

ScholarWorks@GSU

Bicycling for Transportation: Health and Destination, Results of a survey of students and employees from a southern urban university

Authors	Bryan, Joseph M
Citation	Bryan, Joseph M. "Bicycling for Transportation: Health and Destination, Results of a survey of students and employees from a southern urban university." Dissertation, Georgia State University, 2017. https://doi.org/10.57709/10096669
DOI	https://doi.org/10.57709/10096669
Download date	2026-03-09 02:42:30
Link to Item	https://hdl.handle.net/20.500.14694/14230

Bicycling for Transportation: Health and Destination
Results of a survey of students and employees from a southern urban university

By

Joseph Michael Bryan

April 20, 2017

Abstract

Objectives We first sought to assess if bicyclist typology was associated with health. Second, we investigated whether bicyclist typology was related to health through physical activity and commute bicycling. Finally, we sought to develop profiles of disposition toward commute bicycling following proposed changes to a specific destination and the significance of pertinent covariates.

Methods Data from the 2014 Georgia State University-Bicycling Survey were used. We first estimated the adjusted odds of worse health-related quality of life by bicyclist typology. A mediation model was then used to estimate the relative total and direct effects of bicyclist typology on health-related quality of life and relative indirect effects through physical activity and commute bicycling. A finite mixture modeling approach was used to identify latent classes of disposition toward whether proposed changes to a specific destination would increase likelihood of commute bicycling. The manual 3-Step protocol was used to assess the effect of covariates on the probability of latent class membership.

Results Respondents who had never bicycled, were not motivated to commute bicycle, and who required greater bicycle facilities to feel comfortable commute bicycling had higher odds of worse health-related quality of life. Physical activity and, to a lesser extent, commute bicycling status mediated the effect of bicyclist typology on health-related quality of life. The seven-class solution was decided on as the “best” model for disposition toward whether proposed destination improvements would increase the likelihood of commute bicycling. Several covariates were identified that impact the probability of latent class assignment.

Conclusions Initial evidence of a health disparity by bicyclist typology was revealed. Physical activity appears to serve as the primary means through which bicyclist typology has an effect on health. Urban environments that make physical activity, including commute bicycling, more comfortable for a larger proportion of the population may be a potential important health intervention. Understanding the patterns of disposition toward whether proposed destination improvements would increase the likelihood of commute bicycling may assist in targeting and prioritizing commute bicycling-related interventions toward subpopulations of interest.

Bicycling for Transportation: Health and Destination
Results of a Survey of Students and Employees from a Southern Urban University

by

Joseph Michael Bryan

B.S., MERCER UNIVERSITY
M.P.H., EMORY UNIVERSITY

A Dissertation Submitted to the Graduate Faculty
of Georgia State University in Partial Fulfillment
of the
Requirements for the Degree

DOCTOR OF PHILOSOPHY IN PUBLIC HEALTH

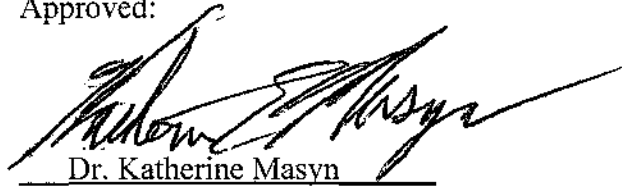
ATLANTA, GEORGIA
30303

Bicycling for Transportation: Health and Destination
Results of a Survey of Students and Employees from a Southern Urban University

by

Joseph Michael Bryan

Approved:



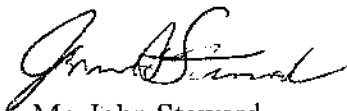
Dr. Katherine Masyn

Committee Chair



Dr. Matthew Magee

Committee Member



Mr. John Steward

Committee Member

April 20, 2017

Date

Acknowledgments

The list of persons to acknowledge is long. I suppose grouping them by their area of support will help.

I would like to thank Mr. John Steward. His vision for healthy cities is infectious and has helped motivate and guide me over the past several years. I am indebted to Dr. Katherine Masyn for all of the support and direction – statistics-related and otherwise - over the past few years, without which, these analyses would have befuddled me and would not be presented here. I have learned so much under her tutelage and realize how much is left to understand. Dr. Matthew Magee has provided a much needed public health-oriented voice. His contributions have kept me focused on the tasks at hand. More broadly, I am grateful to the faculty of Georgia State University. I am certain I have missed some concepts along the way, but I am a better public health practitioner because of you all.

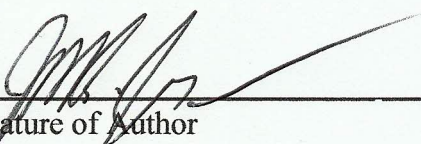
There are so many colleagues I am grateful to have. Dr. Cherie Drenzek and Mrs. Rana Bayakly have allowed me to pursue this dream of mine. Without their support and encouragement, the journey would have been much rougher. Mrs. Audrey Kunkes and Ms. Viani Ramirez-Irizarry are two friends who have been there for me and have been a constant source of encouragement.

Dr. Frances Annor has assisted me in numerous ways in this process. Most notably, he has provided moral support throughout the many struggles of achieving this goal. Without Dr. Moges Ido I would have undoubtedly be years behind where I am now in my understanding of epidemiology and biostatistics. Dr. Ido has always been a source of unadulterated, yet kindhearted advice. D. Matthew Jackson is my public health complement. I am grateful for his perspective and willingness to assist me in my times of need.

I am thankful for my mother and father. Whether I was Pre-Med, Pre-Pharm, working in a bakery, considering pursuing a Ph.D. in Hebrew or Public Health, they have supported me. They have been a steady source of love for so many years.

Finally, I am eternally thankful to my family – Ellyn and James. They have breathed life into me when I was tired. Pursuing the Ph.D. has required so much sacrifice from my family - I will spend the ensuing years attempting to compensate them for this sacrifice. I am so grateful and proud to be a husband and father to them.

In presenting this dissertation as a partial fulfillment of the requirements for an advanced degree from Georgia State University, I agree that the Library of the University shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to quote from, to copy from, or to publish this dissertation may be granted by the author or, in his/her absence, by the professor under whose direction it was written, or in his/her absence, by the Associate Dean, School of Public Health. Such quoting, copying, or publishing must be solely for scholarly purposes and will not involve potential financial gain. It is understood that any copying from or publication of this dissertation which involves potential financial gain will not be allowed without written permission of the author.



Signature of Author

List of Tables

Table 2.1. Descriptive statistics comparison of survey respondents (N=4,374) and university population	63
Table 2.2. Distinction of Bicyclist Typology Definitions	63
Table 2.3. Detailed descriptive statistics of GSU-BS sample included in analyses by bicyclist typology (N=4,374)	64
Table 2.4. Health-Related Quality of Life by Bicyclist Typology in GSU-BS sample	65
Table 2.5. Bicyclist typology and health-related quality of life (2014 GSU-BS).....	66
Table 3.1. Distinction of Bicyclist Typology Definitions	94
Table 3.2. Physical Activity and Commute Bicycling Status by Demographic in the GSU-BS sample	96
Table 3.3. Physical Activity and Commute Bicycling Status by Bicyclist Typology in GSU-BS sample	97
Table 3.4. Relative Effect of Bicyclist Typology on Health-Related Quality of Life Relative to Strong and Fearless Typology*, Georgia State University-Bicycling Survey, 2014	98
Table 3.5. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Strong and Fearless Typology as Reference Group, Georgia State University-Bicycling Survey, 2014	99
Table 3.6. Comparing the Odds of Worse Health-Related Quality of Life for each Condition for Standard Subjects, Georgia State University-Bicycling Survey, 2014	100
Supplemental Table 3.1. Effect of Bicyclist Typology on the Mediating Variables Physical Activity and Cycling for Transportation Status	101
Supplemental Table 3.2. Effect of the Mediating Variables Physical Activity and Commute Bicycling Status on Health-Related Quality of Life	102
Supplemental Table 3.4a. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Enthused and Confident Typology as Reference Groupa, Georgia State University-Bicycling Survey, 2014	104
Supplemental Table 3.4b. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Comfortable but Cautious Typology as Reference Groupa, Georgia State University-Bicycling Survey, 2014	105
Supplemental Table 3.4c. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Interested but Concerned Typology as Reference Groupa, Georgia State University-Bicycling Survey, 2014	106

Supplemental Table 3.4d. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with No Way, No How Typology as Reference Groupa, Georgia State University-Bicycling Survey, 2014	107
Supplemental Table 3.5. Comparing the Odds of Worse Health-Related Quality of Life for each Conditiona for Standard Subjectsb relative to each Bicyclist Typology*, Georgia State University-Bicycling Survey, 2014	108
Supplemental Table 4.1. Distinction of Bicyclist Typology Definitions	143
Table 4.1. Student-Employee Status by Demographic and Destination Disposition Factor in the GSU-BS sample	144
Supplemental Table 4.2. Class Enumeration Description of Latent Class Analysis of Destination Factor Dispositions, Southern Urban University, 2014	145
Table 4.2. Fit Indices for Latent Class Analysis of Destination Factor Dispositions, Southern Urban University, 2014 (n=4186)	146
Supplemental Table 4.3. Fit Indices for 5-, 6-, 7-, and 8-Class Solutions with Split-Half Cross-validation, Southern Urban University, 2014	147
Supplemental Table 4.4. Crosstabulation of Respondents by Class, 6- and 7-Class Solutions, Southern Urban University, 2014	148
Supplemental Table 4.5. Classification Diagnostics for the 7-Class Solution (Entropy=0.785, n=4186), Southern Urban University, 2014	149
Supplementary Table 4.6. Significance of Predictors of Destination Factor Disposition Class Membership and Pairwise Comparisons, Southern Urban University, 2014	153

List of Figures

Figure 1.1. Distribution of General Health Status by Bicyclist Typology	27
Figure 1.2. Number of Healthy Days during the past 30 days by Healthy Days Measure and Bicyclist Typology	27
Figure 1.3. Pathway Diagram for Proposed Study 2	28
Figure 1.4. Distribution of Cycling for Transportation Status by Bicyclist Typology	31
Figure 1.5. Distribution of Physical Activity Status by Bicyclist Typology	31
Figure 1.6. Percent of Respondents that Agree Their Likelihood of Bicycling to, from, or around GSU would Increase by Factor and Commute Cycling Status	37
Figure 1.7. Percent of Respondents that Agree Their Likelihood of Bicycling to, from, or around GSU would Increase by Factor and Bicyclist Typology	38
Figure 3.1. Pathway Diagram to Estimate Effect of Bicyclist Typology on Health-Related Quality of Life through Cycling for Transportation Status and Physical Activity Status	95
Figure 4.1. Estimated Percent of Respondents for each Disposition among Heterogeneously Endorsed Profiles by Factor to Increase Bicycling to, from, or around Campus, Southern Urban University, 2014	150
Figure 4.2. Distribution of Estimated Destination Factor Disposition Profile Membership by Significant Predictors, Southern Urban University, 2014	151

Chapter 1: Literature Review and Statement of Purpose

Literature Review

Commuting by bicycle constitutes a relatively small proportion of the commuting mode share. In 2014, 2.6% of adult workers in Oregon reported they usually commute by bicycle (*commute bicycling*), which was the *highest* among states and well ahead of the national prevalence of 0.6% [1]. Georgia ranked 46th among all states with 0.2% of its population commute bicycling (1 being the greatest) [1]. The City of Atlanta has fared slightly better – in comparison to the 70 largest cities with the highest share of bicycle commuters, Atlanta ranked 37th with 0.7% of the population reporting commute bicycling [2]. Despite current low levels of participation, commute bicycling in Atlanta increased by estimated 128% from 2000 to 2013 [2]. Bridging urban planning with public health efforts to increase bicycling as a valid commute option is a field ripe for research. The relationship between health and efforts to better target bicycling-related plans and policies remains poorly understood. Further, bicycle planning efforts could be informed by an improved understanding of the disposition of all potential beneficiaries toward whether proposed improvements to a specific destination would increase the likelihood of commute bicycling to that destination.

Bicyclist Typology

Our conversation begins by introducing the concept of bicyclist typology germane to many of the analyses performed within this dissertation. The chosen

typology is based on an individual's bicycling status (ever or never), motivation to commute bicycle, and willingness to commute bicycle in varying levels of bicycling facilities. Urban planners throughout the United States, from Atlanta¹ to Portland², make use of this typology to better understand the market for bicycle planning in their districts. By using this typology, results from the proposed analyses should assist in better targeting future health interventions and urban planning projects.

One reason for such low participation in commute bicycling may be that individuals may not be comfortable bicycling unless bicycling facilities are present [3, 4]. In 2006, aiming to better target urban planning efforts towards persons willing to commute bicycle but requiring bicycling facilities to feel comfortable doing so, Roger Geller presented a new bicyclist typology that categorizes individuals based on their motivation to, and comfort with, commute bicycling in different levels of bicycling facilities [3]. Over the past decade, many U.S. cities have adopted Geller's bicyclist typology as part of their transportation plans in an attempt to increase bicycling amongst its residents [4].

Five distinct bicyclist types were identified by Geller: 1) Strong and Fearless, 2) Enthused and Confident, 3) Comfortable but Cautious, 4) Interested but Concerned,

¹ Cf. Atlanta Regional Commission: http://documents.atlantaregional.com/tcc/2014/2014-05-23/Bike_-_Ped_Update.pdf last accessed April 10, 2016.

² Cf. Portland Department of Transportation: <https://www.portlandoregon.gov/transportation/article/158497> last accessed April 20, 2016.

and 5) No Way, No How [5, 6]. The Strong and Fearless bicyclist will ride their bike in any situation as bicycling is part of their identity. The Enthused and Confident bicyclist will share the road with vehicles, but prefers using bicycling facilities. The Comfortable but Cautious bicyclist is comfortable on most roads, but will choose their mode of transportation based on the availability of bicycle facilities. The Interested but Concerned bicyclist is curious to begin bicycling, but will require bicycling-specific facilities before being willing to do so. Finally, the No Way, No How bicyclist is not interested in commute bicycling for any reason (i.e. weather, physical ability, or interest).

Understanding the role of bicyclist typology in commute bicycling is essential to bicycling planning. Each typology may not change their commute bicycling behavior equally following modifications to the urban environment. As Geller suggests, decision makers should target persons who would like to commute bicycle, but are not currently doing so (e.g., Comfortable but Cautious) if the goal is to increase commute bicycling for a greater proportion of the population [3]. For example, the Strong and Fearless and Enthused and Confident are willing to commute bicycle in any environment, while the Comfortable and Cautious and Interested but Concerned types may require an environment with greater bicycling facilities before reaching a level of comfort that makes bicycling a reasonable commute option. Further, transitioning persons of these bicyclist typologies from non-commute bicycling to commute bicycling status will

consequently ease the decision making for bicyclists less impacted by the presence or absence of bicycling facilities (i.e. the Strong & Fearless).

Bicycle planning efforts have an underlying ethical component [3]. Nearly 80% of respondents in the current study are of a bicyclist type that are motivated to commute bicycle but are hesitant to do so without more bicycling facilities. As Pucher notes, environmental factors such as dedicated, separated bike paths are crucial for these persons who are either “unable or unwilling to do battle with cars” despite their desire to partake in bicycling as a transportation mode [7]. Persons who may be inexperienced bicyclists, risk-averse, women, or younger are more likely to indicate that they dislike and fear bicycling with motorized traffic [8]. So long as bicycling is a risk-filled “dance” with vehicular traffic, the majority of citizens, whether they be the elderly, children, women, or persons otherwise unwilling to face the anxiety, tension and safety risk of bicycling in mixed traffic, are likely to continue not partaking in bicycling [7]. Urban planning may help ensure that bravery is not essential to commute bicycling [5]. In doing so, urban planners can enhance transportation equity by making bicycling an accessible transportation option for broader segments of the population.

Health Benefits of Commute Bicycling

Unfortunately for public health researchers and potential commute bicycling advocates, *no known research has been conducted on the relationship between bicyclist typology and health status*. Commute bicycling, however, has enormous positive

public health potential. Active commuting, broader in scope than *commute bicycling* alone as it includes walking and commute bicycling, has been shown to be positive for health. Policies that increase active travelling benefit the health of the individual through increases in active transport and also benefit the health of society through reductions in air and noise pollution [9]. Hence, aside from an individual's health improving when partaking in greater active transportation, that individual is positively benefiting the health of others through the reduction in negative health exposures. Moreover, a significant protective effect against cardiovascular outcomes, especially among women, has been found amongst persons who participate in active commuting [10].

Commute bicycling has received relatively little focus in the health literature. However, one study found a positive influence of bicycling to work on coronary heart disease risk factors, including total cholesterol, low-density lipoprotein (LDL), high-density lipoprotein (HDL), the ratio of total cholesterol (TC) to HDL (TC/HDL), and diastolic blood pressure [11]. A bicycle sharing initiative to increase commute bicycling was demonstrated to have a net health benefit for the city of 12.3 deaths avoided annually [12]. Similarly, a different study showed 76.2 deaths were avoided annually through a reduction by 40% in the number of trips beginning and ending within the city [13]. Rojas-Rueda *et al* reported that substituting long-duration car trips with public transport and bicycling trips could result in significant reductions in the morbidity due

to diabetes, cardiovascular diseases, dementia, injury, breast and colon cancer, and Disability Adjusted Life Years among travelers [14].

A health trade-off does exist when considering commute bicycling. There are risks due to injury and inhalation of air pollution associated with cycling for transportation. However, the benefits of increased physical activity are greater than the expected risks [15]. Persons who switch from driving to cycling to work were estimated to have an increased life expectancy of 3 to 14 months, while the expected life expectancy lost due to air pollution (1-40 days) and accidents (5-9 days) is much smaller [15]. Even when using conservative estimates of physical activity and the most generous estimates for air pollution and accidents, the estimated number of life years gained from commute bicycling exceed the losses [15].

Health-Related Quality of Life

In 1948, the World Health Organization defined health as “a state of complete physical, mental, and social well-being – not merely the absence of disease or infirmity.” In an effort to assess constructs underlying this definition, Health-Related Quality of Life (HRQOL) measures were developed that include the concepts of perceived physical and mental health for a specific time period [16]. By surveying HRQOL, public health practitioners are able to assess, track, protect, and promote *population* health. Additionally, HRQOL provides a means to identify health disparities and inform a more health-focused public policy. For perspective, from our survey, among the 4,496

responses to the question on the number of days where activity was limited because physical or mental health was not good, the mean value was 3.02. Hence, a decrease of one day where physical or mental health was not good, could presumably result in a gain of 4,496 more healthy days for each 30 day period. This increase in days where activity was not limited could increase the educational opportunity for students and make for a more productive workforce. Assessing such change in healthy days is a useful, comprehensible measure to use when creating policies or programs.

Health and Health-Related Quality of Life

The connection between HRQOL measures and health outcomes is well established. Self-perceived health is associated with an individual's objective physical and mental health status and mortality across age and cultural groups [17-24]. Self-perceived health is also an adequate indicator of high-burden chronic disease conditions [25]. Finally, self-perceived health is sensitive to the presence of multiple disease conditions [26]. As it relates to health behaviors, self-perceived health is correlated with several health risk behaviors, including heavy alcohol consumption, smoking, and physical inactivity [27-30].

The number of physician visits was found to differ significantly for categories of HRQOL amongst adult 65 years of age and older [31]. Amongst older adults, the four HRQOL questions used in our survey were significant predictors of 30-day and 1-year hospitalization and mortality [31]. Multiple risk factors for chronic diseases are

associated with activity limitation, including smoking, excessive alcohol consumption, overweight, inadequate seatbelt use, and elevated cholesterol [32-34]. Such health risk results highlight the burden of disability on a population and can aide when weighing the costs and benefits of interventions targeting these risk behaviors.

