week,” and participants answer in hours and minutes.

Crane et al.²⁴ used a self-administered AAS to assess changes in MVPA following the construction of a 2.4-km (1.5-mile) bi-directional protected cycleway in Sydney, Australia. Although no significant changes in MVPA occurred in the intervention population (those living within 3 km of the cycleway), researchers did report those living within 3-km were nearly four times more likely (OR 3.93, 95% CI 1.51, 10.23) to use the cycleway. Additionally, those living 1-2.99 km from the cycleway were more likely to increase their weekly cycling frequency and duration compared to those living <1.0 km (0.6 miles) and >3.0 km (1.9 miles) from the cycleway.

The Connswater Community Greenway (CCG) project in Belfast, Northern Ireland, is an urban regeneration project totaling £40 million (~43.5 million USD) and includes 25 km (15.5

miles) of new or improved greenway and foot/cycle paths, improved bridges and crossings, new signage, upgraded parks and game areas, and lighting along the entire route. Hunter et al.⁴³ conducted a repeat cross-sectional study before and after the completion of the CCG project using interview-based household surveys with questions from the Global Physical Activity Questionnaire (GPAQ)⁴⁴ to assess changes in PA. The GPAQ is a 7-day recall survey instrument that assesses domains of work, active travel, and moderate- and vigorous-intensity recreational physical activities. Results from this study found a significant decrease in the proportion of individuals in the intervention area (those living ≤ 1 mile [1.6 km] from the CCG) meeting the recommended PA guidelines (pre: 68%, post: 61%, $p < .0001$). Additionally, total minutes/day of PA significantly decreased (pre: 89.9 minutes, post: 72.6 minutes, $p = 0.0002$) and minutes of recreational PA significantly decreased (pre: 44.2 minutes, post: 39.8 minutes, $p = 0.0012$). The authors stated there was not a significant difference between the intervention and control groups, and the results were in line with the decline in PA seen in the Northern Ireland population.⁴³

Many studies do not report the PA survey measurement tool used, whether the questionnaires used were reliable/valid, or researchers chose/modified questions to their specific project aims. For example, Merom et al.,²³ assessed changes in PA after the completion of a 16.5-km (10.3-mile) rail-trail cycleway. Researchers administered questions via a telephone-based interview specific to cycling and walking behavior, intention to be more active, and awareness and use of the new trail. Results showed a 4.0% increase ($p < 0.005$) in participants who used the trail; however, “inner” (those living within 1.5 km [0.9 miles] of the trail) pedestrians and “outer” (those living 1.5-5 km [0.9-3.1 miles] from the trail) cyclists had a modest increase in walking per week [+4.2 minutes ($p = 0.778$) and +2.4 minutes ($p = 0.628$)]. Additionally, inner

cyclists reported an increase in cycling per week (+11.4 minutes, $p = 0.233$), while outer cyclists reported a decrease (-14.4 minutes, $p = 0.056$).²³

West & Shores conducted two investigations to assess the impact building a greenway had on PA among proximate residents.^{45,46} For both investigations, researchers used a self-administered 7-day recall and asked participants “In the past 7 days, how many days did you walk for at least 30 minutes?” A similar question was asked specific to a) participating in 30+ minutes of moderate activity and b) participating in 20+ minutes of vigorous activity. After five miles (8.0 km) of greenway was added to an existing greenway, researchers reported an overall increase in the number of days survey respondents (all lived within one mile of the greenway) walked for at least 30 minutes (2.9 vs 3.3 days), participated in 30+ minutes of moderate PA (1.7 vs 2.3 days), and participated in vigorous PA (1.3 vs 1.8 days).⁴⁵ After the completion of a 1.93-mile greenway extension in Mecklenburg County, NC, USA, overall results for survey respondents (all living within three miles of the greenway) showed an increase in the number of days walking for at least 30 minutes (2.6 vs 2.9 days), but a decrease in the number of days of moderate PA (1.8 vs 1.7 days) and vigorous PA (1.6 vs 1.4 days).⁴⁶ Neither investigation reported a significant interaction between proximity to the newly developed greenway and changes in PA.

Gustat et al.¹⁰ assessed changes in PA after the installation of an 8-foot wide walking path in New Orleans, LA, USA. The household interview survey instrument used contained questions explicit to the community social and physical environment, health and well-being, PA (specifically, walking for leisure, walking for transportation, and engaging in other activities like bicycling or jogging), and specific locations where PA was performed. Non-significant increases in the proportion of individuals who walked for leisure and transportation occurred in both the

intervention and control neighborhoods.¹⁰ Additionally, a non-significant increase in walking trail use occurred (pre: 21.9% vs post: 29.6%).

The Connect2 program previously mentioned also assessed changes in walking and cycling for transport using a self-administered 7-day recall questionnaire. Additionally, Goodman and colleagues⁴⁷ used a modified IPAQ short form to only assess changes specific to recreational PA. Results indicated that at 1-year follow-up mean levels of walking or cycling remained relatively steady (+4 minutes), while levels of total PA declined (-13 minutes). Furthermore, proximity to the Connect2 trails did not significantly predict changes in PA at 1-year follow-up. However, at the 2-year follow-up, a significant increase in weekly walking/cycling and total PA (15.3 minutes, 95% CI = 6.5, 24.2] and 12.5 minutes, 95% CI = 1.9, 23.1, respectively) occurred for every one kilometer (0.6 mile) closer to the Connect2 trails someone lived.⁴⁷

Using data from this same Connect2 cohort, Le Gouais et al.²¹ expanded the findings assessed the odds of trail users meeting the United Kingdom (UK) recommendations for PA (i.e., at least 150 minutes of moderate-intensity PA per week). Analyses resulted in trail users being twice as likely (OR = 2.07, 95% CI = 1.37, 3.21) to meet the UK physical activity recommendations compared to non-trail users at one-year follow-up. Those who used the routes at one-year and two-year follow-up were three times more likely (OR = 3.02, 95% CI = 2.02, 4.62) to meet the UK physical activity recommendations. Additionally, those who used the trails for both recreation and transport purposes were two times more likely to meet the PA recommendations (OR = 2.07, 95% CI = 1.18, 3.75).

In Durham, NC, USA, Cook and colleagues²⁰ used repeat cross sectional self-administered trail intercept surveys before and after the completion of 1-mile trail (1.6-km) was constructed to join two existing trail segments. Questions asked were specific to determining

travel distance on the trail, frequency of trail use, purpose of trail use (e.g., recreation, exercise, commute), trail activity mode, and demographic information. Results from this study found that PA minutes on the trail significantly increased (+4 minutes, $p < 0.05$), a 6% increase ($p < 0.05$) in the proportion of cyclists on the trail, a 6% decrease in joggers/runners on the trail ($p < 0.05$), and the average trip distance on the trail increased for walkers (+0.5 miles [0.8 km]), joggers/runners (+0.4 miles [0.6 km]), and cyclists (+2.7 miles [4.3 km]).

Burbridge and Goulias⁴⁸ investigated the impact of a newly built two-way multiuse trail that was separated from existing sidewalks and roads on travel behavior and PA in Salt Lake City, UT, USA. In addition to a household demographic survey, participants completed three self-administered activity diaries (one before trail construction [AD1] and two post-construction [AD2: within 1-month and AD3: ~5-months]). Participants were instructed to complete their activity diary on a prespecified day of the week for each data collection time point. Data from the diaries included activity type, activity duration, location activity was performed, and travel behavior (distance and mode). Between AD1 and AD2 there was no significant change in total PA episodes or minutes, walking trips, or biking trips. However, between AD1 and AD3, a significant decline in mean PA episodes per day (0.90 vs 0.65, $p = 0.036$) and mean walking trips per day (0.64, vs 0.38, $p = 0.008$) occurred. Analyses also showed that residential proximity to the newly constructed trail did not have significant impact on PA episodes or walking trips.

Summary of Self-Report Questionnaires to Assess the Impact of Trail/Greenway Interventions

Results of the fourteen studies reviewed using self-report questionnaires to assess changes PA were more inconsistent compared to using direct observation and electronic trail counters. Ten of the fourteen studies reported increases in PA after a trail/greenway intervention; however, only five of them were statistically significant. Increases in PA per week ranged from 4

minutes to 62.7 minutes. Additionally, increases in the proportion of individuals meeting the PA guidelines (i.e., ≥ 150 minutes per week of moderate PA or ≥ 75 minutes per week of vigorous PA) ranged from 1.8% to 6.2%. The remaining four studies reported decreases in PA, with three of them being significant decreases. Decreases in weekly PA ranged from 4.4 minutes to 70 minutes, while decreases in the proportion of individuals meeting the PA recommendations ranged from 6.6% to 8.3%. The variation reported across studies may be a result of the self-report questionnaire tool used, the sample population, the PA outcome of interest (e.g., total PA minutes, domain-specific PA minutes, activity-specific minutes), and follow-up timeframe.

There are several limitations across these studies that should be considered. In particular, there are well known biases associated with using self-report questionnaires to assess PA (e.g., recall bias, social desirability bias, and selection bias) that can impact the results and generalizability of the findings. If study participants are already physically active, changes in PA at the individual level may not be detected. Some study designs used pre/post cross-sectional measurements of PA which limits the ability to determine if changes in PA occurred at the individual level. Furthermore, the method of administering the surveys to study participants (e.g., telephone-based, face-to-face interviews, self-administered) may have an impact on the PA outcomes measured.⁴⁹ The study designs used limit our ability to determine causality. Many studies had various definitions of moderate PA, vigorous PA, and what was considered 'meeting the PA recommendations.' Finally, most studies assessed overall PA, not trail-specific activity, which leads to the inability to determine if changes in PA were a result of the trail/greenway or some other social or built environment variable.

Summary

Overall, there was a wide variation in results across studies depending on the methodology used and the PA outcome of interest. When assessing changes in the number of people directly observed or counted (via electronic counter) using the trail/greenway after infrastructure modifications there was a 16% to 188% increase and 7.5% to 347.7% increase, respectively. A 2% to 200% increase was reported specific to directly observed changes in MVPA in the trail/greenway location. Self-report measures to assess changes in PA were more mixed with results ranging from a decrease in MVPA (-70 minutes/week) to an increase of +62.7 minutes/week. Additionally, results across studies assessing the change in proportion of survey respondents meeting the PA recommendations ranged from -8.3% to +6.2%.

Study protocols using direct observation and electronic trail counters consistently reported positive outcomes specific to use of the new trail/greenway infrastructure for PA. Investigations using self-report measures were much more inconsistent in their findings with some reporting decreases in PA in their study population. The variety of intervention components, study protocols, and PA measurement tools used across studies makes it difficult identify which aspects of the trail/greenway intervention are most effective at increasing PA. Furthermore, PA outcome measures were limited by either the inability to identify total or domain-specific PA (direct observation and electronic trails counters) or by the domains they captured via self-report. Future studies should strive to use a combination of valid and reliable methods (i.e., direct observation, electronic counter, and/or self-report measures) when assessing the impact trail/greenway interventions have on PA.

Despite these limitations, the findings of these studies offer ample evidence to promote trail/greenway infrastructure changes in communities to positively affect PA levels. Of note, each

of these studies were on traditional, linear-based trails/greenways or rails-to-trails conversions. Also, additional infrastructure amenities that were incorporated alongside the trail/greenway changes in these studies were play equipment, aesthetic improvements, traffic calming measures, and pedestrian/cyclist safety improvements. A recent investigation (Chapter 5) has demonstrated that a nature-based, recreational trail system has similar seasonal and weather response variations in trail use as traditional, linear-based trails/greenways. Furthermore, an investigation (Chapter 6) of a bike park (park design that incorporates features specific to mountain biking and pump track cycling) adjacent to a trail/greenway provided substantial opportunity for performing MVPA. Taking these into account, future research is needed to determine the role nature-based trail systems and bike parks have on PA levels.

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CHAPTER 3
METHODOLOGY

The purpose of these investigations highlighted in Chapter 1 are specific to the Knoxville Urban Wilderness (KUW), a nature-based recreational setting composed of multi-use trails, a bike park, and other physical activity (PA) amenities. First, a systematic review was conducted to provide a synthesis of published research regarding the effects of trail/greenway built environment interventions on PA (Chapter 4). Second, a study was conducted to analyze the relationship between seasonality and varying weather conditions and the use of natural surface trails for PA (Chapter 5). Finally, an investigation was conducted to create a demographic profile of bike park users (gender, age group, race/ethnicity), determine how the bike park is used for PA, and assess the intensity of PA among park users (Chapter 6). This methodology chapter describes the procedures, measures, and analyses that were used in these three investigations.

Investigation 1

Investigation 1 (Chapter 4) is a systematic review that specifically looks at the impact of trail/greenway built environment interventions on physical activity (PA). The review was registered with the international prospective register of systematic reviews (PROSPERO) on July 7, 2023 (registration number: CRD42023403458) and followed the PRISMA guidelines.¹

Eligibility criteria

This review included studies that assessed exposure to trail or greenway interventions (primary exposure) and the impact on PA levels (primary outcome). Trail or greenway interventions included construction of a new trail, trail improvements (e.g., improved access, trail surface enhancement, trail vegetation management, etc.), and/or trail use promotional campaigns (e.g., radio/tv ads, newspaper articles, fitness challenges, etc. promoting use of the trail). The assessment of PA levels included self-report (e.g., questionnaires) and/or objective measures (e.g., trail count data from electronic devices or direct observation). Studies assessing

changes in number of trail users, total PA, moderate PA (MPA), vigorous PA (VPA), moderate-to-vigorous PA (MVPA), transportation PA, leisure-time/recreational PA, walking, cycling, and/or jogging were included.

Studies using longitudinal pre-and-post study designs (i.e., prospective cohort studies, quasi-experimental, and natural experiments) with quantitative measures were included. We also included studies with repeated cross-sectional study designs (i.e., different survey respondents pre- and post-intervention). A comparator/control group was not required to be eligible for this review. Studies must have included a baseline (pre-intervention) measurement and at least one follow-up (post-intervention) measurement of PA to be eligible. Participants included ambulatory, non-institutionalized individuals of all ages.

We excluded strictly qualitative studies, cross-sectional studies, literature reviews, nonpeer reviewed articles, conference abstracts, studies on trails within national parks/forests, and studies not specific to trails (i.e., focus on built environment or green space as a whole).

Search strategy

The following electronic databases were searched: PubMed, Scopus, SPORTDiscus, Sports Medicine & Education Index, Web of Science, CINAHL, APA PsychINFO, ScienceDirect, Transportation Research International Database, Transportation Library, and Engineering Village: Compendex. Additionally, reference lists of included studies and relevant reviews were scanned for additional studies.

The search strategy was created in conjunction with a health science librarian that included medical subject headings and keywords related to ‘trails,’ ‘greenways,’ and ‘physical activity’ (See Appendix A). Keywords pertaining to ‘intervention type’ and ‘study design’ were left out, along with no restrictions on study location or year of publication, to warrant a

comprehensive search of the available literature. The search strategy was adapted to the specific search requirements of the other databases used in our search. Only studies written in English and published in scientific peer-reviewed journals were included.

Study selection

Studies identified in the initial database search (December 21, 2022) were uploaded into EndNote 20 reference management software and duplicates were electronically removed. Remaining studies were then uploaded into Covidence (www.covidence.org; Veritas Health Innovation, Australia), an internet based systematic review management system, where additional duplicates not recognized by EndNote were electronically removed. Four reviewers (DG, AI, EM, and EF) independently screened titles/abstracts. DG screened all titles/abstracts while AI, EM, and EF distributed screening responsibilities. During the title/abstract screening process, additional duplicates identified by the researchers were manually removed. DG and EF performed the full text screening. During full text screening, rationale for the exclusion of studies was documented by the researchers. Any disagreements throughout the screening process were deliberated by the reviewers (DG and EF) until a consensus was reached. A follow-up database search using the same search strategy previously described was completed on May 12, 2023, to identify any newly published peer reviewed articles since the initial search. Identical screening procedures were followed for the articles identified in the updated literature search.

Data extraction

Important characteristics of each included study were extracted and organized. DG performed data extraction on all studies included while AI and EM distributed data extraction responsibilities. Study level data included title, first author, year of publication, data collection timeframe, geographical location, and study design. Population level data included sample size,

age, gender, race/ethnicity, and socioeconomic status for intervention and control/comparator (if included) groups. Exposure level characteristics included type of intervention, trail setting/characteristics, trail exposure criteria, control/comparator group criteria. Outcome level data included type of PA outcome, PA assessment technique (objective vs subjective), PA assessment tool, statistical technique(s) used, estimate type(s), fully adjusted model covariates, and any additional information relevant to the research question. Some studies employed methodologies that collected certain data in the post-intervention timeframe only. Data obtained from only the post-intervention timeframe was not extracted for use in this review.

Synthesis

A qualitative synthesis of the included studies was conducted regarding greenway/trail interventions. The review team decided to place studies into one of two classifications similar to what was used by the Community Preventive Services Task Force (CPSTF)² and Hunter et al.³ Studies were classified as either:

- (I). Greenway or trail infrastructure change with no additional interventions
- (II). Dual approach interventions [greenway or trail infrastructure change combined with additional interventions (e.g., enhanced accessibility and/or community engagement)].

Following analysis of the included studies and based on conversations among the research team, it was decided to further separate dual approach interventions into two categories:

- (I). Trail/greenway infrastructure change plus enhanced accessibility (e.g., improved accessibility to residential, commercial, and/or community/recreation areas, intersection improvement, pedestrian/cyclist amenities, landscaping, etc.)

- (II). Trail/greenway infrastructure change plus enhanced accessibility and community engagement (e.g., community involvement in planning/design of infrastructure changes, media campaigns promoting trail use, PA programming, etc.)

The research team felt the further breakdown of dual approach interventions would provide more useful information to practitioners and policymakers and allow for better recommendations for future research. When determining the effect of the built environment intervention on PA, studies were classified as: 1.) Favorable (reported a statistically significant increase in PA or reported an increase in PA without performing statistical analysis), 2) Unfavorable (reported a statistically significant decrease in PA or reported a decrease in PA without performing statistical analysis), or 3.) Non-significant (reported non-significant changes in PA). Multiple publications from the same study were collapsed into a single study for reporting purposes.

Critical appraisal

Included studies went through a quality assessment process using the Joanna Briggs Institute (JBI) design-specific critical appraisal tool.⁴ DG completed the critical appraisal of all included articles. All studies were then cross-checked by either AI and EM for accuracy. Any discrepancies between the reviewers were resolved through discussion until a consensus was reached. An appraisal score was calculated for each included article. A raw score $\leq 49\%$ indicated low-quality, 50-69% indicated moderate-quality, and $\geq 70\%$ indicated high-quality. All studies were included in this review regardless of appraisal score.

Investigations 2 and 3

Investigations 2 and 3 (Chapters 5 and 6) are part of a larger 'Health and Economic Impact' study of the KUW. This project started when the Appalachian Mountain Bike Club (AMBC) received a \$5,000 grant from the International Mountain Bicycling Association in

August 2020. This grant enabled AMBC to rent two Eco-counter trail counters to begin measuring trail use in the KUW. This led to a collaborative effort by AMBC, the Kinesiology, Recreation, and Sport Studies department, and the Baker Center for Public Policy to study the health and economic impact of the KUW. A timeline of the overall impact study can be found in Figure 3.1. Data specific to Investigation 2 (Chapter 5) includes the ‘Trail User Counts’ and ‘Weather Data’ that were collected from September 2020 through August 2021. Investigation 3 (Chapter 6) includes the ‘SOPARC’ bike park data collected in 2021 (April, July, October) and 2022 (January, April).

Study Area

Knoxville’s Urban Wilderness. Investigations 2 and 3 (See Chapters 5 and 6) highlighted in Chapter 1 were conducted at the Knoxville Urban Wilderness in Knoxville, TN.⁵ The KUW is an urban, nature-based outdoor recreation area centrally located within three miles of downtown Knoxville, TN and provides a pristine natural setting for performing leisure-time PA (See Figure 3.2). Features and amenities in the KUW include, but are not limited to, 50+ miles of mountain biking and hiking/running trails, Baker Creek Bike Park, a natural rock-climbing wall, a nature center, access to the Tennessee River and two water filled quarries for swimming, fishing, and paddle boarding. The trail network has 12 primary trailheads and numerous secondary access points located within neighborhoods that border the urban wilderness. It has been estimated that over 303,000 individual trips were made to the KUW trail system in 2021.⁶ In addition to the high use of the trail system, the economic benefit of the KUW has been estimated at \$25+ million.⁷

Baker Creek Bike Park. Within the KUW, the Baker Creek Bike Park (See Figure 3.3) was built in 2020 and is approximately 15 acres in size.⁸ The bike park contains a total of 13

Data Collection Method	Sep-20	Oct	Nov	Dec	Jan-21	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-22	Feb	Mar	Apr
Trail User Counts																				
Trail DO								¹			²			²			²			³
Weather Data																				
Bike Park SOPARC																				
Online Self-Report Surveys 1 & 2																				

Abbreviations: DO=Direct Observation, SOPARC=System for Observing Play and Recreation in Communities

¹DO performed at eight trails (Baker Creek, Ijams, Marie Myers, William Hastie, Lost Chromosome, Trans Farm, West Perimeter, Red Bud)

²DO performed at two trails (Baker Creek and Ijams)

³DO performed at three trails (Baker Creek, Ijams, Lost Chromosome)

Figure 3.1: Timeline of data collection for the KUW Health and Economic study.



Photo source: <https://www.visitknoxville.com/urban-wilderness/engage/trail-maps/>

Figure 3.2: Map of Knoxville's Urban Wilderness

a.



b.



c.



d.



a. Overhead image of the asphalt jump line and pump track.

b. Short asphalt oval pump track.

c. Climbing structure with slide.

d. Gravel pump track loop.

Figure 3.3: Images of Baker Creek Bike Park.

activity zones. These include various cycling specific activity zones with features such as an asphalt jump line, asphalt pump track, gravel progressive bike skills trail, small oval asphalt pump track, gravel pump track loops with wall features, rock navigation skill-building course, kids dirt/gravel pump track, and linear cycling skill-building structures adjacent to the greenway. Other activity zones contain playground equipment such as a climbing structure with a slide, swings, a Lincoln log climbing structure, and benches for seating. Additionally, a paved greenway runs the length of the park and connects to an extensive greenway and multiuse trail network. The bike park was built to provide various mountain biking skill-building features to enable users to progress to the more advanced Baker Creek Preserve which houses five multi-use trails and three bicycle specific downhill trails. These two areas act as a gateway to Knoxville's Urban Wilderness, an outdoor adventure area with over 50 miles of multiuse trails and other recreational opportunities.⁵

Data collection

The following section describes in detail the procedures and measures associated with each of the investigations (Chapters 4-6).

Infrared Trail User Counts. Hourly trail user counts were measured using a combination of TRAFx Trail Counters (TRAFx Research Ltd., Canmore, Alberta, Canada; N=8)⁹ and PYRO-Box counters (Eco-Counter, Montreal, Quebec, Canada; N=3).¹⁰ Both types of trail counters sense and detect the infrared wavelength emitted by people and records a precise timestamp of that user event (e.g., persons walking, running, cycling). Count data from the TRAFx counters were manually downloaded once per month using the TRAFx G3 Dock. Data from the TRAFx G3 Dock was then uploaded to TRAFx DataNet (online platform for viewing, analyzing, and managing TRAFx data).¹¹ The TRAFx trail count data was then exported from the DataNet

platform as an Excel spreadsheet and imported to the Eco-Visio 5 data platform (online platform for viewing, analyzing, and managing Eco-Counter data).¹² This allowed researchers to have access to all trail count data in one location. PYRO-Box counts were wirelessly transmitted through a cellular network to the Eco-Visio data platform on a daily basis. All count data on the Eco-Visio platform, containing merged data from both types of infrared counters, were then exported to SAS Enterprise Guide 8.3 (SAS Institute Inc., Cary, NC, USA) for analysis. Trail user counts were collected on a continuous 24-hour time period beginning in August 2020. The infrared trail counters were programmed to provide the sum of trail user counts per hour for each hour of the day.

Infrared trail user count data from the Baker Creek and Ijams trail counters were used for Investigation 2 (Chapter 5). The specific timeframe used for this study was September 7, 2020, to August 31, 2021. These two trails and infrared trail counters were chosen due to their varying trail surface material (Ijams having gravel and Baker Creek having dirt), high trail count use, and accessibility. Additionally, the canopy, trailside vegetation, and topography are similar between the two trail locations.

Infrared Trail Counter Validation. A two-phase validation procedure was performed to ensure the varying user events would be captured by the infrared trail counters. Phase I occurred prior to beginning data collection and involved 100 passing trials at walking and running speeds and 100 passing trials riding a mountain bike.

To further assess the validity of the infrared trail counters, Phase II involved direct observation (DO) of trail users on two days (Saturday and Sunday), for four 1-hour intervals (8-9am, 12-1pm, 3-4pm, 6-7pm) each day at six counter locations. Due to staffing, we were unable to have observers at all trail counter locations. During this validation phase, comparisons were

made between the number of directly observed trail users and the number of trail users recorded by the infrared trail counter. These are mixed-use trails; therefore, the total number of walkers, runners, and bikers from DO were compared to the total counts registered by the infrared trail counter.

Investigation 2 (Chapter 5) was limited to the infrared trail counters located at Baker Creek and Ijams. Due to the TRAFx trail counters used in this study not being able to distinguish between trail users going into versus out of the KUW trail system, the infrared counter at Ijams (TRAFx) was replaced with an Eco-Counter model that had this capability part way through the data collection period.

Weather-related measures. Hourly weather-related variables were collected from an onsite weather station (Ambient Weather WS-2902A, Ambient, LLC, Chandler, AZ) located within three-miles of all 11 infrared trail counters. Data for various weather variables is transmitted every five minutes from the weather station to Ambient Weather's online server (AmbientWeather.net)¹³ via a wireless fidelity (Wi-Fi) connection. For the purposes of Investigation 2 (Chapter 5), weather variables included temperature (°F), dew point (°F), humidity (%), atmospheric pressure (Hg), wind speed (mph), precipitation (in.), and ultra-violet solar radiation index (Scale 1-11). These weather variables were chosen based on a 2018 research synthesis calling for studies to include additional weather variables besides temperature and precipitation.¹⁴ Weather data was collected from September 7, 2020, to August 31, 2021, for Investigation 2 (Chapter 5).

Direct Observation of Baker Creek Bike Park Users. Systematic direct observations of users within the Baker Creek Bike Park (Investigation 3, Chapter 6) and KUW trail users were completed using the System for Observing Play and Recreation in Communities (SOPARC)

protocol.¹⁵ SOPARC is a momentary time sampling technique of direct observations that provides data regarding the number of park/trail users, gender, age group, race/ethnicity, activity type and PA level (see Appendix B for a sample data collection form). SOPARC is a reliable¹⁵ and valid¹⁶ tool for assessing park/trail user characteristics and PA levels. Referring back to Figure 3.1, the direct observation of bike park and trail users occurred in 2021 (April, July, October) and 2022 (January, April).

Prior to data collection, researchers mapped out the various physical activity zones throughout the Baker Creek Bike Park. This resulted in 13 activity zones (See Figure 3.4) being identified that were labeled as three types of zones: cycling zones (N=9), playground zones (N=3), and a greenway zone. Table 3.1 provides descriptions of the physical features and user bicycling skill levels of each activity zone. Direct observations using the SOPARC protocol were completed on four days during a week (Mon, Wed, Sat, Sun), across three months in 2021 (April, July, October) and two months in 2022 (January, April), at four 1-hour time periods per day (8-9am, 12-1pm, 3-4pm, 5-6pm). A total of four observers completed the SOPARC activity zone measurements. Two of the observers were previously trained with extensive experience using the SOPARC protocol. The two recruited observers received training prior to data collection in both the classroom and on-site at the bike park on SOPARC procedures.

When scanning an activity zone, researchers would stand in a predetermined location and first analyze the contextual factors. This includes if the zone was accessible to the public (e.g., not locked or rented for a private gathering), usable for PA (e.g., not under repair or excessively wet), equipped (e.g., balls, jump ropes, etc. that are provided by the park, not owned by park users), supervised by designated personnel (e.g., sports official, park rangers, volunteers, etc.),

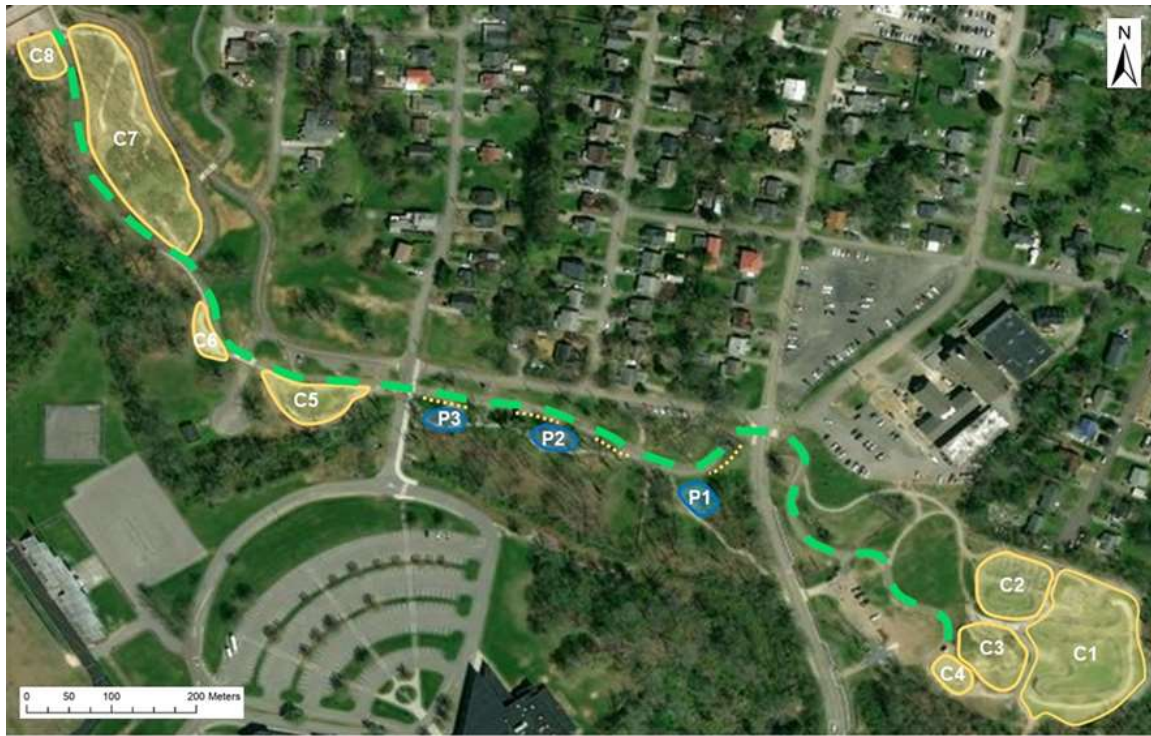


Figure 3.4: Map of Baker Creek Bike Park with labeled activity zones.

Table 3.1: Physical characteristics of the scan zones.

Activity Zone	Description	Cycling Skill Level
Cycling (C)		
1	Pump and jump track with outer stone line. Asphalt jump line with steep and rolled lips.	Intermediate-Advanced
2	Asphalt pump track.	All skill levels
3	Gravel progressive trail bike skills trails.	All skill levels
4	Short oval asphalt pump track.	All skill levels
5	Gravel pump track loop.	All skill levels
6	Rock navigation course for cycling.	Intermediate-Advanced
7	Gravel pump track loop with wall features.	All skill levels
8	Kids dirt/gravel pump track.	Beginner
	Linear cycling skill features adjacent to greenway.	All skill levels
Playground (P)		
1	Climbing structure, slide, and benches.	NA
2	Swings and benches.	NA
3	Climbing structure and benches.	NA
Greenway		
	Paved greenway that connects to extensive greenway and multiuse trail network.	NA

and if the scan zone had organized PA occurring (e.g., a scheduled exercise class or sporting event lead by designated personnel).

Researchers would then systematically scan each activity zone from left to right, first focusing on females and then males in that order. During scans, researchers would record gender (female, male), age group (child, 0-12 years; teen, 13-20 years; adult, 21-59 years; older adult, 60+ years), race/ethnicity (Latino, Black, White, Other), primary PA (the activity choice of the majority of female and male users, separately, within an activity zone), and PA intensity [sedentary (e.g., lying down, standing still, sitting), moderate (e.g., individuals performing PA at an intensity similar to walking at a casual pace), vigorous (e.g., individuals performing activity more vigorous than a casual pace such as jogging, cycling, or climbing)] for each park user. If there were no park users in a scan zone at the time of observation, the activity zone was coded as 'empty.' Researchers completed one scan of all 13 activity zones in order and then repeated the scans for a second time within each 1-hour observation period. The values from the two scans were then totaled for each observation period. A total of 1040 scans were completed across the activity zones. Per the SOPARC protocol, any missed observations due to inclement weather were scheduled for the following week on the same weekday or weekend day and time.¹⁵

Statistical analysis

Investigation 2: Weather Relationship with Varying Natural Trail Surfaces Data Cleaning.

The onsite weather station (Ambient Weather WS-2902A, Ambient, LLC, Chandler, AZ) recorded various weather variables every five minutes for 24 hours each day. Data from the Ambient Weather online server was exported into an Excel document. For analysis purposes, the weather variable data set was first collapsed to only include the weather information that was recorded on the hour for each day (i.e., 7:00am, 8:00am, etc.). The data set was then reviewed to

identify any times/days where weather information was missing and to ensure each hour of each day for the study timeline (September 7, 2020 – August 31, 2021) was included in the data set.

The infrared trail user count data from the Baker Creek and Ijams trails (Investigation 2, Chapter 5) were exported from the Eco-Visio platform into an Excel document. The data were then carefully reviewed to identify any missing data and to ensure each hour of each day for the study timeline was included in the data set. Hourly trail user count data was then adjusted to account for the measurement error associated with each counter (trail counter error was measured during the Phase II direct observation validation protocol). For example, if DO resulted in 179 counts of trail users and the trail counter measured 187 users, the researcher divided $179/187$ which resulted in an adjustment factor of 0.957 for that trail counter. This was repeated for each trail counter included in Investigation 2 (Chapter 5). Hourly trail counts were then multiplied by their respective adjustment factor and rounded to the nearest whole number.

After trail user count adjustments were made, the weather variable data set was then merged with the trail user count data set by date and time of day. The combined data set was then collapsed to only include data specific to civil twilight hours.¹⁷ Civil twilight was chosen as this is the time when normal daily activities can still be performed without artificial light sources.¹⁸ As an example of how this related to data coding, if civil twilight occurred at 6:23 AM and 8:26 PM, data analysis was conducted for those hours between 6 AM and 9 PM. The total number of daylight hours varied across the study period due to seasonal variations in daylight.

Statistical Analysis. The final data set was then imported into SAS Enterprise Guide 8.3 (SAS Institute Inc., Cary, NC, USA) for analysis. The Kolmogorov-Smirnov test was used to determine whether trail user count data was normally distributed. Spearman correlations were used to assess the association between trail user counts and weather-related measures and to

determine if multicollinearity existed between the weather variables. Weather measures found to be highly correlated ($\rho > 0.5$) were examined to determine which of the two variables had the greatest correlation with user counts and was thus retained. Visual inspection of the data detected a curvilinear relationship between temperature and trail counts; therefore, a polynomial term, temperature squared, was added to more precisely determine the effect increasing temperature had on trail counts.

The dependent variable in this analysis was hourly trail user counts (count data). Poisson regression models are a common choice for such data. However, the data from this investigation was highly skewed, contained many zeroes, and was overdispersed; therefore, negative binomial regression models were a better fit for the data.^{19,20} The negative binomial regression models also resulted in a lower Akaike Information Criterion (AIC) compared to Poisson regression models, further supporting their use with the data. To confirm that negative binomial without zero inflation was appropriate, the PROBCOUNTS SAS macro was used to compare the observed zero counts with the predicted zero counts based on the model.²¹

Investigation 3: Baker Creek Bike Park SOPARC Data Cleaning. Bike park SOPARC information from the data collection sheets (see Appendix B) was input into Excel specific to the month of observation (January, April, July, October), day of the week (Monday, Wednesday, Saturday, Sunday), time of day (morning, noon, afternoon, evening), activity scan zone, and gender (female, male). The data set was then imported into SAS Enterprise Guide 8.3. For certain analyses, the 13 activity zones were collapsed into three separate categories based on the physical activity features associated with the activity zone (refer back to Table 3.1, page 61). Also, to calculate percentages for demographic variables and to assess PA intensity of bike park users, the following variables were calculated:

1. Total park users by scan zone: Sum of the number of children, teens, adults, and older adults observed.
2. Total ‘Non-white’ race/ethnicity: Latino, Black, or Other observed bike park users were summed together due to relatively small representation from each group.
3. Sedentary metabolic equivalents (METs): Multiplied the number of persons observed in sedentary behavior by 1.5 METs for each activity zone.²²
4. Moderate-intensity METs: Multiplied the number of persons observed in moderate-intensity activities by 3.0 METs for each activity zone.²²
5. Vigorous-intensity METs: Multiplied the number of persons observed in vigorous-intensity activities by 6.0 METs for each activity zone.²²
6. Total METs: Sum of sedentary METs, moderate-intensity METs, and vigorous-intensity METs for each activity zone.
7. Mean METs: Divided the ‘Total METs’ variable by the sum of the number of people observed in sedentary, moderate-intensity, and vigorous-intensity activities for each activity zone.
8. Activity zone features: This variable coded the activity zones based on its physical activity features [1 = cycling features (N=9); 2 = playground features (N=3); 3 = greenway (N=1)].

Statistical Analysis. Data were analyzed using SAS Enterprise Guide 8.3. Percentages were calculated for all categorical measures (gender, age group, race/ethnicity, PA intensity) and classified by activity zone features (cycling features, playground features, and greenway). Gender and race/ethnicity were compared to the 2020 Knox County, TN census population data using Chi-square statistics. Kappa statistics were calculated to determine inter-observer

agreement for age group, ethnicity, and PA intensity of bike park users. Binary regression analysis was performed to determine the odds of at least one park user (female versus male) occupying an activity zone. T-tests were used to compare mean PA intensity (METs) between females and males by activity zone features.

Summary

The methods explained here provide details for three investigations. Two of the investigations (2 and 3) are a part of a larger ‘Health and Economic Impact’ study of Knoxville’s Urban Wilderness in Knoxville, TN. Specifically, the systematic review protocol is explicit to Investigation 1 (Chapter 4). The infrared trail user count and weather-related measures methodology is explicit to Investigation 2 (Chapter 5), while the Bike Park SOPARC methodology is exclusive to Investigation 3 (Chapter 6). The methods described here will also appear in Chapters 4-6 of this document.

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CHAPTER 4

TRAILS AND PHYSICAL ACTIVITY:

AN UPDATED SYSTEMATIC REVIEW

Abstract

One factor that can influence physical activity (PA) is the built environment in which people live and recreate. Specifically, accessible trails and greenways may provide the infrastructure needed to increase PA. Therefore, the purpose of this investigation was to perform a systematic review of the evidence specific to trail/greenway (T/G) built environment interventions and the impact on PA. **METHODS:** The systematic review was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Relevant studies published through May 12, 2023, were identified by searching 11 electronic databases across public health, recreation, social sciences, and transportation domains. Eligible studies must have included a T/G infrastructure change and pre- and post-outcomes specific to PA. **RESULTS:** 21 studies met the inclusion criteria. Study designs included were primarily pre-post natural/quasi-experiments with control groups (n=10), without control groups (n=5), repeat cross-sectional surveys or trail user counts (n=5). One study used an ecological study design. Overall, 67% (n=14) of the included studies reported favorable PA outcomes, whereas the remaining seven studies reported unfavorable or non-significant findings. **CONCLUSIONS:** In spite of the limitations of included studies, there is supportive evidence for recommending the use of built environment T/G interventions for promoting PA. It is strongly encouraged that an intersectoral and multi-faceted approach is taken when designing T/G interventions. Study limitations need to be addressed to increase the quality of future investigations. To enhance the translation of this research into policy and practice, future investigations should consider other potential benefits associated with T/G interventions including health (e.g., mental health, well-being), social (e.g., social disorder, social capital), environmental (e.g., air quality, natural environment preservation), and economic (e.g., cost-benefit, health economics).

Introduction

The health benefits of regular physical activity (PA) have been well documented and include decreased risk of diabetes, cardiovascular disease, hypertension, obesity, and certain types of cancer.^{1,2} Additionally, PA has been shown to increase both quality of life and well-being.³ Despite these known benefits, globally, approximately 27.5% of adults and 81.0% of adolescents (11-17 years) are insufficiently active.^{4,5}

One potential factor that could contribute to insufficient levels of PA at the community level is the built environment where people live and work. Built environment infrastructure designed to promote PA has been correlated with higher levels of leisure-time PA (LTPA) across all age groups.⁶⁻⁸ Furthermore, both the Office of Disease Prevention and Health Promotion's Healthy People 2030 initiative and the World Health Organization's Global Action Plan on Physical Activity 2018-2030 include objectives focused on improving the built environment to increase population PA.^{9,10}

One aspect of the built environment that has received particular attention are parks, trails, and greenways that could potentially impact PA. In July 2021, based on a systematic review of 38 studies, the Community Preventive Services Task Force (CPSTF) reported mixed findings regarding the impact parks, trails, and greenways have on various PA outcomes.¹¹ This review combined studies identified from a previously published systematic review on built environment urban green space interventions by Hunter et al.,¹² and using the same search strategy, performed an updated search through July 2020. The CPSTF¹¹ found insufficient evidence to determine the effectiveness of park, trail, or greenway infrastructure changes when implemented alone to increase PA. However, when these built environment changes (i.e., infrastructure improvements to parks, trails, or greenways) were combined with other promotional programs (e.g., community

engagement, media campaigns, programs offering structured opportunities for PA), they found sufficient evidence of increased PA within the park, trail, or greenway and increased overall PA.¹¹

The recommendations from the CPSTF¹¹ were based on the combined results of studies that examined infrastructure changes to parks, trails, and/or greenways. However, upon further examination of the results specific to trails and greenways (12 studies), the direction of the effect was more inconsistent. Explicit to the combined interventions (n = 9) included in the CPSTF review,¹¹ only changes in total PA and those meeting recommended PA levels were reported as having an overall favorable direction of effect in combined intervention studies. Inconsistent results were found regarding PA in the infrastructure location and other measures of PA (e.g., activity specific PA, active transportation, etc.) in combined intervention studies. When looking at the studies that only made infrastructure changes to trails and greenways (n = 3), results on all PA outcomes were either inconsistent or not applicable. Limitations identified by both the CPSTF¹¹ and Hunter and colleagues¹² included the limited number of available studies and heterogeneity in interventions implemented.

Thus, performing an updated review that is specific to trails and greenways is needed to identify additional studies published since the CPSTF report and extend the current evidence base. This may allow for a more comprehensive synthesis of available studies and recommendations regarding the effect trails and greenways have on PA. Therefore, the aims of this study are to: 1) identify additional research since the CPSTF review; 2) provide a synthesis of published research regarding the effects of trail and greenway interventions on PA; 3) identify gaps in the current evidence base; and 4) provide recommendations for future research.

Methods

The review protocol described below was registered with the international prospective register of systematic reviews (PROSPERO) on July 7, 2023 (registration number: CRD42023403458). This review follows PRISMA guidelines.¹³

Eligibility criteria

This review included studies that assessed exposure to trail or greenway interventions (primary exposure) and the impact on PA levels (primary outcome). Trail or greenway interventions included construction of a new trail, trail improvements (e.g., improved access, trail surface enhancement, trail vegetation management, etc.), and/or trail use promotional campaigns (e.g., radio/tv ads, newspaper articles, fitness challenges, etc. promoting use of the trail). The assessment of PA levels included self-report (e.g., questionnaires) and/or objective measures (e.g., trail count data from electronic devices or direct observation). Studies assessing changes in number of trail users, total PA, moderate PA (MPA), vigorous PA (VPA), moderate-to-vigorous PA (MVPA), transportation PA, leisure-time/recreational PA, walking, cycling, and/or jogging were included.

Studies using longitudinal pre-and-post study designs (i.e., prospective cohort studies, quasi-experimental, and natural experiments) with quantitative measures were included. We also included studies with repeated cross-sectional study designs (i.e., different survey respondents pre- and post-intervention). A comparator/control group was not required to be eligible for this review. Studies must have included a baseline (pre-intervention) measurement and at least one follow-up (post-intervention) measurement of PA to be eligible. Participants included ambulatory, non-institutionalized individuals of all ages.

We excluded strictly qualitative studies, cross-sectional studies, literature reviews, nonpeer reviewed articles, conference abstracts, studies on trails within national parks/forests, and studies not specific to trails (i.e., focus on built environment or green space as a whole).

Search strategy

The following electronic databases were searched: PubMed, Scopus, SPORTDiscus, Sports Medicine & Education Index, Web of Science, CINAHL, APA PsychINFO, ScienceDirect, Transportation Research International Database, Transportation Library, and Engineering Village: Compendex. Additionally, reference lists of included studies and relevant reviews were scanned for additional studies.

The search strategy was created in conjunction with a health science librarian that included medical subject headings and keywords related to ‘trails,’ ‘greenways,’ and ‘physical activity’ (Appendix A). Keywords pertaining to ‘intervention type’ and ‘study design’ were left out, along with no restrictions on study location or year of publication, to warrant a comprehensive search of the available literature. The search strategy was adapted to the specific search requirements of the other databases used in our search. Only studies written in English and published in scientific peer-reviewed journals were included.

Study selection

Studies identified in the initial database search (December 21, 2022) were uploaded into EndNote 20 reference management software and duplicates were electronically removed. Remaining studies were then uploaded into Covidence (www.covidence.org; Veritas Health Innovation, Australia), an internet based systematic review management system, where additional duplicates not recognized by EndNote were electronically removed. Four reviewers (DG, AI, EM, and EF) independently screened titles/abstracts. DG screened all titles/abstracts

while AI, EM, and EF distributed screening responsibilities. During the title/abstract screening process, additional duplicates identified by the researchers were manually removed. DG and EF performed the full text screening. During full text screening, rationale for the exclusion of studies was documented by the researchers. Any disagreements throughout the screening process were deliberated by the reviewers (DG and EF) until a consensus was reached. A follow-up database search using the same search strategy previously described was completed on May 12, 2023, to identify any newly published peer reviewed articles since the initial search. Identical screening procedures were followed for the articles identified in the updated literature search.

Data extraction

Important characteristics of each included study were extracted and organized. DG performed data extraction on all studies included while AI, EM, and EF distributed data extraction responsibilities. Study level data included title, first author, year of publication, data collection timeframe, geographical location, and study design. Population level data included sample size, age, gender, race/ethnicity, and socioeconomic status for intervention and control/comparator (if included) groups. Exposure level characteristics included type of intervention, trial setting/characteristics, trial exposure criteria, control/comparator group criteria. Outcome level data included type of PA outcome, PA assessment technique (objective vs subjective), PA assessment tool, statistical technique(s) used, estimate type(s), fully adjusted model covariates, and any additional information relevant to the research question. Some studies employed methodologies that collected certain data in the post-intervention timeframe only. Data obtained from only the post-intervention timeframe was not extracted for use in this review.

Analysis and synthesis

It was decided by the review team that a meta-analysis was not suitable due to the heterogeneity in research design, statistical procedures used, and PA outcomes reported across the various studies included in this review. Therefore, we conducted a qualitative synthesis of the included studies regarding greenway/trail interventions. The review team decided to place studies into one of two classifications similar to what was used by the CPSTF¹¹ and Hunter et al.¹² Studies were classified as either:

- (I). Greenway or trail infrastructure change with no additional interventions
- (II). Dual approach interventions [greenway or trail infrastructure change combined with additional interventions (e.g., enhanced accessibility and/or community engagement)].

Following analysis of the included studies and based on conversations among the research team, it was decided to further separate dual approach interventions into two categories:

- (I). Trail/greenway infrastructure change plus enhanced accessibility (e.g., improved accessibility to residential, commercial, and/or community/recreation areas, intersection improvement, pedestrian/cyclist amenities, landscaping, etc.)
- (II). Trail/greenway infrastructure change plus enhanced accessibility and community engagement (e.g., community involvement in planning/design of infrastructure changes, media campaigns promoting trail use, PA programming, etc.)

The research team felt the further breakdown of dual approach interventions would provide more useful information to practitioners and policymakers and allow for better recommendations for future research. When determining the effect of the built environment intervention on PA, studies were classified as: 1) Favorable (reported a statistically significant increase in PA or reported an increase in PA without performing statistical analysis), 2) Unfavorable (reported a

statistically significant decrease in PA or reported a decrease in PA without performing statistical analysis), or 3) Non-significant (reported non-significant changes in PA). Multiple publications from the same study were collapsed into a single study for reporting purposes.

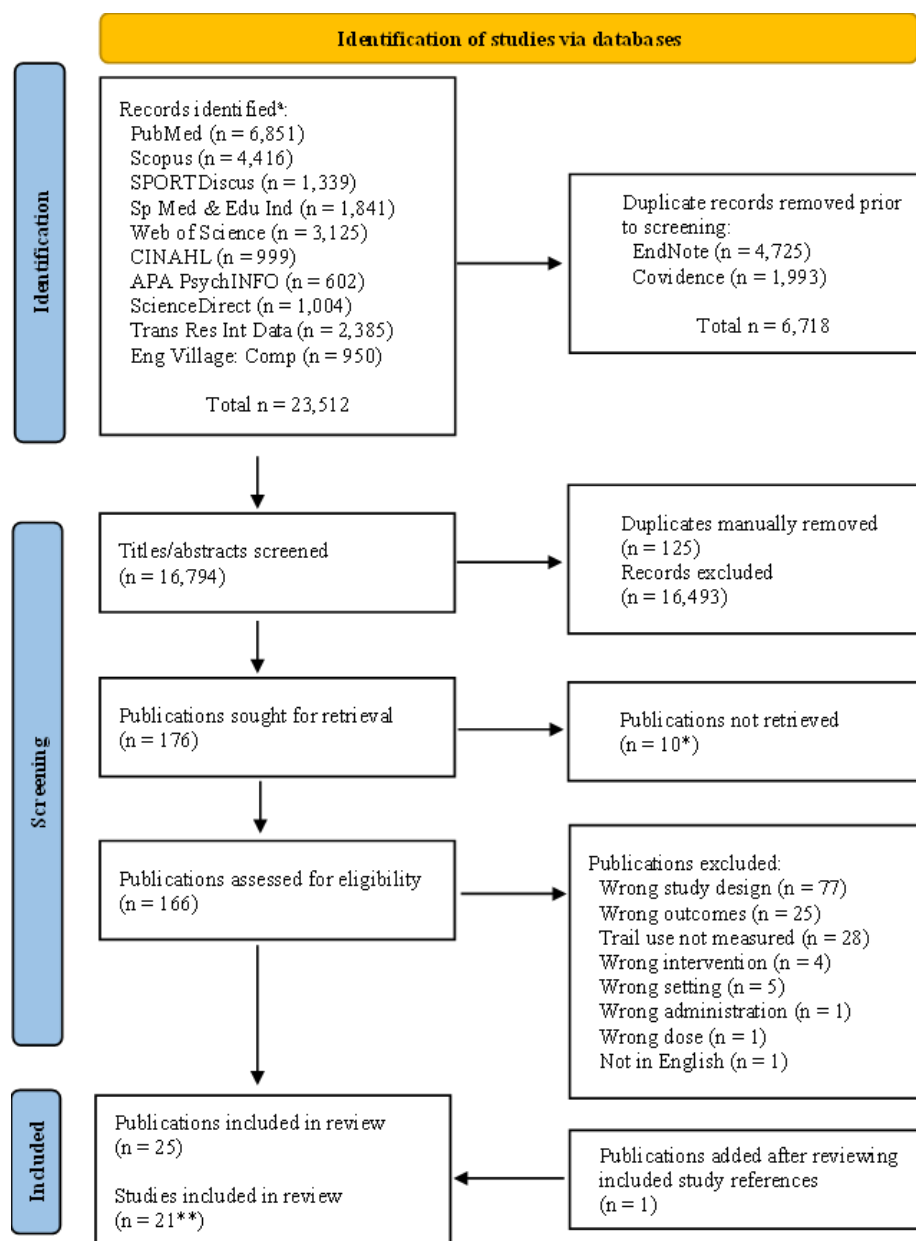
Critical appraisal

Included studies went through a quality assessment process using the Joanna Briggs Institute (JBI) design-specific critical appraisal tool.¹⁴ DG completed the critical appraisal of all included articles. All studies were then cross-checked by either AI, EM, or EF for accuracy. Any discrepancies between the reviewers were resolved through discussion until a consensus was reached. An appraisal score was calculated for each included article. A raw score $\leq 49\%$ indicated low-quality, 50-69% indicated moderate-quality, and $\geq 70\%$ indicated high-quality. All studies were included in this review regardless of appraisal score.