Commute Bicycling and Health-Related Quality of Life

Despite the vast research on health-related quality of life and health outcomes, *the association between health-related quality of life and commute bicycling is not well understood*. Relevant to this study, bicycling to work is likely to improve health-related quality of life in previously non-bicycling to work individuals [11]. However, as previously mentioned, bicycling to work is only a subset of commute bicycling. To the knowledge of the author, **no other articles assess the association between commute bicycling and HRQOL**. Crane *et al* found a significant association between bicycling not specific to intent and physical quality of life and psychological wellbeing among men [35]. Because there was a need to assess health and there was no existing health literature indicating which measures to focus on, Study 1 and Study 2, as described below, leverage health-related quality of life as broad health outcomes of interest. In doing so, future health studies may better target which health outcomes to assess. Study 1 and Study 2 will add to the sparse healthy literature by assessing if and why bicyclist typology is associated with HRQOL.

Factors Impacting Commute Bicycling

Commuting mode choice is a complex process shaped by commuters' "social worlds", decision-making ambiguities, and emotions [36]. An environment that simplifies the decision-making process in such a way that either encourages, or reduces the barriers to, commute bicycling may increase the behavior of commute bicycling.

Multiple modifiable environmental factors have been identified that impact commute bicycling. Recent systematic reviews found several environmental factors were positively associated with commute bicycling: dedicated bicycle routes that were separated from vehicular traffic, shorter distance to bicycle path, presence of greenspace, land use mix, and street trees [37, 38]. A recent worldwide systematic review found seven environmental factors were positively associated with commute bicycling: dedicated cycle routes, 'safe routes to school' programs, high population density, separation from vehicular traffic, short trip distance, short distance to cycle path, presence of greenspace, land use mix, and street trees [37, 38]. Similarly, five factors were identified that were negatively associated with bicycling for transport: long trip distance, steep inclines along route, distance from a dedicated cycle path, and perceived or objective danger from traffic [37]. A review of European research found that walkability, residential density, access to shops, services, and work, walking or bicycling facilities, traffic-related safety, crime-related safety, and urbanization were all associated with commute bicycling [39]. Further, the 'invitingness' of an environment

for bicycling was also found to be impacted by environmental characteristics like separation of bicycle path from motorized traffic, traffic level (presence of driving cars), traffic calming (speed bumps), bicycle path condition, maintenance of route, and presence of vegetation [40].

Environmental factors may also impact bicycling regardless of intent – recreation or transportation. Separate paths and/or lanes are favored over bicycling on roadways with traffic [8]. Bicyclists prefer streets with fewer travel lanes, lower volumes of motorized traffic, slower speeds, and lacking car parking [8]. Several studies have demonstrated the positive impact of bike lanes (here defined as a dedicated space for bicyclists on roadways typically separated from motorized travel with white lines on the roadway) on bicycling [8]. A one percent increase in bicycling for each one mile increase in bike lanes has been documented [41]. Cycle tracks (defined here as protected or separated bike lanes) can result in more positive riding experiences and increases in bicycling [42-44].

Previous research had similar findings for individual bicycling behavior. Cycle tracks were shown to increase both the number and share of bicycle trips [45, 46]. To avoid bicycling on the roadway, bicyclists are willing to travel up to 20 minutes longer on bicycle tracks [47]. Bicyclists and non-bicyclists prefer bicycle tracks over bike lanes, especially women and inexperienced bicyclists [48-52].

Several studies have indicated current and potential bicyclists' preferences for their bicycling environment. For example, many studies demonstrate that bicyclists *and* non-bicyclists generally prefer and feel safer on bike lanes even minimally separated from vehicular traffic (i.e. a white stripe) than directly in vehicular traffic [53-55]. Similarly, bicyclists and non-cyclists, prefer dedicated paths, separated from vehicular traffic [48-52]. To an extent, bicycling networks with more bicycling tracks are associated with a higher prevalence of bicycling for transportation [56].

Despite all the aforementioned literature indicating the significant impact of the environment on commute bicycling, relatively little research has investigated the impact of a specific destination on commute bicycling. Study 3 attempts to build on the relatively little literature by assessing dispositions toward whether bicycling-related destination improvements would increase the likelihood of potential beneficiaries of these improvements to commute bicycle to the destination.

Gaps in Knowledge

Further research efforts are needed to elucidate the *public health significance of bicyclist typology and the role of the destination on the behavior of commute bicycling.* ***Our long-term research goal is to understand the overall impact of how the environment relates to the behavior of commute bicycling.*** The critical barrier to progress in solving this problem is the negligible research investigating (1) if and how an individual's bicycling status, motivation to commute bicycle, and comfort commute bicycling given

varying levels of bicycling facilities is related to health and (2) disposition toward whether bicycling-related improvements to a destination environment will increase the likelihood of commute bicycling to that destination. Our study contributes to this vein of research by investigating:

1. If the odds of worse health-related quality of life are different by bicyclist typology,
2. The extent to which the effect of bicyclist typology on health-related quality of life is explained by indirect effect(s) through commute bicycling status and/or physical activity status, and
3. Patterns of disposition towards bicycling-related destination improvements and important predictors thereof.

Statement of Purpose

The association between bicyclist typology and health is poorly understood, as are the dispositions toward specific destination changes intended to improve commute bicycling. Study 1 will assess if broad measures of health are associated with a modified version of Geller's bicyclist typology, while Study 2 will assess if that relationship may be explained by an indirect effect through either physical activity or commute bicycling status. Profiles of disposition toward destination improvements intended to increase commute bicycling may be used to increase existing levels of commute bicycling to, from, or around an urban campus (Study 3). The present study pre-emptively implements a bicycle policy on an urban university campus; as such, this study will inform the creation of this policy and, hopefully, other urban campuses with similar goals. What follows is a description of the data source used for all analyses and a brief summary of each study performed in fulfillment of this dissertation.

Data Source

Data from the 2014 Georgia State University Bicycling Survey (GSU-BS) will be used for the analyses described below (see Appendix I for the full questionnaire). The GSU-BS was created to inform decision makers on the development of a campus bicycling plan. The GSU-BS is a cross-sectional study assessing a range of items pertinent to

bicycling behaviors and barriers among Georgia State University (GSU) employees and students, including:

1. Modes of transportation to, from, or around GSU's campus,
2. Lifetime bicycling experience,
3. Bicycling to, from, around campus,
4. Perceptions of bicycling on campus and in the neighborhood,
5. Disposition toward whether proposed destination improvements would increasing the likelihood of bicycling to, from, or around campus,
6. Health-Related Quality of Life, and
7. Physical activity.

The questionnaire was originally developed in 2009. The GSU-BS was then pilot tested on small samples of students and employees at GSU via paper-and-pencil surveys.

Prior to administration of the survey, the paper-and-pencil survey was transformed into a web-based survey, meaning logical skip patterns were incorporated to reduce time to completion of survey (i.e. persons who had never ridden a bike were not asked about bicycling behavior). Investigators took into account the estimated time to complete pilot surveys to aide in the maximization of survey participation and completeness. The study received approval from GSU's Institutional Review Board and Office of Institutional Effectiveness.

Overall, the GSU-BS is comprised of 40 questions. Qualtrics® was used to deliver the survey electronically. The survey was delivered to 41,016 Georgia State e-mail addresses: 31,642 students and 9,374 faculty members. No incentives were provided for participation. Of those invited to participate, 13.4% responded. Of those who began the survey, 91.5% produced usable responses.

Study 1: Bicyclist typology and health-related quality of life: A cross-sectional study of students and employees at a southern urban university

The proposed study will examine if the odds of poorer health-related quality of life are different by bicyclist typology. *No known research has been conducted on the relationship between bicyclist typology and health.* Understanding the health impact of commute bicycling is a field ripe for public health research. The results of Study 1 will increase current understanding of whether bicyclist typology is associated with broad indicators of health. Investigating this relationship will assist urban planners, health practitioners, and decision makers in understanding the potential health implications of efforts to increase the availability of bicycle facilities. Future urban planning efforts and/or commute bicycling interventions may have better justification for focusing on individuals who would like to bicycle but are not comfortable doing so without bicycling facilities as Geller suggests if there are important health disparities.

Research Questions and Hypotheses

Research Question 1

Are the odds of worse health-related quality of life greater for respondents who had never bicycled than respondents who had ever bicycled?

Hypothesis 1

H₁: We hypothesize that respondents who had never bicycled would have greater odds of worse health-related quality of life than respondents who had ever bicycled.

Research Question 2

Are the odds of worse health-related quality of life greater for respondents who were not motivated to commute bicycle than respondents who were motivated to commute bicycle?

Hypothesis 2

H₂: We hypothesize that respondents who were not motivated to commute bicycle would have greater odds of worse health-related quality of life than respondents who were motivated to commute bicycle.

Research Question 3

Among respondents who are motivated to commute bicycle, do those who require more bicycling facilities to feel comfortable commute bicycling have greater odds of worse health-related quality of life than respondents requiring less bicycling facilities to feel comfortable commute bicycling?

Hypothesis 2.1

H₁: We hypothesize that respondents who require more bicycling facilities to feel comfortable commute bicycling will have greater odds of worse health-related quality of life than respondents who require less bicycling facilities to feel comfortable commute bicycling.

Initial Results

The Strong & Fearless bicyclist type appears to have the greatest proportion of respondents who report either Excellent or Very Good health, followed by the Enthused & Confident, and Comfortable but Cautious types (Figure 1.1). When looking at the Healthy Days measures, the Strong & Fearless and Enthused & Confident bicyclist types appear to have more healthy days than their Interested but Concerned and No way, No how counterparts (Figure 1.2). The Strong & Fearless and Enthused & Confident bicyclist types have a mean physically healthy days that is over half a day greater than the mean for Interested but Concerned and No way, No how types. Regarding mentally healthy days, the Strong & Fearless and Enthused & Confident bicyclist types have about two more mentally healthy days than Interested but Concerned and No way, No how respondents. Finally, the Strong & Fearless and Enthused & Confident bicyclist types have about a day more than their Interested but Concerned counterparts where activity was not limited. Consider what it would mean for a university to gain an extra two days each month of mental health or one less day of having activity limited amongst 80% of its students and employees. These initial results indicate that there the odds of poorer health-related quality of life may differ by bicyclist typology.

Figure 1.1. Distribution of General Health Status by Bicyclist Typology

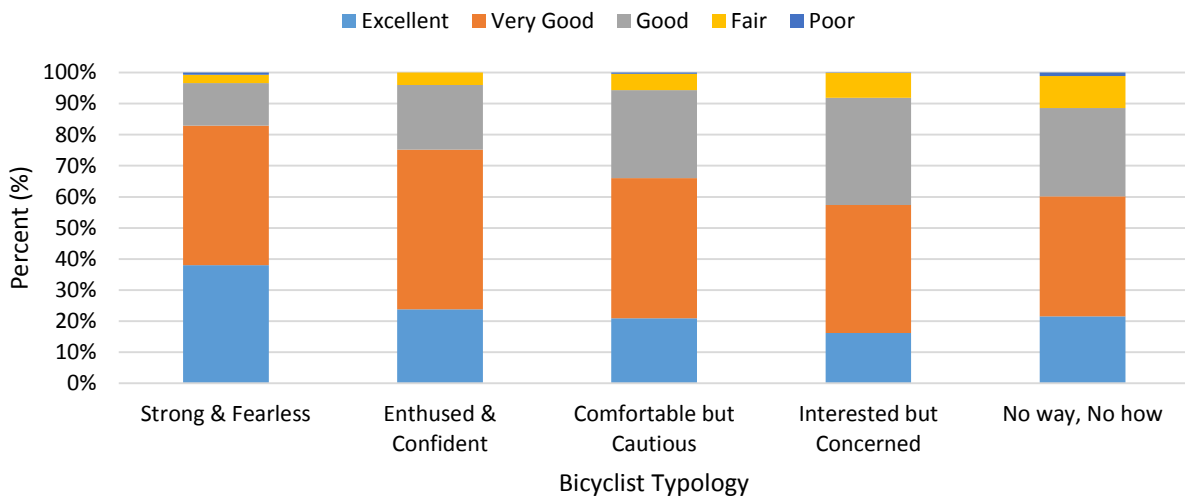
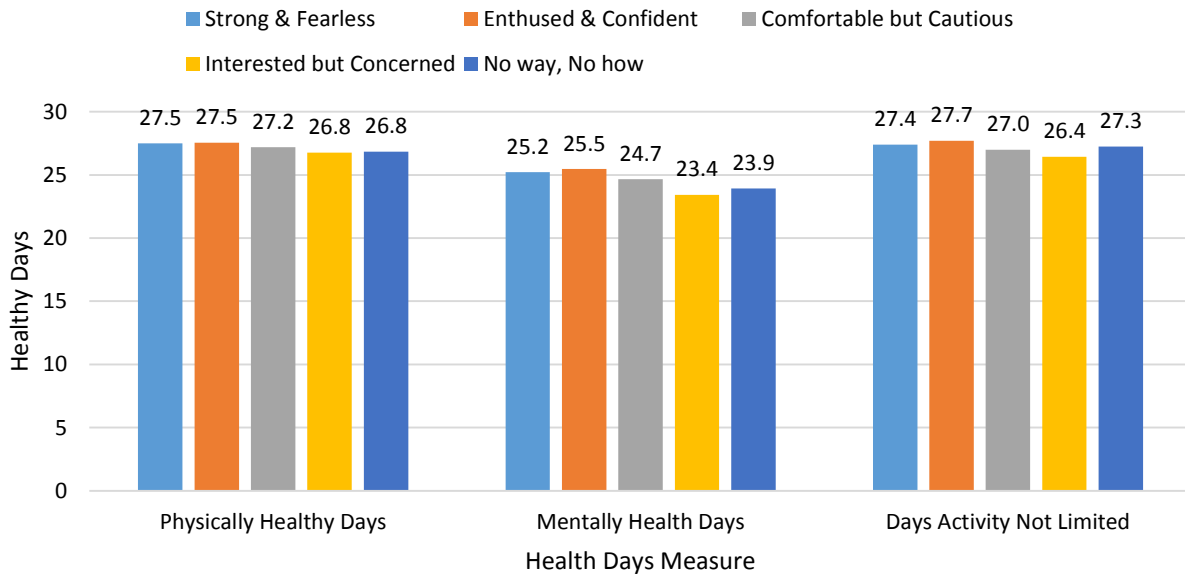


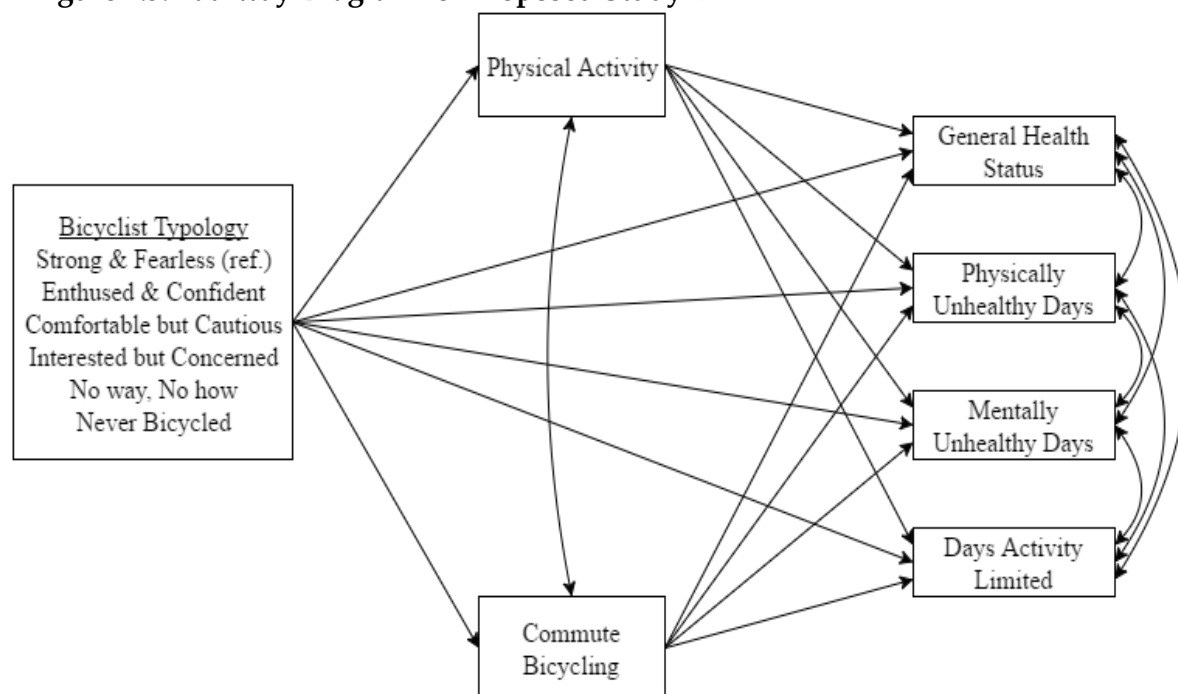
Figure 1.2. Number of Healthy Days during the past 30 days by Healthy Days Measure and Bicyclist Typology



Study 2: The relative effect of bicyclist typology on health-related quality of life through physical activity status and bicycling for transportation status: a multiple mediator model

The proposed study will examine if the relative total effect of bicyclist typology on health-related quality of life may be explained by a *relative indirect effect* through physical activity status and/or commute bicycling status. *No known research has been conducted that assesses why bicyclist typologies may have differing health outcomes.* Overall, little is understood about commute bicycling and health; hence, this study seeks to buttress the nascent research. Once it has been determined if bicyclist typology is associated to health-related quality of life (Study 1), urban planners and public health practitioners would benefit from knowing why the relationship exists – namely if there is an indirect effect of bicyclist typology on health through commute bicycling and/or physical activity (Figure 1.3). This analysis should inform related urban planning efforts

Figure 1.3. Pathway Diagram for Proposed Study 2



as interventions aiming to improve health through increasing physical activity writ large are likely to be different than aiming to specifically improve health through increasing commute bicycling.

Research Questions and Hypotheses

Research Question 1

Controlling for the indirect effect through *physical activity*, does bicyclist typology have a relative indirect effect on *general health status, physically unhealthy days, mentally unhealthy days*, and/or *activity limited days* through the indirect effect of *commute bicycling* status?

Hypothesis 1

H₁: We hypothesize that bicyclist typology will have a significant indirect effect on *general health status, physically unhealthy days, mentally unhealthy days, and activity limited days* through *commute bicycling* status, controlling for the indirect effect through *physical activity*.

Research Question 2

Controlling for the indirect effect through *commute bicycling*, does bicyclist typology have a relative indirect effect on *general health status, physically unhealthy days, mentally unhealthy days*, and/or *activity limited days* through the indirect effect of *physical activity* status?

Hypothesis 2

H₁: We hypothesize that bicyclist typology will have a significant indirect effect on *general health status, physically unhealthy days, mentally unhealthy days, and activity limited days* through *physical activity* status, controlling for the indirect effect through *commute bicycling*.

Initial Results

A greater proportion of respondents who identify as a bicyclist typology more comfortable commute bicycling regardless of the presence of bicycling facilities have commute bicycled to, from, or around campus during the past week – either Strong & Fearless or Enthused & Confident at 41% and 27%, respectively (Figure 1.3).

Conversely, nearly zero percent of respondents who identify as a bicyclist type less comfortable bicycling without bicycling facilities have bicycled for transportation to, from, or around campus during the past week. A greater proportion of respondents who identify as Strong & Fearless and Enthused & Confident bicyclist types report exercising in the past week – 82% and 80%, respectively - than respondents who identify as bicyclist types that desire a more bicycle-friendly environment in order to bicycle (58%-73%) (Figure 1.4). These initial results demonstrate that investigating the indirect effect of bicyclist typology on health-related quality of life through commute bicycling and/or physical activity status is a reasonable endeavor.