Results

The search strategy and updated publication timeline (through May 2023) used in the current investigation resulted in an additional nine studies that provided PA outcomes across 13 publications. Of these 13 additional publications, six were from the timeline used for the CPSTF review (through July 2020) and the remaining seven occurred after the CPSTF search timeline. Studies from the CPSTF review¹¹ (n = 12) were included by default.

Figure 4.1 shows the flow diagram for identification of studies included in this review. The database search identified 23,512 publications (combined initial and follow-up searches). 176 publications remained for full text review after duplicates were removed and titles/abstracts were screened. Full text screening (including reference screening) resulted in 25 publications for inclusion in this systematic review. The final sample size of 21 studies was due to some interventions having multiple publications reporting various PA outcomes. The combined



*Combined n from December 21, 2022, and May 12, 2023, database searches.

*Conference abstracts only

**Due to multiple publications from individual studies

Figure 4.1: PRISMA flow diagram for the identification of studies.

proportion of agreement between reviewers was 98.9% and inter-rater agreement was moderate (Cohen's $\kappa = 0.48$) for the title/abstract and full text screening.

Table 4.1 shows the majority of studies (86%, $n = 18$) employed a dual approach intervention while three studies employed a built environment trail/greenway infrastructure intervention only approach (no additional intervention). The bulk of all included studies (57%) were conducted in the United States ($n = 12$), followed by the United Kingdom ($n = 3$), Australia ($n = 3$), Canada ($n = 2$), and China ($n = 1$). Twenty of the interventions (95%) were conducted in urban/suburban settings with only one being conducted in rural Hawaii.²⁹ Two studies included in this review were conducted in low-income and/or minority neighborhoods,^{15,28} while the remaining were in more affluent, primarily white areas. Study designs included natural/quasi-experiments with controlled pre-post design (48%, $n = 10$), uncontrolled pre-post design ($n = 5$), pre-post design with repeated cross-sectional surveys ($n = 3$), and two studies used a pre-post design with repeat measures of trail user counts. One study used an ecological study design.²⁹ Trail/greenway lengths of the included studies ranged from 2-km²⁴ to 102-km.³⁰

Evidence Synthesis

Table 4.2 presents a summary of overall study outcomes by type of intervention. When looking at the effect of trail interventions on various PA outcomes, 14 studies (67%) reported an overall favorable effect,^{16,17,19,20,22,23,25,27-30,34-36} two of which reported favorable PA outcomes without performing analysis.^{29,34} Three studies (14%) reported an unfavorable effect,^{21,33,37} and four studies (19%) reported no statistically significant effect.^{15,24,38,39} A total of 18 investigations (86%) used a dual approach intervention (trail/greenway infrastructure changes with additional interventions) and found an overall favorable result regarding PA outcomes.

Table 4.1: Summary of trail intervention studies.

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
<i>Dual approach interventions (infrastructure change and additional intervention)</i>							
Auchincloss et al., 2019 ¹⁵	Philadelphia, PA, USA	Quasi-experiment, pre-post with comparison	Census data: Pop. density 5666 per km ² ; 91% NH-Black; Median income of \$27,240; 8% had bachelor's degree or higher	Construction of 1.5-mi greenway along arterial streets, including intersection improvements, bus stop shelter, streetlights, planted trees, bicycle racks, and storm water management	Baseline (Fall 2011) and follow-up (Fall 2014) ~16-months post-construction	Persons observed per hour (SOPARC) Proportion of users participating in MVPA (SOPARC)	n = 8783 Increase in persons/hr observed at both INT (pre: 100, post: 116) and CON (pre: 128, post: 159). Non-sig difference between INT and CON Increase in proportion of users participating in MVPA at both INT and CON. Non-sig difference between INT and CON (p = 0.76)
Benton et al., 2021 ¹⁶	Manchester, UK	Natural experiment, pre-post with two comparison sites	58.82% female and 98.04% White	Phase 1 (May 2018) included new and resurfaced footpaths, improved entrance points, vegetation clean-up, new benches, signage, and informal play equipment. Phase 2 (Feb 2019) included new footpaths linked to residential housing.	Baseline (Nov 2017) and follow-up (7-mo (Jun 2018), 12-mo (Nov 2018), and 24-mo (Nov 2019))	Median persons observed per observation (MOHAWk) Persons observed in walking or vigorous PA (MOHAWk)	n = NR Sig increase in persons observed in INT compared to CON at 7-mo (IRR 1.67, p < 0.001), 12-mo (IRR 2.10, p < 0.001), and 24-mo (IRR 2.42, p < 0.001) follow-up Sig increase in persons observed walking at 7-mo (p = 0.005), 12-mo (p < 0.001), and 24-mo (p < 0.001). Sig increase in persons observed in VPA at 7-mo (p = 0.009) and 24-mo (p = 0.002)
Clark et al., 2014 ¹⁷ ; Clark et al., 2015 ¹⁸	Las Vegas, NV, USA	Quasi-experiment, pre-post with control	NR	Media campaign promoting trail use (0-6 months); wayfinding and distance markers installed (6-12 months). Both INT and CON were exposed to the media campaign	Baseline (Oct 2011) and follow-up (6-mo (Apr 2012) and 12-mo (Oct 2012))	Trail user counts (TRAFx infrared trail counter)	n = NR Sig increase in mean users/day from baseline to 12-mo follow-up in both INT (pre: 79, 6-mo: 141, 12-mo: 107, p < 0.01) and CON (pre: 112, 6-mo: 144, 12-mo: 147, p = 0.039)

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
Cook et al., 2016 ¹⁹	Durham, NC, USA	Natural experiment, repeated cross-sectional survey, pre-post with no control	Pre-construction survey (n = 1301), Post-construction survey (n = 2245) Typical trail user was male (~55% of users), 26-54 yrs, had advanced degree, and household income between \$60k-\$119,999.	Construction of bicycle/pedestrian bridge and paved connections that linked two trail segments to create a continuous 22-mile shared-use path.	Baseline (May/June 2013) and follow-up (May 2014).	Manual direct observation trail counts (tool NR) Trail intercept surveys (tool NR)	Raw trail counts: Pre: 9,266 Post: 21,365 Sig increase in PA minutes on the trail (pre:59 min, post: 63 min, p < 0.05) Sig increase in proportion of cyclists (+6%, p < 0.05), but sig decrease in proportion of joggers/runners (-6%, p < 0.05) Reported increase in average distance traveled in miles by all user groups.
Crane et al., 2017 ²⁰	Sydney, Australia	Quasi-experiment, pre-post design with control	n = 189 INT group: Female: 56.6% Age (yrs): -18-34: 40.7% -35-55: 59.3% Education: -≥Tertiary: 73.0% Income (\$AU): -≥\$80k: 57.1% Reported differences between INT and CON including age, children in household, owned a car and bicycle, and less skewed income.	Construction of a 2.4-km bi-directional protected (via raised curbs) cycleway. Traffic calming measures, improved footpaths, pedestrian crossings, and tree coverage were also implemented.	Baseline (Oct 2013) and follow-up post-construction (4-mo (Sep/Oct 2014) and 16-mo (Sep-Nov 2015))	Bicycle counts (electronic counter) Self-report total PA minutes (Active Australia Survey)	Living <3km associated with 4x greater likelihood of using trail (OR 3.93, 1.51, 10.23). Those living 1-2.99 km were more likely to increase cycling frequency and duration compared to those living >3km. Cycling (minutes): <1 km to cycleway p = 0.007 Pre: 9.1 (-48.3, 66.4) 4-mo: 30.5 (-36.6, 97.6) 16-mo: -37.1 (-105.9, 31.7) 1-2.99 km to cycleway Pre: -2.8 (-63.0, 57.4) 4-mo: 76.8 (4.8, 148.9) 16-mo: 96.2 (19, 173.4) MVPA (minutes): p = 0.1 Pre: 7.3 (-29.8, 44.4) 4-mo: -25.5 (-70.4, 19.3) 16-mo: -2.9 (-85.0, 26.4)

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
							1-2.99 km to cycleway Pre: 24.6 (-15.3, 64.4) 4-mo: 29.6 (-21.0, 80.1) 16-mo: -29.3 (-85.0, 26.4)
Evenson et al., 2005 ²¹	Durham, NC, USA	Quasi-experiment, natural experiment, pre-post design with no control	n = 366 Female: 64.7% Age (yrs): -18-29: 8.9% -30-39: 25.0% -40-49: 23.6% -50-64: 29.4% -> 65: 13.1% Education (yrs): -< 12: 9.7% -13-15: 15.2% -> 16: 75.1 Employment: -% Employed: 70.5% Race/ethnicity: -NH-white: 58.5% -NH-black: 34.2% -Other: 7.4%	Construction of a 2.8-mi trail, along with a 2.0-mi spur (completed in Sept 2002).	Baseline (Jul 2000-Apr 2001) and follow-up (Nov 2002)	Self-report minutes/week of leisure activity (1984-2000 BRFSS) Self-report minutes/week of MVPA, walking, and bicycling (2001 BRFSS) Self-report minutes/week transportation PA (30-day recall)	NS effect on leisure activity (min/wk), walking and bicycling (min/wk), or moderate PA (min/wk) in those who had ever or had never used the trail. Vigorous PA (min/wk): Ever used trail (median & IQR): Pre: 90 (0-180) Post: 20 (0-120) p = 0.01 Never used trail: Pre: 0 (0-120) Post: 0 (0-60) p < 0.0001 A significant decline in bicycling for transportation was found in those who never used the trail. Participants who used the trail were more likely to decrease bicycling time and was not associated with meeting PA recommendations.
Fields et al., 2022 ²²	Minneapolis, MN, USA	Natural experiment, longitudinal repeated measures	NR	Over 76-mi of new facilities to increase cycling network connectivity including sidewalks and improved connections to transit stations, schools, residences, businesses, and recreation areas.	Baseline (Sept 2007) and yearly follow-up in Sept through 2013	Manual bicycle counts on weekday during high commute times (tool NR)	Bicycle counts: Mean (SD) 2007: 138 (114) 2008: 172 (154) 2009: 161 (149) 2010: 151 (141) 2011: 188 (187) 2012: 185 (187) 2013: 211 (198)

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
				Construction occurred between 2007-2013. 7-mi of the new facilities were protected bicycle lanes (6-mi of trails and 1-mi on-street protected)			Growth in cyclists observed: # of cyclists (95% CI) Protected bikeways: +21.47 (7.51, 35.44) No on-site facility: +1.4 (-7.88, 10.67) % increase in cyclist observed: Protected bikeways (69% increase); On-street bike lanes (26% increase); No on-site facility (-10% increase) For each mile of protected bikeway added, 11.57 (95% CI 0.76, 22.38) more cyclists were observed.
Fitzhugh et al., 2010 ²³	Knoxville, TN, USA	Quasi-experiment, pre-post design with control	Census data: INT group: Median age: 30.0 yrs % Female: 50.2 % Unemployed: 5.6 % Black: 6.9 % <high school: 9.3 Median household income (\$): 36,563	Retrofit a neighborhood with a 2.9-mi, 8-ft wide urban greenway/trail that improved access to retail and businesses, schools, and other public spaces.	Baseline (Mar 2005) and follow-up (Mar 2007)	Neighborhood observation of PA (Langford, 2001) School-level observation of active travel to school (Suminski et al., 2006))	Neighborhood 2-hr PA counts (median): INT: Pre: 4.5 INT: Post: 13.0 (p = 0.000) CON: Pre: 3.0 CON: Post: 1.0 (p = 0.000) Reported a sig increase in observed pedestrians (p = 0.0001) and cyclists (p = 0.038). School-level 2-hr PA counts (median): INT: Pre: 8.5 INT: Post: 9.0 CON: Pre: 30.0 CON: Post: 19.0
Frank et al., 2019 ²⁴	Vancouver, Canada	Natural experiment, pre-post design with control	n = 524 INT group: Mean (95% CI) Age (yrs): -46.2 (44.3, 48.1) % Female: -0.55 (0.49, 0.62)	Construction of a 2-km greenway consisting of cycling facilities and streetscape improvements. The greenway included shared on-street lanes (22%), one-way protected (29%), and two-way shared on-street lanes.	Baseline (Oct 2012-Mar 2013) and follow-up (Oct 2014-Mar 2015)	Minutes/week of MVPA (IPAQ-SF) Minutes/day of sedentary (IPAQ-SF)	MVPA (min/wk): Mean (95% CI) INT (NS increase): Pre: 51.9 (43.2, 60.5) Post: 62.9 (47.6, 78.2) CON (NS decrease): Pre: 58.7 (48.1, 69.3) Post: 52.8 (43.6, 62.0)

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
			% White: -0.86 (0.82, 0.91) Employment status: -0.73 (0.67, 0.78) Post-secondary education: -0.72 (0.67, 0.78)				Met MVPA guidelines (>20 min/day): % (95% CI) INT (NS increase) Pre: 67.6 (61.3, 73.8) Post: 69.4 (63.3, 75.6) CON (NS decrease) Pre: 68.7 (63.1, 74.3) Post: 60.8 (54.8, 66.7) Odds of achieving MVPA guidelines: OR (95% CI) INT: 2.00 (1.00, 3.98) Odds of achieving MVPA guidelines decreased as distance from greenway increased.
Goodman et al., 2014 ²⁵ ; Le Gouais et al., 2021 ²⁶	Cardiff, Kenilworth, and Southampton, UK	Quasi-experiment, longitudinal design with no control Le Gouais et al. (2021) use repeated cross-sectional surveys	n = 1465 2-yr follow-up cohort sample: Female: 56.7% Age (yrs): -18-34: 9.7% -35-49: 19.9% -50-64: 35.5% -65-89: 34.9% White: 96.9% Post-secondary education: 39.5% Annual household income (£): ->40,000: 32.1% -20,001-40,000: 33.7% -< 20,000: 34.3% The cross-sectional cohorts were more commonly male, working age, employed full-time, white, in good health, from more deprived	Connect2 program included creation of 84 walking and cycling routes across the UK. Goodman et al. (2014) focused on the following: Cardiff and Kenilworth constructed a traffic-free bridge; Southampton renovated a footpath into a boardwalk. Additional improvements included improved signage, on- and off-road feeder routes to the larger projects.	Baseline (Apr 2010) and follow-up (1-yr (Apr 2011) and 2-yr (Apr 2012)	Total walking and cycling minutes (7-day recall & IPAQ-SF) Total PA minutes (7-day recall & IPAQ-SF) Trail counts (manual) Meeting PA guidelines (7-day recall)	Manual trail counts (across all sites): Pre: 189,250 Post: 319,531 Total walking and cycling minutes per km closer to trails: Parameter est. (95% CI) 1-yr: 4.6 (-4.2, 13.4) 2-yr: 15.3 (6.5, 24.2) Total PA minutes per km closer to trails: Parameter est. (95% CI) 1-yr: 4.3 (-5.9, 14.5) 2-yr: 12.5 (1.9, 23.1) 2-yr follow-up showed those living closer to the Connect2 project significantly increased their previous week PA.

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
			areas, and without children.				Meeting PA guidelines: Route users were more likely to meet the PA guidelines compared to non-users. Walking and cycling on the new routes associated with meeting PA guidelines.
Grunseit et al., 2019 ²⁷	Sydney, Australia	Natural experiment, pre-post design with no control	NR for trail count data	Completion of an off-road, 8.5-km loop trail around a lagoon that linked two suburbs.	Baseline (Nov 2012) and follow-up (Jul 2015)	Trail user counts (EcoCounter)	Sig increase in bicycle counts (average/week) at Middle Creek (+1391) and Jamieson Park (+1899). Sig increase in pedestrian counts (average/week) at Middle Creek (+1149) and Jamieson Park (+812)
Gustat et al., 2012 ²⁸	New Orleans, LA, USA	Pre-post design, repeat cross-sectional survey with control	n = 105 (trail INT neighborhood) African Amer: 85.7% Female: 54.7% Employed: 61.2% >GED/HS: 82.9% Age (SD): 41.6 (14.3) Annual income (\$): ->20,000: 36.0%	Installation of an 8-ft wide walking path that spanned 6 blocks through a grassy median	Baseline (Sep 2006-Feb 2007) and follow-up (Oct 2008-Jan 2009)	Directly observed neighborhood PA (SOPARC) Walking for leisure and transportation (self-report) Engagement in other activities (self-report)	Observed neighborhood MVPA: Pre: 36.7% Post: 41.0% p < 0.001 Observed neighborhood VPA: Pre: 10.5% Post: 13.7% p < 0.001 Control neighborhoods had decrease in % observed in MVPA & VPA. Walk for transport and leisure: Trail INT neighborhood Pre (transport): 29.3% Pre (leisure): 60.0% Post (transport): 34.8% Post (leisure): 65.3%
Harding et al., 2017 ²⁹	Oahu, HI, USA	Ecological, pre-post design with no comparison	NR	Construction of a 2.43-m wide, 1.4-mi long paved mixed-use path that connected two towns	Baseline (2009) and follow-up (2012)	% participating in LTPA (BRFSS)	% participating in LTPA (95% CI): Pre: 82.6% (71.3, 90.1) Post (2012): 87.6% (78.6, 93.2)

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
He et al., 2021 ³⁰ ; He et al., 2022 ³¹ ; Xie et al., 2021 ³²	Wuhan, China	Natural experiment, pre-post design with comparison	n=1,020 (Residents living within 5-km of three greenway entrances) Female: 56.9% Mean age: 50.8 yr Employed: 55.9% Mean annual household income (in 1000 CNY): 202.3	Conversion of a motorized vehicle road into a 102-km traffic-free greenway with walking trails and biking lanes. -Phase I completed Dec 2016 -Phase II completed Dec 2017	Baseline (Apr 2016) and follow-up (Apr 2019)	Walking minutes and overall PA minutes (IPAQ)	Overall weekly walking minutes sig increased: Mean (SD) Pre: 530.2 (657.5) Post: 561.4 (399.2) Change: 31.2 (206.2) p < 0.001 As distance from the greenway increased the effect on weekly walking minutes decreased. The greenway intervention had a stronger effect on females, those with low SES, and the working-age group. MVPA (METs/wk): INT Pre: 657.2 (676.8) INT Post: 719.9 (706.0) Change: 62.7 (318.0), p<.001 CON Pre: 668.5 (596.9) CON Post: 675.0 (604.3) Change: 6.5 (156.9), NS change Total PA (MET-min/wk): INT Pre: 4304.5 (3678.6) INT Post: 4753.4 (3814.3) Change: 448.9 (1733.0), p<.001 CON Pre: 4502.5 (3420.2) CON Post: 4482.3 (3464.1) Change: -20.3 (904.6), NS change
Hunter et al., 2021 ³³	Belfast, Northern Ireland, UK	Quasi-experiment, pre-post design with control, repeated cross-sectional surveys	Pre (n=1037) Post (n=968) Residents living within 29 electoral wards -Pre- and post-samples had similar characteristics	Regeneration included 9-km urban greenway, 16-km of new or improved foot and cycle paths, 23 new or improved bridges/crossings, 22 signage points, public art, upgraded parks, and	Baseline (2010-2011) and follow-up (2016-2017)	Proportion meeting UK PA guidelines Total PA minutes via domains of work, active travel, and recreational PA (GPAQ)	INT area: % meeting guideline Pre: 68% Post: 61% p < 0.0001

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
			Baseline sample: Male: 41.0% Mean age: 50.3 (18.9) Post-secondary education: 34.7% Weekly household income (£): -60-230: 35.6% -231-580: 37.0% ->580: 27.4%	lighting columns along the entire route. Promotional programs to encourage use of the greenway.			Total PA min/day (SD) Pre: 89.9 (125.8) Post: 72.6 (102.7) p = 0.0002 PA minutes excluding work (SD) Pre: 44.2 (55.1) Post: 39.8 (50.3) p < 0.0012 Results not significantly different between INT and CON areas. Distance from greenway had no significant effect on PA outcomes.
Matsuoka et al., 2005 ³⁴	West Hawaii, USA	Longitudinal design, repeat measures with no control	NR	Revitalize walking/jogging paths. -Began 2002 Conduct community-wide trail use promotional campaigns. -Apr 2003, Jan 2004, Jan 2005	Baseline: -Jan/June 2003 (after revitalization had begun, but prior to promotion campaigns) Follow-up: -Jan/June (2004 and 2005)	Trail user counts (Tool NR) -Walking counts taken morning, noon, and evening on two weekday and one weekend day in January and June (2003-2005)	Trail use counts: January Pre (2003): 582 Post (2005): 721 June Pre (2003): 361 Post (2005): 471
McGavok et al., 2019 ³⁵	Winnipeg, Manitoba, Canada	Natural experiment, pre-post design with comparison time frame	n=218 (trail user demographics from a post-intervention survey) Female: 58% Annual household income >\$50k: 60% >35 yrs: 58% Caucasian: 75.2%	Seasonal 10-km waterway trail created on two frozen rivers that is added to an existing urban trail network. Includes art displays, distance markers, and warming huts. -Trail last ~10 wks	Baseline: Pre-control -Dec 2017-Jan 2018 & Dec 2018-Jan 2019 Intervention -Jan-Mar 2018 & Jan-Mar 2019 Post-control -Mar-Apr 2018 & Mar-Apr 2019	Trail user counts (EcoCounter)	Trail use counts: 2017/2018 Pre-control: 51,183 Intervention: 266,581 Post-control: 41,728 2018/2019 Pre-control: 25,849 Intervention: 182,298 Post-control: 21,709 Interrupted time series analysis showed significant increase (p < 0.001) in trail counts when frozen waterway opened and decreased significantly (p < 0.001) upon closure of trail.