Figure 1.4. Distribution of Cycling for Transportation Status by Bicyclist Typology

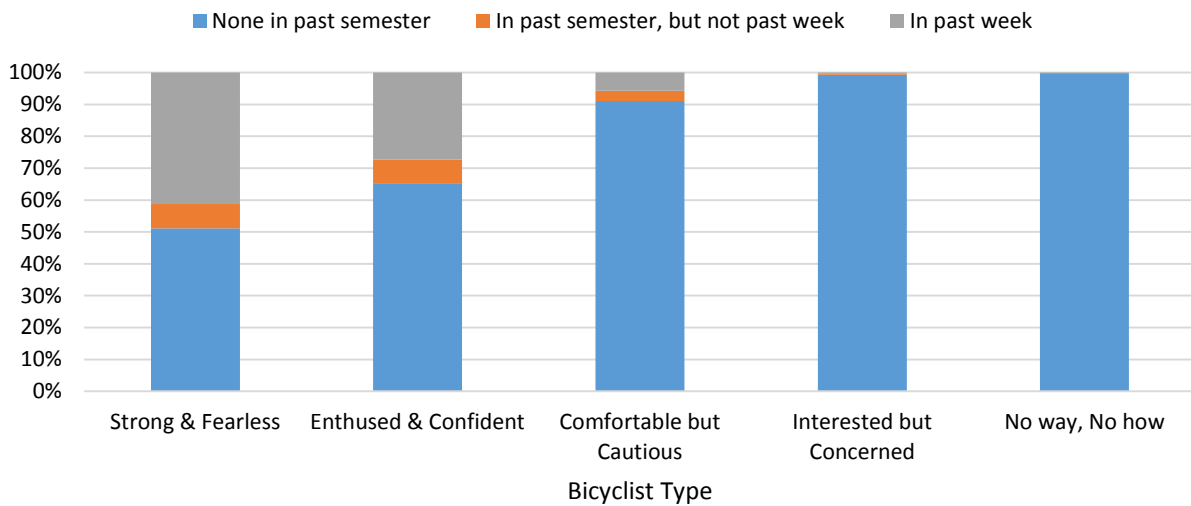
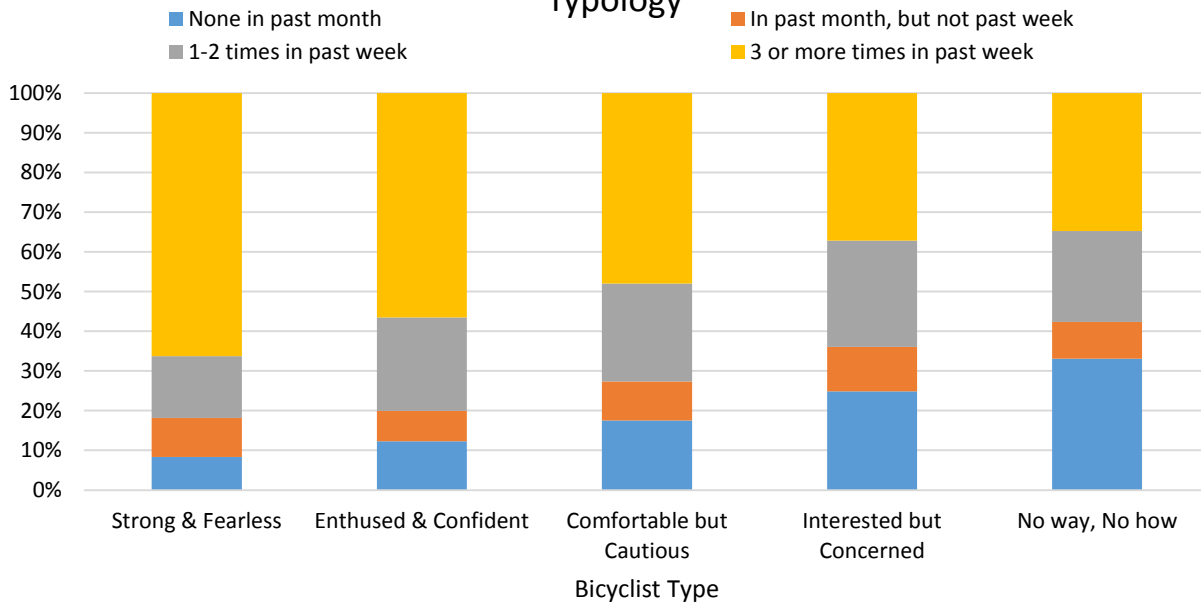


Figure 1.5. Distribution of Physical Activity Status by Bicyclist Typology



Study 3: Profiles of disposition towards factors to increase the likelihood of bicycling to, from, or around an urban university campus: a latent class analysis.

In Study 3, we will use a finite mixture modeling approach to develop classes, or profiles, of disposition toward whether bicycling-related improvements to a specific destination – a southern, university campus - will increase the likelihood of commute bicycling. Improvements assessed will include: 1) separated bicycling lanes were available, 2) bicycle learning activities were available on campus, 3) bicycle route information was available, 4) bicycle repair facility was available on campus, 5) bicycle parking was more convenient, 6) bicycle parking was safer and more secure, 7) place to shower and change was more convenient, 8) low or no cost bicycles were available, and 9) better public transportation was available, and 10) proximity of residence to destination. We are proposing a “person-centered” methodology that will allow for the creation of patterns of dispositions. Respondents may then be conceived as having a particular pattern or subset of patterns of dispositions toward destination improvements. This is statistically different from assessing the likelihood of a person endorsing a single item or the likelihood that a person who endorses one item will endorse another item. Thus far, this researcher has found no examples of a person-centered approach in the commute bicycling literature.

Planning and health professionals may leverage these patterns of responses to better understand how best to intervene. Once the most likely and substantive patterns

are identified and understood, the significance of pertinent covariates may be assessed. In the case of this study, we may be interested in knowing the distribution of bicyclist types within each class. As Geller suggests, we may choose to focus efforts on Comfortable but Cautious and/or Interested but Concerned [3]. Similarly, we may wish to better target bicycle planning efforts by understanding the estimated probability of belonging to each class by other covariates of interest like demographic, bicyclist characteristics (ever bicycled status, current commute bicycling status), and mode of transportation. Hence, this study aims to improve and assist in the prioritization of commute bicycling projects. Results from the proposed study will improve upon existing research and open up new lines of future research on the relationship between variables pertinent to commute bicycling and destination environment factors related to bicycling for transportation. Finally, results of this study should prove more functional for decision makers than studies focusing on each disposition towards destination changes independent of each other or only on current commute bicyclists.

Research Questions and Hypotheses

We will initially establish a measurement model of latent profiles of disposition toward whether destination improvements will increase the likelihood of commute bicycling. We will apply a methodology described by Masyn [57]. The development of profiles of response patterns, or classes, does not involve a stated hypothesis to test. However, once the classes are finalized we will test multiple hypotheses on the

covariates of interest using the Wald Chi-Square. The following research questions are related to the structural relationship between the measurement model and covariates of interest.

Research Question 1

Is bicyclist typology associated with class membership?

Hypothesis 1

H₁₁: We hypothesize that respondents who are either not motivated to commute bicycle or who have never bicycled will have greater odds of belonging to profiles typified by uniform disagreement toward destination improvements than respondents motivated to commute bicycle.

H₁₂: We hypothesize that respondents who are motivated to commute bicycle will have greater odds of belonging to profiles typified by agreement toward destination improvements as compared to respondents not motivated to commute bicycle and respondents who had never bicycled.

Research Question 2. Is bicyclist status associated with class membership?

H₂₁: We hypothesize that respondents who rode a bicycle during the past 12 months will have greater odds of belonging to profiles characterized by uniform or heterogeneous agreement in disposition toward destination improvements as compared to respondents who had not ridden a bicycle during the past 12 months.

Research Question 3. Is current commute bicycling status associated with class membership?

H₃₁: We hypothesize that respondents who commute bicycled during the past semester will have greater odds of belonging to profiles characterized by uniform agreement or agreement with bicycling amenities and bicycling education items as compared to respondents who had not commute bicycled during the past semester.

Research Question 4. Is physical activity status associated with class membership?

H₄₁: We hypothesize that respondents with more physical activity will have greater odds of belonging to profiles characterized by uniform agreement or agreement with bicycling amenities and education items than respondents with less physical activity.

Research Question 5. Is transportation mode associated with class membership?

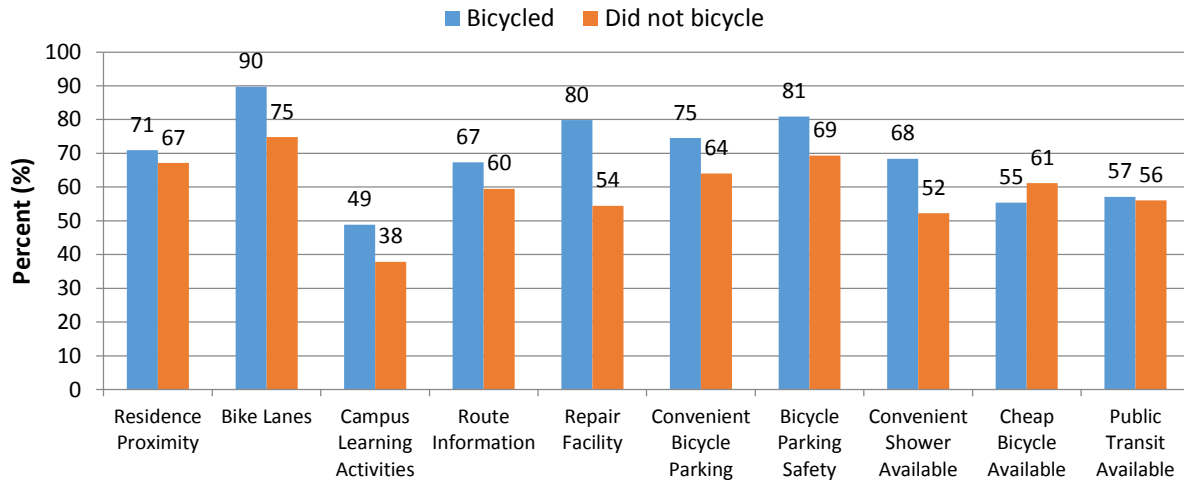
H₅₁: We hypothesize that respondents who drove most or all of the time will have greater odds of belonging to profiles characterized by uniform disagreement as compared to respondents who did not drive most or all of the time.

H₅₂: We hypothesize that respondents who rode a bicycle most or all of the time will have greater odds of belonging to profiles characterized by uniform agreement or agreement in cycling amenities and education items as compared to respondents who did not ride a bicycle most or all of the time.

Initial Results

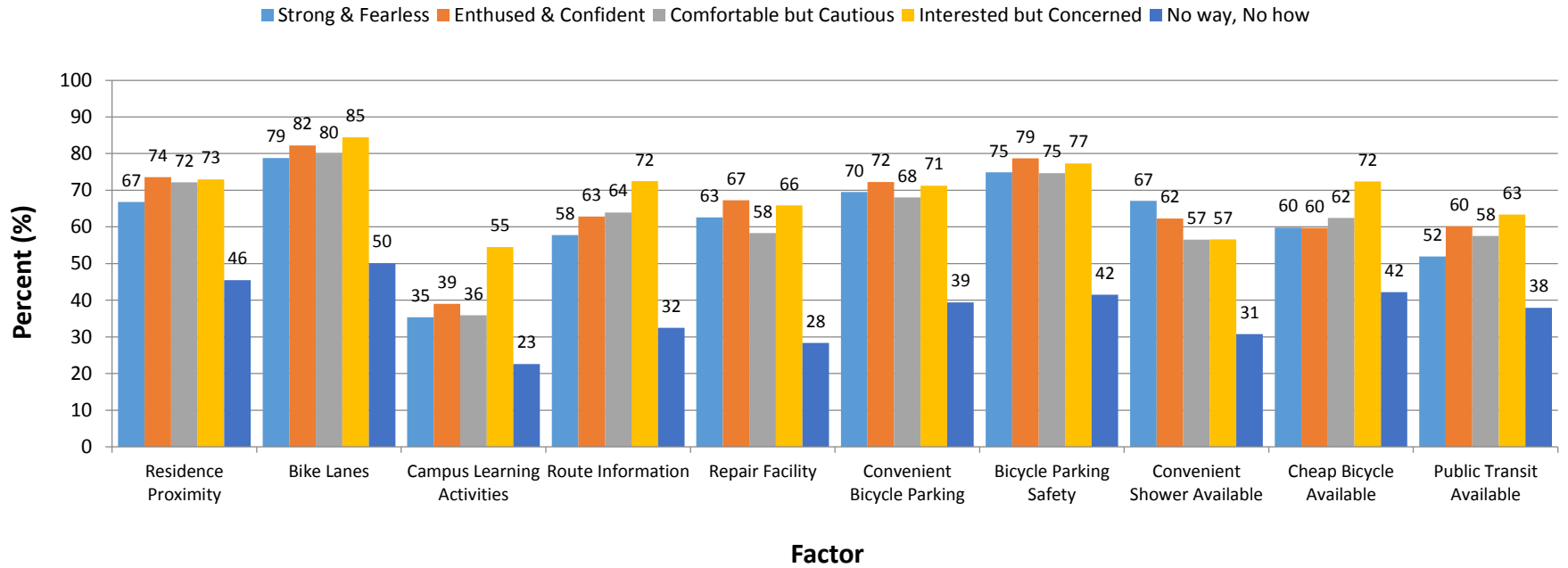
Respondents who commute bicycled to campus during the past seven days appear to agree with each factor differently than respondents who had not commute bicycled (Figure 1.5). A greater proportion of respondents who had commute bicycled agree that having dedicated, separated bike lanes, repair facility, convenient and safe bicycle parking, and having a convenient place to shower or change items would increase their likelihood of cycling to campus than persons who had not bicycled. Persons who identify as No way, No how show some agreement with each factor, thus indicating that, though they may not be motivated to commute bicycle, they may still commute bicycle following the proposed improvements (Figure 1.6). A greater proportion of Interested but Concerned respondents appear to agree that having access to a cheap bicycle would increase their likelihood of commute bicycling. The proposed analysis would be able to assess this topic in a more comprehensive manner and assist decision makers in prioritizing bicycling-related improvements changes.

Figure 1.6. Percent of Respondents that Agree Their Likelihood of Bicycling to, from, or around GSU would Increase by Factor and Commute Cycling Status*



*Rode bicycle to, from, or around campus during the past 7 days **Factor**

Figure 1.7. Percent of Respondents that Agree Their Likelihood of Bicycling to, from, or around GSU would Increase by Factor and Bicyclist Typology*



References

1. United States Census Bureau. *2014 American Community Survey 1-Year Estimates*. [cited 2016 April 5, 2016]; Available from: <http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>.
2. McLeod, K. and E. Murphy, *Where We Ride 2014: Analysis of Bike Commuting*. 2015. p. 41.
3. Geller, R. *Four Types of Cyclists*. 2006.
4. Dill, J. and N. McNeil *Four Types of Cyclists? Examining a Typology to Better Understand Bicycling Behavior and Potential*. 2012. 22.
5. Geller, R. *Four Types of Cyclists*. 2006 [cited 2015 February 28]; Available from: <http://www.portlandoregon.gov/transportation/article/264746>.
6. Dill, J. and N. McNeil, *Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential*. *Transportation Research Record*, 2013(2387): p. 129-138.
7. Pucher, J. and R. Buehler, *Cycling for a Few or for Everyone: The Importance of Social Justice in Cycling Policy*. *World Transport Policy & Practice*, 2009. **15**(1): p. 8.
8. Buehler, R. and J. Dill, *Bikeway Networks: A Review of Effects on Cycling*. *Transport Review*, 2015: p. 19.
9. de Nazelle, A., et al., *Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment*. *Environ Int*, 2011. **37**(4): p. 766-77.
10. Hamer, M. and Y. Chida, *Active commuting and cardiovascular risk: A meta-analytic review*. *Preventive Medicine*, 2008. **46**(1): p. 9-13.
11. de Geus, B., et al., *Cycling to work: influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and quality of life*. *Scand J Med Sci Sports*, 2008. **18**(4): p. 498-510.
12. Rojas-Rueda, D., *The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study (vol 343, d4521, 2011)*. *British Medical Journal*, 2011. **343**: p. 1.
13. Rojas-Rueda, D., et al., *Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study*. *Environ Int*, 2012. **49**: p. 100-9.
14. Rojas-Rueda, D., et al., *Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach*. *Preventive Medicine*, 2013. **57**(5): p. 573-579.
15. de Hartog, J.J., et al., *Do the Health Benefits of Cycling Outweigh the Risks?* *Ciencia & Saude Coletiva*, 2011. **16**(12): p. 4731-4744.

16. Moriarty, D.G., M.M. Zack, and R. Kobau, *The Centers for Disease Control and Prevention's Healthy Days Measures - population tracking of perceived physical and mental health over time*. Health Qual Life Outcomes, 2003. **1**: p. 37.
17. De Forge, B.R., J. Sobal, and J.P. Krick, *Relation of perceived health with psychosocial variables in elderly osteoarthritis patients*. Psychol Rep, 1989. **64**(1): p. 147-56.
18. Kivela, S.L. and K. Pahkala, *The prognosis of depression in old age*. Int Psychogeriatr, 1989. **1**(2): p. 119-33.
19. Permanyer-Miralda, G., et al., *Comparison of perceived health status and conventional functional evaluation in stable patients with coronary artery disease*. J Clin Epidemiol, 1991. **44**(8): p. 779-86.
20. Wannamethee, G. and A.G. Shaper, *Self-assessment of health status and mortality in middle-aged British men*. Int J Epidemiol, 1991. **20**(1): p. 239-45.
21. Idler, E.L., L.B. Russell, and D. Davis, *Survival, functional limitations, and self-rated health in the NHANES I Epidemiologic Follow-up Study, 1992. First National Health and Nutrition Examination Survey*. Am J Epidemiol, 2000. **152**(9): p. 874-83.
22. Fernandez-Ruiz, M., et al., *The ability of self-rated health to predict mortality among community-dwelling elderly individuals differs according to the specific cause of death: data from the NEDICES cohort*. Gerontology, 2013. **59**(4): p. 368-77.
23. Regidor, E., et al., *Socioeconomic variation in the magnitude of the association between self-rated health and mortality*. Ann Epidemiol, 2010. **20**(5): p. 395-400.
24. Heidrich, J., et al., *Self-rated health and its relation to all-cause and cardiovascular mortality in southern Germany. Results from the MONICA Augsburg cohort study 1984-1995*. Ann Epidemiol, 2002. **12**(5): p. 338-45.
25. Idler, E.L. and R.J. Angel, *Self-rated health and mortality in the NHANES-I Epidemiologic Follow-up Study*. Am J Public Health, 1990. **80**(4): p. 446-52.
26. Stewart, A.L., et al., *Functional status and well-being of patients with chronic conditions. Results from the Medical Outcomes Study*. Jama, 1989. **262**(7): p. 907-13.
27. Colsher, P.L. and R.B. Wallace, *Elderly men with histories of heavy drinking: correlates and consequences*. J Stud Alcohol, 1990. **51**(6): p. 528-35.
28. Colsher, P.L., et al., *Demographic and health characteristics of elderly smokers: results from established populations for epidemiologic studies of the elderly*. Am J Prev Med, 1990. **6**(2): p. 61-70.
29. Lamb, K.L., et al., *A comparison of selected health-related data from surveys of a general population and a sporting population*. Soc Sci Med, 1991. **33**(7): p. 835-9.
30. Segovia, J., R.F. Bartlett, and A.C. Edwards, *The association between self-assessed health status and individual health practices*. Can J Public Health, 1989. **80**(1): p. 32-7.
31. Dominick, K.L., et al., *Relationship of health-related quality of life to health care utilization and mortality among older adults*. Aging Clin Exp Res, 2002. **14**(6): p. 499-508.

32. Bertera, R.L., *The effects of behavioral risks on absenteeism and health-care costs in the workplace*. J Occup Med, 1991. **33**(11): p. 1119-24.
33. Jenkins, R., et al., *A six year longitudinal study of the occupational consequences of drinking over "safe limits" of alcohol*. Br J Ind Med, 1992. **49**(5): p. 369-74.
34. Batenburg, M. and J.A. Reinken, *The relationship between sickness absence from work and pattern of cigarette smoking*. N Z Med J, 1990. **103**(882): p. 11-3.
35. Crane, M., et al., *Associations between the frequency of cycling and domains of quality of life*. Health Promot J Austr, 2014. **25**(3): p. 182-5.
36. Guell, C., et al., *Towards a differentiated understanding of active travel behaviour: Using social theory to explore everyday commuting*. Social Science & Medicine, 2012. **75**(1): p. 233-239.
37. Fraser, S.D.S. and K. Lock, *Cycling for transport and public health: a systematic review of the effect of the environment on cycling*. European Journal of Public Health, 2011. **21**(6): p. 738-743.
38. Saelens, B.E., J.F. Sallis, and L.D. Frank, *Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures*. Ann Behav Med, 2003. **25**(2): p. 80-91.
39. Van Holle, V., et al., *Relationship between the physical environment and different domains of physical activity in European adults: a systematic review*. BMC Public Health, 2012. **12**: p. 807.
40. Mertens, L., et al., *The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs*. International Journal of Behavioral Nutrition and Physical Activity, 2014. **11**: p. 12.
41. Dill, J. and T. Carr, *Bicycle commuting and facilities in major U.S. cities: If you build them, commuters will use them*. Transportation Research Record: Journal of the Transportation Research Board, 2003. **1828**: p. 8.
42. Monsere, C., et al., *Lessons from the Green Lanes: Evaluating protected bike lanes in the U.S.*, in *Civil and Environmental Engineering Faculty Publications and Presentations*, PDXScholar, Editor. 2014, Portland State University. p. 181.
43. Goodno, M., et al., *Evaluation of innovative bicycle facilities in Washington, DC Pennsylvania avenue median lanes and 15th street cycle track*. Transportation Research Record: Journal of the Transportation Research Board, 2013. **2387**: p. 10.
44. Snizek, B., T.A.S. Nielsen, and H. Skov-Petersen, *Mapping bicyclists' experiences in Copenhagen*. Journal of Transport Geography, 2013. **30**: p. 7.
45. Barnes, G., K. Thompson, and K.J. Krizek, *A longitudinal analysis of the effect of bicycling facilities on the commute share*, in *Eighty-fifth transportation research board annual meeting*. 2006: Washington, DC.

46. Heinen, E., B. van Wee, and K. Maat, *Commuting by bicycle: An overview of the literature*. *Transport Reviews*, 2010. **20**(1): p. 38.
47. Tilahun, N.Y., D.M. Levinson, and K.J. Krizek, *Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey*. *Transportation Research Part A*, 2007. **41**: p. 15.
48. Broach, J., J. Dill, and J. Gliebe, *Where do cyclists ride? A route choice model developed with revealed preference GPS data*. *Transportation Research Part A: Policy and Practice*, 2012. **46**(10): p. 11.
49. Kang, L. and J.D. Fricker, *Bicyclist commuters' choice of on-street versus off-street route segments*. *Transportation*, 2013. **40**: p. 16.
50. Winters, M. and K. Teschke, *Route preferences among adults in the near market for bicycling: Findings of the cycling in cities study*. *American Journal of Health Promotion*, 2010. **25**(1): p. 8.
51. Garrard, J., G. Rose, and S.K. Lo, *Promoting transportation cycling for women: The role of bicycle infrastructure*. *Preventive Medicine*, 2008. **46**(1): p. 5.
52. Jackson, M. and E. Ruehr, *Let the people be heard: San Diego county bicycle use and attitude survey*. *Transportation Research Board: Journal of the Transportation Research Board*, 1998. **1636**: p. 5.
53. Sanders, R.L. and J.F. Cooper, *Do all roadway users want the same thing? Results from roadway design survey of San Francisco bay area pedestrians, drivers, bicyclists, and transit users*. *Transportation Research Board: Journal of the Transportation Research Board*, 2013. **2393**: p. 10.
54. Fishman, E., et al., *Factors influencing bike share membership: An analysis of Melbourne and Brisbane*. *Transportation Research Part A: Policy and Practice*, 2015. **71**: p. 14.
55. Sener, I.N., N. Eluru, and C.R. Bhat, *An analysis of bicycle route choice preferences in Texas, US*. *Transportation*, 2009. **36**: p. 29.
56. Parkin, J., M. Wardman, and M. Page, *Estimation of the determinants of bicycle mode share for the journey to work using census data*. *Transportation*, 2008. **35**: p. 17.
57. Masyn, K.E., *Latent Class Analysis and Finite Mixture Modeling*, in *The Oxford Handbook of Quantitative Methods*, T. Little, Editor. 2013, Oxford University Press: Oxford.

Chapter 2: Bicyclist typology and health-related quality of life: A cross-sectional study of students and employees at a southern urban university

Title: Bicyclist typology and health-related quality of life: A cross-sectional study of students and employees at a southern urban university

Authors:

J. Michael Bryan, MPH, jbryan8@student.gsu.edu, School of Public Health, Georgia State University

Katherine Masyn, PhD, kmasyn@gsu.edu, School of Public Health, Georgia State University

Matthew Magee, PhD, mjmagee@gsu.edu, School of Public Health, Georgia State University

John Steward, MPH, jsteward@gsu.edu, School of Public Health, Georgia State University

Affiliations: School of Public Health, Georgia State University

Keywords: Bicycle, Typology, Health, Health-Related Quality of Life

Corresponding Author: J. Michael Bryan, jbryan8@student.gsu.edu

Article Type: Research Article

Word Count: 3,958

Abstract

Objectives We sought to assess if there were health disparities by (1) bicycling status (ever versus never), (2) motivation to commute bicycle, and (3) comfort with commute bicycling given varying levels of bicycle facilities.

Methods Data from the 2014 Georgia State University-Bicycling Survey was used. The sample was compared to the university population. Descriptive statistics were performed on demographics by bicyclist typology. Bivariate statistics were performed on health-related quality of life by bicyclist typology. The adjusted odds of worse health-related quality of life by bicyclist typology were calculated.

Results All Chi-Square tests comparing the distribution of health-related quality of life by bicyclist typology were significant (p -value < 0.01). Respondents who had never bicycled did not have significantly different odds of worse health than the least motivated respondents. Respondents not motivated to commute bicycle had similar odds of worse health as compared to motivated respondents requiring the most bicycle facilities to commute bicycle. Among the motivated respondents, as respondents required more bicycle facilities to commute bicycle, the odds of worse health-related quality of life increased.

Conclusions These results are initial evidence of the existence of a health disparity by bicyclist typology. Urban planning and bicycling-related interventions may help reduce these disparities. Future research may investigate the mechanism for this disparity and whether there are disparities for more specific health outcomes by bicyclist typology.

1. Introduction

2 Bicycle commuting can help protect against cardiovascular diseases, the leading cause of
3 death among U.S. adults, and related risk factors [1-3]. However, as of 2014, less than one
4 percent of U.S. adult workers usually commuted by bicycle [4]. Roger Geller's conceptualization
5 of the different types of bicyclists may help explain the relatively low modal share of
6 commuting by bicycle (*bicycle commuting*). According to Geller's typology, though the majority
7 of persons may be motivated to bicycle, they do not perceive themselves as having access to the
8 necessary environment (i.e. bicycle facilities) to do so [5, 6]. Persons with greater access to
9 bicycle commuting may have better health outcomes primarily due to the greater levels of
10 physical activity associated with active transportation [7]. Investigations into the potential
11 association between access to bicycle commuting, as indicated in Geller's bicyclist typology, and
12 health outcomes have not been published yet. The present research examined the relationship
13 between bicyclist typology and broad indicators of health. Analyses were based on a survey of
14 students and employees of a university in Atlanta, Georgia.

15 *1.1 Access to transportation and health disparities*

16 Health may vary by an individual's perceived access to bicycling facilities. Those whose
17 bicycling needs are met may have better health than those whose bicycling needs are not met
18 due to an unequal distribution of a healthy transportation option. By definition, a difference in
19 health by bicyclist typology may be considered a social inequality as it could reasonably be
20 systematic, socially produced, and unfair [8]. Research has yet to determine whether there is
21 variation in health by motivation to and comfort with bicycling in different levels of bicycling

22 facilities. The notion that social processes produce health differences is applied in this
23 circumstance as there appears to be “No Law of Nature” determining that one bicyclist
24 typology has better health outcomes than another [8]. Finally, such a health disparity would be
25 unfair as unjust social arrangements may prevent the population from having equal access to
26 bicycling as a transportation option [8]. Focusing bicycling infrastructure projects on those who
27 are motivated to commute bicycle but require appropriate bicycling facilities to do so, as Geller
28 suggests doing, may either be furthering health disparities amongst an already disadvantaged
29 population or mitigating those health disparities. To this point in time, there is no evidence
30 either way.

31 *1.2 Benefits of bicycle commuting*

32 Research indicates that bicycle commuting improves human health. Overall, active
33 transportation may reduce the risk of cardiovascular outcomes by 11%, with a stronger
34 protective effect seen for women than men [1]. Male active commuters had 0.6 times the risk of
35 myocardial infarction as compared to non-active commuters [9]. Among adults in Flanders who
36 had previously not bicycle commuted, persons who began bicycle commuting had lower blood
37 levels of coronary heart disease risk factors, including total cholesterol and low-density
38 lipoprotein and higher levels of high-density lipoprotein – a protective factor for coronary heart
39 disease [2]. Adolescents who bicycle to school may have significantly lower Body Mass Index
40 [10] and healthier levels of triglycerides, cholesterol, fasting glucose, as well as better
41 cardiovascular risk profiles than their non-bicycling counterparts [11]. de Hartog *et al* estimated
42 that switching from driving to bicycling to work may increase life expectancy by 3 to 14 months

43 due to the benefits of physical activity [12]. Though individuals who commute by bicycle may
44 incur extra risk related to increased air pollution exposure, the health benefits of increased
45 physical activity far outweigh the potential risks in most urban areas [13].

46 *1.3 Access to bicycle commuting*

47 The built environment impacts the accessibility of bicycling as a form of transportation.
48 For example, regardless of actual bicycling status, people prefer and feel safer on dedicated
49 paths, separated from vehicular traffic, especially women, inexperienced bicyclists, and risk
50 averse individuals [14-22]. Regarding accessibility of transportation options, the World Health
51 Organization identifies the following as a transportation goal: “Transport systems should be
52 designed to serve the needs of all people, addressing the barriers that prevent mobility,
53 especially for disadvantaged groups” [23]. Nations that have successfully made bicycling a
54 significant portion of the modal share have made bicycling a safe and convenient alternative to
55 motor vehicle transportation. In these nations, bicyclists are not “forced to muster the courage
56 and willingness to battle motorists on streets without separate bike lanes or paths... Even timid,
57 risk-averse and safety-conscious individuals can be found cycling” [24]. Consequentially, as
58 compared to the U.S., these nations have a more equitable distribution of bicycle commuting,
59 particularly by gender and age [24].

60 Urban planners in the U.S. have attempted to enhance the equitable distribution of
61 bicycling as a transportation option. In 2006, Roger Geller published a bicyclist typology to
62 better understand the potential market for bicycle commuting [5, 6]. In the ensuing decade,
63 cities and regions across the U.S. adopted Geller’s bicyclist typology in various forms to better

64 defend investments in bicycle facilities [6]. Geller's typology classifies persons based on
65 motivation to bicycle for transportation, comfort with bicycling in different levels of bicycle
66 facilities, and physical ability to bicycle. With this typology, Geller aimed to better address the
67 "concerns of the majority" – persons who want to bicycle, but who do not feel safe or
68 comfortable enough to do so [5]. Urban planners may work towards meeting the needs of this
69 "majority" through the development of an environment that reduces the role of fear or
70 perceived risk in bicycling and, thereby, increasing the modal share of bicycle commuting [6]. In
71 effect, urban planners may impact motivation to and comfort with commute bicycling among
72 their respective residents.

73 *1.4 The current study*

74 As Borrell recently noted, "research on social inequalities in transport systems and
75 health should be promoted" [25]. Our study aims to contribute to this effort by examining
76 whether health varies by self-ascribed bicyclist typology among students and employees of a
77 southern urban university. Because there is a need to assess health outcomes to reveal this
78 relationship, we focus on health-related quality of life. Specifically, we use the Centers for
79 Disease Control and Prevention's Health-Related Quality of Life-4 (HRQOL). HRQOL provides
80 an efficient means to identify health disparities and inform a more health-focused public policy
81 [26-32]. The present study is part of a larger effort to inform the development of a transportation
82 plan specific to bicycling for a southern, urban university. Like many municipalities before, we
83 modified Geller's bicyclist typology to better suit the needs of our region of interest [6]. For
84 example, we parsed out persons who reported never having ridden a bicycle into a separate

85 typology (“Never bicycled”). Specifically, we wanted to investigate the association between
86 self-reported bicyclist typology and health-related quality of life. We expected to find that that
87 respondents who had never bicycled had greater odds of worse HRQOL than respondents who
88 had ever bicycle. Further, respondents who were not motivated to commute bicycle to have
89 greater odds of worse HRQOL than respondents who were motivated to commute bicycle.
90 Finally, we expected that, among respondents motivated to commute bicycle, those who require
91 more bicycle facilities before doing so would have greater odds of worse HRQOL than their
92 counterparts.

93

94

95 **2. Methods**

96 *2.1 Participants*

97 The data presented here come from the 2014 Georgia State University-Bicycling Survey
98 (GSU-BS). The GSU-BS is a cross-sectional study designed to inform the development of
99 bicycling policy and a bicycle-specific transportation plan for the university. Information
100 pertinent to bicycling behaviors and barriers was ascertained. Overall, the GSU-BS is comprised
101 of 40 questions. Data was collected for a period of two weeks, beginning October 6, 2014.
102 Qualtrics® was used to deliver the survey electronically to 41,016 Georgia State University e-
103 mail addresses: 31,642 students and 9,374 employees. Among respondents who agreed to
104 participate in the survey, only those who had ever been to the university campus were included
105 in this study. Responses missing data on the independent variables or on all dependent
106 variables were excluded. The study received Institutional Review Board and Office of
107 Institutional Effectiveness approval at Georgia State University. No incentives were provided
108 for participation.

109 Table 1 details key characteristics of survey respondents by student-employee status and
110 overall. These characteristics are compared to that of the campus population. There is a
111 discrepancy in the representation of the sample by both gender and race/ethnicity. Overall,
112 females and white, non-hispanics are overrepresented in the sample as compared to the campus
113 population. Due to the exploratory nature of the study and the self-selected sample employed,
114 we decided against weighting the data.

115 2.2 *Bicyclist Typology*

116 *Table 1* describes the differences between the bicyclist typologies. Respondents who had
117 ever bicycled self-reported their bicyclist typology based on a modified version of Geller's
118 original typology. Among this group, for respondents motivated to bicycle, the typology
119 options included (in order of increasing need for bicycle facilities to bicycle): (1) Strong and
120 Fearless, (2) Enthused and Confident, (3) Comfortable but Cautious, and (4) Interested but
121 Concerned. Respondents who identified as the No Way, No How typology were considered to
122 not be motivated to commute bicycle. The Never Bicycled typology included all respondents
123 who reported that they had never ridden a bicycle.

124 2.3 *Health-Related Quality of Life*

125 The dependent variables of interest - the Health-Related Quality of Life-4 - were each
126 treated as ordinal. The first item, general health status, assessed respondents' self-perceived
127 health status. General health status was coded such that higher values indicate worse self-
128 perceived health status. The other three indicators of health-related quality of life were the
129 "Unhealthy Days" items. These items were used to measure the self-reported number of days
130 where (1) physical health was not good, (2) mental health was not good, and (3) activity was
131 limited during the past month. Sensitivity analyses were performed to determine the most
132 parsimonious means of consistently categorizing these three measures. The Unhealthy Days
133 items were categorized such that higher values indicate more unhealthy days. The category
134 with zero unhealthy days was the reference group for the Unhealthy Days measures. Each
135 Health-Related Quality of Life-4 indicator is a significant predictor of 30-day and 1-year

136 hospitalization and mortality [26]. Further, the Health-Related Quality of Life-4 has good to
137 excellent test-retest reliability, and construct and concurrent validity across populations and
138 settings [33-40].

139 *2.4 Covariates*

140 In the GSU-BS, respondents were asked to identify their gender, race, ethnicity, age, and
141 student-employee status. Gender was treated as dichotomous. Race and ethnicity was dummy
142 coded such that white, non-Hispanic was the reference group, while (1) black, non-Hispanic, (2)
143 Hispanic, and (3) Other, non-Hispanic were entered into the model. Age was maintained as a
144 continuous variable. Student-Employee status was treated as dichotomous, whereby employee
145 status captured any respondent who indicated they were employed, regardless of whether they
146 were also a student.

147 *2.5 Analysis*

148 Data were summarized using proportions for categorical variables and means and
149 standard deviations for continuous variables using SAS Version 9.4. The Kruskal-Wallis Chi-
150 Square test was used to assess differences in the distribution of Health-Related Quality of Life
151 by bicyclist typology also in SAS Version 9.4. All other analyses were performed using MPlus
152 Version 7.4. The Brant test of proportional odds was used to determine whether each effect of
153 bicyclist typology on health-related quality of life violated the parallel regression assumption.
154 We performed a Wald test to determine if bicyclist typology was associated with health-related
155 quality of life. Ordinal logistic regression was used to estimate the adjusted log odds of worse
156 health-related quality of life for each bicyclist typology as compared to a reference typology.

157 These estimates are expressed as odds ratios and the corresponding 95% confidence intervals.
158 The models for each health-related quality of life item were estimated simultaneously. Previous
159 research indicates that access to bicycling as a transportation option differs by demographic
160 status [6, 22, 41]. To mitigate the potential confounding effect of demographics, we controlled
161 for sex, race/ethnicity, age, and student-employee status when estimating the adjusted odds
162 ratio. Student-Employee status was also assessed as a moderator of the effect of bicyclist
163 typology on health-related quality of life.

164

165

166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186

3. Results

3.1 Demographics

The final sample for analysis in this study had 4,374 participants. Descriptive statistics of these participants by bicyclist typology are shown in *Table 3*. Three-fourths of the sample was motivated to bicycle, but either prefers (Enthused and Confident) or requires (Comfortable but Cautious, Interested but Concerned) bicycle facilities to be comfortable doing so. Similar percentages of the sample reported they were comfortable with commute bicycling in any environment (Strong and Fearless) or had never ridden a bicycle (Never Bicycled) - 6% and 5%, respectively. Nearly two-thirds of the sample was female. There was not a majority race/ethnicity. The distribution of gender, race/ethnicity, and student-employee status was different by bicyclist typology, as was the mean age. Each of the Brant tests of proportional odds were insignificant ($p > 0.01$), indicating that the proportional odds assumption was not violated (data not shown).

3.2 Bicyclist Typology

As shown in *Table 4*, the distribution of each health-related quality of life measure was significantly different by bicyclist typology ($p < 0.01$). Over 60% of the sample reported either Very Good or Excellent health. Across each Unhealthy Days measure, as compared to the Strong and Fearless, a greater percentage of the other bicyclist typologies reported one or more unhealthy days during the past 30 days. For example, while 53% of respondents motivated to, and comfortable with, commute bicycling in any environment reported zero days where activity was limited during the past 30 days, 38% of respondents motivated to bicycle but who

187 are unwilling to do so without bicycling facilities, 48% of respondents not motivated to
188 commute bicycle, and 37% of respondents who had never bicycled reported zero days of
189 activity limitation.

190 *3.3 Health-Related Quality of Life*

191 Bicyclist typology was associated with health-related quality of life (Wald $X^2=185.4$ (20,
192 $p<0.01$). The adjusted odds ratios of worse health-related quality of life are shown in *Table 5*.
193 Among respondents motivated to commute bicycle, the odds of worse health-related quality of
194 life were higher among respondents requiring more bicycling facilities before they would be
195 comfortable doing so. For example, the Enthused and Confident, Comfortable but Cautious,
196 and Interested but Concerned had 1.9, 2.6, and 3.5 times the odds, respectively, of worse general
197 health status as compared to the Strong and Fearless. Further, as motivated respondents
198 required greater bicycle facilities to be comfortable commute bicycling, the odds of worse
199 health-related quality of life also tended to increase. As compared to the Enthused and
200 Confident, the Comfortable but Cautious and Interested but Concerned had 1.4 and 1.9 times
201 the odds of worse general health status, respectively. Further, Comfortable but Cautious
202 respondents had 1.4 times the odds of worse general health status as compared to the Interested
203 but Concerned respondents.