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
Merom et al., 2003 ³⁶	Sydney, Australia	Quasi-experiment, pre-post design with no control	n=450 (cohort that completed both surveys) 2/3 of baseline sample were 'inner' residents (<1.5-km to trail). Male: 57% Age 35-55: 52% > HS education: 44% Full-time job: 58% Characteristics for 'inner' and 'outer' residents were similar.	Construction of a 16.5-km rail trail in Dec 2000. Short-term (Dec 2000-Feb 2001) promotional campaign that targeted people living within 5-km of the rail trail.	Baseline (Nov-Dec 2000) and follow-up (Mar 2001)	Bicycle user counts (Device NR) Walking and cycling behavior (self-report) Use of new trail (self-report)	Bike count data (Mean daily counts): Cabramatta Pre (weekday): 11.4 Pre (weekend): 17.6 Post (weekday): 14.7 Post (weekend): 24.0 Guildford Pre (weekday): 16.8 Pre (weekend): 19.8 Post (weekday): 24.2 Post (weekend): 26.2 Significant increase in trail usage from baseline (1.6%) to follow-up (5.6%). p < 0.005 Trail use significantly higher among bike-owners (8.9 vs 3.3%, p = 0.014). Significant between group change in mean cycling hours between 'inner' and 'outer' cyclists. (F=4.4, p = 0.035). NS findings for change in mean walking hours or % walking/cycling at 'sufficient' level.
<i>Built environment trail/greenway infrastructure intervention only (no additional intervention)</i>							
Burbridge & Goulias, 2009 ³⁷	West Valley City, UT, USA	Quasi-experiment, pre-post design with no control	n = 107 % male: 45.1% Mean age: 47.77 yr % 18+ yr: 82.5% Household income: -< \$40k: 37.8% -\$40,001 - \$80k: 43.9% -> 80,001: 18.3%	Construct a Class I (two-way separated multiuse trail) on a canal right-of-way. Created a 2.5-mi loop.	Baseline: Questionnaire -Oct. 2006 Activity Diary -Feb. 2007 Follow-up: Activity Diary 1-month -Oct. 2007 5-month -Feb. 2008	Total PA episodes and minutes (Activity Diary)	AD1 vs AD2: NS change in PA episodes or minutes AD1 vs AD3: Total PA episodes (SD): AD1: 0.90 (1.17) AD3: 0.65 (0.96) p = 0.036 Total PA minutes NS change

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
							AD1 vs AD3: Total PA episodes (coeff): AD1: -0.245 AD3: -2.13 p = 0.036 Sig. reduction in total PA episodes and walking trips (AD1-AD3). Proximity to trail not a sig. factor. Those 18-64 had a significant increase in PA episodes.
West & Shores 2011 ³⁸	Southeastern US city, USA	Quasi-experiment, pre-post design with control	n = 95 (INT group): % Female: 51.1 % Caucasian: 85.7 Age category (yrs): < 30: 14.3% 31-50: 41.8% 51-70: 32.9% > 70: 11.0% Annual household income (\$): < 15k: 13.8% 15k-45k: 31.0% 45,001-100k: 34.5% >100,000: 20.7%	5-mi of greenway was developed and added to an existing greenway.	Baseline (Dec 2007) and follow-up (Dec 2008)	# of days walking for > 30 min, moderate PA for > 30 min, and vigorous PA for > 20 min (7-day recall)	Overall results for # of days walking, moderate PA, and vigorous PA: Pre: Walking: 2.9 days Moderate PA: 1.7 days Vigorous PA: 1.3 days Post: Walking: 3.3 days Moderate PA: 2.3 days Vigorous PA: 1.8 days A significant interaction between greenway development and residential proximity was not detected for # of days walking (F=.832, p = 0.363), moderate PA (F=.509, p = 0.476), or vigorous PA (F=.002, p = 0.962).
West & Shores 2015 ³⁹	Mecklenburg County, NC, USA	Quasi-experiment, pre-post design with control	n = 118 (INT group): % Female: 41.6 % Caucasian: 88.8	1.93-mi of greenway developed and added to an existing greenway.	Baseline (Nov 2009) and follow-up (Nov 2011).	# of days walking for > 30 min, moderate PA for > 30 min, and vigorous PA for > 20 min (7-day recall)	# of days walking, moderate PA, and vigorous PA:

Table 4.1: Continued

Reference	Location	Study Design	Population (INT group)	Intervention Details	Study Timeline	Outcome measures (Tool)	Results
			Age category (yrs): -< 30: 1.5% -31-50: 43.7% -51-70: 45.6% -> 70: 8.5% Annual household income (\$): -< 15k: 1.6% -15k-45k: 25.7% -45,001-100k: 62.4% ->100,000: 6.4%				INT: Mean (SD) Pre : Walking: 2.57 (2.17) Moderate PA: 1.68 (1.91) Vigorous PA: 1.42 (1.79) Post: Walking: 2.91 (2.21) Moderate PA: 1.60 (1.96) Vigorous PA: 1.40 (1.86) CON: Mean (SD) Pre : Walking: 2.71 (2.09) Moderate PA: 1.94 (2.07) Vigorous PA: 1.86 (2.21) Post: Walking: 2.88 (2.28) Moderate PA: 1.76 (2.19) Vigorous PA: 1.51 (2.32) A significant interaction between greenway development and residential proximity was not detected for # of days walking (F=.354, p = 0.998), moderate PA (F=.461, p = 0.998), or vigorous PA (F=3.546, p = 0.982). Travel distance to the greenway was not predictive of walking, MPA, or VPA

Abbreviations: NR=not reported; INT=intervention; CON=control/comparison; SOPARC=System for Observing Play and Recreation in Communities; NS = non-significant; PA=physical activity; MPA=moderate physical activity; VPA=vigorous physical activity; MVPA=moderate-to-vigorous physical activity; LTPA=leisure-time physical activity; MOHAWk=Method for Observing pHysical Activity and Wellbeing; IRR=incident rate ratio; CI=confidence interval; OR=odds ratio; IPAQ=International Physical Activity Questionnaire; IPAQ-SF= International Physical Activity Questionnaire-Short Form; BRFSS=Behavioral Risk Factor Surveillance System; GPAQ=Global Physical Activity Questionnaire; AD=activity diary

Table 4.2: Summary of overall study outcomes for dual approach interventions (infrastructure change with additional intervention) and infrastructure only interventions (no additional intervention).

Intervention component(s)	n	Favorable result	Unfavorable result	Non-significant result
Dual approach	18	14*	2	2
Infrastructure only	3	0	1	2

*One study reported an increase in trail counts³⁴ and one study reported an increase in the proportion of people being physically active according to the Behavioral Risk Factor Surveillance System survey,²⁹ but did not perform statistical analysis.

Whereas those studies that only implemented trail/greenway infrastructure changes without additional interventions (n = 3, 14%) reported unfavorable³⁷ or non-significant results.^{38,39}

Dual approach interventions

A total of 18 investigations looked at the impact of greenway/trail infrastructure changes combined with additional interventions. Table 4.3 provides a summary of the study outcomes reported from dual approach interventions specific to the additional intervention components. Each of the dual approach interventions involved a physical change to the trail/greenway infrastructure in addition to enhanced accessibility (n = 11) and enhanced accessibility plus community campaigns (n = 7).

Trail/greenway infrastructure changes plus enhanced accessibility. In addition to the built environment trail/greenway infrastructure changes, these 11 studies reported additional interventions involving enhanced accessibility to residential areas,^{16,19-23,27,30-32} business/commercial areas,^{19-23,27,30-32} schools,^{19,21-24} and parks/recreation areas.^{15,16,19,22-24,27,30-32} Additional intervention components that enhanced accessibility were amenities that included improving street intersections/crossings,^{15,20} signage,^{15,16,35} new bus shelters,¹⁵ benches,¹⁶ bicycle racks,¹⁵ service facilities,^{30-32,35} and play equipment.¹⁶

Eight of the 11 (73%) studies reported overall favorable changes in PA outcomes after trail/greenway infrastructure changes in conjunction with enhanced accessibility.^{16,19,20,22,23,27,30,35} Benton et al.¹⁶ reported increases in the number of people using the intervention path at 7-month follow-up (IRR 1.67, 95% CI 1.44, 1.95), 12-month (IRR 2.10, 95% CI 1.79, 2.48), and 24-month follow-up (IRR 2.42, 95% CI 1.80, 3.24). Cook et al.¹⁹ reported a 130% increase in manual trail user counts and a significant increase in the average duration of PA on the trail

Table 4.3: Summary of overall study outcomes for dual approach interventions (trail/greenway infrastructure change with additional intervention) by intervention components.

Intervention component(s)	n	Favorable result	Unfavorable result	Non-significant result
T/G + Access	11	8	1	2
T/G + Access + CE	7	6*	1	0

Abbreviations: T/G = Trail/greenway infrastructure change; Access = Enhanced accessibility; CE = Community engagement

*One study reported an increase in trail counts³⁴ and one study reported an increase in the proportion of people being physically active according to the Behavioral Risk Factor Surveillance System survey,²⁹ but did not perform statistical analysis.

(pre: 59 minutes, post: 63 minutes, $p < .05$) after the construction of a pedestrian/bicycle bridge over a major interstate that connected two existing greenways in Durham, NC, USA.

Construction of a 2.4-km (1.5-mile) protected cycleway in Sydney, Australia reported those living $< 3\text{km}$ (1.9 miles) to the cycleway were four times (OR 3.93, 95% CI 1.51, 10.23) as likely to use the trail and a

significant increase in cycling minutes per week (+96.2 minutes) occurred in those living 1-2.99 km (0.6-1.9 miles) from the cycleway.²⁰ Another study from Sydney, Australia reported significant increases in pre- and post-intervention trail user counts following the completion of an 8.5-km (5.3-mile) loop trail.²⁷

Fields et al.²² investigated the impact of improvements to the bicycle facilities in Minneapolis, MN, USA and reported a 69% increase in observed cyclists on protected cycleways. In Knoxville, TN, USA, a neighborhood was retrofitted with a 2.9-mile greenway and found a significant increase in observed total PA ($p = 0.028$), walkers ($p = 0.002$), and cyclists ($p = .036$) compared to the control neighborhood.²³ In Wuhan, China, where a 102-km (63.4-mile) motorized vehicle road was converted to a traffic-free greenway with service facilities, investigators found those living within 5-km (3.1-miles) increased walking minutes per week (+31.2 minutes, $p < 0.001$) and those within 2-km (1.2-miles) significantly increased their minutes of MVPA per week (+62.7 minutes, $p < 0.001$) and MET-minutes per week (+448.9 MET-minutes, $p < 0.001$).³⁰⁻³² A 10-km (6.2-mile) seasonal waterway trail in Winnipeg, Manitoba, Canada attracted nearly 2- to 4-fold the number of daily user counts when compared to control periods when the trail wasn't open.³⁵

Three studies reported insignificant^{15,24} or unfavorable²¹ outcomes following their respective interventions. An investigation that occurred in a low-income, disadvantaged urban

community in Philadelphia, PA, USA, reported increases in observed trail users post-intervention (pre: 100 person per hour, post: 116 person per hour), but they were not significantly different than those seen in the control area (pre: 128 person per hour, post: 159 person per hour).¹⁵ Similar to their trail user count results, Auchincloss et al.¹⁵ also reported no significant difference in the adjusted change in observed proportion of users performing MVPA post-intervention between the experimental and control areas (+2% vs +3%, respectively). Frank et al.²⁴ found favorable, but insignificant changes in minutes of MVPA per day (+16.9 minutes) and odds of achieving MVPA guidelines after retrofitting an urban greenway in downtown Vancouver, Canada. After extending a pre-existing greenway, Evenson and colleagues²¹ reported significant decreases in weekly median VPA (90 minutes vs 80 minutes) and non-significant changes in median leisure activity (180 minutes vs 180 minutes), MPA (162.5 minutes vs 140 minutes), walking (105 minutes vs 70 minutes), and cycling (0 minutes vs 0 minutes).

Trail/greenway infrastructure changes plus enhanced accessibility and community engagement. These studies (n = 7) reported similar enhancements in accessibility as previously mentioned but also employed a variety of community engagement mechanisms including community partnerships in planning/design,^{25,28,29,33,34} formal opening events,^{25,36} and promotional awareness campaigns.^{17,25,33,34,36}

Six of the seven studies reported favorable PA outcomes post-intervention,^{17,25,28,29,34,36} two of which did not perform statistical analysis.^{29,34} Clark et al.¹⁷ reported a significant increase in mean trail users per day in both the intervention group (pre: 79 users, 6-mo: 141 users, 12-mo: 107 users) and control group (pre: 112 users, 6-mo: 144 users, 12-mo: 147 users) following an 8-week media campaign (radio, print, online ads, billboards, and signage) promoting trail use and the addition of wayfinding signs and distance markers on the trails. A large investment

(Connect2 program) involved upgrading or creating 84 walking and cycling routes along with improved road crossings in various locations throughout the United Kingdom. Additionally, an opening event was held along with additional promotion of the new infrastructure.^{25,26} Goodman and colleagues²⁵ reported a significant increase in residents total PA (+12.5 minutes per week) and cycling and walking (+15.3 minutes per week) per km closer to the trails at 2-yr follow-up. Increased trail user counts and significantly increased odds of route users meeting PA recommendations at both 1-yr and 2-yr follow-up were also reported.²⁶

An investigation in a low-income, primarily African American neighborhood in New Orleans, Louisiana, USA reported a significant increase in the proportion of people observed in MVPA in the neighborhood between baseline (36.7%) and follow-up (41.0%, $p < 0.001$) after the installation of an 8-foot-wide walking path that spanned 6-blocks.²⁸ Harding and colleagues,²⁹ after the construction of a 1.4-mile (2.3-km) paved mixed-use path in rural Hawaii, reported a five percent increase (pre: 82.6%, post: 87.6%) post-intervention in the rate of people participating in leisure-time PA using survey data from the Behavioral Risk Factor Surveillance System. In West Hawaii, USA, the revitalization of a walking/jogging path, community-wide promotions, and PA programming resulted in a 24% increase (January 2003-2005) and 30% increase (June 2003-2005) in observed trail user counts.³⁴ Merom et al.³⁶ reported a significant difference between groups ($F = 4.4$, $p = 0.035$) with ‘inner’ cyclists increasing mean cycling (+11.9 minutes/week) compared to ‘outer’ cyclists decreasing mean cycling (-14.3 minutes/week) after construction of a 16.5-km (10.3-mile) rail trail and targeted promotional campaign.

Only one study in this group reported unfavorable results.³³ A major infrastructure overhaul in Northern Ireland involved 16-km (9.9-mile) of new or improved foot and cycle

paths, improved bridges/crossing, signage, lighting along the whole route, social engagement, promotional activities/events, and other regeneration projects. Based on the results of repeat cross-sectional surveys before-and-after the intervention, a significant reduction in the mean minutes of total PA per day occurred in the intervention group from 89.9 minutes to 72.6 minutes ($p = 0.002$); however, a similar decline occurred in the control group.³³ Additionally, a significant decrease in the proportion of participants in the intervention group (pre: 68%, post: 61%, $p < .0001$) meeting the UK recommendations for PA [minimum of 150 min/week of moderate-intensity PA or 75 min/week of vigorous-intensity PA (or a combination of the two)] and non-work PA was found; however, neither were significantly different than what was observed in the control group.³³

Trail/greenway infrastructure changes only

Three studies looked at the impact of trail/greenway infrastructure changes without additional interventions and results were either unfavorable³⁷ or non-significant.^{38,39} The two studies by West & Shores^{38,39} resulted in non-significant changes in the number of days people participated in 30+ minutes of walking, moderate PA, or vigorous PA after adding additional mileage to existing greenways in two southeastern US cities. Burbridge & Goulias³⁷ used activity diaries to monitor changes in PA after the construction of a two-way separated multiuse trail in West Valley City, Utah, USA. Results showed a significant decrease in mean PA episodes per day post-intervention (pre: 0.90, post: 0.65, $p = 0.036$) and mean walking trips per day (pre: 0.64, post: 0.38, $p = 0.008$); however, a separate analysis found those age 18-64 had a significant increase in PA episodes.

Method of Physical Activity Measurement

Various methods of PA measurement were used in the included studies. The majority of studies (n = 16) used one method of PA assessment (e.g., direct observation or self-report questionnaire), while the remaining five^{19,20,26,28,36} used multiple methods to measure PA. Table 4.4 shows the various methods of PA measurement and an overall summary of their study outcomes. Eight studies assessed PA in the built environment trail/greenway infrastructure location (i.e., user counts) via direct observation,^{15,16,19,22,23,26,28,34} while five studies used electronic counters.^{17,20,27,35,36} Twelve of these studies^{16,17,19,20,22,23,26-28,34-36} reported favorable results (three of which did not use statistical analysis for this outcome),^{19,20,34} while one reported insignificant results.¹⁵ An increase in trail user counts post-intervention was found for all studies (100%, n = 12),^{15-17,19,20,22,23,26,27,34-36} six of which reported a statistically significant increase.^{16,17,22,23,27,35} Although an increase in trail users was detected by Auchincloss et al.,¹⁵ results were not significantly different than the increase found in the control neighborhood. Additionally, Gustat et al.²⁸ reported increases in observed users participating in MVPA post-intervention, but this was measured at the neighborhood level, not specific to the trail/greenway.

Additionally, nine investigations used self-administered questionnaires to assess PA outcomes^{19-21,24-26,37-39} and five used interview-based methods via telephone or face-to-face interviews.^{28-30,33,36} Questions for assessing PA outcomes came from the Global Physical Activity Questionnaire,³³ International Physical Activity Questionnaire,^{24,25,30} Behavioral Risk Factor Surveillance System,^{21,29} Active Australia Survey,²⁰ or other survey questionnaires.^{19,26,28,36-39} Of the 14 studies using self-report measures, six reported favorable outcomes,^{19,20,25,26,29,30} (one of which did not perform statistical analysis)²⁹ three reported unfavorable outcomes,^{21,33,37} and five reported non-significant findings.^{24,28,36,38,39}

Table 4.4: Summary of study outcomes based on method of physical activity measurement.

Method of PA measurement	n	Favorable result	Unfavorable result	Non-significant result
Direct observation	8	7 ^b	0	1
Electronic counters	5	5 ^c	0	0
SA questionnaire	9	4	2	3
Interview-based ^a	5	2 ^d	1	2
Total	27	18	3	6

^aIncludes telephone-based or face-to-face interviews.

^bTwo studies reported increases in trail counts but did not perform statistical analysis.^{19,34}

^cOne study reported an increase in trail counts but did not perform statistical analysis.²⁰

^dOne study reported an increase in the proportion of people being physically active according to the Behavioral Risk Factor Surveillance System survey but did not perform statistical analysis.²⁹

Abbreviations: SA=self-administered

Five studies reported using a combination of PA measurement.^{19,20,26,28,36} Outcomes specific to direct observation or electronic trail counters were favorable for all five studies. Regarding self-report measures of PA, three of the five studies reported favorable results,^{19,20,26} while the remaining two reported non-significant findings.^{28,36}

Quality assessment

The results of the quality assessment are presented in Table 4.5. Overall quality scores ranged from 11% to 100% (mean 62.3%). Six studies (25%) were classified as high quality, 14 studies (58%) were classified as moderate quality, and four studies (17%) were low quality. For dual approach interventions the mean quality score was 63.7% (range 11-100%) and infrastructure only interventions had a mean quality score of 52.0% (range 44-56%). The most common factors that negatively impacted study quality were comparison populations not similar (n = 11, Question 2), lack of a control group (n = 11, Question 4), not taking multiple measurements of the outcome both pre- and post-intervention (n = 17, Question 5), differences between groups not adequately described or analyzed (n = 23, Question 6) and unclear if the PA assessment tool was reliable (n = 9, Question 8).

Discussion

The findings of this review extend the current knowledge related to the effect built environment trail/greenway interventions have on various PA outcomes. Compared to the CPSTF findings,¹¹ the review team was able to identify an additional nine interventions (13 publications), nearly doubling the available literature which provides the opportunity for a more comprehensive understanding of the effect of built environment trail/greenway interventions on PA. The additional literature also allowed the review team to categorize dual approach interventions based on what was included in the interventions (i.e., enhanced accessibility and/or

Table 4.5: Quality assessment of studies using the Joanna Briggs Institute critical appraisal checklist.

Reference (n=24*)	JBI Critical Appraisal Checklist for Quasi-experimental Study Design									
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Score
<i>Dual approach interventions (infrastructure change and additional intervention)</i>										
Crane et al. 2017 ²⁰	Y	Y	Y	Y	Y	Y	Y	Y	Y	9/9 (100%)
Auchincloss et al. 2019 ¹⁵	Y	Y	Y	Y	Y	NA	Y	Y	Y	8/9 (89%)
Benton et al. 2021 ¹⁶	Y	Y	Y	Y	Y	NA	Y	Y	Y	8/9 (89%)
Fitzhugh et al. 2010 ²³	Y	Y	Y	Y	N	NA	Y	Y	Y	7/9 (78%)
Frank et al. 2019 ²⁴	Y	N	Y	Y	Y	U	Y	Y	Y	7/9 (78%)
Hunter et al. 2021 ³³	Y	Y	Y	Y	N	NA	Y	Y	Y	7/9 (78%)
Goodman et al. 2014 ²⁵	Y	Y	U	Y	N	U	Y	Y	Y	6/9 (67%)
Gustat et al. 2012 ²⁸	Y	Y	Y	Y	N	N	Y	U	Y	6/9 (67%)
He et al. 2022 ³¹	Y	Y	U	Y	N	U	Y	Y	Y	6/9 (67%)
McGavock et al. 2019 ³⁵	Y	NA	Y	N	Y	NA	Y	Y	Y	6/9 (67%)
Xie et al. 2021 ³²	Y	Y	U	Y	N	U	Y	Y	Y	6/9 (67%)
Clark et al. 2014 ¹⁷	Y	U	Y	N	N	NA	Y	Y	Y	5/9 (56%)
Clark et al. 2015 ¹⁸	Y	U	N	Y	N	NA	Y	Y	Y	5/9 (56%)
Cook et al. 2016 ¹⁹	Y	Y	Y	N	Y	NA	Y	U	Y	5/9 (56%)
Le Gouais et al. 2021 ²⁶	Y	Y	U	N	N	U	Y	Y	Y	5/9 (56%)
Grunseit et al. 2019 ²⁷	Y	N	Y	N	Y	NA	Y	U	Y	5/9 (56%)
Merom et al. 2003 ³⁶	Y	Y	Y	N	N	U	Y	U	Y	5/9 (56%)
He et al. 2021 ³⁰	Y	Y	U	N	N	U	Y	Y	Y	5/9 (56%)
Evenson et al. 2005 ²¹	Y	U	Y	N	N	N	Y	N	Y	4/9 (44%)
Fields et al. 2022 ²²	Y	NA	NA	N	U	NA	Y	Y	Y	4/9 (44%)
Matsuoka et al. 2005 ³⁴	Y	U	U	N	N	NA	NA	U	N	1/9 (11%)
Total (% Yes)	100%	72%	72%	61%	39%	6%	94%	83%	94%	63.7%
<i>Infrastructure intervention only with no additional intervention</i>										
West & Shores 2015 ³⁹	Y	U	Y	Y	N	N	Y	U	Y	6/9 (56%)
West & Shores 2011 ³⁸	Y	U	Y	Y	N	N	Y	U	Y	5/9 (56%)
Burbridge & Goulas 2009 ³⁷	Y	U	Y	N	N	N	Y	U	Y	4/9 (44%)
Total (% Yes)	100%	0%	100%	67%	0%	0%	100%	0%	100%	52.0%

*Does not include article by Harding et al. (2017) due to different study design.

Abbreviations: Q = Question, Y = Yes, U = Unclear, N = No, NA = Not applicable

Q1: Is it clear in the study what is the 'cause' and what is the 'effect'? **Q2:** Were participants included in any comparisons similar? **Q3:** Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest? **Q4:** Was there a control group? **Q5:** Were there multiple measurements of the outcome both pre and post the intervention/exposure? **Q6:** Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed? **Q7:** Were the outcomes of participants included in any comparisons measure the same way? **Q8:** Were outcomes measured in a reliable way? **Q9:** Was appropriate statistical analysis used?

community engagement).

Summary of findings

In summary, this review included 21 trail/greenway intervention studies (25 publications). The majority of studies (n = 18) used dual approach interventions (i.e., greenway or trail infrastructure improvements combined with additional interventions) and reported overall favorable results. The results from this review provides additional supportive evidence to recommend the use of dual approach trail/greenway interventions for increasing PA, consistent with the recommendations provided by the CPSTF.¹¹ Only three studies implemented a trail/greenway intervention without additional interventions and the overall results were inconclusive. The current review did not identify any additional published studies that used this approach outside of those reported by the CPSTF¹¹; therefore, the previous recommendation is maintained that little evidence is available to support the use of trail/greenway interventions alone without additional interventions.

The additional studies identified by the current review also allowed for further categorization of dual approach interventions. Overall, the available evidence supports using dual approach interventions that include enhanced accessibility alone (e.g., improved accessibility to residential, commercial, and/or community/recreation areas, intersection improvement, pedestrian/cyclist amenities, landscaping, etc.) or enhanced accessibility plus community engagement (e.g., community involvement in planning/design of infrastructure changes, media campaigns promoting trail use, PA programming, etc.).

Due to the heterogeneity in intervention characteristics, we are unable to determine which aspects of the built environment or community engagement are most effective at increasing PA. Another finding of note is that nearly all studies (12 out of 13) that used direct observation or

electronic counters reported favorable results in their respective PA outcomes. Compare this to only six of the 14 studies reporting favorable outcomes when measuring PA via self-report or interview-based questionnaires. This may be due to new or improved trails/greenways providing a substitute location for individuals to perform PA as opposed to increasing their levels of PA.

Practice and policy recommendations

The findings from this review provide practitioners with sufficient evidence to recommend incorporating trail/greenway interventions, particularly dual approach interventions, in their communities. Integrating strategies to increase the likelihood of these interventions producing long-term effects on PA will be necessary. For example, the need to incorporate local citizens and community organizations with differing sociodemographic backgrounds in the planning and implementation process can help with engaging all residents of the community in the intervention project and promote PA.^{40,41} Additionally, Salvo et al.⁴⁰ has highlighted the need for a multi-disciplinary approach (transportation/urban planning, landscape architecture, parks and recreation, public health, and health economics) when designing built environments that support PA.

Another important opportunity for improving PA in our communities is facilitating the knowledge from these findings into actionable strategies to influence built environment policies, such as building accessible trails and greenways. This can prove challenging as multiple studies have identified low participation among local health departments⁴² and public health officials⁴³ in community physical activity and built environment policy development. Similar to the recommendations in the previous paragraph for practitioners, policymakers should encourage intersectoral collaboration and alignment between local government, researchers, and community

members/organizations to enhance the effectiveness of PA promoting built environment changes.⁴⁴⁻⁴⁶

The dual approach interventions used by many of the studies included in this review coincides with the ‘Increasing Physical Activity Through Community Design’ priority strategy from the Center for Disease Control and Prevention.⁴⁷ This strategy encourages communities to incorporate activity-friendly routes (e.g., improved street design/connectivity, pedestrian/cyclist infrastructure, public transit) to everyday destinations to promote PA.⁴⁷ It is also important for practitioners and policymakers to consider measuring the impact trail/greenway interventions have on their communities. At a minimum, it is strongly encouraged to use electronic counters and/or direct observation to measure PA in the new infrastructure location.