204 Respondents not motivated to bicycle (e.g., the “No way, No how” typology) tended to
205 have greater odds of worse health-related quality of life than their motivated counterparts,
206 particularly in comparison to respondents comfortable bicycling regardless of the availability of
207 bicycle facilities (e.g., Strong and Fearless). In comparison to the Strong and Fearless,

208 unmotivated respondents had 3.3 times the odds of worse general health status, 1.6 times the
209 odds of more physically unhealthy days, 1.5 times the odds of more mentally unhealthy days,
210 and 1.3 times the odds of activity limited days. When comparing unmotivated persons to
211 motivated persons requiring the greatest amount of bicycling facilities before they would be
212 willing to commute bicycle (e.g., the Interested but Concerned), unmotivated persons had 0.7
213 times the odds of activity limited days – this difference in odds was the only significant
214 difference when comparing the Interested but Concerned, No Way, No How, and Never
215 Bicycled typologies.

216 Respondents who had never bicycled were more likely to have worse health-related
217 quality of life as compared to those who were motivated to bicycle and comfortable doing so
218 with minimal bicycling facilities – the Strong and Fearless and Enthused and Confident. For
219 example, as compared to the Enthused and Confident, respondents who had never bicycled had
220 1.4 times the odds of physically unhealthy days, mentally unhealthy days, and days where
221 activity was limited and 1.9 times the odds of worse general health status. As compared to
222 respondents requiring some level of bicycle facilities to feel comfortable commute bicycling
223 (e.g., Comfortable but Cautious), those who had never bicycled and who were unmotivated to
224 do so only had significantly greater odds of worse general health status.

225

226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245

4. Discussion

This study investigated the relationship between self-reported bicyclist typology and health-related quality of life among a self-selected sample of students and employees at a southern urban university in the United States. Despite the widespread national use of Geller's bicyclist typology, few, if any, studies have examined if health outcomes are different by bicyclist typology status. These results indicated that, among respondents already motivated to commute bicycle, respondents requiring less bicycle facilities to be comfortable commute bicycling had better health-related quality of life. Respondents motivated to commute bicycle tended to have better health-related quality of life. Finally, respondents who had never bicycled had worse health-related quality of life than respondents who motivated to commute bicycle and required few bicycle facilities to do so.

As previously described, persons who commute bicycle have better health outcomes than their non-commute bicycling counterparts. We may then expect that persons who report ever bicycling to have better health outcomes than their never bicycling counterparts. Our research indicates that, indeed, there is a disparity in health-related quality of life by bicycling status. However, the disparity we found is more specific than bicycling status alone. Our results suggest that individuals who have bicycled and are motivated to commute bicycle have better health-related quality of life than individuals who had never bicycled. Conversely, there was no difference in health-related quality of life when comparing respondents who had never bicycled to respondents unmotivated to commute bicycle. This finding suggests that persons who have

246 never bicycled and persons who are not motivated to commute bicycle may equally not be
247 experiencing the health benefits associated with motivation to commute bicycle.

248 Commute bicycling is a modifiable behavior. Researchers have concluded that the most
249 effective means of enhancing bicycling is through coordinated and complementary packages, as
250 standalone interventions are less efficacious [41, 42]. A recent systematic review found that the
251 place of work may be an effective setting for such interventions [43]. For example, intensive
252 work-based active transportation behavior change interventions that include counseling or
253 advice and the provision of a bike have been shown to increase the likelihood of commute
254 bicycling and physical activity levels, as well as improve cardiorespiratory and metabolic health
255 outcomes [44, 45]. These interventions suggest that, in lieu of only pursuing changes to bicycle
256 infrastructure, changing an individual's motivation to commute bicycle can impact both the
257 behavior and the health of the individual. Similarly, the results of this study indicate that
258 persons motivated to commute bicycle have better health outcomes than their unmotivated
259 counterparts. If we conceive of students commuting to class as akin to employees commuting to
260 work, the university could be an effective setting to implement work-based interventions
261 aiming to increase commute bicycling and, thereby, reducing a potential health disparity.

262 Our results concur with previous literature assessing the relationship between comfort
263 with, or accessibility to, commute bicycling and health outcomes. We found that increasing
264 comfort with commute bicycling in the absence of bicycle facilities was associated with better
265 health-related quality of life among persons motivated bicycle. Research indicates that
266 enhanced access bicycle infrastructure designed to increase the comfort and accessibility of

267 bicycling can have positive health impacts. For example, the construction of travel-associated
268 bicycle infrastructure (e.g., bicycle “lanes” and “highways”) has been demonstrated to be
269 associated with decreased mortality and morbidity primarily through increases physical
270 activity [7, 46]. Our results are also consistent with Morckel’s finding that increasing mobility
271 options alone is insufficient to explain engagement in physical activity [47]. Rather, there is an
272 attitudinal component, whereby an individual’s perception of their mobility options influences
273 their participation in physical activity [47]. Hence, our results may be indicating that, in order to
274 reduce the health disparity among persons already motivated to commute bicycle, interventions
275 may need to address both the physical (e.g., bicycle infrastructure) and psychological (e.g.,
276 attitudinal) barriers to commute bicycling.

277 Future studies could assess the mechanism for the poorer health-related quality of life
278 by bicyclist typology status. Falconer *et al* recently demonstrated that transitioning to active
279 travel from passive travel may increase physical activity [10]. However, uncertainty remains
280 around if the health disparity this study found can solely be attributed to differences in physical
281 activity. Research also remains unclear as to the extent to which the differences in physical
282 activity by bicyclist typology may be attributed to participation in commute bicycling or
283 another modality of physical activity. If there are differences in physical activity by bicyclist
284 typology not attributable to commute bicycling, this may be an indication that bicyclist
285 typology is also capturing a component of attitudinal disposition towards performing physical
286 activity in the environment. Public health interventions may be more efficacious if they are
287 better able to account for this relationship. For example, it would benefit public health
288 practitioners to know if the effect of never bicycling on health-related quality of life is partially

289 or completely explained through differences in physical activity. Depending on such results,
290 public health practitioners may emphasize or reduce the role of physical activity in promoted
291 interventions.

292 These results have several limitations. A causal pathway cannot be confidently claimed
293 as the data are cross-sectional. Establishing the directionality of the causal pathway was beyond
294 the scope of this analysis and not essential to identifying the health disparity of interest.
295 Treating persons who had never bicycled as a separate typology has not been validated.
296 Including respondents who had never bicycled in the analysis while not assuming they belong
297 to a particular typology (e.g., the No way, No how) has enhanced the substantive nature of
298 these findings. As demonstrated in Table 1, the sample is not generalizable to the broader
299 university population. We were unable to conclude that our results would be representative of
300 all students and employee at the institution and, much less, across the city or all urban
301 universities. Future research may want to replicate similar analyses with a representative
302 sample of the respective population. Using a single item to identify an individual's bicyclist
303 typology has yet to be fully validated or proven reliable. Despite uncertain validity, our
304 typology is consistent with Geller's suggestion to utilize it in support of bicycle planning efforts,
305 which we have done in collaboration with regional urban planning partners. Respondents may
306 misclassify into perceived health-related quality of life differentially by bicyclist typology.
307 When possible, research using objective measures of health could overcome this limitation.
308 Finally, longitudinal studies may pursue assessing bicycling typology as a dynamic response
309 option instead of a fixed or static position. Though there is an implied uni-directionality in this

310 analysis, a longitudinal study may better assess if such an assumption is correct. Our research
311 was necessary to justify such a resource intensive endeavor.

312 **5. Conclusion**

313 This study is initial evidence of health disparities by bicyclist typology. Understanding
314 the potential health impact of bicycle planning efforts that use Geller's bicyclist typology should
315 be assigned a greater priority for public health research than it is currently. This study is the
316 first to provide evidence that there are substantial health disparities by bicycling status,
317 motivation to commute bicycle, and comfort with commute bicycling in different levels of
318 bicycling facilities. With this knowledge, public health practitioners may want to work
319 alongside urban planners to assess and communicate the differences in health by bicyclist
320 typology for their particular locale. Further research is needed to understand why this disparity
321 exists. Once the mechanism for this disparity is better understood, public health practitioners
322 may be more confident in advocating for more targeted interventions to either motivate persons
323 to commute bicycle or make commute bicycling a more comfortable and/or accessible mode of
324 transportation for a larger proportion of the population.

325

326

327

328

329

6. Tables and Figures

330 *Table 1. Descriptive statistics comparison of survey respondents (N=4,374) and university*
 331 *population.*

Variables	Percentages (%)					
	Students		Employees		Overall	
	Sample	Campus	Sample	Campus	Sample	Campus
Gender						
Male	32.9	41.0	37.8	52.2	34.4	41.4
Female	67.1	59.0	62.2	47.8	65.6	58.6
Race/Ethnicity						
White, Non-Hispanic	40.3	33.4	65.7	74.5	47.9	35.0
Black, Non-Hispanic	31.2	36.5	21.6	9.3	28.3	35.4
Hispanic	10.5	8.2	3.9	2.6	8.6	8.0
Other, Non-Hispanic	18.0	21.9	8.8	13.6	15.2	21.6

332

333

334

335 *Table 2. Distinction of Bicyclist Typology Definitions.*

Bicyclist Typology	Motivated to Commute Bicycle	Require Commute Bicycling Facilities ^a (4=Most, 1=Least)	Ever Bicycled
Strong and Fearless	Yes	1	Yes
Enthusied and Confident	Yes	2	Yes
Comfortable but Cautious	Yes	3	Yes
Interested but Concerned	Yes	4	Yes
No way, No how	No	N/A	Yes
Never Bicycled	N/A	N/A	No

336 ^aBefore being comfortable commute bicycling

Table 3. Detailed descriptive statistics of GSU-BS sample included in analyses by bicyclist typology (N=4,374).

	Total sample	Strong and Fearless	Enthused and Confident	Comfortable but Cautious	Interested but Concerned	No way, No how	Never Bicycled	P-value ^a
N (%)	4,374	257 (5.9)	694 (15.9)	1752 (40.1)	835 (19.1)	600 (13.7)	236 (5.4)	
Mean Age (SD)	30.3 (12.4)	28.5 (11.0)	30.2 (11.9)	30.4 (12.3)	29.4 (11.6)	32.0 (14.2)	30.7 (13.9)	<0.01
Gender								
Male	34.0	11.4	26.7	38.9	10.6	9.0	3.5	<0.01
Female	66.0	3.1	10.3	40.6	23.5	16.2	6.4	
Race/Ethnicity								
White, Non-Hispanic	48.4	6.7	18.0	42.6	17.2	12.6	3.0	<0.01
Black, Non-Hispanic	28.1	4.9	12.4	35.4	22.3	17.7	7.4	
Hispanic	8.5	7.0	19.4	36.1	19.4	12.7	5.4	
Other, Non-Hispanic	15.0	4.6	13.6	42.9	19.0	10.5	9.4	
Student-Employee Status								
Student	69.9	6.6	16.2	39.2	19.5	12.6	5.9	<0.01
Employee	30.1	4.3	15.0	42.1	18.1	16.3	4.3	

Note: For each demographic we present the percentage unless otherwise stated.

^aFrom chi-squared test for differences for categorical variables and Analysis of Variance for the continuous variable.

Table 4. Distribution of Health-Related Quality of Life by Bicyclist Typology in GSU-BS sample.

Health-Related Quality of Life	Total sample (%)	Strong & Fearless (%)	Enthused & Confident (%)	Comfortable but Cautious (%)	Interested but Concerned (%)	No way, No how (%)	Never Bicycled (%)	P-value ^a
General health status								
Excellent	21.5	38.7	23.9	20.9	16.4	21.1	19.5	<0.01
Very Good	43.9	44.9	51.0	45.0	41.0	38.5	37.7	
Good	27.6	13.3	21.0	28.4	34.4	28.8	30.1	
Fair	6.5	2.7	4.0	5.3	8.2	10.4	10.6	
Poor	0.5	0.4	0.0	0.4	0.1	1.2	2.1	
Physically unhealthy days								
0 days	34.7	48.2	39.0	33.6	29.7	36.2	29.0	<0.01
1 to 3 days	43.9	34.9	42.2	46.1	46.3	38.9	46.5	
4 to 7 days	13.5	10.6	12.9	13.2	14.4	15.0	14.5	
8 to 14 days	4.0	2.8	2.9	3.5	5.1	6.1	3.5	
15 or more days	3.9	3.5	3.0	3.7	4.5	3.9	6.6	
Mentally unhealthy days								
0 days	26.7	37.0	28.8	26.9	20.1	30.0	22.6	<0.01
1 to 3 days	32.2	28.0	36.3	32.5	32.3	28.3	31.3	
4 to 7 days	17.6	15.4	17.0	18.4	18.4	14.4	20.4	
8 to 14 days	10.7	7.9	8.3	10.8	12.8	11.7	10.4	
15 or more days	12.9	11.8	9.7	11.4	16.5	15.6	15.2	
Days activity limited								
0 days	44.0	53.4	46.4	43.9	38.4	47.8	37.4	<0.01
1 to 3 days	32.5	26.9	34.7	32.7	32.2	30.2	38.3	
4 to 7 days	12.1	9.9	12.0	12.1	13.7	10.7	12.8	
8 to 14 days	6.5	5.9	4.2	6.3	9.4	7.3	3.5	
15 or more days	4.8	4.0	2.8	4.9	6.3	4.1	7.9	

^aFrom Kruskal-Wallis chi-squared test.

Table 5. Bicyclist typology and health-related quality of life (GSU-BS 2014).

Bicyclist Typology ^a	General Health Status		Physically Unhealthy Days		Mentally Unhealthy Days		Activity Limited Days	
	OR (95% CI)	P-value	OR (95% CI)	P-value	OR (95% CI)	P-value	OR (95% CI)	P-value
Strong and Fearless (ref.)								
Enthusied and Confident	1.86 (1.43, 2.43)	<0.001	1.38 (1.04, 1.81)	0.024	1.21 (0.92, 1.57)	0.169	1.20 (0.91, 1.58)	0.206
Comfortable but Cautious	2.55 (1.98, 3.27)	<0.001	1.54 (1.19, 1.99)	0.001	1.30 (1.02, 1.67)	0.037	1.35 (1.04, 1.75)	0.024
Interested but Concerned	3.52 (2.68, 4.61)	<0.001	1.76 (1.34, 2.32)	<0.001	1.76 (1.35, 2.29)	<0.001	1.72 (1.30, 2.27)	<0.001
No Way, No How	3.30 (2.48, 4.38)	<0.001	1.64 (1.22, 2.19)	0.001	1.46 (1.10, 1.94)	0.008	1.25 (0.93, 1.67)	0.138
Never Bicycled	3.46 (2.46, 4.88)	<0.001	1.91 (1.35, 2.69)	<0.001	1.65 (1.19, 2.31)	0.003	1.65 (1.17, 2.33)	0.004
Enthusied and Confident (ref.)								
Comfortable but Cautious	1.37 (1.16, 1.61)	<0.001	1.12 (0.94, 1.32)	0.195	1.08 (0.92, 1.27)	0.347	1.13 (0.95, 1.34)	0.159
Interested but Concerned	1.89 (1.56, 2.29)	<0.001	1.28 (1.06, 1.56)	0.012	1.46 (1.21, 1.76)	<0.001	1.44 (1.18, 1.74)	<0.001
No Way, No How	1.77 (1.44, 2.18)	<0.001	1.19 (0.96, 1.47)	0.108	1.21 (0.99, 1.49)	0.071	1.04 (0.84, 1.29)	0.701
Never Bicycled	1.86 (1.39, 2.47)	<0.001	1.39 (1.04, 1.84)	0.024	1.37 (1.04, 1.80)	0.023	1.38 (1.04, 1.83)	0.025
Comfortable but Cautious (ref.)								
Interested but Concerned	1.38 (1.18, 1.61)	<0.001	1.15 (0.98, 1.34)	0.081	1.35 (1.16, 1.56)	<0.001	1.27 (1.09, 1.49)	0.002
No Way, No How	1.29 (1.08, 1.54)	0.004	1.07 (0.89, 1.27)	0.482	1.12 (0.94, 1.33)	0.202	0.92 (0.77, 1.10)	0.386
Never Bicycled	1.36 (1.05, 1.76)	0.021	1.24 (0.96, 1.61)	0.099	1.27 (0.99, 1.63)	0.061	1.22 (0.95, 1.58)	0.124
Interested but Concerned (ref.)								
No Way, No How	0.94 (0.77, 1.14)	0.912	0.93 (0.76, 1.13)	0.470	0.83 (0.68, 1.01)	0.062	0.73 (0.59, 0.89)	0.002
Never Bicycled	0.99 (0.75, 1.29)	0.271	1.08 (0.82, 1.42)	0.564	0.94 (0.72, 1.22)	0.653	0.96 (0.73, 1.26)	0.771
No way, No how (ref.)								
Never Bicycled	1.05 (0.79, 1.40)	0.738	1.17 (0.88, 1.55)	0.294	1.13 (0.86, 1.49)	0.378	1.32 (1.00, 1.76)	0.054

Note: Analyses controlled for gender, age, race/ethnicity, and student-employee status. Each of the Health-Related Quality of Life variables were treated as ordinal.

7. References

1. Hamer, M. and Y. Chida, *Active commuting and cardiovascular risk: A meta-analytic review*. Preventive Medicine, 2008. **46**(1): p. 9-13.
2. de Geus, B., et al., *Cycling to work: influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and quality of life*. Scand J Med Sci Sports, 2008. **18**(4): p. 498-510.
3. Centers for Disease Control and Prevention, National Center for Health Statistics, *Underlying Cause of Death 1999-2014 on CDC WONDER Database, released 2015. Data are from the Multiple Cause of Death Files, 1999-2014, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program*.
4. United States Census Bureau. *2014 American Community Survey 1-Year Estimates*. [cited 2016 April 5, 2016]; Available from: <http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>.
5. Geller, R. *Four Types of Cyclists*. 2006.
6. Dill, J. and N. McNeil *Four Types of Cyclists? Examining a Typology to Better Understand Bicycling Behavior and Potential*. 2012. 22.
7. Schepers, P., et al., *The mortality impact of bicycle paths and lanes related to physical activity, air pollution exposure and road safety*. Journal of Transport & Health, 2015. **2**(4): p. 460-473.
8. Whitehead, M. and G. Dahlgren, *Concepts and principles for tackling social inequities in health. Levelling up (part 1)*. in *Studies on Social and Economic Determinants of Population Health no. 2*. 2006, World Health Organization: Denmark.
9. Wennberg, P., et al., *The effects of commuting activity and occupational and leisure time physical activity on risk of myocardial infarction*. Eur J Cardiovasc Prev Rehabil, 2006. **13**(6): p. 924-30.
10. Falconer, C.L., et al., *The tracking of active travel and its relationship with body composition in UK adolescents*. Journal of Transport & Health, 2015. **2**(4): p. 483-489.
11. Andersen, L.B., et al., *Cycling to school and cardiovascular risk factors: a longitudinal study*. J Phys Act Health, 2011. **8**(8): p. 1025-33.
12. de Hartog, J.J., et al., *Do the Health Benefits of Cycling Outweigh the Risks?* Ciencia & Saude Coletiva, 2011. **16**(12): p. 4731-4744.
13. Tainio, M., et al., *Can air pollution negate the health benefits of cycling and walking?* Prev Med, 2016. **87**: p. 233-6.
14. Broach, J., J. Dill, and J. Gliebe, *Where do cyclists ride? A route choice model developed with revealed preference GPS data*. Transportation Research Part A: Policy and Practice, 2012. **46**(10): p. 11.