Another consideration that could help support practitioners and policymakers is measuring the economic impact, both direct (i.e., local tax revenue) and indirect (i.e., averted healthcare costs), these interventions have. An economic analysis of the Atlanta Beltline, a multi-use trail project in Atlanta, GA, USA, estimated a cost-benefit ratio of 2.93 (i.e., the benefits of the trail/greenway project are 2.93 times greater than the total cost) over 30 years.⁴⁸ Similarly, Hunter and colleagues⁴⁹ assessed the potential cost-benefit ratio of a 9-km greenway and reported a range from 2.88 (worst-case scenario) to 5.81 (best-case scenario).

Future research

Even with the overall findings from this review favoring built environment trail/greenway interventions, particularly dual approach interventions, we are still unable to determine what specific combination of interventions are most effective at increasing PA. The positive effects may be coming from the built environment intervention (i.e., trail/greenway infrastructure change) or from some other component of the intervention (i.e., enhanced

accessibility or community engagement). Future studies are encouraged to adopt research designs and methods that allow for partitioning of effects by intervention. For example, measure the built environment intervention by itself before adding a new intervention.

Results from this review are still based on relatively few studies. Additional quasi-experimental intervention studies should be conducted to further our understanding of the effects trails have on PA. The quality of the studies in the current review averaged 62.3% (moderate quality) and should be improved upon in future intervention studies. Only ten studies in the current review included a control/comparison group. To better quantify the effect built environment trail/greenway interventions have on PA, future intervention studies should strive to incorporate at least one control/comparison group. Also, a previous review on trails and physical activity noted that many studies using instruments that had not been validated.⁵⁰ Although this metric has improved according to this review, there were still 42% (n = 9) of studies in the current review that either reported unvalidated tools or it was unclear if the tools they used were reliable and valid.

As highlighted in the results, researchers should strive to use a combination of PA measures (e.g., self-report questionnaires, direct observation, trail counters) when assessing the impact trail/greenway interventions have on PA. It's possible the studies in this review that only used self-report measures of PA and reported unfavorable^{21,27,33} or non-significant^{24,38,39} findings may have found favorable outcomes if direct observation or electronic trail counters were also used. Self-report measures only provide information specific to the individual changes in PA but don't necessarily represent whether or not the infrastructure location is being used more at the community level. Using a combination of self-report measures and direct observation/electronic trail counters could provide a more well-rounded look at the individual and community level

changes in PA that may occur. Additionally, a recent study using accelerometers and GPS to measure PA found that trail users accumulated more PA on days when they used the trails compared to non-trail use days.⁵¹ None of the studies in the current review used accelerometers, global positioning system (GPS), or pedometers. With the limitations faced by self-report questionnaires,⁵² future studies may benefit from incorporating these innovative devices alone or in combination with self-report measures.

When designing future built environment trail/greenway intervention studies, researchers should also consider assessing other health-related outcomes (e.g., well-being, quality of life, mental health, etc.). A recent meta-analysis found that LTPA and transportation PA were positively associated with mental health.⁵³ Furthermore, researchers have connected trail use with higher self-rated wellness and health.^{54,55} Only five studies in the current review reported on other health-related outcomes including well-being,^{16,33} quality of life,^{20,33} sedentary behavior,²⁴ and body mass index.³¹

It should be noted, the current findings have limited generalizability due to 95% occurring in urban/suburban areas and only two studies (10%) occurring in low-income, racial/ethnic minority neighborhoods. The prevalence of those meeting PA guidelines is lowest among rural residents⁵⁵ and those from low-income or racial/ethnic minority groups.⁵⁶ Common barriers identified by these populations are neighborhoods with low walkability, lack of PA resources, and/or safety concerns.⁵⁷⁻⁶⁰ Perhaps the construction of new trails/greenways in these areas could lead to increased levels of PA in at risk populations. Future intervention studies in non-urban/suburban areas, low-income neighborhoods, and rural areas should be prioritized. Additionally, each of these investigations were performed using traditional, linear-based

greenways/trails or rails-to-trails conversions. It would prove beneficial to study various types of trail settings (e.g., nature-based, multiuse trail networks) to see if similar impacts on PA occur.

Limitations and strengths

Many of the studies included in this review stated limitations related to methodological and sampling concerns. The limitations associated with self-report questionnaires (i.e., recall bias) and use of direct observation (i.e., distinguishing between domains of PA, observer bias) were cited by a number of studies. The heterogeneity in study and intervention designs, population demographics, PA outcome measures, and measurement tools used across included studies limits our capacity to draw conclusions or conduct a more rigorous meta-analysis. Overall, included studies had relatively short follow-up (≤ 24 months) which provides ambiguity regarding long-term impacts of built environment trail/greenway interventions. The generalizability of the findings from this review are limited due to the vast majority of studies occurring in middle-to-high income, majority white, urban/suburban neighborhoods. Furthermore, 86% ($n = 18$) of the studies occurred in three developed countries (United States, Australia, and UK). The review team recognizes that including and classifying studies that did not perform statistical analysis in this review can introduce bias. However, even if those studies/study outcomes were removed, the evidence to support trail/greenway built environment intervention would remain. The review team felt it worthwhile to include these studies for the purposes of informing practitioners/policymakers and researchers in designing future trail/greenway interventions.

Despite the limitations associated with the included studies, strengths of this review and the included literature should be noted as well. The current review performed a thorough search of 11 databases across public health, recreation, social sciences, and transportation domains. The

natural/quasi-experimental research design used by the included studies provides researchers a more cost-effective alternative to randomized controlled trials for exploring causal associations. Furthermore, the increased use of pre-post study designs with control/comparison groups among the included studies compared to previous reviews^{12,50} is promising and permits better quantification of the effect trail/greenway interventions have on PA.

Conclusions

The available literature, despite its limitations and heterogeneous nature, provides overall supportive evidence for recommending the use of built environment trail/greenway interventions, particularly dual approach interventions, for promoting PA in our communities and neighborhoods. This reaffirms the conclusions and recommendations from previous reviews by the CPSTF¹¹ and Hunter et al.¹² Favorable outcomes were seen at varying greenway lengths (2-km [1.2-miles] to 102-km [63.4-miles]) and at several scales of enhanced accessibility and/or community engagement. It is strongly encouraged that practitioners, policymakers, and researchers employ an intersectoral and multi-faceted approach when designing trail/greenway interventions to enhance the effectiveness and long-term outcomes. Nevertheless, there continues to be a need to address limitations and increase the quality of future natural experiment designs and reporting. Identification of more appropriate control sites, publishing study protocols a priori, adequate outcome measures, and better reporting of samples and interventions are a few recommendations for increasing study quality and will allow for better translation into practice and policy.⁶²

We must also consider the additional benefits of trail/greenway interventions. Very few studies in the current review assessed outcomes other than PA. A multi-dimensional approach including the effect trail/greenway interventions have on other outcomes related to health (e.g.,

mental health, well-being, quality of life), social (e.g., social disorder, crime rates, social capital), environmental (e.g., air quality and preservation of natural environments), and economics (e.g., cost-benefit, eco-tourism, health economics) would enhance the translation of this research into policy and practice.

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CHAPTER 5

WEATHER EFFECTS ON NATURAL SURFACE TRAIL USE IN AN URBAN WILDERNESS MULTI-USE TRAIL SYSTEM

This chapter is a paper by the same name that has been accepted for publication in the Journal of Outdoor Recreation and Tourism by Douglas Gregory, Kristina Kintziger, Scott Crouter, Charles Sims, Matthew Kellogg, and Eugene Fitzhugh.

Gregory, D., Kintziger, K., Crouter, S., Sims, C., Kellogg, M., & Fitzhugh, E. (2024). Weather effects on natural surface trail use in an urban wilderness multi-use trail system. *Journal of Outdoor Recreation and Tourism*, 46, 100757.

Abstract

Previous research has concluded weather conditions can influence physical activity (PA) on trails. However, these studies focused primarily on mixed-use paved surface trails. Many recreational areas use natural surface trails for mountain biking, trail running, and walking. The purpose of this study was to analyze the association between weather conditions and the use of natural surface trails for PA. In addition, this investigation sought to determine if the type of trail surface material, gravel vs. dirt, impacted PA differently by weather factors. METHODS:

Infrared trail counters were used to measure hourly trail use within Knoxville's Urban Wilderness in Knoxville, TN. An onsite weather station was used to obtain hourly weather variables. Negative binomial regression models were used to analyze the relationship between trail use and weather conditions. RESULTS: Both trail locations experienced bi-modal peaks in usage with Spring and Fall months showing the highest usage. As temperature increased, so did trail use ($\beta=.115$, $p=.00$); however, gravel trail use began to decrease at temperatures above 86°F. Precipitation negatively impacted trail use on both gravel ($\beta=-3.114$, $p=.00$) and dirt ($\beta=-2.281$, $p=.00$) trails. Relative humidity had a negative relationship with trail use on both trails.

UVRI ($\beta=-.036$) was only significantly associated with dirt trail use. CONCLUSIONS: The direction of the effect of weather measures on natural surface trail use is similar to previous studies on paved trails; however, the magnitude of the effect varies. Gravel trail use was more sensitive to temperature and precipitation, while relative humidity, absolute pressure, and UVRI had a greater impact on dirt trail use. The variations in the magnitude of the effect may be a

function of the activity performed on the different trail surfaces. Trail surface material should be considered to fully understand the impact weather has on trail use.

Introduction

Environmental factors such as weather and seasonality have been shown to impact outdoor recreation visitation to parks and nature-based recreation areas. For example, visitors to White Mountain National Forest in New Hampshire were surveyed regarding how social, situational, and ecological factors (e.g., weather and seasonality) influenced their behaviors, decision-making, and overall experiences. Results from this study suggested that ecological factors be integrated with social and situational factors to predict visitor satisfaction and decision-making.¹ Additionally, McCreary et al.² found that visitors to a nature-based tourism area in Minnesota reported increased attentiveness to weather information prior to and during their trips. A research synthesis also identified weather conditions, experiences with weather, and season as critical factors in outdoor recreation and nature-based tourism studies.³

The number of studies investigating the influence weather has on outdoor recreation behaviors has grown considerably. This led Verbos & Brownlee⁴ to develop the weather dependency framework (WDF), which provides guidance for conducting and interpreting weather-based studies in outdoor recreation. They defined weather dependency as “the degree to which a specific outdoor recreation activity is reliant on particular weather and resulting conditions” (p. 88). This framework identified numerous variables including, but not limited to, site characteristics, season, experiences with weather, and weather conditions related to the weather dependency of outdoor recreation activities. Some activities are going to be more seasonal and weather dependent compared to others. For example, walking and cycling can be performed year-round in many different weather conditions; however, skiing and swimming are seasonal and rely on specific weather conditions.

One area of study based upon the WDF that needs further attention is outdoor recreation within urban-proximate parks and nature-based areas that have complex multiuse trail systems. These areas can be important locations for urban dwellers to attain physical activity (PA). Research has shown that the presence of, access to, and use of trails and green space is associated with increased levels of physical activity and higher self-rated health compared to non-trail users.⁵⁻⁸ In addition, the presence of nature and scenery that can be found on trails has been shown to be an important incentive for people to acquire more leisure-time PA (LTPA).^{7,9}

When analyzing trail use of people who walk, run, or bicycle, the impact ecological factors have on LTPA should be considered. A review by Turrisi et al.¹⁰ looked at seasonal and weather-specific differences in device-measured PA on trails. The study noted higher volume (step counts or accelerometer counts) and intensity of LTPA among trail users during the summer months compared to winter months. Also, among trail users, PA volume and moderate-vigorous PA duration was positively associated with temperature and negatively associated with precipitation. They concluded the natural environment can both positively and negatively influence PA on trails.

Specific to trail use as it relates to weather, previous research has shown a curvilinear relationship in trail use with air temperature. Basically, trail use increases as temperature increases until a certain temperature point is reached, at which time trail use begins to decrease as the temperature continues to increase. However, the maximum temperature deflection points at which trail counts begin to decrease varies by the type of PA and the study location, ranging from 76°F to 91.6°F.¹¹⁻¹⁶ On the other hand, precipitation consistently results in a negative impact on trail use when analyzed as a continuous^{11,14,17} and categorical measure.^{12,16,18}

In addition to temperature and precipitation, other weather factors shown to be associated with trail use and PA include humidity^{11-13,18} and wind speed.^{14,16,17,19,20} All aforementioned studies, except two, were conducted on paved surfaces including on- and off-road bike lanes, urban greenways, and rail trails. Only one study conducted by Zajchowski et al.¹⁵ involved a dirt trail, while Ermagun et al.¹⁷ reported one trail in their analysis of trail use across 32 trails as having crushed limestone. While the other trails were paved, this study did not consider the impact of trail surface on how people used trails.

The effect that varying weather conditions has on trail use has been extensively studied on paved surfaces; however, there is a clear gap in the research on the impact weather has on physical activity on natural surface trails. Many recreational areas have a complex system of natural surface trails (e.g., dirt, natural rock, or gravel) for mountain biking, trail running, and hiking/walking which may respond differently to varying weather conditions than the more traditional, linear paved trails/greenways. It's possible that during rain events trail users may transition to gravel trails to avoid muddy trails (i.e., dirt trails). Additionally, the site characteristics of nature-based, complex natural surface trail systems may influence the relationship between weather and trail use different than paved trails/greenways. Understanding how weather impacts natural surface trail use and PA could inform trail planners and resource managers on which surface material is more conducive to higher use, lead to more careful predictions of outdoor recreation participation, and needed maintenance of natural surface trails.

Furthermore, there is a need for more research that includes a broader range of weather variables and types of physical activities within urban outdoor recreation settings.^{3,4} The current investigation would provide information to expand on a more complex set of specific WDF salient factors including site characteristics (e.g., site characteristics and management practices),

trip characteristics (e.g., transportation mode and route traveled), season (e.g., natural and institutional seasonality), and weather conditions (e.g., temperature, relative humidity, wind speed, and precipitation). Therefore, the purpose of this investigation is to analyze the relationship between varying weather conditions and the use of natural surface trails for PA in an urban, nature-based recreation setting. The following research questions will be addressed: 1) what are the temporal trends in trail use, 2) how do various weather conditions impact trail use, and 3) does the type of trail surface material, gravel vs. dirt, impact trail use differently by weather factors?

Methods

Knoxville's Urban Wilderness

This study was conducted at Knoxville's Urban Wilderness (KUW) in Knoxville, TN (<https://www.visitknoxville.com/urban-wilderness/>). The KUW is an urban mixed-use wilderness trail network centrally located within the city of Knoxville and provides a pristine natural setting for performing LTPA (Figure 5.1). Features and amenities in the KUW include, but are not limited to, 50+ miles of mountain biking and hiking/running trails, a natural rock-climbing wall, and access to the Tennessee River and two water filled quarries for swimming, fishing, and paddle boarding. The trail network has 12 primary trailheads and numerous secondary access points located within neighborhoods that border the urban wilderness. It has been estimated that over 300,000 people used the KUW trail system in 2021.²¹ In addition to the high use of the trail system, the economic benefit of the KUW has been estimated at \$14+ million.²²

Two trails were chosen for the current investigation, Baker Creek and Ijams. These two locations were chosen due to their accessibility, high usage, and varying trail surface materials (Baker Creek having a dirt surface and Ijams having a gravel surface). These trails were built and

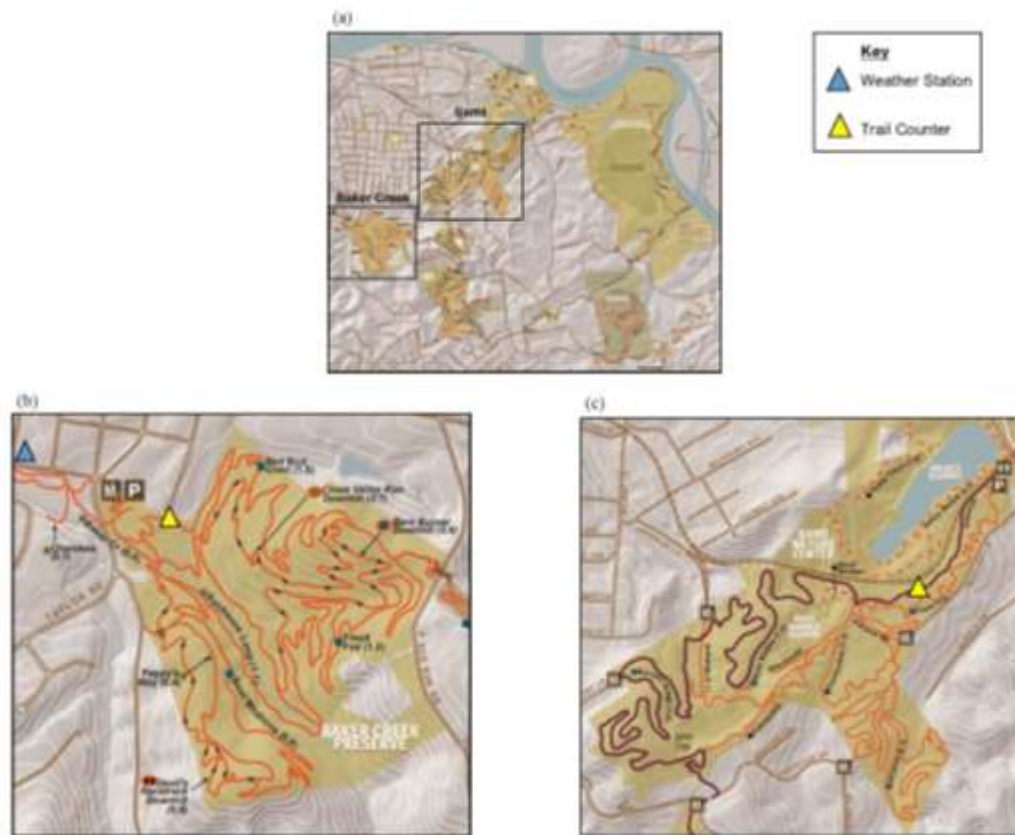


Figure 5.1: Images of (a) Knoxville's Urban Wilderness, (b) Baker Creek trail network with weather and counter location, and (c) Ijams trail network with counter location.

are maintained by the same construction team, are approximately 1.5 straight-line miles apart; therefore, experiencing similar weather conditions. In addition, outside of trail surface material, the canopy, understory, trailside vegetation, and topography are similar at both trail locations.

Trail User Measurement

Hourly trail user counts were measured using a combination of TRAFx Trail Counters (N=1)²³ and PYRO-Box counters (N=2)²⁴. Both types of trail counters sense and detect the infrared wavelength emitted by people and records a precise timestamp of that user event (e.g., persons walking, running, cycling). The TRAFx trail counter at Ijams was replaced with a PYRO-Box part-way through the data collection period so we could measure the in-versus-out ratio of trail users daily (not possible with TRAFx counter). Count data from the TRAFx counter were downloaded once per month using the TRAFx G3 Dock, then imported to the Eco-Visio data platform. PYRO-Box counts were wirelessly transmitted through a cellular network to the Eco-Visio data platform daily. All count data on the Eco-Visio platform were then exported to SAS Enterprise Guide 8.3 (SAS Institute Inc., Cary, NC, USA) for analysis.

User counts were collected on a continuous 24-hour time period from September 7, 2020, to August 31, 2021, for a total of 358 days. There were no curfews due to Covid-19 during the data collection timeframe. User counts were summed for each hour of daylight across this timeframe. Civil twilight hours were used to define daylight for this study.²⁵ Civil twilight was chosen as this is a time when normal daily activities can still be performed without artificial light sources.²⁶ As an example of how this is related to data coding, if civil twilight occurred at 6:23 AM and 8:26 PM, data analysis was conducted for those hours between 6 AM and 9 PM. The total number of daylight hours varied across the study period due to seasonal variations in daylight. Over the course of the study, there were 113 hours of missing data. This accounted for

1% of the total hours observed across both counting locations. The missing data was lost due to equipment failure (i.e., persons tampering with the counters or the weather station not capturing weather data).

Trail Counter Validation

Prior to data collection, a two-phase walking/running and cycling validation procedure was performed to ensure the varying user events would be captured. Phase I involved 100 passing trials at walking and running speeds and 100 passing trials riding a mountain bike. The overall accuracy of all trail counters for the walking/running and biking trials was $99.7 \pm 0.6\%$ and $99.4 \pm 1.5\%$, respectively. To further assess the validity of the trail counters, Phase II involved direct observation (DO) of trail users and their PA performed on two days (Saturday and Sunday), during four 1-hour intervals (8-9am, 12-1pm, 3-4pm, 6-7pm) each day. A comparison was made between the number of observed trail users and the number of trail users recorded by the trail counter. These are mixed-use trails; therefore, the total number of walkers, runners, and bikers from DO were compared to the total counts registered by the trail counter. The DO phase resulted in an overall accuracy of $92.1 \pm 10.1\%$. Most trail count error associated with this phase was a result of two or more users passing the trail counter at the same time; therefore, the counter was only able to detect the infrared wavelength emitted by one user. Other potential sources of error in trail counts encountered during routine checks and DO were dogs tall enough to trigger the infrared sensor, insect infestation over the sensor, and overgrown brush.

Trail User Count Adjustment

Using the counts obtained from DO, the researchers were able to calculate an adjustment factor for each of the trail counters. This adjustment was used to correct for the error in counts observed during DO. This adjustment was calculated by dividing the observed counts (from DO)

by the actual counts (measured by trail counters). For example, if DO resulted in 179 counts of trail users and the trail counter measured 187 users, the researcher divided 179/187 which equated to an adjustment factor of 0.957 for that trail counter. This process was repeated for all trail counters, and each counter had their own unique adjustment factor. Hourly trail counts were then multiplied by their respective adjustment factor (hourly counts registered by trail counter device $\times$ trail counter adjustment factor) and was then rounded to the nearest whole number. To address the concern of introducing error, researchers conducted the same statistical analyses on the raw count data and found no differences in the results of the regressions.

Weather-Related Measures

Hourly weather-related variables were collected from an onsite weather station (Ambient Weather WS-2902A, Ambient, LLC, Chandler, AZ) located within two-miles of all trail counters. For the purposes of this study, weather variables included temperature ($^{\circ}\text{F}$), dew point ($^{\circ}\text{F}$), humidity (%), atmospheric pressure (Hg), wind speed (mph), precipitation (in.), and ultra-violet solar radiation index (Scale 1-11). Visual inspection of our data detected a curvilinear relationship between temperature and trail counts; therefore, a polynomial term, temperature squared, was added to more precisely determine the effect increasing temperature had on trail counts.

Statistical Analysis

Descriptive statistics were run on all measures. User counts (dependent variable) were not normally distributed based on the Kolmogorov-Smirnov test of normality. Therefore, Spearman correlations were used to assess the association between user counts and weather-related measures and to determine if multicollinearity existed between the weather variables. Weather measures found to be highly correlated ($\rho > 0.5$) were examined to determine which of

the two variables had the greatest correlation with user counts and was thus retained. This resulted in the following weather variables being used in regression analysis: temperature, temperature squared, humidity, atmospheric pressure, wind speed, precipitation, and ultra-violet solar radiation index (UVRI).

The dependent variable in the current analysis was hourly trail user counts (count data). Poisson regression models are a common choice for such data. However, the data from the current investigation was highly skewed, contained many zeroes, and was overdispersed; therefore, negative binomial regression models were a better fit for our data.^{27,28} Additionally, a lower Akaike Information Criterion (AIC) was obtained, which confirmed the use of negative binomial regression models. To confirm that negative binomial without zero inflation was appropriate, the PROBCOUNTS SAS macro was used to compare the observed zero counts with the predicted zero counts based on the model.²⁹ Statistical methods were performed in SAS Enterprise Guide 8.3 (SAS Institute Inc., Cary, NC, USA).

Results

Trail User Count Summary

The raw trail counts for Baker Creek and Ijams were 117,705 and 66,514, respectively. The trail counter error adjustment factor for Baker Creek was 0.99160 (Eco-Counter) which resulted in adjusted total trail user counts of 116,791 (22.3 user counts per hour). The trail counter adjustment factors for Ijams were 1.25000 (Eco-Counter) and 1.15942 (TRAFx counter). This resulted in adjusted total trail user counts of 78,834 (15.3 user counts per hour). All analyses, tables, and figures were based on the adjusted trail user counts. Table 5.1 provides a descriptive summary of the monthly user counts and weather-related measures across the length of the study.

Table 5.1: Summary of trail counts and weather-related measures at Baker Creek and Ijams.

Month	Trail User Counts ^a				Weather-Related Measures ^b											
	<u>Baker Creek</u>		<u>Ijams</u>		<u>Temperature</u>		<u>Humidity</u>		<u>Precipitation</u>		<u>Wind Speed</u>		<u>Pressure</u>		<u>UVRI</u>	
	Total	Hourly	Total	Hourly	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2020																
Sept	10,475	29.1	4,675	13.0	70.2	10.0	80.2	16.5	.006	.03	1.0	1.3	29.2	.1	1.7	2.1
Oct	11,934	26.3	7,310	16.1	63.4	10.1	79.4	18.9	.005	.05	1.1	1.5	29.2	.2	1.3	1.8
Nov	11,827	30.1	7,394	18.9	54.2	12.7	70.2	23.1	.001	.02	1.5	2.1	29.3	.2	1.1	1.4
Dec	5,116	12.4	4,546	11.1	40.7	10.7	80.4	15.9	.008	.04	1.3	1.7	29.2	.2	0.5	1.0
2021																
Jan	3,789	11.3	4,550	13.6	41.2	8.7	76.6	19.9	.007	.04	1.8	2.1	29.2	.2	0.6	1.1
Feb	3,823	9.8	4,785	12.2	42.6	12.0	74.9	20.7	.009	.03	2.0	2.3	29.2	.1	0.9	1.5
Mar	10,434	23.5	5,288	14.9	55.8	11.1	63.5	25.6	.015	.07	2.0	2.4	29.2	.2	1.5	2.0
Apr	12,502	26.0	7,663	16.0	59.5	12.9	60.6	23.1	.003	.02	2.1	2.2	29.1	.2	2.1	2.5
May	15,600	31.5	9,723	19.6	67.6	11.1	67.4	21.2	.006	.05	1.5	1.6	29.2	.2	2.3	2.6
Jun	12,339	25.7	8,155	17.0	77.1	8.1	72.7	18.7	.007	.08	1.4	1.4	29.1	.1	2.7	2.8
Jul	10,941	22.1	9,577	19.3	79.5	7.7	74.0	17.1	.006	.06	1.5	1.6	29.1	.1	2.5	2.6
Aug	8,011	16.2	5,168	10.4	79.2	8.0	77.4	17.3	.017	.15	1.1	1.2	29.2	.1	2.1	2.5
Total	116,791	22.3	78,834	15.3	62.1	17.1	72.8	21.0	.008	.07	1.5	1.8	29.2	.2	1.7	2.2

^a Hourly trail user mean counts based on civil twilight hours only.

^b Hourly mean and SD weather measures based on civil twilight hours only.

Weather-related units and abbreviations: Temperature (°F), Humidity (%), Precipitation (inches), Wind Speed (mph), Pressure (mmHg), UVRI: Ultra-violet radiation index (Scale 1-11), SD: Standard Deviation.

Temporal Trends in Trail Usage

Both Baker Creek and Ijams experienced bi-modal peaks (Table 5.1 and Figure 5.2) in usage, with the Spring and Fall months showing the highest total and hourly trail user counts. Decreases in usage occurred during the colder months (December-February) and the warmest months (July-August). Usage remained consistent during the week with Thursday experiencing the lowest usage for both trails (Figure 5.3a). Baker Creek and Ijams experienced an increase of 84.5% ($p<.0001$) and 95.1% ($p<.0001$), respectively, in hourly trail user counts over the weekend compared to the weekdays (Figure 5.3a). During the weekdays, Baker Creek showed a steady increase in mean hourly trail counts, peaking around 4:00-5:00pm before dropping off in the evening hours (Figure 5.3b). However, during the weekdays, Ijams showed an increase in mean hourly trail counts until they leveled off around noon. Counts then remained consistent until around 5:00pm and then began to decline (Figure 5.3b). Over the weekend both Baker Creek and Ijams show a more rapid increase in mean hourly trail counts until leveling off around 12:00-3:00pm. Following 3:00pm, both trails experience a steady decline in trail user counts until sunset (Figure 5.3c).

Weather-Related Trends in Trail Usage

Table 5.2 and Figure 5.4 show the relationship that weather-related variables have on hourly trail user counts. Figure 5.4 includes a 10-point moving average (black line) to represent the association more clearly between trail use and temperature for overall counts and by site. Table 5.2 shows, when looking at the general model (both locations combined), there was an increase in hourly trail user counts ($\beta=0.115$, $p=.00$) with increasing temperature. Figure 5.4a shows overall trail user counts plateauing around 86°F. Trail user counts decreased with precipitation ($\beta=-2.626$, $p=.00$). Increasing wind speed ($\beta=-0.011$), humidity ($\beta=-0.025$), and

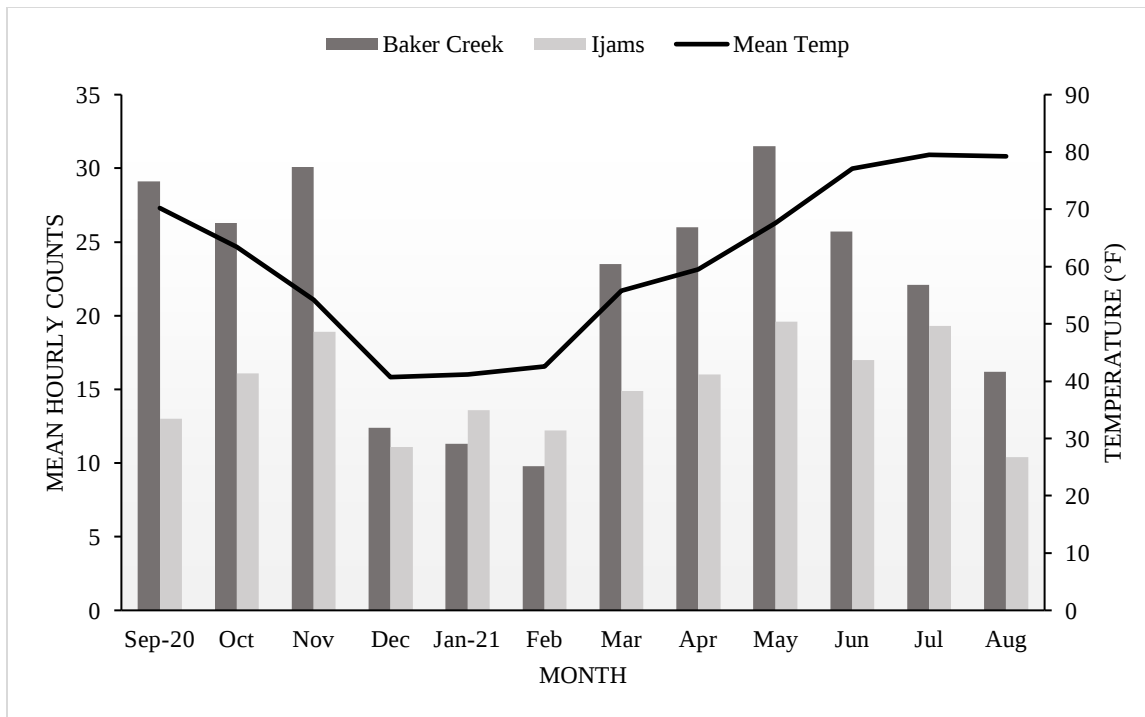


Figure 5.2: Monthly variation in mean user trail counts and mean temperature (°F).

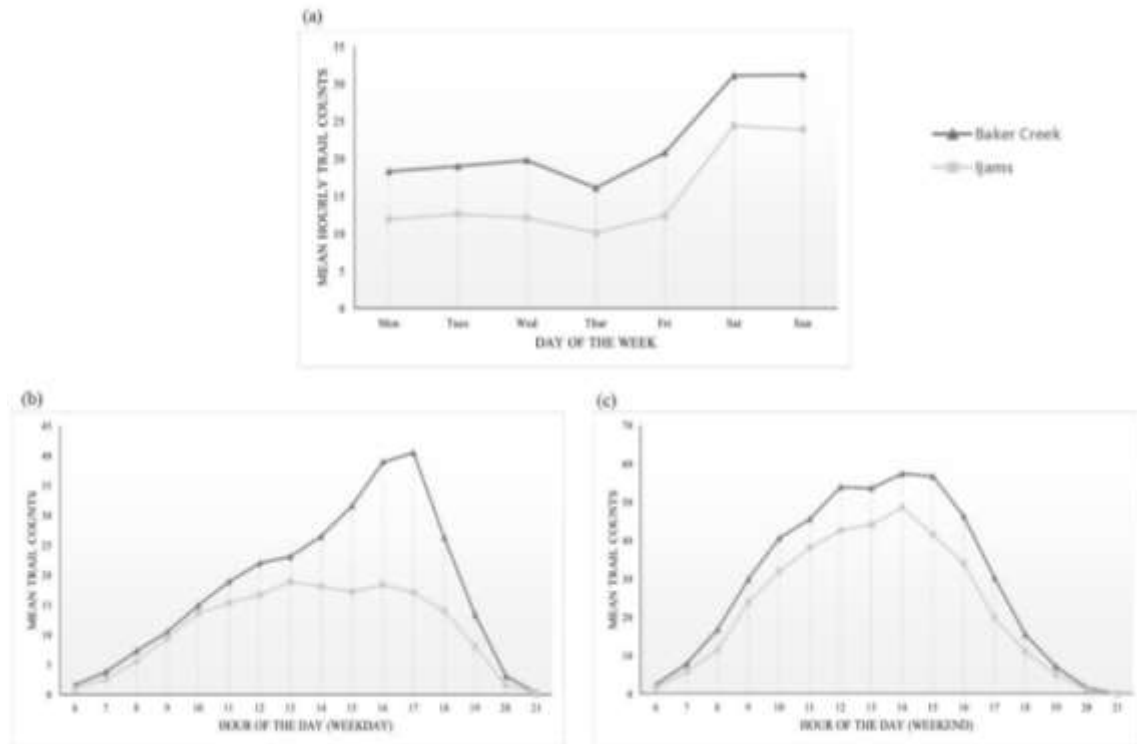


Figure 5.3: Temporal variations in hourly mean user trail counts by (a) day of the week, (b) hour of day on weekdays, and (c) hour of day on weekends at Baker Creek and Ijams.

Table 5.2: Results of negative binomial regression models using trail user counts.

	Trail-Specific Models					
	General Model		Baker Creek		Ijams	
	<i>n</i> = 10,363		<i>n</i> = 5,229		<i>n</i> = 5,134	
	Coeff.	<i>p</i> -value	Coeff.	<i>p</i> -value	Coeff.	<i>p</i> -value
Weather Variables						
Temperature	0.115	.00	0.112	.00	0.127	.00
Temperature ²	-0.001	.00	-0.001	.00	-0.001	.00
Wind Speed	-0.011	.10	-0.017	.05	-0.007	.44
Rel. Humidity	-0.025	.00	-0.032	.00	-0.019	.00
Precipitation	-2.626	.00	-2.281	.00	-3.114	.00
Abs. Pressure	1.029	.00	1.165	.00	0.837	.00
UVR Index	-0.027	.00	-0.036	.00	-0.013	.23
Temporal						
Weekend	0.632	.00	0.613	.00	0.668	.00
Trail Surface						
Dirt Trail	0.265	.00	-	-	-	-
Model Statistics						
Intercept	-31.691	.00	-34.798	.00	-26.868	.00
Dispersion	0.823	-	0.778	-	0.755	-

n = number of hours analyzed. Number of hours vary due to equipment failure (*i.e.*, dead batteries, persons tampering, or missing weather data)

Regression models also control for month, year, hour of the day, and counter model.

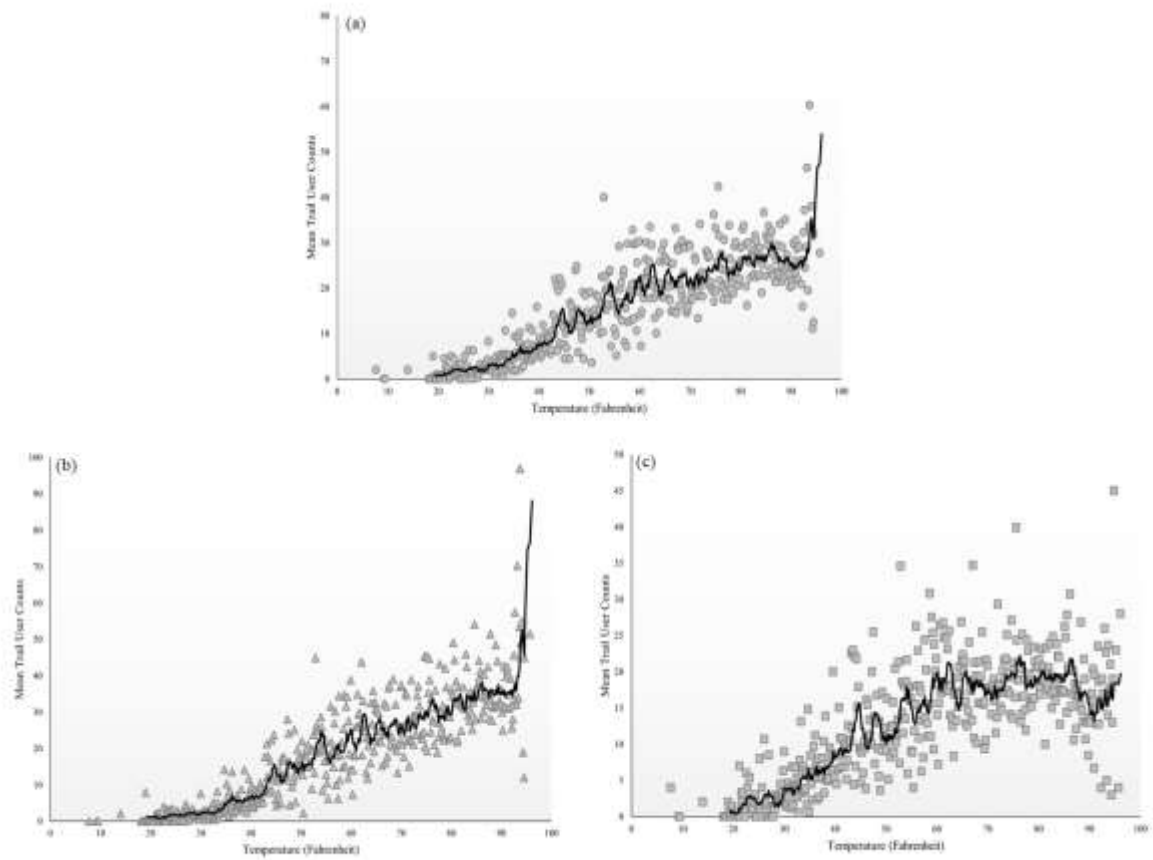


Figure 5.4: Relationship of outdoor temperature (°F) and mean trail user counts at (a) both locations combined, (b) Baker Creek, and (c) Ijams.

UVRI ($\beta=-0.027$) were associated with a modest decrease in trail users counts; however, wind speed was not found to be significant (Table 5.2).

Finally, when looking at the general model, the dirt trail surface was a significant predictor of trail user counts ($\beta=0.265$, $p=.00$); therefore, trail-specific models were used to analyze the relationship weather has on different trail surfaces.

As temperature increased, Baker Creek (dirt trail) experienced an increase in trail user counts to 88°F before plateauing (Figure 5.4b). Ijams (gravel trail) showed a curvilinear relationship in trail user counts in response to increasing temperature (Figure 5.4c). Wind speed (Table 5.2) was not found to be significant at Baker Creek ($\beta=-0.017$, $p=.05$) or Ijams ($\beta=-0.007$, $p=.44$). Precipitation had the largest magnitude of effect on hourly trail user counts (Table 5.2) for both Baker Creek ($\beta=-2.281$, $p=.00$) and Ijams ($\beta=-3.114$, $p=.00$). As absolute pressure increased, so did hourly trail user counts (Table 5.2). UVRI was only found to be significant on the Baker Creek trail ($\beta=-0.036$).

Discussion

To our knowledge, this is the first exploration into how weather relates to recreational trail use on differing natural trail surface materials (gravel vs. dirt). A previous study by Reed et al.³⁰ explored PA differences and perceptions between natural-surface and paved trail users, but overall usage and weather variables were not measured. Also, this is one of few studies to analyze natural surface trails in an urban wilderness trail network setting.¹⁵ Several studies have analyzed the relationship between weather and utilitarian trail use,^{12,16,19,31} recreational trail use,^{13,15,32-35} and multiuse trails.^{11,14,17,18,20} The PA performed on previously studied trails varied; however, the trail surface material was consistently concrete/asphalt, materials that may not be impacted like dirt and gravel trails. Based on direct observation, these trails in the current

investigation primarily serve walkers/hikers and mountain bikers (E. Fitzhugh, personal communication, July 25, 2021). Also, many of these studies did not mention trail surface material, nor was it accounted for in their respective analyses if there were differing trail surfaces. In the current investigation, weather variables affected trail use in the expected manner; yet the magnitude of the effect of certain weather factors varied based on trail surface material. Dirt trail users were more impacted by relative humidity, absolute pressure, and UVRI, while gravel trail users were more impacted by temperature and precipitation. Therefore, trail surface material may be an important factor to consider when determining recreational trail use in response to varying weather conditions.

Temporal Variations in Trail User Counts

Hour of the day and day of the week trail use volume from the current investigation is consistent with previous research analyzing recreational trail usage.^{11,13,14,18,19} Results of Baker Creek and Ijams show a unimodal peak in trail use on weekdays and weekends. These results are similar to the hourly trends in trail volume found by Nosal et al.¹⁸ However, our results are inconsistent with Zajchowski and colleagues,¹⁵ who studied a similar type of urban wilderness trail network and found bimodal peaks in trail use from 8a-9a and 6p-8p. Though, in that study only 32 days over summer months were analyzed. Perhaps our results are indicative of the accessibility of the KUW, which allows for more usage throughout the workday as opposed to before and after typical work hours.

Specific to days of the week, mean hourly trail counts on the weekend were 84.5% higher for Baker Creek and 95.1% higher for Ijams when compared to the weekday. The daily temporal trends in the data are consistent with Burchfield et al.,¹¹ Nosal et al.,¹⁸ Paudyal et al.,¹³ and Wolff & Fitzhugh,¹⁴ who all found significant increases in trail counts on weekend days. Previous

research has shown recreational trail use is highest in warmer months (May-September) and lowest in colder months of December-February,^{14,17} In the current investigation, Ijams closely mimics these trends; however, there was a dip in trail use in August. On the other hand, Baker Creek peaked in usage during May (31.5 counts/hr), steadily declined until August (16.2 counts/hr), and then increased to 30.1 counts/hr in November. According to the WDF, systematic increases in visitation around summer school holidays (institutional seasonality) indicates a low level of weather dependency.⁴ The KUW trails in this investigation experienced decreases in trail use during summer, which may indicate a higher level of weather dependency for this trail system. Additionally, this decrease in trail use may be explained by the combination of higher air temperatures and higher humidity over the summer months. Heat index is what the temperature feels like when air temperature is combined with relative humidity.³⁶ Although unmeasured in the current investigation, Paudyal et al.¹³ identified heat index as a weather factor that significantly decreased trail counts in Florida. The higher air temperature and humidity may also diminish trail user thermal comfort, causing changes in trail user behavior and comfort in outdoor spaces.³⁷ The large decrease in trail use on Baker Creek and Ijams in August may also be credited to Knoxville receiving 2.7 inches more rain (7.51 inches total) than the 10-year average of 4.81 inches for August.³⁸ This may indicate gravel and dirt trail use are more susceptible to precipitation compared to paved trails.

Weather-Related Variations in Trail User Counts

Concurrent with previous findings, gravel trail user counts have a curvilinear relationship with temperature.^{11-16,32} Ijams, the gravel trail, saw a 13.5% increase in mean trail users for every 1°F increase in air temperature up to 76°F. Mean trail user counts then remained steady before beginning to decline at temperatures above 86°F. Baker Creek (dirt trail) on the other hand,

experienced an 11.9% increase in mean trail users for every 1°F increase in air temperature up to 88°F before plateauing. This indicates users of Baker Creek, which may be primarily mountain bikers, potentially tolerate higher air temperatures compared to those who use Ijams, which may be primarily walkers/runners (E. Fitzhugh, personal communication, July 25, 2021). Similarly, Zhao et al.¹⁶ observed cyclist counts increasing to 86°F, while pedestrian counts only increased to 77°F before declining as temperature increased. Ermagun et al.¹⁷ observed cyclists counts began decreasing around 91.6°F and pedestrians counts began to decrease around 75°F. Zajchowski et al.¹⁵ found trail use began to decline at 82°F, but these results are limited as they only analyzed 32 days in June, July, and August. Also, the higher air temperature before trail use declines in the current study may be credited to the dense tree coverage over the trails at the KUW. This could indicate densely covered trails, like the KUW trails, may promote a higher resiliency to increasing temperatures, an important component of the WDF.

Precipitation negatively impacted trail user counts on both Baker Creek (89.8% reduction per 1-inch of rain) and Ijams (95.6% reduction per 1-inch of rain). One might expect dirt trails (Baker Creek) to be more impacted by rain compared to gravel trails (Ijams), especially when mountain bikers, one of the primary users of the KUW, are discouraged from riding muddy trails.³⁹ However, our results indicate that gravel trails are more impacted by precipitation than dirt trails. Zhao et al.¹⁶ reported that walkers were more impacted by rainfall than cyclists. Based on direct observation, walkers may make up the majority of gravel trail users (E. Fitzhugh, personal communication, July 25, 2021). This may explain why the gravel trail, Ijams, was impacted more by precipitation. Another explanation could be that Baker Creek is the advertised access point to an area within the KUW known as ‘The Year Round Get Down,’ a set of gravel-surfaced trails built to withstand all weather conditions.⁴⁰ This could indicate those who use the

KUW during rain events (walkers, runners, and/or bikers) may be accessing this area via the Baker Creek trailhead. The weather dependency framework concluded that hiking, one of the primary activities in the KUW, was moderately dependent on precipitation.⁴ In contrast, the current investigation found KUW trail users were highly impacted by precipitation (92.8% decrease in trail use per inch of rain). The effect of precipitation in the data is similar to previous research conducted in the Knoxville, TN area by Burchfield et al.¹¹; however, the magnitude of the effect of precipitation in the current study was higher. This may be due to Burchfield et al.¹¹ only analyzing eight months of data on a multiuse paved greenway.

Relative humidity was found to be significant in the current investigation, but only resulted in a combined 2.5% reduction in trail users for every 1% increase in relative humidity. These results are similar to what was found previously on utilitarian,¹² multiuse,¹⁸ and recreational trails.¹³ Wind speed was not found to have a significant impact on trail use; however, UVRI was found to be significant on the dirt trail (Baker Creek), but the magnitude of the effect was relatively small (3.5% decrease in trail user count for a 1-unit increase in UVRI). The limited impact of wind speed and UVRI on trail user counts may also be due to the site characteristics of the KUW (e.g., the densely wooded area surrounding the trails). These characteristics may provide a buffer to wind and ultra-violet radiation from the sun, possibly indicating more resilient trail system characteristics to these weather variables.

Limitations and Strengths

The current investigation has some inherent limitations that should be noted. Trail user counts were monitored using an infrared trail counter which cannot distinguish if more than one individual passes the counter at the same time. This could result in inaccurate estimations of trail use. To address this limitation, direct observation of trail users occurred at the trail counter sites.

This enabled the research team to calculate an adjustment factor that was used to account for measurement errors. To address the concern of introducing error, researchers conducted the same statistical analyses on the raw count data and found no differences in the results of the regressions.

Additional limitations when using an infrared trail counter are the inability to identify the mode and intensity of the activity. Specifically, the counters used in the current investigation could not distinguish between walkers/runners or cyclists. In the current investigation, it is also possible that activity type, not just trail surface material, may be influencing the results found on the various trail surfaces. However, the direct observation previously mentioned was limited to one weekend (Saturday and Sunday) during the data collection time frame; therefore, our ability to control for activity type is limited.⁴¹ Also, the lack of trail user characteristics (i.e., gender, age, race/ethnicity, socioeconomic status, etc.) limits the inferences that can be made regarding how weather variables impact trail use. Trail counters in the current study experienced equipment malfunctions and tampering from the general public. In addition, the onsite weather station malfunctioned and resulted in missing weather data for a short period of time. As a result, 1% of data (113 hours) was lost over the duration of the study due to these problems.

There are several strengths to note from the current study. First, the inclusion of a year's worth of data on trail use from September 2020 to August 2021. Additionally, this is one of few studies analyzing trail use in an urban wilderness setting and using natural surface trails. This provides additional data to further develop the weather dependency framework specific to site characteristics and weather variables. Previous research has primarily used total counts registered by the trail counter, while this investigation applied an adjustment factor to account for trail counter error. The use of DO to validate the trail counters before and during the study period are

also relatively unique to this investigation. Finally, this is the first investigation to factor in trail surface material (gravel vs. dirt) in the analysis.

Future Research

It is important to note the generalizability of the current results are specific to climate regions similar to East Tennessee. Exploring trail use in response to varying weather conditions across differing climate regions is essential; however, based on the current findings, trail surface material should also be considered during data analysis. Future studies on natural surface mixed-use urban trails should incorporate trail counters that can distinguish between walkers/runners and cyclists to better quantify the impact weather has on specific activities within the WDF framework. Since outdoor PA is associated with perceived weather conditions, as opposed to objective measures,⁴² future investigations should also collect data specific to trail user perceptions of weather and the impact it has on PA. This would provide additional information to urban designers and trail planners when designing trails that promote use in all weather conditions.

Additional research is warranted regarding how weather conditions impact natural surface trails. Previous research also identified precipitation negatively impacted trail use in the hours prior to¹² and post-rain events.^{16,20} This impact may be more pronounced on natural surface trails but was not analyzed in the current investigation. Future research should also examine the user burden placed upon natural surface trails as it relates to maintenance needs linked to weather.

Management Implications

By understanding the behaviors of natural surface trail users in response to various weather conditions, managers can adapt their trail planning (i.e., type of trail, surface material),

maintenance, and funding for various projects. Managers could collect weather-related information in conjunction with trail surface conditions to inform users of more user-friendly trails during adverse weather events. This could decrease trail maintenance by shifting users to trails that can tolerate more use in poor weather. Additionally, this information would enable managers to develop programs more effectively (e.g., special events, learning clinics) and thus engage more people in outdoor recreation.

Conclusions

This paper expands the current body of knowledge by analyzing trail use on natural surface trails (gravel and dirt) in urban nature-based recreation areas. Based on the current findings, the direction of the effect of weather measures on trail use is similar to previous studies; however, the magnitude of the effect varies considerably depending on the trail surface material. Gravel trail users were more sensitive to temperature and precipitation, while dirt trail users were more impacted by relative humidity, absolute pressure, and UVRI. The variations in the magnitude of effect may also be a function of the type of activity performed on the different trail surfaces or possibly activity choice. Hourly and daily temporal changes in natural surface trail use closely mimic those of paved recreation trails; however, yearly temporal changes in the current study observed bimodal peaks in use (May and November), which differs from the unimodal peak found in previous investigations. This work also highlights the importance of considering trail surface material to fully understand the impact weather has on trail use.