15. Kang, L. and J.D. Fricker, *Bicyclist commuters' choice of on-street versus off-street route segments*. *Transportation*, 2013. **40**: p. 16.
16. Winters, M. and K. Teschke, *Route preferences among adults in the near market for bicycling: Findings of the cycling in cities study*. *American Journal of Health Promotion*, 2010. **25**(1): p. 8.
17. Garrard, J., G. Rose, and S.K. Lo, *Promoting transportation cycling for women: The role of bicycle infrastructure*. *Preventive Medicine*, 2008. **46**(1): p. 5.
18. Jackson, M. and E. Ruehr, *Let the people be heard: San Diego county bicycle use and attitude survey*. *Transportation Research Board: Journal of the Transportation Research Board*, 1998. **1636**: p. 5.
19. Sanders, R.L. and J.F. Cooper, *Do all roadway users want the same thing? Results from roadway design survey of San Francisco bay area pedestrians, drivers, bicyclists, and transit users*. *Transportation Research Board: Journal of the Transportation Research Board*, 2013. **2393**: p. 10.
20. Fishman, E., et al., *Factors influencing bike share membership: An analysis of Melbourne and Brisbane*. *Transportation Research Part A: Policy and Practice*, 2015. **71**: p. 14.
21. Sener, I.N., N. Eluru, and C.R. Bhat, *An analysis of bicycle route choice preferences in Texas, US*. *Transportation*, 2009. **36**: p. 29.
22. Buehler, R. and J. Dill, *Bikeway Networks: A Review of Effects on Cycling*. *Transport Review*, 2015: p. 19.
23. Albrecht, D., et al., *Social Determinants of Health. Sectoral briefing series 3. Transport (road transport): Shared interest in Sustainable Outcomes*. 2011, World Health Organization: Geneva.
24. Pucher, J. and R. Buehler, *Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany*. *Transport Reviews*, 2008. **28**(4): p. 495-528.
25. Borrell, C., *Social inequalities in transport: Going beyond the evidence*. *Journal of Transport & Health*, 2015. **2**(2): p. 101-102.
26. Dominick, K., et al., *Relationship of health-related quality of life to health care utilization and mortality among older adults*. *Aging Clinical and Experimental Research*, 2002. **14**(6): p. 499-508.
27. Colsher, P.L. and R.B. Wallace, *Elderly men with histories of heavy drinking: correlates and consequences*. *Journal of studies on alcohol*, 1990. **51**(6): p. 528-535.
28. Colsher, P.L., et al., *Demographic and health characteristics of elderly smokers: results from established populations for epidemiologic studies of the elderly*. *American journal of preventive medicine*, 1990. **6**(2): p. 61-70.

29. Lamb, K.L., et al., *A comparison of selected health-related data from surveys of a general population and a sporting population*. *Social Science & Medicine*, 1991. **33**(7): p. 835-839.
30. De Forge, B.R., J. Sobal, and J.P. Krick, *Relation of Perceived Health with Psychosocial Variables in Elderly Osteoarthritis Patients*. *Psychological Reports*, 1989. **64**(1): p. 147-156.
31. Permanyer-Miralda, G., et al., *Comparison of perceived health status and conventional functional evaluation in stable patients with coronary artery disease*. Elsevier, 1991. **44**(8): p. 8.
32. Wannamethee, G. and A.G. Shaper, *Self-assessment of health status and mortality in middle-aged British men*. *International Journal of Epidemiology*, 1991. **20**(1): p. 239-245.
33. Andresen, E.M., et al., *Retest reliability of surveillance questions on health related quality of life*. *Journal of Epidemiology and Community Health*, 2003. **57**(5): p. 339-343.
34. Toet, J., H. Raat, and E.J. van Ameijden, *Validation of the Dutch Version of the CDC Core Healthy Days Measures in a Community Sample*. *Quality of Life Research*, 2006. **15**(1): p. 179-184.
35. Pierannunzi, C., S.S. Hu, and L. Balluz, *A systematic review of publications assessing reliability and validity of the Behavioral Risk Factor Surveillance System (BRFSS), 2004-2011*. *BMC Med Res Methodol*, 2013. **13**: p. 49.
36. Ounpuu, S., et al., *Validity of the US Behavioral Risk Factor Surveillance System's health related quality of life survey tool in a group of older Canadians*. *Chronic diseases in Canada*, 2001. **22**(3-4): p. 93-101.
37. Centers for Disease Control and Prevention, *Health-related quality of life and activity limitation - eight states, 1995*. *Morbidity Mortality Weekly Report*, 1998. **47**(7): p. 7.
38. Centers for Disease Control and Prevention, *Health-related quality of life - Puerto Rico, 1996-2000*. *Morbidity Mortality Weekly Report*, 2002. **51**(8): p. 3.
39. Andresen, E.M., et al., *Performance of health-related quality-of-life instruments in a spinal cord injured population*. *Archives of Physical Medicine and Rehabilitation*, 1999. **80**(8): p. 877-884.
40. Currey, S.S., et al., *Performance of a generic health-related quality of life measure in a clinic population with rheumatic disease*. *Arthritis Care & Research*, 2003. **49**(5): p. 658-664.
41. Pucher, J. and R. Buehler, *Cycling for a Few or for Everyone: The Importance of Social Justice in Cycling Policy*. *World Transport Policy & Practice*, 2009. **15**(1): p. 8.
42. Pucher, J., J. Dill, and S. Handy, *Infrastructure, programs, and policies to increase bicycling: An international review*. *Preventive Medicine*, 2010. **50**, **Supplement**(0): p. S106-S125.
43. Petrunoff, N., C. Rissel, and L.M. Wen, *The effect of active travel interventions conducted in work settings on driving to work: A systematic review*. *Journal of Transport & Health*, 2016. **3**(1): p. 61-76.

44. Hemmingsson, E., et al., *Increased physical activity in abdominally obese women through support for changed commuting habits: a randomized clinical trial*. *Int J Obes*, 2009. **33**(6): p. 645-652.
45. Oja, P., I. Vuori, and O. Paronen, *Daily walking and cycling to work: their utility as health-enhancing physical activity*. *Patient Educ Couns*, 1998. **33**(1 Suppl): p. S87-94.
46. Buekers, J., et al., *Health impact model for modal shift from car use to cycling or walking in Flanders: application to two bicycle highways*. *Journal of Transport & Health*, 2015. **2**(4): p. 549-562.
47. Morckel, V.C., *Examining the relationships between perceived neighborhood mobility characteristics, perceived incivilities, travel attitudes, and physical activity amongst university faculty and staff*. *Journal of Transport & Health*, 2016. **3**(1): p. 86-95.

Chapter 3: The relative effect of bicyclist typology on health-related quality of life through physical activity status and bicycling for transportation status: a multiple mediator model

The relative effect of bicyclist typology on health-related quality of life through physical activity status and bicycling for transportation status: a multiple mediator model

Authors:

J. Michael Bryan, MPH, jbryan8@student.gsu.edu, School of Public Health, Georgia State University

Katherine Masyn, PhD, kmasyn@gsu.edu, School of Public Health, Georgia State University

Matthew Magee, PhD, mjmagee@gsu.edu, School of Public Health, Georgia State University

John Steward, MPH, jsteward@gsu.edu, School of Public Health, Georgia State University

Affiliations: School of Public Health, Georgia State University

Keywords: Bicycle, Typology, Health, Health-Related Quality of Life

Corresponding Author: J. Michael Bryan, jbryan8@student.gsu.edu

Article Type: Research Article

Word Count: 4,907

Abstract

Objectives We sought to investigate the relative direct effect of bicyclist typology on health and the relative indirect effect through physical activity and commute bicycling mediated the effect of bicyclist typology on health.

Methods Data from the 2014 Georgia State University-Bicycling Survey were used. Relative total and direct effects of bicyclist typology on health-related quality of life and indirect effects through physical activity and bicycling for transportation were estimated using a probit model. Differences in the relative indirect effects were then assessed. Finally, the marginal effects for a standard subject were calculated and expressed using odds ratios.

Results The effect of bicyclist typology on health was at least partially mediated through physical activity. The relative indirect effect through physical activity was different by motivation status and by comfort with commute bicycle given different levels of bicycling facilities. There was no difference in the relative indirect effect through physical activity when comparing respondents who were not motivated to commute bicycle, respondents who had never bicycled, and respondents requiring the most bicycle facilities to be comfortable commute bicycling. The effect of bicyclist typology on health was mediated to a lesser extent through the indirect effect of commute bicycling.

Conclusions These results help explain how bicyclist typology may affect health. Physical activity appears to serve as the primary means through which bicyclist typology has an effect on health. Interventions aiming to make physical activity and/or commute bicycling more comfortable for a larger proportion of the population may help reduce health disparities by bicyclist typology.

Introduction

Cardiovascular diseases are the leading cause of death among U.S. adults [1].

Commuting by bicycle (*commute bicycling*) may help mitigate the public health burden posed by cardiovascular diseases and related risk factors [2, 3]. As of 2015, only approximately 0.6% of the working population commute bicycled in the United States [4]. During the past decade, urban and regional planners have been utilizing Roger Geller's bicyclist typology to help guide efforts to increase commute bicycling [5]. The relationship between bicyclist typology and health outcomes remains unclear. The current study assessed whether physical activity or commute bicycling mediated the effect of bicyclist typology on broad indicators of health. Data from a survey of students and employees of a southern university located in an urban core setting were used for all analyses.

1.1 Bicycle commuting and health

There is a growing body of evidence indicating that commute bicycling positively influences health. A meta-analysis indicated that persons who do not participate in active transportation, inclusive of both bicycling and walking for transportation, have 12% greater risk of cardiovascular outcomes like coronary heart disease and stroke [2]. Commute bicycling specifically may positively influence risk factors for cardiovascular diseases, including total cholesterol, low-density lipoprotein, high-density lipoprotein, the ratio of total cholesterol to high-density lipoprotein, and diastolic blood pressure among adults [3] and Body Mass Index, triglycerides, cholesterol, and fasting glucose among adolescents [6, 7]. The decreased risk of mortality associated with commute bicycling is primarily attributed to the health benefits of

22 physical activity even after controlling for the negative health impact of air pollution exposure
23 [8, 9]. Other studies estimating the impact of commute bicycling initiatives on health have also
24 concluded that the health benefits related to increases in physical activity are much greater than
25 the health costs of commute bicycling due to the risk associated with increased exposure to
26 pollution and injury [10-12]. Hence, not only does it appear that commute bicycling is a healthy
27 behavior, but that the mechanism for its positive health impact is through the increased levels of
28 physical activity, while the mechanism for negative health impacts through increased exposure
29 to air pollution and injury is separate.

30 *1.2 Bicyclist typology*

31 As previously indicated, the prevalence of bicycle commuting amongst U.S. workers
32 remains well below that of several other industrialized nations industrialized [13]. One reason
33 for such low participation in commute bicycling in the U.S. may be that the majority of the
34 population is not comfortable with commuting by bicycle unless bicycle facilities are present [5,
35 14]. Roger Geller proposed a new bicyclist typology in 2006, which aimed to better understand
36 the market for commute bicycling [14]. Geller's bicyclist typology categorizes individuals based
37 on their motivation and comfort with commute bicycling in the presence of different levels of
38 bicycling facilities. Geller's typology helps urban planning efforts address the "concerns of the
39 majority" by better targeting persons who are willing to commute by bicycle, but require bicycle
40 facilities to feel comfortable doing so [14]. Such an environment, where the role of fear in
41 making the decision to commute bicycle is reduced, may increase the accessibility of bicycling
42 as a form of transportation [5]; urban planners may, consequently, impact motivation and

43 willingness to commute bicycle through urban design. Such planning efforts benefit from
44 previous research demonstrating the numerous environmental factors associated with commute
45 bicycling (e.g., the construction of dedicated, separated bicycle lanes) [15-17].

46 Since 2006, many U.S. cities have adopted versions of Geller's bicyclist typology as part
47 of their transportation plans [5]. This ongoing prioritization of urban environmental changes
48 based on applications of Geller's bicyclist typology in cities across the United States is of public
49 health importance due to the potential ramifications on the performance of healthy behaviors
50 such as physical activity and commute bicycling, or through exposure to air pollution and
51 injury. However, there is scarce research assessing the effect of bicyclist typology on health.
52 Only recently has a significant health disparity by bicyclist typology status been identified [18].
53 Researchers have also demonstrated that there are differences in participation in commute
54 bicycling by bicyclist typology [5, 19]. Beyond these studies little progress has been made in
55 investigating the effect of bicyclist typology on health or health behaviors.

56 *1.3 The present study*

57 We aim to examine why bicyclist typology may be related to health. Understanding this
58 mechanism could help improve urban planning and public health efforts targeting commute
59 bicycling. Physical activity and commute bicycling were selected as our mediators of interest
60 because previously described research indicated their importance in predicting health outcomes
61 related to bicycling initiatives. As noted elsewhere, due to the need to assess health outcomes
62 for this line of investigation, we chose the Centers for Disease Control and Prevention's Health-

63 Related Quality of Life-4 (HRQOL-4) as our health outcomes of interest [18]. The HRQOL-4 has
64 demonstrated validity and reliability in identifying population-level health disparities [20-26].

65 The current investigation is part of a broader effort to educate stakeholders developing a
66 bicycling plan for a southern urban university. In conjunction with regional partners, this
67 investigation modified Geller's original bicyclist typology. Such modification, encouraged by
68 Geller [14], is consistent with the many municipalities that have sought to create a typology that
69 meets their planning needs [5]. Specifically, we wanted to examine if bicyclist typology has an
70 indirect effect on health-related quality of life through the indirect effect of physical activity
71 and/or commute bicycling. If so, we wanted to assess whether the indirect effect was different
72 by bicyclist typology. We expected to find that the effect of bicyclist typology on health-related
73 quality of life was at least partially mediated by physical activity and commute bicycling.
74 Finally, we also expected to find significant differences in the indirect effects by bicyclist
75 typology.

76

2. Methods

2.1 Participants

78 Study participants were part of the 2014 Georgia State University-Bicycling Survey
79 (GSU-BS). Study procedures have been detailed elsewhere [18]. The study received Institutional
80 Review Board and Office of Institutional Effectiveness approval at Georgia State University.

2.2 Bicyclist Typology

82 The independent variable of interest, bicyclist typology, was treated as a categorical
83 variable. Only respondents who had ever bicycled self-reported their bicyclist typology based
84 on a modified version of Geller's original typology. These categories are consistent with the
85 previous study by Bryan *et al* [18]. *Table 1* describes the differences between the typologies.
86 Among respondents motivated to commute bicycle, the order from most to least willing to
87 commute bicycle given any level of bicycling facilities was: Strong and Fearless, Enthused and
88 Confident, Comfortable but Cautious, and Interested but Concerned. The Never Bicycled
89 typology included all respondents reporting never having ridden a bicycle. Bicyclist typology
90 was dummy coded such that one typology would serve as the reference group in each analysis.

2.3 Health-Related Quality of Life

92 There were four outcomes of interest: (1) general health status, (2) physically unhealthy
93 days, (3) mentally unhealthy days, and (4) activity limited days. These items were derived from
94 previously validated measures with proven reliability from the Centers for Disease Control and
95 Prevention's Health-Related Quality of Life-4 settings [27-34]. General health status, a 5-point
96 Likert item, was coded from a self-reported "excellent" to "poor" health status, such that higher

97 values indicate worse health status. The three “Unhealthy Days” items measured the self-
98 reported number of days where (1) physical health was not good, (2) mental health was not
99 good, and (3) activity was limited during the past month. As in Bryan *et al* (2017), the most
100 parsimonious means of consistently categorizing the three measures was assessed through
101 sensitivity analyses [18]. The Unhealthy Days items were treated as ordinal such that higher
102 values indicate more unhealthy days: (1) zero unhealthy days, (2) 1 to 3 unhealthy days, (3) 4 to
103 7 unhealthy days, (4) 8 to 14 unhealthy days, and (5) 15 or more unhealthy days. The category
104 with zero unhealthy days served as the reference group.

105 *2.4 Physical Activity Status*

106 Physical activity status was an ordinal variable discretized such that: (1) have not
107 performed physical activity or exercise in which the heart rate and breathing was above normal
108 for more than ten minutes (hereafter referred to as “physical activity”), (2) performed physical
109 activity in the past month but not during the past week, (3) performed one or two days of
110 physical activity during the past week, and (4) performed three or more days of physical
111 activity during the past week.

112 *2.5 Commute Bicycling Status*

113 Commute bicycling status was an ordinal variable discretized such that: (1) have not
114 bicycled for transportation to campus during the past semester, (2) have bicycled for
115 transportation to campus during the past semester, but not during the past week, and (3)
116 bicycled for transportation to campus during the past week.

117 2.6 Covariates

118 Covariates controlled for in this analysis include gender, race-ethnicity, age, and
119 student-employee status. Each covariate was entered into the model as in Bryan *et al* [18].

120 2.7 Analysis

121 Descriptive statistics were performed in SAS Version 9.4. Differences in the distribution
122 of Health-Related Quality of Life by physical activity and commute bicycling status were
123 assessed using the Kruskal-Wallis Chi-Square test in SAS Version 9.4. All other analyses were
124 performed using MPlus Version 7.4. Because the goal of the study was to better understand the
125 mechanism through which bicyclist typology may impact health-related quality of life, we
126 employed a mediation model whereby both physical activity status and commute bicycling
127 status were treated as mediators (Figure 1). Through this multi-categorical, multiple mediator,
128 multiple outcome mediation model we estimated the total, direct, and indirect effects relative to
129 a bicyclist typology [35]. All effects were estimated simultaneously to prevent spurious
130 significance. The model controlled for covariation between the mediators and, separately, for
131 the health-related quality of life dependent variables. The effect of gender, race/ethnicity, age,
132 and student-employee status was controlled for in each direct effect modeled. The robust
133 weighted least squares (WLSMV) estimator was used to account for the ordinal mediators. Bias-
134 corrected bootstrapping was used to estimate the significance of indirect effects. Significance in
135 the differences in each relative indirect effect was estimated. Because estimating the effect of
136 bicyclist typology on each health-related quality of life indicator required estimating five effects
137 simultaneously, a two-tailed p-value of less than 0.01 was considered significant. The

138 moderating effect of student-employee status was assessed in anticipation of the potential
139 differences between the two groups – students may be more likely to live closer to campus and
140 in dormitories, whereas employees may have access to greater resources.

141 Marginal effects were calculated for a standard subject. The standard subject reflected
142 the mean age and the category of each other covariate with the greatest number of respondents.
143 The odds of worse health-related quality of life relative to a given bicyclist typology for the
144 standard subject was estimated for three different conditions for each bicyclist typology. The
145 first condition, $\Phi(1,1)$, estimated the odds of worse health for the bicyclist typology of interest
146 who performed physical activity three or more times during the past week. The second
147 condition, $\Phi(1,0)$, estimated the odds of worse health for the bicyclist typology of interest who
148 did not perform physical activity three or more times during the past week. The third condition,
149 $\Phi(0,0)$, estimated the odds of worse health for the referent bicyclist typology who did not
150 perform physical activity three or more times during the past 30 days. For the general health
151 status dependent variable, we estimated the odds of good, fair, or poor versus very good or
152 excellent health status. For the Unhealthy Days items, we estimated the odds of more than three
153 unhealthy days versus three or fewer unhealthy days. We then calculated odds ratios to
154 demonstrate the direct and indirect effect of bicyclist typology on worse health-related quality
155 of life relative to the Strong and Fearless for the standard subject. More information on
156 estimating the indirect effect and direct effect odds ratios may be found in *Technical Appendix 1*.

157

158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178

3. Results

3.1 Demographics

There were 4,375 respondents in the final sample for analysis in this study. A univariate characterization of the demographics of this sample and a comparison of the distribution of the demographics by bicyclist typology have been provided elsewhere [18]. Descriptive statistics of the sample by physical activity status and commute cycling status are shown in *Table 2*. Nearly half the sample had performed physical activity three or more times during the past week (46%), while the majority of the sample (88%) had not commute bicycled during the past semester. The mean age and the distribution of gender and race/ethnicity was significantly different by physical activity and commute bicycling status. The distribution of employee status was different by physical activity status, but not by commute bicycling status.