Additionally, the models used in the current investigation can help nature-based recreation groups estimate trail use based on weather conditions. This may allow for better allocation of staffing and resource management (e.g., trail maintenance). The higher air temperature before trail use declined may indicate the cooling effect large, canopy-dense, urban

green spaces like the KUW have on mitigating heat⁴³; therefore, providing a more tolerable, weather resilient location for PA on warmer days. This could influence policymakers to incorporate nature-based trail networks to provide alternative opportunities for people to engage in outdoor recreation during warmer months.

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CHAPTER 6
A PROFILE OF USERS AND PHYSICAL ACTIVITY WITHIN
AN URBAN BIKE PARK

Abstract

Bike parks are growing in popularity across the United States; however, little research exists on who uses or how they use features of the park for physical activity (PA). The purpose of this study was to create a profile of bike park users, determine how bike parks are used for PA, and determine the intensity of PA among park users. **METHODS:** Baker Creek Bike Park in Knoxville, TN has thirteen PA zones that include bicycle features (N=9), playground features (N=3), and a greenway (N=1). The System for Observing Play and Recreation in Communities (SOPARC) was used to measure gender, age, race/ethnicity, primary activity, and activity intensity of users. SOPARC scans were completed on four days during a week (M, W, Sa, Su) in 2021 (April, July, October) and 2022 (January, April) at four 1-h time periods per day (8a, 12p, 3p, 6p). A total of 1040 scans were conducted across the thirteen PA zones. SOPARC count data were analyzed for descriptive statistics of users and their associated energy expenditure. Chi-square tests were used to compare user groups to 2020 Knox County census data. Binary regression analysis was performed to determine the odds of at least one park user occupying an activity zone. T-tests were then used to compare mean PA intensity between females and males by activity zone features. **RESULTS:** In total, 3443 individuals were observed using the bike park over the study period. Most bike park users were observed in PA zones with cycling features (54.3%), followed by the greenway (27.1%). Among users, 68.8% were male ($p < 0.001$, $df=1$), most were adults (54.0%), with 43.5% being youth. 5.6% of users observed were minorities ($p < 0.05$, $df=3$). Regarding PA intensity, 64.2% of park users engaged in moderate-vigorous PA. Males participated at a higher intensity (METs) compared to females in PA zones with cycling features (4.03 vs 3.30, $p < 0.0001$) and on the greenway (4.60 vs 3.94, $p = 0.0001$). **CONCLUSIONS:** Physically active visits are relatively high at Baker Creek Bike Park compared

to other park studies which indicate users are more likely to participate in MVPA. People mostly use the park as intended, to bike. Males used the bike park more and participating at a higher intensity compared to females. Future research should investigate if a newly built bicycle park increases LTPA or simply provides an additional location for PA.

Introduction

Participation in physical activity (PA) on a regular basis has been shown to reduce the risk of numerous chronic health conditions¹ and improve both quality of life and well-being.² Despite these known benefits of PA, 40% of adults (18+ years) and 72.0% of adolescents are insufficiently active (i.e., not obtaining the equivalent of 150 minutes or more per week of moderate intensity PA for adults and 60 minutes or more per day of moderate-vigorous PA for adolescents).³⁻⁵ Research has shown leisure-time PA (LTPA) tends to be higher in areas where the built environment promotes activity across all age groups.^{6,7} Additionally, several objectives and strategies of Healthy People 2030 focus on improving the built environment to increase population PA.⁸

One feature of the built environment that can promote PA are community parks. Therefore, understanding who uses and how these recreational spaces (e.g., community parks) are used can be vital to promoting PA within the community. Previous research specific to parks has shown they play a significant role in PA levels. For example, Liu et al.⁹ reported higher levels of moderate and vigorous PA in park users compared to non-park users. Evenson and colleagues¹⁰ found on days when a park was visited the minutes of moderate to vigorous PA (MVPA) were higher compared to days when a park was not visited.

In recent years, a new type of park design focusing on bicycling has gained popularity all over the world. These new park designs incorporate features specific to mountain biking and pump track cycling and are often referred to as bike parks, bike hubs, bike skills parks, or pump tracks.¹¹ A pump track consists of a series of rollers (i.e., bumps or small hills in the track) and berms (i.e., corners of the track) that can be ridden continuously and allows riders to propel themselves around the track by a pushing down and pulling up action on a bike (i.e.,

“pumping”).¹² According to trailforks.com, 1,200+ bike parks can be found across the United States in all 50 states as well as around the world.¹³ A study conducted by Schipperijn et al.¹⁴ looked at the use, PA level, and user experiences of three newly built bicycle playgrounds in Copenhagen, Denmark. The researchers conducted 84 observations from May-July 2013 and observed 331 park users. They reported 70% of users were male, 78% of users were children and teens, no older adults were observed, and 63% of users were active. Based on the user survey, researchers reported users were satisfied with the bicycle playgrounds and felt they added a new way to be active. However, this study was limited by the low number observations and observed users. Additionally, the neighborhoods surrounding the bicycle playgrounds (i.e., potential users with highest accessibility) consisted of a high number of unemployed residents and a low average educational status, which may be indicative of lower overall PA participation.^{15,16}

To our knowledge, Schipperijn and colleagues¹⁴ have conducted the only bicycle park study on user experiences. More research would contribute to a better understanding of who uses and how they use features of the bike park for PA. This information could be useful for parks and recreation departments to help determine if building a new bike park in their community could lead to increased levels of PA in their community. Additionally, bike park designers and builders could use this information to understand what types of features are used the most and what type of users are attracted to bike parks. Therefore, the purpose of the present study was to create a profile of bike park users (gender, age group, race/ethnicity), determine how bike parks are used for PA, and determine the intensity of PA among park users.

Methods

Study area

Baker Creek Bike Park in Knoxville, TN was built in 2020 and is approximately 15 acres.¹⁷ The bike park (See Figure 6.1) contains 13 physical activity zones (See Table 6.1) that consist of cycling features (N=9), playground features (N=3), and a greenway. The bike park was built to provide an all-weather progression to Baker Creek Preserve which houses five multi-use trails and three bicycle specific downhill trails. These two areas act as a gateway to Knoxville's Urban Wilderness, an outdoor adventure area with over 60 miles of multiuse trails and other recreational opportunities.¹⁸

Data collection

Data for this study was derived from systematic observations of park users and their physical activity across the Baker Creek Bike Park using the System for Observing Play and Recreation in Communities (SOPARC) protocol.¹⁹ SOPARC is a momentary time sampling technique that provides data regarding the number of park users, gender, age group, race/ethnicity, activity type and PA level. SOPARC is a reliable¹⁹ and valid²⁰ tool for assessing park user characteristics and PA levels. A total of four observers completed the SOPARC activity zone scans. Two of the observers were previously trained with extensive experience using the SOPARC protocol. The two recruited observers received substantial training prior to data collection in both the classroom and on-site at the bike park on SOPARC procedures. Interrater reliability (Cohen's κ) was 0.77 for age, 0.81 for race, and 0.66 for PA intensity, indicating substantial agreement.

The Baker Creek Bike Park was divided into 13 activity zones covering the entire bike park. Observations were completed on four days (M, W, Sa, Su) during a week in three months

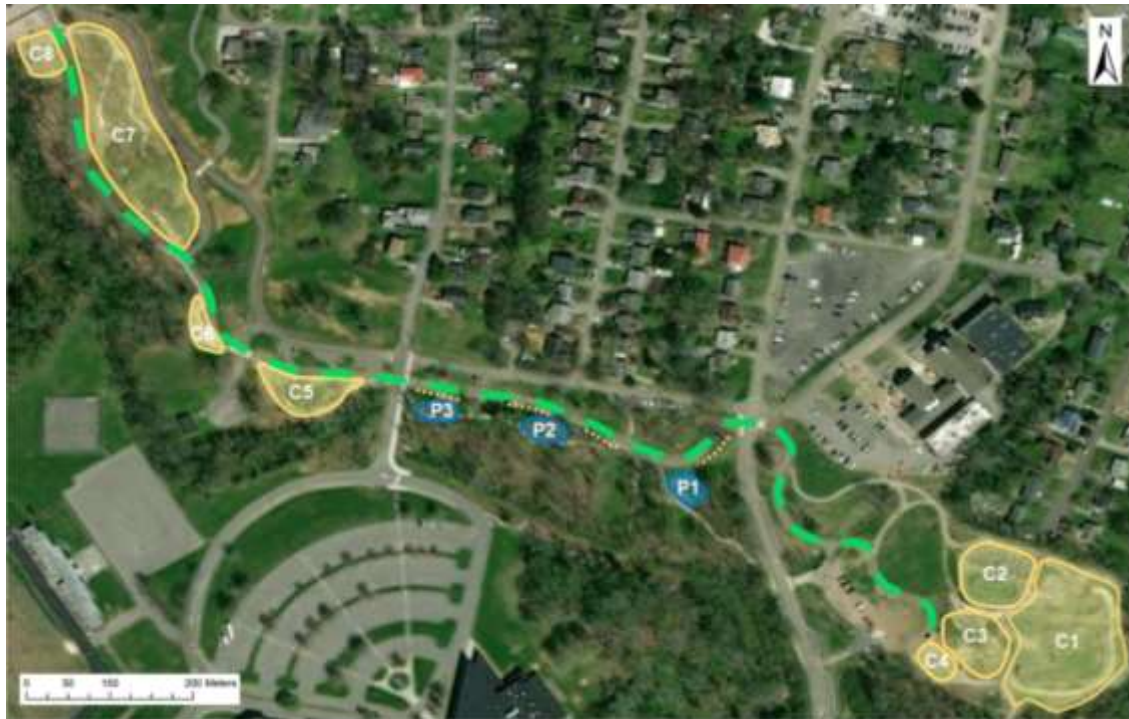


Figure 6.1: Map of Baker Creek Bike Park with activity zones outlined.

Table 6.1: Physical characteristics of the scan zones.

Activity Zone	Description	Skill Level
Cycling (C)		
C1	Pump and jump track with outer stone line.	Intermediate-
	Asphalt jump line with steep and rolled lips.	Advanced
C2	Asphalt pump track.	All skill levels
C3	Gravel progressive trail bike skills trails.	All skill levels
C4	Short oval asphalt pump track.	All skill levels
C5	Gravel pump track loop.	All skill levels
C6	Rock navigation course for cycling.	Intermediate-
		Advanced
C7	Gravel pump track loop with wall features.	All skill levels
C8	Kids dirt/gravel pump track.	Beginner
■ ■ ■	Linear cycling skill features adjacent to greenway.	All skill levels
Playground (P)		
P1	Climbing structure, slide, and benches.	-
P2	Swings and benches.	-
P3	Climbing structure and benches.	-
Greenway		
■ ■	Paved greenway that connects to extensive greenway and multiuse trail network.	-

of 2021 (April, July, October) and two months of 2022 (January, April) at four 1-hour time periods per day (8-9a, 12-1p, 3-4p, and 5-6p). During scans, researchers stood in a pre-determined location within each activity zone that allowed them to see the entire activity zone. For the greenway, a walking scan was completed as the researcher progressed through the various cycling and playground activity zone scans. As a greenway user passed the researcher, demographic and PA-related information was be recorded. One scan of each activity zone was completed in order, followed by a second scan (both scans were completed within the 1-hour observation window). The values from the two scans were then totaled for each observation period. A total of 1040 scans were completed across the activity zones. Per the SOPARC protocol, any missed observations due to poor weather were scheduled for the following week on the same weekday or weekend day and time.¹⁹

When scanning an activity zone, researchers would stand in a predetermined location and first analyze the contextual factors (i.e., accessible, usable, organized, supervised, equipped) of the activity zone. Researchers would then systematically scan each activity zone from left to right, focusing on females first and then males. During scans, researchers would record gender (female, male), age group (child, 0-12 years; teen, 13-20 years; adult, 21-59 years; older adult, 60+ years), race/ethnicity (Latino, black, white, other), primary activity (the activity choice of the majority of female and male users, separately, within an activity zone), and PA intensity (sedentary, moderate, vigorous) for each park user.

Data cleaning

For certain analyses the 13 activity zones were collapsed into three separate categories based on the physical activity features associated with the activity zone (cycling features, C1-C9; playground features, P1-P3; greenway). PA intensity (sedentary, moderate, vigorous) were

converted to metabolic equivalents (METs) consistent with previously determined formulae.²¹ The intensity value assigned to sedentary was 1.5 METs, moderate was 3.0 METs, and vigorous was 6.0 METs. To assess physical activity intensity of park users within each activity zone, the below formula was used to calculate mean METs for the total sample and for each gender:

$$\frac{(\# \text{ Sedentary} \times 1.5 \text{ METs}) + (\# \text{ Moderate} \times 3 \text{ METs}) + (\# \text{ Vigorous} \times 6 \text{ METs})}{\text{Total \# of persons observed within activity zone}}$$

Statistical analysis

Data were analyzed using SAS Enterprise Guide 8.3 (SAS Institute Inc., Cary, NC, USA). Percentages were calculated for all categorical measures (gender, age group, race/ethnicity, PA intensity) and classified by activity zone features. The proportion of park users by gender and race/ethnicity were compared to the 2020 Knox County, TN census population²² data using Chi-square statistics. Binary regression analysis was performed to determine the odds of at least one park user (female vs. male) occupying an activity zone. T-tests were used to compare mean PA intensity (METs) between females and males by activity zone features.

Results

Park user characteristics

Table 6.2 provides the demographics of the bicycle park users in our analysis. Total user characteristics were compared to the 2020 Knox County, TN census population data.²² More males (68.8%) than females (31.2%) were observed ($\chi^2 = 15.85$, $df=1$, $p < 0.0001$). The majority of users observed were adults (54.0%), followed by children (29.1%), teens (14.4%), and older adults (2.4%). For race/ethnicity, a relatively small percentage of users (5.6%) represented minority populations ($\chi^2 = 10.87$, $df=3$, $p = 0.013$).

Regarding user characteristics by activity zone features (Table 6.2), zones with cycling

Table 6.2: Bicycle park user demographics in total and by activity zone features.

Demographic Measure	Total n = 3,443 n (%)	Cycling Features n = 1,870 n (%)	Playground Features n = 639 n (%)	Greenway n = 934 n (%)
Gender				
Female	1,073 (31.2)	398 (21.3)	308 (48.2)	367 (39.3)
Male	2,370 (68.8)	1,472 (78.7)	331 (51.8)	567 (60.7)
Age group				
Child	1,002 (29.1)	437 (23.4)	311 (48.7)	254 (27.2)
Teen	497 (14.4)	365 (19.5)	44 (6.9)	88 (9.4)
Adult	1,860 (54.0)	1032 (55.2)	282 (44.1)	546 (58.5)
Older adults	84 (2.4)	36 (1.9)	2 (0.3)	46 (4.9)
Race/Ethnicity				
White	3,209 (94.4)	1,783 (97.0)	560 (89.2)	866 (92.9)
Other ^a	190 (5.6)	56 (3.0)	68 (10.8)	66 (7.1)

Note: n values for Ethnicity may not equal the Total n due to park users entering/leaving the PA scan zones during observations.

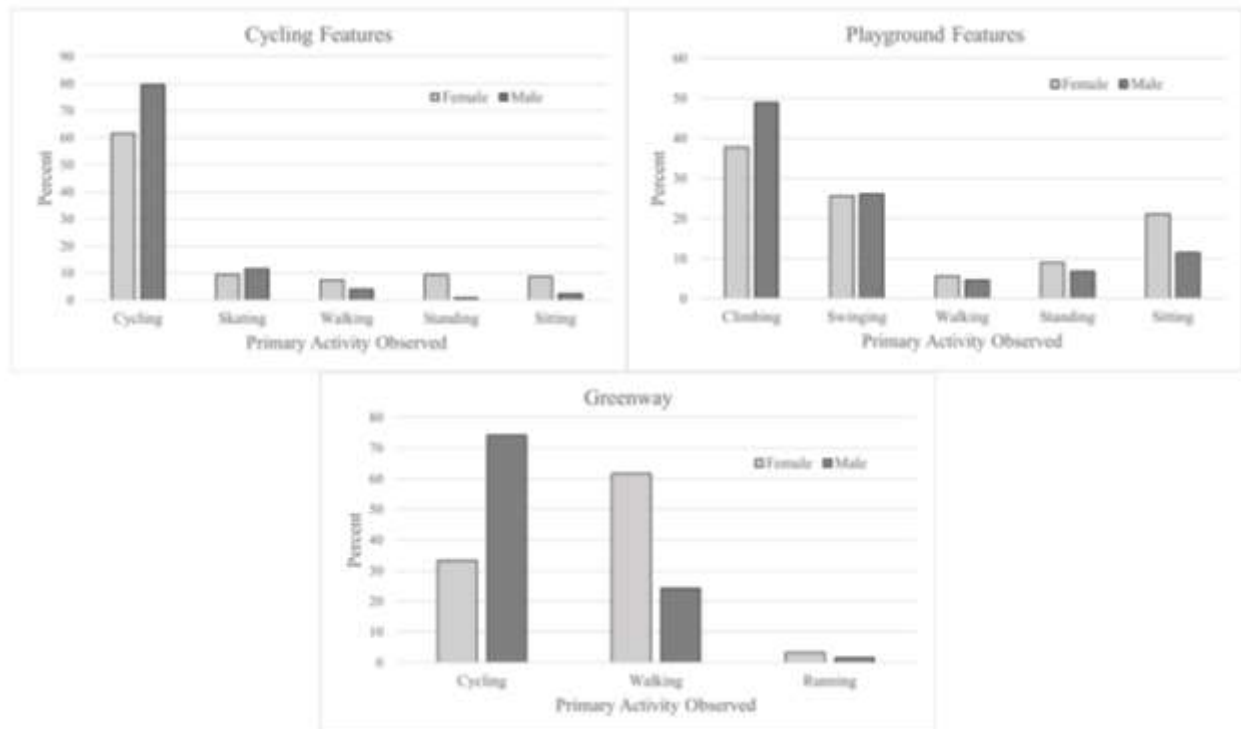
^aLatino, Black, or Other were collapsed together due to a relatively small representation from each group.

features (n=9) had that highest number of observed users (n=1,870) and were primarily occupied by males (78.7%). Females comprised 48.2% of observed users in activity zones with playground features (n=3). Adults were the majority for zones with cycling features (55.2%) and on the greenway (58.5%). However, children and teens made up the majority of users (55.6%) in zones with playground features. The highest proportion of users that were older adults were on the greenway (4.9%), compared to only 3.0% in zones with cycling features and 0.3% in zones with playground features. Overall, minorities had a small representation within the park during our observations. The highest percentage of minorities were observed in the playground areas (10.8%) and the greenway (7.1%), with only 3.0% observed in zones with cycling features.

Characteristics of bicycle park use

Figure 6.2 shows information regarding the primary physical activity observed by gender when an activity zone was occupied. At least one male occupied an activity zone during 25.6% (266/1040) of scans, while at least one female occupied an activity zone during 19.6% (204/1040) of scans. Cycling was the highest observed primary physical activity for both females (38.5%) and males (61.8%). Other physical activities observed were climbing (females = 11.2% vs males = 10.6%), running (female = 1.0% vs males = 0.5%), and swinging (females = 8.0% vs males = 6.0%). Walking was the second highest physical activity observed for females at 17.3% compared to 7.2% in males. Additionally, females were observed more than males sitting (10.6% vs 3.9%) and standing (7.4% vs 1.9%).

Table 6.3 shows the results of regression analysis predicting at least one person occupying a scan zone by gender. For most cycling zones, females were less likely to be present ($p < 0.0001$). Males had a similar trend of lower odds of occupying cycling zones C3-C9. However, males were more likely to occupy zone C1 (OR=9.80, 95% CI [4.67, 20.54]) and zone



Note: Only the top five primary activities are shown for activity zones with cycling and playground features, and the top three primary activities for the greenway are shown.

Figure 6.2: Primary activity observed when an activity zone was occupied during a scan by gender and activity zone feature (total n: male = 266, female = 204).

Table 6.3: Binary logistic regression to predict at least one person in an activity zone by gender.

Predictor	Females			Males		
	OR	(95% CI)	p-value	OR	(95% CI)	p-value
<u>Cycling Zones</u>						
Non-cycle zones	-	-	<0.0001	-	-	<0.0001
C1	1.20	(.70, 2.06)		9.80	(4.67, 20.54)	
C2	.94	(.55, 1.62)		4.07	(2.18, 7.59)	
C3	.15	(.07, .30)		.21	(.11, .39)	
C4	.94	(.55, 1.62)		1.70	(.97, 2.98)	
C5	.15	(.07, .30)		.21	(.11, .39)	
C6	.10	(.05, .22)		.13	(.06, .26)	
C7	.16	(.08, .33)		.31	(.17, .56)	
C8	.05	(.02, .13)		.04	(.01, .11)	
C9	.18	(.09, .36)		.14	(.07, .28)	
<u>Playground Zones</u>						
Non-PG zones	-	-	<0.0001	-	-	0.0044
P1	3.01	(1.82, 4.99)		1.60	(.98, 2.62)	
P2	1.67	(1.01, 2.78)		.95	(.58, 1.56)	
P3	.70	(.39, 1.24)		.43	(.25, .76)	
<u>Greenway Zone</u>						
Non-GW zones	-	-	<0.0001	-	-	<0.0001
Greenway	10.16	(5.70, 18.12)		10.97	(5.83, 20.63)	

Notes: Models also control for day of the week, time of day, season, and year. Non-cycle zones include playground and greenway activity zones. Non-PG zones include cycling and greenway activity zones. Non-GW zones include cycling and playground activity zones.

Abbreviations: PG=playground, GW=greenway, C1=Pump and jump track, C2=Asphalt pump track, C3=Gravel progressive bike skills trails, C4=Short oval asphalt pump track, C5=Gravel pump track loop, C6=Rock navigation course, C7=Gravel pump track loop with wall features, C8=Kids dirt/gravel pump track, C9=Linear cycling features adjacent to greenway, P1=Climbing structure with slide and benches, P2=Swings and benches, P3=Climbing structure with benches.

C2 (OR=4.07, 95% CI [2.18, 7.59]) when compared to non-cycle zones. Females had significantly higher odds of occupying two of the activity zones with playground features (P1: OR=3.01, 95% CI [1.82, 4.99] and P2: OR=1.67, 95% CI [1.01, 2.78]) compared to non-playground zones. Females (OR=10.16, 95% CI [5.70, 18.12]) and males (OR=10.97, 95% CI [5.83, 20.63]) were significantly more likely to occupy the greenway when compared to non-greenway zones.

Physical activity intensity of park users

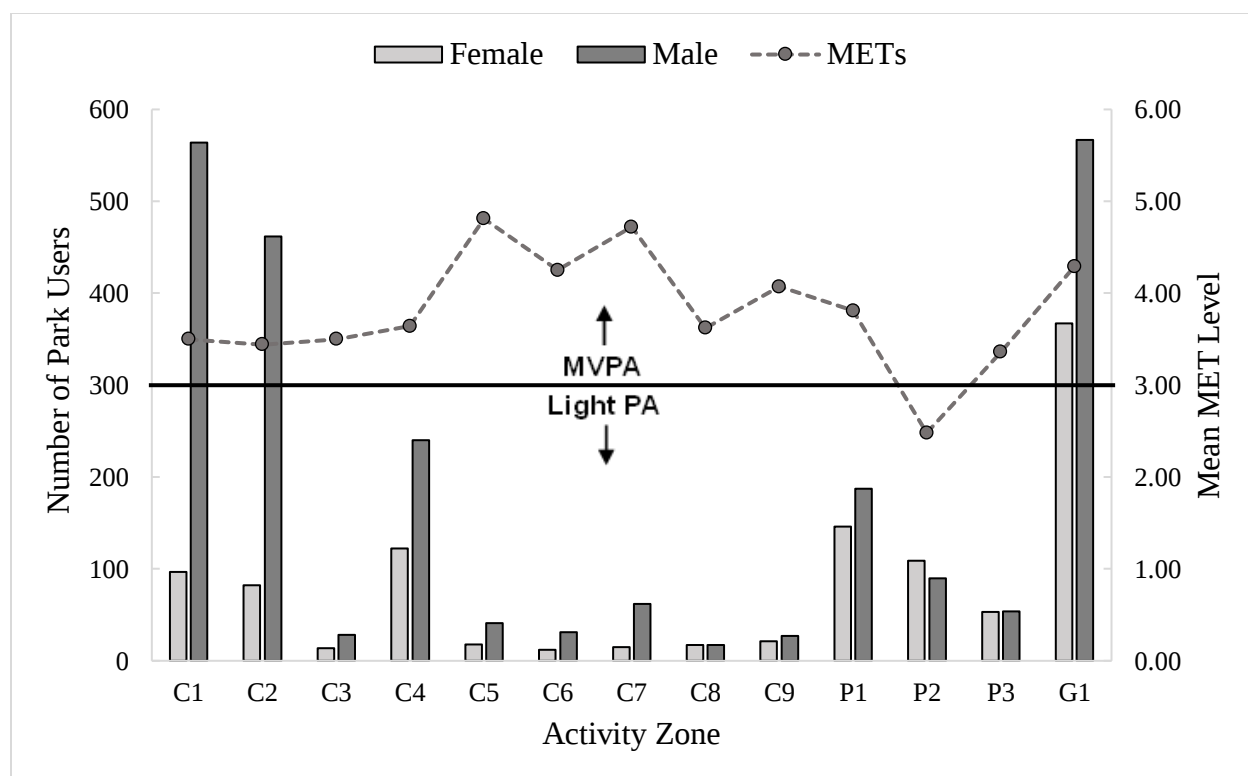
Overall, 35.8% of park users were observed being sedentary, 22.4% of park users were observed participating in moderate intensity activity, and 41.8% were observed participating in vigorous intensity activity (See Table 6.4). The greenway had the highest percentage of observed users (92.8%) participating in moderate-to-vigorous physical activity (MVPA). The cycling and activity zones had similar percentages of observed users participating in MVPA (53.4% and 53.9%, respectively).

Figure 6.3 shows the number of park users observed by gender and the mean intensity (METs) of all users observed in each activity zone. The dashed line highlights the mean PA intensity observed among the park users. Cycling zones C1, C2, and C4 had the most observed users compared to the other cycling zones; however, they also had some of the lowest mean MET values (3.50, 3.44, and 3.64, respectively). Two of the three playground zones (P1 and P3) had a mean intensity above the MVPA threshold (≥ 3.0 METs). The greenway had the highest use by both males and females with a mean intensity of 4.29 METs.

When comparing PA intensity by gender (See Figure 6.4), males had a significantly higher mean MET intensity value than females in activity zones with cycling features (4.03 vs 3.30, $p < 0.0001$) and on the greenway (4.60 vs. 3.94, $p = 0.0001$). There was not a significant

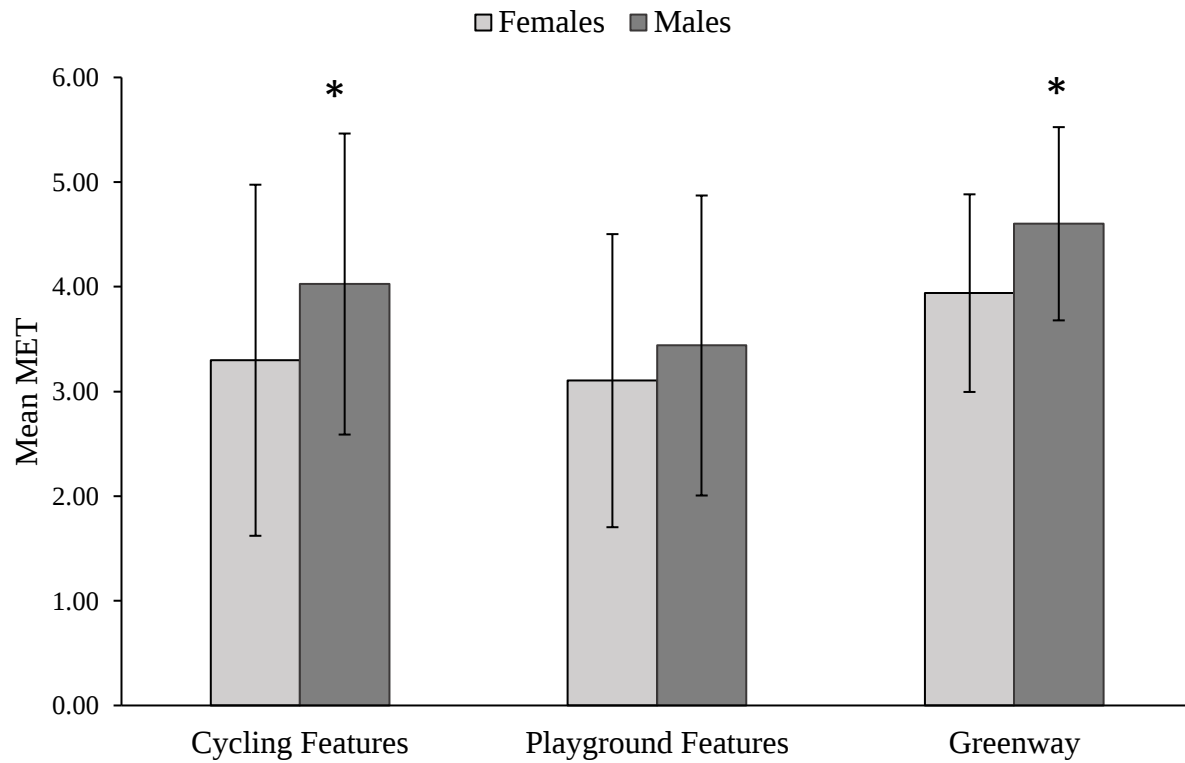
Table 6.4: Physical activity intensity by physical activity zone features.

Intensity	Total n = 3,431 n (%)	Cycling Features n = 1,864 n (%)	Playground Features n = 634 n (%)	Greenway n = 933 n (%)
Sedentary	1,228 (35.8)	869 (46.6)	292 (46.1)	67 (7.2)
Moderate	768 (22.4)	246 (13.2)	142 (22.4)	380 (40.7)
Vigorous	1,435 (41.8)	749 (40.2)	200 (31.5)	486 (52.1)



Abbreviations: C1= Pump and jump track, C2= Asphalt pump track, C3= Gravel progressive bike skills trails, C4= Short oval asphalt pump track, C5= Gravel pump track loop, C6= Rock navigation course, C7= Gravel pump track loop with wall features, C8= Kids dirt/gravel pump track, C9= Linear cycling features adjacent to greenway, P1= Climbing structure with slide and benches, P2= Swings and benches, P3= Climbing structure with benches. G1= Greenway.

Figure 6.3: Use of physical activity zones by gender and mean intensity (METs).



*Significant difference between female and male mean METs.

Figure 6.4: Comparison of mean physical activity intensity by gender and activity zone feature.

difference in mean METs between males and females in activity zones with playground features (3.44 vs. 3.10, $p = 0.1163$).

Discussion

The current study was able to expand on the limited body of knowledge surrounding bike parks by studying a large, newly built urban bike park. The bike park primarily attracted users who were adults, male, and white. Only 5.6% of bike park users were minorities. Cycling was the primary physical activity observed by both females and males. Overall, the majority of bike park users (64.2%) were active during their visit with males tending to participate at a higher intensity. Certain PA features attracted more users compared to others within the park.

Characteristics of park users

Overall, the demographic characteristics of bike park users, compared to the local community population,²² was significantly different; however, the demographics of the bike park users were found to be representative of mountain biking in general (80%+ male, 90%+ white, and middle-aged adults).^{23,24} Males used the bike park considerably more than females (68.8% vs. 31.2%, respectively). This is similar to the proportion of observed males (70.4%) by Schipperijn et al.¹⁴ in the only other bike park study. Similar trends of males being the majority observed park user has been found in previous park studies as well.²⁵⁻²⁸

Schipperijn and colleagues¹⁴ reported that 77.6% of bike park users were children or teens, whereas the current investigation found only 43.5% of users to be children and teens. Adults in the current study had the highest percentage of users observed at 54.0%. This may have been due to the different types of features and amenities located at and around Baker Creek Bike Park compared to the bicycle playgrounds. Compared to park users across the park system in the City of Knoxville, TN,²⁹ fewer older adults (≥ 60 years) were observed in the bike park (6% in

Knoxville vs. 2.4% at the bike park). The percentage of older adults observed at the bike park was also less than the percentage of older adults observed (3.9%) in a nationally representative sample of parks.²⁸ One explanation can be linked to a study by Rasch which found mountain biking to have one of the lowest participation rates among individuals 65 years and older (only 2% of survey respondents).³⁰ Rasch also concluded that safety concerns were a significant constraint to outdoor recreation in older adults.

Our results indicate that only 5.6% of bicycle park users were minorities. Previous research has argued that residential proximity to parks is associated with park use^{31,32}; however, the census tracts surrounding the bike park in this study had a much higher percentage of minorities, ranging from 8-24%.²² Possible barriers to racial and ethnic groups using the bicycle park may include different preferences for park amenities or having different leisure time preferences.³³⁻³⁷ Additionally, racial and ethnic groups may not perceive the bicycle park as safe or may feel ‘unwelcome’ in the park.³⁸⁻⁴⁰

Physical activity behaviors

Compared to the PA behaviors of park users observed in the overall park system in the City of Knoxville,²⁹ the primary observed PA in the bike park was cycling in both males (61.8% at the bike park vs. 3.8% in Knoxville) and females (38.5% at the bike park vs. 3.5% in Knoxville). This makes sense as the design of the park was intended to facilitate biking as the primary activity choice of users. Though cycling was the primary activity observed for females in the current study, only 37.1% of female park users were observed in cycling zones. Additionally, females were overall less likely to occupy cycling zones compared to non-cycling zones. This may be due to females being less likely to participate in cycling^{41,42} and mountain biking^{23,24} as forms of PA compared to males.

Females were more likely to be observed sitting, standing, walking, or occupying playground activity zones. These results are similar to those found at the local²⁹ and national²⁸ level regarding gender specific activity choices within parks. In many circumstances, adult females were observed sitting, standing, or walking alongside as they watched children and teens use various park features. A study of urban neighborhood park users across the United States identified the top reason for women to visit parks was to bring children.⁴² This study also reported women and girls were more likely to use playgrounds and walking paths for PA, similar to what was found in the current investigation.

Physical activity intensity

The mean PA intensity of park users in all bike park zones surpassed the moderate intensity threshold (≥ 3.0 METs), with the exception of one activity zone (P2: 2.48 METs). This is likely due to many of the users in zone P2 being observed sitting on the swings (coded as sedentary) and not actively swinging. Furthermore, the climbing structures in playground zones P1 and P3 appear to promote more active use as indicated by the higher average intensity of users compared to P2.

Interestingly, the most used cycling zones (C1, C2, and C4) had the lowest mean PA intensity compared to other cycling zones. Zone C1 is a single tract pump and jump track with a start and end point. Zone C2 is a large pump track riders can use various features like rollers (i.e., bumps or small hills) and berms (i.e., corners of the track), while zone C4 is a short, oval pump track with berms. These design features only support a limited number of riders to participate at any given time and resulted in a number of users being observed ‘waiting their turn,’ and were therefore identified as sedentary per the SOPARC protocol. The least used cycling zones may be

more conducive to a higher mean intensity since users were not competing as much for riding time.

As a whole, each of the PA zone features supported a mean PA intensity above the moderate intensity threshold of 3.0 METs. However, when comparing males versus females, mean intensity per male was significantly higher than the mean intensity per female in the cycling zones and on the greenway. The mean PA intensity per male in the playground zones was higher than that of females (3.44 vs 3.10 METs); however, it was not statistically significant. This is similar to previous research that has found males participate in more MVPA in parks when compared to females.^{28,32,39}

Limitations and strengths

The current study is not without its limitations. The SOPARC protocol only provides park use information for a moment in time. An individual who was active for the majority of their park visit may have sat down at the time of the scan and would have been coded as sedentary. Data collected were grouped into categories for age, race/ethnicity, and physical activity by gender. This meant we could only analyze PA by gender, not by age group or race/ethnicity. Due to the nature of SOPARC direct observation protocol, misclassification of any of the variables (gender, age group, race/ethnicity, and PA intensity) can occur. Also, there is the potential for over-sampling of greenway users due to performing a walking scan of this activity zone.

One of the primary strengths of the current study was the systematic observation schedule employed. A study by Cohen et al.⁴³ showed an abbreviated observation schedule of 4 days/week and 4 times/day provided a reliable estimate of park use when compared to observations done 14 hours/day for an entire week. Additionally, researchers performed observations over multiple seasons which added to the reliability of our estimates of overall park use.

Conclusions

People primarily use the bicycle park as intended by the design, to bike. The demographic profile of park users was significantly different than that of the surrounding community; however, they were representative of mountain biking, in general. Males used the park more than females and tend to participate at a higher PA intensity. This is similar to other park studies and what the literature shows regarding gender differences in PA participation. Since these park designs are relatively new and growing in popularity, future studies should investigate if a newly built bicycle park increases LTPA, or simply replaces time spent doing other LTPA. Moreover, future research should examine why there is lower participation among minorities and women and how to increase their use of these types of parks.

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CHAPTER 7
CONCLUSION

In 2021, the Community Preventive Services Task Force (CPSTF) recommended combining park, trail, and greenway built environment interventions (i.e., park, trail, and greenway infrastructure changes) with additional interventions (e.g., increased accessibility, physical activity promotional programs, community engagement) to see a positive impact on population-level physical activity (PA).¹ In addition to this recommendation, there are several national health strategies that focus on improving the built environment to enable individuals to walk and bike more,² and global initiatives to increase access to green spaces and recreational spaces for all.³ Furthermore, an adapted version of the health impact pyramid (See Figure 7.1) indicates that changes to the built environment can have a much larger impact on increasing PA at the population-level.⁴

Limitations to previous research on parks, trails, and greenways is what made the Knoxville Urban Wilderness (KUW) and Baker Creek Bike Park attractive sites for the investigations in this dissertation. Previous work on trails and greenways has been focused around more traditional, linear-based trails and greenways, whereas the KUW is a nature-based series of non-linear multiuse recreational trails. Additionally, only one previous study has been conducted on PA in bike parks in Copenhagen, Denmark.⁵ Further research is needed to better understand the impact nature-based recreational trail systems and bike parks have on PA.

In order to explore the effect trails and bike parks have on PA, this dissertation conducted three investigations to: 1) determine the impact of trail/greenway built environment interventions on PA outcomes, 2) investigate how seasonality and weather variables influence nature-based recreational trail use, and 3) develop a demographic (gender, age group, race/ethnicity) and physical activity (type and intensity) profile of bike park users. The findings from this dissertation provide insights into the impact of trail/greenway interventions, nature-based

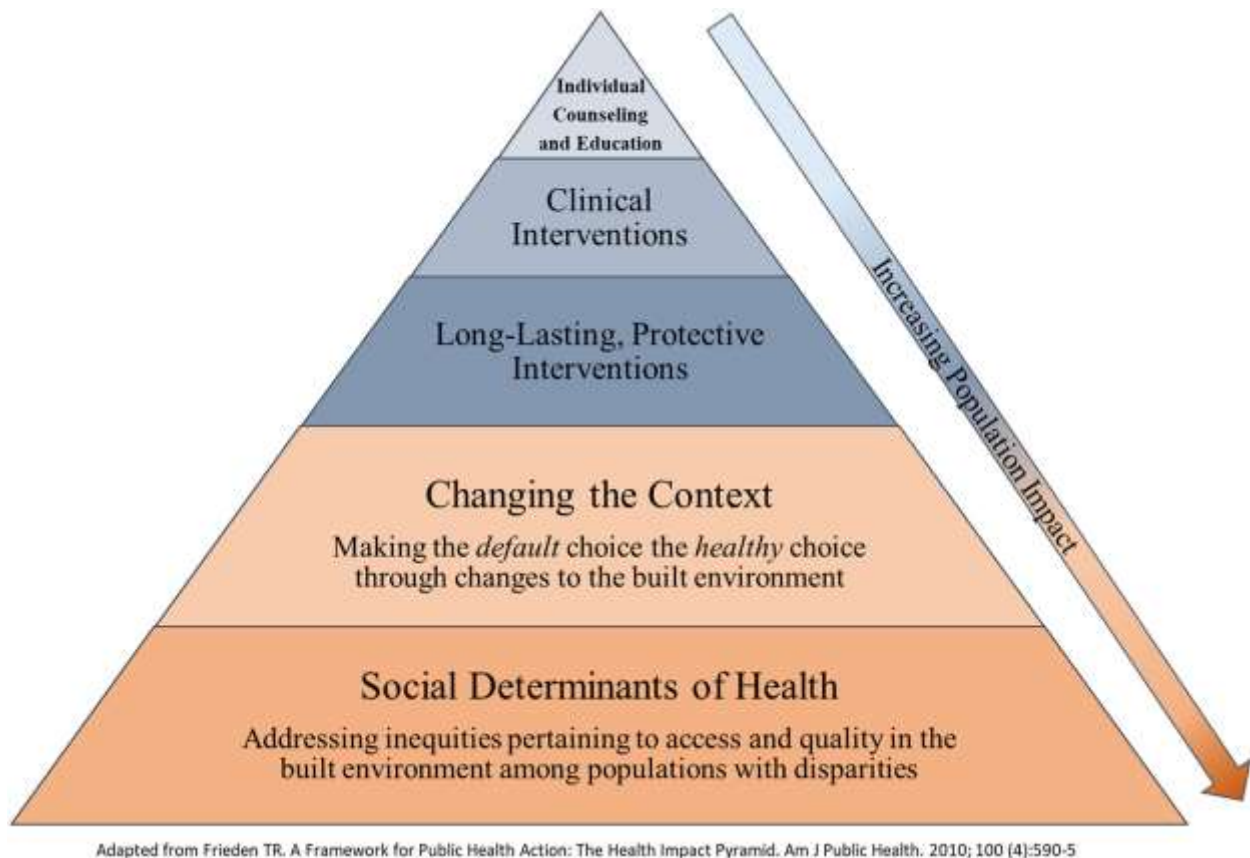


Figure 7.1: A Framework for Public Health Action: The Health Impact Pyramid. Adapted from Frieden TR (2010). From “The role of the built environment in promoting movement and physical activity across the lifespan: Implications for public health,” by D. Laddu, AE Paluch, MJ Lamonte. Progress in Cardiovascular Disease (p. 37), 2021, Volume 64.

recreational trail networks, and bike parks on PA and has implications for practitioners, policymakers, and future research.

Practitioners and policymakers

The findings from the systematic review (Chapter 4) further reinforced the CPSTF recommendation of using dual approach trail/greenway interventions [greenway or trail infrastructure change combined with additional interventions (e.g., enhanced accessibility and/or community engagement)].¹ Therefore, practitioners and policymakers should strongly consider using these types of interventions to increase PA in the community. Trail planners should consider how the trail design (e.g., surface material) may attract a certain type of user or how the trails are used in various weather conditions. As seen in the second investigation (Chapter 5), dirt trails were more attractive to mountain bikers, while gravel trails were more attractive to walkers/runners. Trail managers could simultaneously collect weather-related information and trail surface conditions to inform users of more user-friendly routes during adverse weather events. This could potentially mitigate trail maintenance costs by shifting trail users to trails that can tolerate higher use in poor weather. The third investigation (Chapter 6) found that 64.2% of bike park users were observed participating in moderate-to-vigorous PA. This is similar to the only other bike park investigation which found 63% of users being active.⁵ Thus, to promote a higher proportion of park users being active, community parks and recreation departments should consider incorporating bike-specific features and amenities within existing parks or in the development of new community parks.

Some of the methods used in Chapters 5 and 6 could also be employed by parks and recreation departments or stakeholders interested in improving PA within their community. For example, the use of infrared trail counters (Chapter 5) could provide valuable insight to the

number of individuals using the trail/greenway. Due to the error associated with these counters, it is highly recommended to perform periodic direct observations to compare observed counts to those registered by the trail counters. Not only would this allow individuals to formulate a more careful estimation of trail use, but it would also provide a platform to collect demographic (gender, age group, race/ethnicity) and physical activity (type and intensity) data on trail users. Although direct observation can be time consuming and may require numerous observers, Dilley et al.⁶ successfully demonstrated using community volunteers to collect PA patterns and demographics of greenway users in North Carolina. Trail use information could then support the projection of an economic benefit which could be useful when approaching policymakers for more funding for trail projects. For example, trail use data collected from the overall KUW health and economic impact study allowed Evans et al.⁷ to estimate that the KUW generates \$24.9 million annually to the local economy.

Future research

There are also a number of considerations regarding future research around trails/greenways and bike parks. The systematic review (Chapter 4) revealed that PA assessment methods matter when conducting research on trails and greenways. This review found that 12 of the 13 studies employing direct observation or electronic trail counters to assess PA in the trail/greenway infrastructure location reported positive changes in PA outcomes. Compare this to only six of the 14 studies reporting positive outcomes when assessing PA using self-report questionnaires. Knowing this will impact study costs and needed research assistants, we strongly recommend future investigations consider using multiple methods to assess changes in PA following trail/greenway interventions. Certain methods (direct observation and/or electronic trail counters) will provide information specific to use and PA within the infrastructure location,

while self-report questionnaires will help determine if changes in PA occur at the individual level.

Future investigations should also consider assessing other health-related outcomes (e.g., well-being, quality of life, mental health, etc.) to get a multi-faceted look at how trail/greenway interventions may be impacting overall health outcomes. The first investigation (Chapter 4) also highlighted the need for more research in non-urban/suburban areas, low-income neighborhoods, and rural areas. Additionally, the studies from this review were performed on traditional, linear-based greenways/trails or rails-to-trails conversions; therefore, future investigations should also be done on various types of trail settings (e.g., nature-based, multiuse trail networks).

Investigation 2 (Chapter 5) found that the direction of effect of the impact of weather on trail use was similar to previous studies; however, the magnitude of effect varied based on trail surface material (gravel vs. dirt). Future investigations should consider trail surface material when assessing how weather conditions impact natural surface trail use. Also, the investigation from Chapter 5 was not able to determine if the variation between trail surfaces was a function of the activity performed on the different trail surfaces. Future investigations would benefit from using trail counters that can distinguish between walkers/runners and cyclists to better understand this relationship.

Specific to Investigation 3 (Chapter 6), bike parks promote a high proportion of users being physically active; however, it is unclear if the PA performed is in addition to what they were previously doing prior to the construction of the bike park. Future studies should investigate if newly built bike parks increase leisure-time PA, or simply provide a substitute location for performing PA. Qualitative studies would also be beneficial to understand why individuals use certain bike park amenities. Additionally, Investigation 3 identified significant

gender and racial/ethnic disparities in bike park use and intensity of PA performed. Males were the primary users (68.8%) of the bike park and participated at a higher intensity compared to females. Additionally, only 5.6% of park users were racial/ethnic minorities. It's possible the amenities and activities available at the bike park are not the preferred choices of these populations.^{8,9} Furthermore, the bike park may not be perceived as a safe place or certain groups of people may feel 'unwelcome' at the park.^{10,11} Future research should qualitatively examine why there is lower participation among minorities and women and how to increase their use of these types of parks.

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APPENDICES

Appendix A: Trails and Physical Activity Systematic Review Search Strategy

Search Terms	
#1	“Parks, Recreational”[Mesh]
#2	trail*[Title/Abstract] OR greenway*[Title/Abstract] OR "rail trail*" [Title/Abstract] OR "green space"[Title/Abstract]
#3	"Exercise"[Mesh] OR "Recreation"[Mesh]
#4	"physical activity"[Title/Abstract] OR exercise*[Title/Abstract] OR fitness[Title/Abstract] OR walk*[Title/Abstract] OR run[Title/Abstract] OR runn*[Title/Abstract] OR jog[Title/Abstract] OR jogg*[Title/Abstract] OR cycl*[Title/Abstract] OR bike*[Title/Abstract] OR biking[Title/Abstract] OR hike*[Title/Abstract] OR hiking[Title/Abstract] OR recreation*[Title/Abstract] OR activ*[Title/Abstract] OR inactiv*[Title/Abstract]
#5	"trail making test"[Text Word] OR "TRAIL receptor"[Text Word] OR apoptosis[Text Word]
#6	(#1 OR #2) AND (#3 OR #4) NOT (#5)

**Search terms and strategy were developed in collaboration with a Health Science Librarian.*

Appendix B: Bike Park SOPARC Data Collection Form

DATE 4/17 PARK ID # BC OBSERVER ID # Gregory PERIOD: ☐ Morning ☐ Lunch ☒ Afternoon ☐ Evening
 TARGET AREA 1 START TIME 3:00 pm
 Target Area # Subtarget Area #

CONDITIONS OF TARGET AREA

Accessible (e.g., not locked or rented to others) ☒ Yes ☐ No
 Usable (e.g., is not excessively wet or windy) ☒ Yes ☐ No
 Equipped (e.g., removable balls available) ☐ Yes ☒ No
 Supervised (e.g., not locked or rented to others) ☐ Yes ☒ No
 Organized (e.g., team sporting event) ☐ Yes ☒ No

Dark (e.g., insufficiently lit) ☐ Yes ☒ No
 Empty (i.e., scan area is empty) ☐ Yes ☒ No

Comments:

PEOPLE	ACTIVITY	AGE GROUP				ETHNICITY				ACTIVITY LEVEL		
		Child	Teen	Adult	Old	L	B	W	O	S	W	V
Participants	Primary Activity											
Female												
Male	Bike											
Participants	Secondary Activity											
Female												
Male	Skateboard											
Spectators	Organized Activity											
Female												
Male												

Fitness Related Codes:
 aerobics (dance/step aerobics)
 fitness stations
 jogging/running
 strengthening exercises (pull ups)
 walking

Sport Related Codes:
 baseball
 basketball
 cheer leading
 dance
 football
 gymnastics
 handball
 horseshoes
 soccer
 tennis/racquet
 tetherball
 volleyball

Active Game Related Codes:
 climbing/sliding
 jumping (rope, hop scotch)
 manipulatives/racquet
 tag/chasing games

Sedentary Related Codes:
 chess/checkers/cards
 lying down
 picnic (food involved)
 reading
 standing
 sitting

VITA

Douglas Adam Gregory was born on June 20, 1986, in Baytown, Texas where he spent most of his childhood. In 2001, he and his family moved to Aiken, South Carolina where he graduated from South Aiken High School in 2004. Douglas then enrolled at the University of South Carolina, Aiken where he graduated with a Bachelor of Science degree in Exercise and Sport Science in 2008. Immediately following completion of his Bachelor's, Douglas enrolled at The University of Tennessee, Knoxville where he completed a Master of Science degree in Exercise Physiology in 2010. After completing his Master's, Douglas worked in a clinical setting until accepting a faculty position at Tennessee Wesleyan University in 2017. While maintaining his faculty role, Douglas began pursuing a Doctor of Philosophy degree in Kinesiology and Sport Studies with a concentration in Physical Activity Epidemiology.