3.2 Bicyclist Typology

Bryan *et al* previously demonstrated that bicyclist typology was associated with health-related quality of life and that the effect of bicyclist typology on health-related quality of life did not violate the proportional odds assumption [18]. As shown in *Table 3*, the distribution of physical activity status and commute bicycling status was different by bicyclist typology. While about 8% of Strong and Fearless respondents reported performing no physical activity during the past month, nearly one-third of No way, No how – those not motivated to commute bicycle - and Never Bicycled respondents had not performed physical activity during the past month. The percentage of Strong and Fearless respondents who reporting commute bicycling during the past semester was greater than that of the other typologies motivated to bicycle, but either

179 prefer or require bicycling facilities before doing so – the Enthused and Confident (28%),
180 Comfortable but Cautious (6%), and Interested but Concerned (0.2%).

181 *3.3 Mediation Model*

182 3.3.1 Total, Direct, and Indirect Effects

183 The total, direct, and indirect effect of each bicyclist typology on all health-related
184 quality of life items relative to the Strong and Fearless typology are presented in *Table 4*. Each
185 bicyclist typology had greater probability of poorer general health status than the Strong and
186 Fearless after controlling for the effect of all covariates. Respondents requiring bicycling
187 facilities to be comfortable commute bicycling had an increased probability of poorer general
188 health status through the indirect effect of physical activity, but not through the indirect effect
189 of commute bicycling. Similarly, except for the Enthused and Confident, each bicyclist typology
190 had a greater chance of more unhealthy days relative to the Strong and Fearless.

191 The relative indirect effect through physical activity explained the entirety of several
192 total effects of bicyclist typology on health-related quality of life. Comfortable but Cautious and
193 Interested but Concerned respondents - those requiring the most bicycle facilities to be
194 comfortable commute bicycling - had a greater probability of unhealthy days through physical
195 activity. Conversely, both the Comfortable and Cautious and Interested but Concerned had a
196 lower probability of activity limited days through commute bicycling, while only the
197 Comfortable but Cautious had a lower probability of mentally unhealthy days through
198 commute bicycling. All other indirect effects through commute bicycling relative to the Strong
199 and Fearless were insignificant.

200 As indicated in *Supplemental Table 1* and *Supplemental Table 2*, the increased chance of
201 unhealthy days through physical activity is due to the combined effect of a decreased
202 probability of physical activity among persons not comfortable with bicycling in the absence of
203 bicycling facilities and a decreased probability of worse health-related quality of life among
204 persons who perform more physical activity. Similarly, the decreased chance of unhealthy days
205 through commute bicycling was due to the combined effect of the decreased probability of
206 commute bicycling among persons not comfortable bicycling in the absence of bicycling
207 facilities and the increased probability of mentally unhealthy days and activity limited days
208 among persons who commute bicycle more.

209 3.3.2 Difference in Relative Indirect Effects

210 Differences in the relative indirect effects through physical activity and commute
211 bicycling status are shown in *Table 5*. The relative indirect effect on health-related quality of life
212 through physical activity for respondents who had never bicycled was not different from
213 respondents who were either not motivated (e.g., No way, No how) or not comfortable
214 commute bicycling without bicycle-specific facilities (e.g., Interested but Concerned).
215 Respondents who were not motivated to commute bicycle tended to have a higher probability
216 of worse health-related quality of life through physical activity than their motivated
217 counterparts. Similarly, among motivated respondents, as willingness to commute bicycle in the
218 absence of bicycling facilities decreased, the probability of worse health-related quality of life
219 through physical activity tended to increase. Further, among motivated respondents, those
220 requiring more bicycle facilities to commute bicycle tended to have a lower probability of

221 mentally unhealthy days and activity limited days through the indirect effect of commute
222 bicycling.

223 *Student-Employee Status as Moderator* There was no indication that the effects were different for
224 students and employees ($X^2=12.0$ (16, $p=0.74$)).

225 3.3.3 Odds of Worse Health-Related Quality of Life for a Standard Subject

226 Because the model was estimated using probits, we chose a standard subject to express
227 the direct and indirect effect of bicyclist typology on worse health-related quality of life through
228 odds ratios. The standard subject was a female, white, Non-Hispanic, student, 30 years of age,
229 who had not commute bicycled during the past 30 days. *Table 6* provides the odds ratios when
230 comparing the three conditions previously described. For example, a standard subject who
231 identified as Comfortable but Cautious had 2.07 times the odds of reporting a worse general
232 health status through the direct effect as compared to the Strong and Fearless. Through the
233 indirect effect of physical activity, a standard subject who identified as Comfortable but
234 Cautious had 1.23 times the odds of worse general health status relative to the Strong and
235 Fearless typology. No way, No how standard subjects had nearly twice the odds of more
236 activity limited days through the direct effect as compared to the Strong and Fearless. Similarly,
237 relative to the Strong and Fearless, a standard subject reporting a typology of No way, No how
238 had 1.21 times the odds of reporting more activity limited days through the indirect effect of
239 physical activity.

240 3.3.4 Supplemental Results Using the Other Typologies as a Reference Group

241 Though the results above were with the Strong and Fearless as the reference group, each
242 of the other typologies could have been considered as the reference group. These results may be

243 found in Supplemental Tables 3, 4a, 4b, 4c, 4d, and 5. These results concur with the previous
244 results and can further elucidate the interpretation of the relative effects.

245 As shown in *Supplemental Table 3*, among respondents motivated to commute bicycle, as
246 more bicycling facilities are required to feel comfortable commute bicycling, there was an
247 increased probability of worse health-related quality of life through the relative indirect effect of
248 physical activity. Controlling for the relative indirect effect of physical activity and commute
249 bicycling, the relative direct effects of Interested but Concerned, No Way, No How, and Never
250 Bicycled on health-related quality of life were not different, nor was there a difference in the
251 relative indirect effects through commute bicycling. Among these three typologies, No Way, No
252 How respondents having a greater chance of activity limited days and worse general health
253 status than Interested but Concerned respondents through the relative indirect effect of physical
254 activity were the only significant indirect effects.

255 Regarding differences in the estimated relative indirect effects shown in *Supplemental*
256 *Tables 4a-4d*, respondents who had never bicycled had few significant differences from the least
257 motivated respondents (Interested but Concerned and No Way, No How) respondents.
258 Regardless of the reference group, respondents not motivated to commute bicycle tended to
259 have a greater chance of worse general health status and activity limited days through the
260 relative indirect effect of physical activity than Interested but Concerned respondents.
261 Motivated respondents who required the most bicycling facilities to be comfortable commute
262 bicycling (e.g., Interested but Concerned) and respondents who had never bicycled tended to
263 have a lower probability of more mentally unhealthy days and activity limited days through the

264 relative indirect effect of commute bicycling than motivated respondents requiring less
265 bicycling facilities.

266 As shown in *Supplemental Table 5*, there is little difference in the odds of worse health
267 through the indirect effect of physical activity among the least motivated respondents (e.g.,
268 Interested but Concerned and No Way, No How) and respondents who had never bicycled.
269 Respondents not motivated to commute bicycle had about 0.8 times the odds of more mentally
270 unhealthy and activity limited days through the direct effect as compared to respondents
271 motivated to commute bicycle, but who require the most bicycling facilities before doing so.
272 Conversely, standard subjects who had never bicycled had 25% and 36% greater odds of more
273 mentally unhealthy and activity limited days, respectively, through the direct effect as
274 compared to standard subjects not motivated to commute bicycle. Among motivated
275 respondents, as standard subjects required more bicycling facilities to feel comfortable commute
276 bicycling, the odds of worse health increased, particularly through the direct effect.

277

278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298

4. Discussion

This study assessed the effect of self-reported bicyclist typology on health-related quality of life through physical activity and commute bicycling among a convenience sample of students and employees at a southern urban university. This relationship was previously uninvestigated. Building on a previous study indicating the existence of health disparities by bicyclist typology, the present study found that the effect of bicyclist typology on health-related quality of life is at least partially mediated through physical activity and, to a lesser extent, commute bicycling [18]. Multiple relative indirect effects through physical activity explained the entire effect of certain bicyclist typologies on physically and mentally unhealthy days. Further, this study provides initial evidence that respondents who (1) had never bicycled, (2) were not motivated to commute bicycle, or (3) were less willing to commute bicycle in the absence of bicycling facilities had an increased probability of worse health outcomes through physical activity as compared to their counterparts.

Previous research has indicated that health-related quality of life is associated with bicycling status, motivation to commute bicycle, and willingness to commute bicycle in the absence of bicycling facilities [18]. The current study builds on this finding by investigating the mechanism for the health disparity. Our results indicate that the effect of bicyclist typology on health-related quality of life through physical activity was not different for respondents who had never bicycled, who were not motivated to commute bicycle, and who were motivated to commute bicycle, but require bicycle-specific facilities to do so. Similarly, respondents who were not motivated to commute bicycle had a greater chance of worse health through the

299 indirect effect of physical activity than respondents motivated to commute bicycle. Among
300 respondents motivated to commute bicycle, the relative indirect effect through physical activity
301 tended to increase as comfort with commute bicycling in the absence of bicycle facilities
302 decreased. These findings suggest that persons who have never bicycled and persons who are
303 not motivated to commute bicycle may not experience the same health benefits associated with
304 higher levels of physical activity as motivated persons who require less bicycle facilities to be
305 comfortable commute bicycling.

306 Interventions targeting the reduction of health disparities by bicyclist typology may
307 consider increasing physical activity among persons identifying as one of the three typologies
308 with similar effects on health-related quality of life (e.g., Interested but Concerned, No Way, No
309 How, and Never Bicycled). One such intervention may be transitioning these persons from
310 passive to active transportation. Falconer *et al* found that doing so can increase physical activity
311 levels [6]. Similarly, comprehensive work-based active transportation interventions that include
312 counseling and the provision of a bicycle can also increase physical activity levels [36, 37].

313 Previous research indicates that an environment more comfortable for bicyclists
314 increases the likelihood of commute bicycling. Multiple environmental factors have been
315 identified as being positively associated with commute bicycling, including dedicated cycle
316 routes, high population density, separation from vehicular traffic, short trip distance, short
317 distance to cycle path, walkability, walking or bicycling facilities, traffic- and crime-related
318 safety [15, 17, 38]. Conversely, several environmental characteristics have been identified that
319 negatively influence commute bicycling, such as long trip distance, steep inclines along route,

320 or distance from a dedicated cycle path [15]. Bicyclists and non-bicyclists alike generally prefer
321 and feel safer in bike lanes even minimally separated from vehicular traffic (i.e. a white stripe)
322 than directly in vehicular traffic [39-41] Bicyclists and non-cyclists also favor dedicated cycle
323 paths, separated from vehicular traffic, especially amongst women and inexperienced bicyclists
324 [42-46]. Results from the current study parallel these findings by investigating an individual's
325 comfort with commute bicycling in different levels of bicycle facilities. We found that as
326 respondents reported being more comfortable commute bicycling in any bicycling environment
327 that their physical activity and commute bicycling increased, which partially explained the
328 existing health disparity by bicyclist typology. Such results indicate that making a larger
329 proportion of the population comfortable commute bicycling may decrease the health disparity
330 by bicyclist typology.

331 The health disparities associated with Geller's bicyclist typology may be due to reasons
332 other than the two mediators examined. Most of the relative direct effects were significant after
333 accounting for mediating pathways through both physical activity and commute bicycling.
334 Such results appear to be consistent with Morckel's finding that transportation choice is
335 influenced by environmental characteristics and attitudes [47]. Self-classification with Geller's
336 bicyclist typology may reflect an individual's overall disposition towards their environment.
337 Hence, when assessing motivation and willingness to commute bicycle in the absence of
338 bicycling facilities, we may be capturing an individual's proclivity toward performing active
339 transportation and/or other forms of physical activity due to their overall comfort in their
340 environment.

341 The import of Geller’s typology for public health practitioners may then be in aiming
342 urban planning efforts toward increasing the comfort level of persons in their environment
343 beyond environmental characteristics specific to commute bicycling. Not only would “bravery”
344 be reduced as a prerequisite for commute bicycling in particular, but also for active
345 transportation and other physical activities more generally. Interventions might be more
346 successful in improving health, and thereby reducing health disparities, if the aforementioned
347 bicycling environment barriers were mitigated in addition to the barriers influencing an
348 individual’s perception of comfort in their environment. Future research may want to
349 investigate the potential effect of such “environmental comfort” on physical activity, active
350 transportation, and health outcomes.

351 These results have several limitations. Given that these data are cross-sectional, the
352 pathways assessed cannot confidently claim causality. The theoretical pathway modeled,
353 however, follows an intuitive time delineation whereby an individual’s motivation and comfort
354 with their environment precedes the behaviors of physical activity and/or bicycling for
355 transportation, while the behaviors precede the health outcomes of interest. Overlapping time
356 scales could be accounted for in a longitudinal study. There are potential autoregressive
357 relationships between the effects estimated. Our cross-sectional data was not the correct dataset
358 to assess this relationship, nor was doing so necessary to test the mechanism through which
359 bicyclist typology affects health. Future studies with multiple time points may be better suited
360 for an autoregressive analysis. The mediators of interest, physical activity and commute
361 bicycling, were self-reported and may be subject to recall bias. Assessing precise measures of

362 each mediator (i.e. kilocalories burned through physical activity) was beyond the scope of this
363 study. Rather, this study was interested in the presence of healthy behaviors within a given time
364 frame. Using a single self-reported item to assess bicyclist typology has not been previously
365 validated or shown to be reliable. This single item demonstrated construct validity when
366 estimating each relationship. That is, the effect of bicyclist typology on physical activity,
367 commute bicycling, and health-related quality of life were all in the direction one would expect.
368 Further, Geller encouraged the modification of the typology to support bicycle planning efforts,
369 which we have done in collaboration with regional planning partners. Misclassification into
370 perceived health-related quality of life results may be different by bicyclist typology. Future
371 research could use objective measures of health to correct for potential differential
372 misclassification. As previously demonstrated, our results are not generalizable to the broader
373 university population [18]. The aim of this study was to estimate effect sizes and to determine if
374 the effects were significant, not to be representative of all students and employees. Future
375 bicycle planning efforts by municipalities and/or research institutions may want to replicate
376 similar analyses with a representative sample of their respective population. Our research could
377 assist with justifying such a resource intensive behavior.

378

379
380
381
382
383
384
385
386
387
388

389
390
391
392
393
394
395
396
397

398
399

5. Conclusion

This study builds on previous research which indicated the presence of health disparities among various bicyclist typologies. Our findings suggest that the effect of bicyclist typology on health-related quality of life is at least partially mediated through physical activity. Bicyclist typology also has a significant indirect effect on mentally unhealthy days and activity limited days through commute bicycling after accounting for the effect through physical activity. Interventions designed to reduce the existing health disparities might be improved by further investigation that explores the residual relative direct effect of bicyclist typology on health-related quality of life, the differences in physical activity by bicyclist typology, as well as the differences in mental health and activity limitation by commute bicycling status.

To our knowledge, this study is the first to provide evidence that there are differences in the relative indirect effect of bicyclist typology on health through physical activity by motivation to commute bicycle, willingness to commute bicycle in the absence of bicycling facilities, and by bicycling status. These results suggest that there are opportunities to decrease existing health disparities by improving physical activity among those bicycling typologies with poorer health outcomes. Public health practitioners may consider working alongside urban planners to promote urban development that makes physical activity - whether recreational, leisure, or for transport - more comfortable among a larger proportion of residents; particularly those who may be risk averse.

400

6. Tables and Figures401 *Table 1. Distinction of Bicyclist Typology Definitions.*

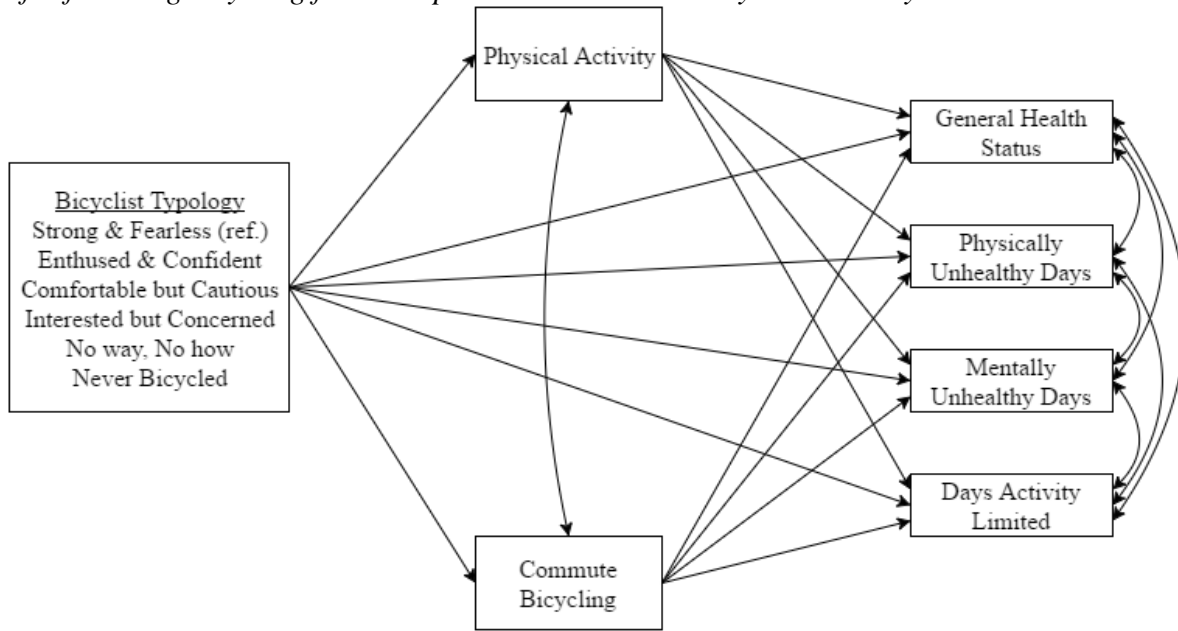
Bicyclist Typology	Motivated to Commute Bicycle	Require Commute Bicycling Facilities ^a (4=Most, 1=Least)	Ever Bicycled
Strong and Fearless	Yes	1	Yes
Enthusied and Confident	Yes	2	Yes
Comfortable but Cautious	Yes	3	Yes
Interested but Concerned	Yes	4	Yes
No way, No how	No	N/A	Yes
Never Bicycled	N/A	N/A	No

402 ^aBefore being comfortable commute bicycling

403

404

405 *Figure 1. Pathway Diagram to Estimate Effect of Bicyclist Typology on Health-Related Quality*
406 *of Life through Cycling for Transportation Status and Physical Activity Status*



407

408

1 *Table 2. Physical Activity and Commute Bicycling Status by Demographic in the GSU-BS sample.*

	Physical Activity Status					P-value ^a	Commute Bicycling Status			P-value ^a
	Total sample	Not in Past Month	In Past Month, but Not Past Week	1 or 2 Days in Past Week	3 or More Days in Past Week		Not in Past Semester	In Past Semester but Not Past Week	In Past Week	
N (%)	4,375	890 (20.5)	418 (9.6)	1037 (23.9)	1995 (46.0)		3836 (87.8)	132 (3.0)	403 (9.2)	
Mean Age (SD)	30.3 (12.4)	27.7 (11.0)	29.4 (13.1)	30.0 (11.7)	31.9 (13.0)	<0.01	30.5 (12.7)	30.0 (10.6)	28.1 (9.6)	<0.01
Gender										
Male	34.0	14.6	8.1	22.2	55.2	<0.01	92.5	2.2	5.3	<0.01
Female	66.0	23.6	10.4	24.8	41.2		78.6	4.6	16.9	
Race/Ethnicity										
White, Non-Hispanic	48.4	14.9	7.8	24.3	53.0	<0.01	83.1	4.0	12.9	<0.01
Black, Non-Hispanic	28.1	26.8	12.4	23.4	37.4		95.0	1.3	3.7	
Hispanic	8.5	22.1	8.5	23.5	45.9		83.0	4.6	12.4	
Other, Non-Hispanic	15.0	25.7	11.0	23.7	39.5		91.8	2.1	6.1	
Employee Status										
Student	69.9	23.8	10.1	24.3	41.8	<0.01	87.2	2.9	9.9	0.08
Employee	30.1	12.8	8.5	23.0	55.7		89.0	3.3	7.8	

2 *Note:* For each demographic we present the percentage unless otherwise stated.

3 ^aFrom chi-squared test for differences for categorical variables and Analysis of Variance for the continuous variable.

4

5

6 *Table 3. Distribution of Physical Activity and Commute Bicycling Status by Bicyclist Typology in GSU-BS sample.*

	Strong & Fearless (%)	Enthused & Confident (%)	Comfortable but Cautious (%)	Interested but Concerned (%)	No way, No how (%)	Never Bicycled (%)	P-value^a
Physical Activity Status							
Not in Past Month	8.2	12.3	17.5	24.9	33.5	33.0	<0.01
In Past Month, but Not Past Week	10.1	7.8	9.6	11.5	9.0	10.0	
1 or 2 Days in Past Week	15.6	23.5	24.8	26.8	22.8	20.0	
3 or More Days in Past Week	66.2	56.4	48.2	36.8	34.7	37.0	
Commute Bicycling Status							
Not in Past Semester	50.6	64.4	91.1	99.4	99.8	100.0	<0.01
In Past Semester but Not Past Week	7.8	7.8	3.1	0.4	0.0	0.0	
In Past Week	41.6	27.8	5.8	0.2	0.2	0.0	

7 ^aFrom Kruskal-Wallis chi-squared test.8
9

Table 4. Relative Effect of Bicyclist Typology on Health-Related Quality of Life Relative to Strong and Fearless Typology*, Georgia State University-Bicycling Survey, 2014

Dependent Variable	Bicyclist Typology (Strong and Fearless ref.)	Total Effect Φ (<i>p</i> -value)	Direct Effect Φ (<i>p</i> -value)	Indirect Effect	
				Physical Activity Φ (<i>p</i> -value)	Commute Bicycling Φ (<i>p</i> -value)
General Health Status	Enthused and Confident	0.35 (<0.01)	0.29 (<0.01)	0.07 (0.01 ^a)	-0.01 (0.44)
	Comfortable but Cautious	0.54 (<0.01)	0.45 (<0.01)	0.12 (<0.01)	-0.04 (0.42)
	Interested but Concerned	0.72 (<0.01)	0.60 (<0.01)	0.19 (<0.01)	-0.07 (0.43)
	No way, No how	0.70 (<0.01)	0.54 (<0.01)	0.25 (<0.01)	-0.09 (0.53)
	Never Bicycled	0.74 (<0.01)	0.53 (<0.01)	0.21 (<0.01)	<0.01 (0.88)
Physically Unhealthy Days	Enthused and Confident	0.17 (0.06)	0.15 (0.09)	0.02 (0.03)	<-0.01 (0.50)
	Comfortable but Cautious	0.24 (<0.01)	0.23 (0.02)	0.04 (<0.01)	-0.03 (0.48)
	Interested but Concerned	0.32 (<0.01)	0.32 (0.01)	0.06 (<0.01)	-0.06 (0.50)
	No way, No how	0.28 (<0.01)	0.27 (0.09)	0.08 (<0.01)	-0.07 (0.59)
	Never Bicycled	0.38 (<0.01)	0.31 (<0.01)	0.07 (<0.01)	<0.01 (0.89)
Mentally Unhealthy Days	Enthused and Confident	0.10 (0.25)	0.10 (0.23)	0.03 (0.02)	-0.03 (0.03)
	Comfortable but Cautious	0.15 (0.05)	0.23 (0.01)	0.05 (<0.01)	-0.12 (<0.01)
	Interested but Concerned	0.33 (<0.01)	0.49 (<0.01)	0.07 (<0.01)	-0.24 (0.01)
	No way, No how	0.22 (0.01)	0.40 (0.03)	0.10 (<0.01)	-0.28 (0.09)
	Never Bicycled	0.31 (<0.01)	0.23 (0.03)	0.08 (<0.01)	<-0.01 (0.76)
Activity Limited Days	Enthused and Confident	0.09 (0.30)	0.10 (0.26)	0.04 (0.02)	-0.04 (0.01)
	Comfortable but Cautious	0.18 (0.03)	0.28 (<0.01)	0.06 (<0.01)	-0.16 (<0.01)
	Interested but Concerned	0.31 (<0.01)	0.54 (<0.01)	0.09 (<0.01)	-0.32 (<0.01)
	No way, No how	0.14 (0.14)	0.39 (0.05)	0.12 (<0.01)	-0.37 (0.04)
	Never Bicycled	0.30 (<0.01)	0.20 (0.06)	0.10 (<0.01)	<-0.01 (0.74)

*Adjusting for the effect of gender, race/ethnicity, age, and student-employee status

^aSignificant effect

1 *Table 5. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Strong and Fearless*
 2 *Typology as Reference Group, Georgia State University-Bicycling Survey, 2014*
 3

Dependent Variable	Mediator	Bicyclist Typology	Enthused and Confident	Comfortable but Cautious	Interested but Concerned	No way, No how	Never Bicycled
			$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)
General Health Status ^a	Physical Activity	Enthused and Confident	X	-0.05 (<0.01)	-0.12 (<0.01)	-0.18 (<0.01)	-0.14 (<0.01)
		Comfortable but Cautious		X	-0.07 (<0.01)	-0.12 (<0.01)	-0.09 (<0.01)
		Interested but Concerned			X	-0.06 (<0.01)	-0.02 (0.45)
		No way, No how				X	0.04 (0.21)
		Never Bicycled					X
Physically Unhealthy Days ^a	Physical Activity	Enthused and Confident	X	-0.02 (0.01)	-0.04 (<0.01)	-0.06 (<0.01)	-0.04 (<0.01)
		Comfortable but Cautious		X	-0.02 (<0.01)	-0.04 (<0.01)	-0.03 (<0.01)
		Interested but Concerned			X	-0.02 (0.02)	-0.01 (0.46)
		No way, No how				X	0.01 (0.24)
		Never Bicycled					X
Mentally Unhealthy Days	Physical Activity	Enthused and Confident	X	-0.02 (<0.01)	-0.05 (<0.01)	-0.07 (<0.01)	-0.06 (<0.01)
		Comfortable but Cautious		X	-0.03 (<0.01)	-0.05 (<0.01)	-0.03 (<0.01)
		Interested but Concerned			X	-0.02 (0.01)	-0.01 (0.46)
		No way, No how				X	0.01 (0.23)
		Never Bicycled					X
	Commute Cycling	Enthused and Confident	X	0.09 (<0.01)	0.20 (0.01)	0.24 (0.12)	-0.03 (0.03)
		Comfortable but Cautious		X	0.11 (0.03)	0.16 (0.25)	-0.12 (<0.01)
		Interested but Concerned			X	0.04 (0.73)	-0.23 (0.01)
		No way, No how				X	-0.28 (0.09)
		Never Bicycled					X
Activity Limited Days	Physical Activity	Enthused and Confident	X	-0.03 (<0.01)	-0.06 (<0.01)	-0.09 (<0.01)	-0.07 (<0.01)
		Comfortable but Cautious		X	-0.03 (<0.01)	-0.06 (<0.01)	-0.04 (<0.01)
		Interested but Concerned			X	-0.03 (<0.01)	-0.01 (0.45)
		No way, No how				X	0.02 (0.22)
		Never Bicycled					X
	Commute Cycling	Enthused and Confident	X	0.12 (<0.01)	0.27 (<0.01)	0.33 (0.06)	-0.04 (0.01)
		Comfortable but Cautious		X	0.15 (0.01)	0.21 (0.20)	-0.16 (<0.01)
		Interested but Concerned			X	0.06 (0.71)	-0.31 (<0.01)
		No way, No how				X	-0.37 (0.04)
		Never Bicycled					X

4 *Adjusting for the effect of gender, race/ethnicity, age, and student-employee status

5 ^aIndirect effects through commute cycling were not significantly different for this dependent variable and are not shown in this table.

6 *Table 6. Comparing the Odds of Worse Health-Related Quality of Life for each Condition^a for Standard Subjects^b, Georgia State*
 7 *University-Bicycling Survey, 2014*

Bicyclist Typology	General Health Status ^c		Physically Unhealthy Days ^d		Mentally Unhealthy Days ^d		Activity Limited Days ^d	
	<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>
Enthusied and Confident	1.12	1.59	1.04	1.27	1.05	1.23	1.06	1.18
Comfortable but Cautious	1.23	2.07	1.06	1.44	1.10	1.57	1.10	1.58
Interested but Concerned	1.40	2.64	1.10	1.67	1.15	2.65	1.16	2.41
No way, No how	1.53	2.38	1.13	1.54	1.20	2.27	1.21	1.91
Never Bicycled	1.45	2.36	1.11	1.66	1.16	1.56	1.18	1.38

8 ^a $\Phi(1,1)$ estimated the odds for standard subjects who exercised 3 or more times a week and identified as the bicyclist typology of
 9 interest relative to the Strong and Fearless. $\Phi(1,0)$ estimated the odds for standard subjects who did not exercise 3 or more times a
 10 week and were the bicyclist typology of interest relative to the Strong and Fearless. $\Phi(0,0)$ estimated the odds for standard subjects
 11 who did not exercise 3 or more times a week and were Strong and Fearless

12 ^bFemale, white, Non-Hispanic, 30 years old, student, not commute cycle during past semester

13 ^cProbability of good, fair, or poor general health status versus very good or excellent

14 ^dProbability of more than three unhealthy days

15 ^e*OR_{indirect}* was calculated by dividing the odds from $\Phi(1,1)$ by the odds from $\Phi(1,0)$

16 ^f*OR_{direct}* was calculated by dividing the odds from $\Phi(1,0)$ by the odds from $\Phi(0,0)$

1 *Supplemental Table 1. Effect of Bicyclist Typology on the Mediating Variables Physical Activity*
 2 *and Cycling for Transportation Status**

Mediating Variable	Bicyclist Typology	Φ (<i>p</i> -value)
Physical Activity Status	Enthused and Confident	-0.2 (<0.01)
	Comfortable but Cautious	-0.4 (<0.01)
	Interested but Concerned	-0.6 (<0.01)
	No way, No how	-0.8 (<0.01)
	Never Bicycled	-0.7 (<0.01)
Commute Bicycling Status	Enthused and Confident	-0.3 (<0.01)
	Comfortable but Cautious	-1.3 (<0.01)
	Interested but Concerned	-2.4 (<0.01)
	No way, No how	-2.9 (<0.01)
	Never Bicycled	**

3 *Adjusting for the effect of sex, race/ethnicity, age, and student-employee status

4 **No variation in response for Never Bicycled typology exists in their endorsement to cycling for transportation status items.

5

6 *Supplemental Table 2. Effect of the Mediating Variables Physical Activity and Commute*
 7 *Bicycling Status on Health-Related Quality of Life**

Mediating Variable	Health-Related Quality of Life	Φ (<i>p</i> -value)
Physical Activity Status	General Health Status	-0.30 (<0.01)
	Physically Unhealthy Days	-0.09 (<0.01)
	Mentally Unhealthy Days	-0.12 (<0.01)
	Activity Limited Days	-0.15 (<0.01)
Commute Bicycling Status	General Health Status	-0.03 (0.41)
	Physically Unhealthy Days	0.03 (0.48)
	Mentally Unhealthy Days	0.10 (<0.01)
	Activity Limited Days	0.13 (<0.01)

8 *Adjusting for the effect of sex, race/ethnicity, age, and student-employee status

9

1 *Supplemental Table 3. Effect of Bicyclist Typology on Health-Related Quality of Life Relative to Each Remaining Bicyclist Typology*, Georgia State*
 2 *University-Bicycling Survey, 2014*

Reference Bicyclist Typology	Dependent Variable	Bicyclist Typology	Total Effect Φ (<i>p-value</i>)	Direct Effect Φ (<i>p-value</i>)	Indirect Effect	
					Physical Activity Φ (<i>p-value</i>)	Commute Bicycling Φ (<i>p-value</i>)
ENTHUSED AND CONFIDENT	General Health Status	Comfortable but Cautious	0.18 (<0.01)	0.16 (<0.01)	0.05 (<0.01)	-0.03 (0.40)
		Interested but Concerned	0.36 (<0.01)	0.31 (<0.01)	0.12 (<0.01)	-0.06 (0.43)
		No way, No how	0.35 (<0.01)	0.25 (0.06)	0.18 (<0.01)	-0.08 (0.54)
		Never Bicycled	0.39 (<0.01)	0.38 (0.04)	0.14 (<0.01)	-0.14 (0.41)
	Physically Unhealthy Days	Comfortable but Cautious	0.07 (0.16)	0.08 (0.21)	0.02 (0.01)	-0.02 (0.48)
		Interested but Concerned	0.15 (<0.01)	0.17 (0.08)	0.04 (<0.01)	-0.05 (0.50)
		No way, No how	0.11 (0.09)	0.12 (0.37)	0.06 (<0.01)	-0.06 (0.60)
		Never Bicycled	0.21 (0.01)	0.28 (0.12)	0.04 (<0.01)	-0.11 (0.48)
	Mentally Unhealthy Days	Comfortable but Cautious	0.06 (0.26)	0.12 (0.03)	0.02 (<0.01)	-0.09 (<0.01)
		Interested but Concerned	0.23 (<0.01)	0.39 (<0.01)	0.05 (<0.01)	-0.20 (0.01)
		No way, No how	0.12 (0.05)	0.30 (0.07)	0.07 (<0.01)	-0.24 (0.12)
		Never Bicycled	0.21 (0.01)	0.60 (<0.01)	0.06 (<0.01)	-0.44 (<0.01)
	Activity Limited Days	Comfortable but Cautious	0.09 (0.08)	0.18 (<0.01)	0.03 (<0.01)	-0.12 (<0.01)
		Interested but Concerned	0.22 (<0.01)	0.44 (<0.01)	0.06 (<0.01)	-0.27 (<0.01)
		No way, No how	0.05 (0.47)	0.29 (0.12)	0.09 (<0.01)	-0.33 (0.07)
		Never Bicycled	0.21 (0.01)	0.73 (<0.01)	0.07 (<0.01)	-0.59 (<0.01)
COMFORTABLE BUT CAUTIOUS	General Health Status	Interested but Concerned	0.18 (<0.01)	0.15 (0.02)	0.07 (<0.01)	-0.04 (0.47)
		No way, No how	0.16 (<0.01)	0.09 (0.41)	0.12 (<0.01)	-0.05 (0.63)
		Never Bicycled	0.20 (0.02)	0.12 (0.16)	0.09 (<0.01)	<-0.01 (0.94)
	Physically Unhealthy Days	Interested but Concerned	0.08 (0.07)	0.09 (0.15)	0.02 (<0.01)	-0.03 (0.52)
		No way, No how	0.04 (0.44)	0.04 (0.68)	0.04 (<0.01)	-0.04 (0.68)
		Never Bicycled	0.14 (0.07)	0.12 (0.14)	0.03 (<0.01)	<-0.01 (0.96)
	Mentally Unhealthy Days	Interested but Concerned	0.18 (<0.01)	0.27 (<0.01)	0.03 (<0.01)	-0.11 (0.04)
		No way, No how	0.07 (0.20)	0.18 (0.23)	0.05 (<0.01)	-0.16 (0.27)
		Never Bicycled	0.16 (0.04)	0.13 (0.11)	0.03 (<0.01)	<-0.01 (0.91)
	Activity Limited Days	Interested but Concerned	0.14 (<0.01)	0.26 (<0.01)	0.03 (<0.01)	-0.15 (0.01)
		No way, No how	-0.04 (0.47)	0.11 (0.53)	0.06 (<0.01)	-0.21 (0.22)
		Never Bicycled	0.13 (0.10)	0.09 (0.28)	0.04 (<0.01)	<-0.01 (0.91)
INTERESTED BUT CONCERNED	General Health Status	No way, No how	-0.02 (0.78)	-0.06 (0.50)	0.06 (<0.01)	-0.01 (0.85)
		Never Bicycled	0.02 (0.82)	<0.01 (1.00)	0.02 (0.44)	<-0.01 (0.89)
	Physically Unhealthy Days	No way, No how	-0.04 (0.51)	-0.05 (0.59)	0.02 (0.02)	-0.01 (0.87)
		Never Bicycled	0.06 (0.45)	0.06 (0.49)	<0.01 (0.46)	<-0.01 (0.90)
	Mentally Unhealthy Days	No way, No how	-0.11 (0.07)	-0.09 (0.52)	0.02 (0.01)	-0.04 (0.75)
		Never Bicycled	-0.02 (0.81)	-0.03 (0.76)	<0.01 (0.45)	<-0.01 (0.81)
	Activity Limited Days	No way, No how	-0.18 (<0.01)	-0.15 (0.39)	0.03 (<0.01)	-0.06 (0.74)
		Never Bicycled	<-0.01 (0.91)	-0.02 (0.85)	0.01 (0.45)	<-0.01 (0.80)
NO WAY, NO HOW	General Health Status	Never Bicycled	0.04 (0.69)	0.07 (0.42)	-0.04 (0.22)	<-0.01 (0.92)
	Physically Unhealthy Days	Never Bicycled	0.10 (0.24)	0.11 (0.20)	-0.01 (0.24)	<-0.01 (0.93)

Mentally Unhealthy Days	Never Bicycled	0.09 (0.30)	0.10 (0.23)	-0.01 (0.23)	<0.01 (0.89)
Activity Limited Days	Never Bicycled	0.17 (0.05)	0.18 (0.03)	-0.02 (0.23)	<0.01 (0.88)

3

*Except for Strong and Fearless and adjusting for the effect of gender, race/ethnicity, age, and student-employee status

4

^aSignificant effect

5

6 *Supplemental Table 4a. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Enthused and*
 7 *Confident Typology as Reference Group^a, Georgia State University-Bicycling Survey, 2014*

Dependent Variable	Mediator	Bicyclist Typology	Strong and Fearless	Comfortable but Cautious	Interested but Concerned	No way, No how	Never Bicycled
			$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)
General Health Status ^b	Physical Activity	Strong and Fearless	X	-0.12 (<0.01)	-0.19 (<0.01)	-0.25 (<0.01)	-0.21 (<0.01)
		Comfortable but Cautious		X	-0.07 (<0.01)	-0.12 (<0.01)	-0.09 (<0.01)
		Interested but Concerned			X	-0.06 (<0.01)	-0.02 (0.45)
		No way, No how				X	0.04 (0.21)
		Never Bicycled					X
Physically Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.04 (<0.01)	-0.06 (<0.01)	-0.08 (<0.01)	-0.07 (<0.01)
		Comfortable but Cautious		X	-0.02 (<0.01)	-0.04 (<0.01)	-0.03 (<0.01)
		Interested but Concerned			X	-0.02 (0.02)	<-0.01 (0.46)
		No way, No how				X	0.01 (0.24)
		Never Bicycled					X
Mentally Unhealthy Days	Physical Activity	Strong and Fearless	X	-0.05 (<0.01)	-0.07 (<0.01)	-0.10 (<0.01)	-0.08 (<0.01)
		Comfortable but Cautious		X	-0.03 (<0.01)	-0.05 (<0.01)	-0.03 (<0.01)
		Interested but Concerned			X	-0.02 (0.01)	<-0.01 (0.45)
		No way, No how				X	0.01 (0.23)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.12 (<0.01)	0.24 (0.01)	0.28 (0.09)	0.47 (<0.01)
		Comfortable but Cautious		X	0.11 (0.03)	0.15 (0.26)	0.35 (<0.01)
		Interested but Concerned			X	0.04 (0.73)	0.23 (0.02)
		No way, No how				X	0.19 (0.13)
		Never Bicycled					X
Activity Limited Days	Physical Activity	Strong and Fearless	X	-0.06 (<0.01)	-0.09 (<0.01)	-0.12 (<0.01)	-0.10 (<0.01)
		Comfortable but Cautious		X	-0.03 (<0.01)	-0.06 (<0.01)	-0.04 (<0.01)
		Interested but Concerned			X	-0.03 (<0.01)	-0.01 (0.45)
		No way, No how				X	0.02 (0.22)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.16 (<0.01)	0.32 (<0.01)	0.37 (0.05)	0.63 (<0.01)
		Comfortable but Cautious		X	0.15 (0.01)	0.21 (0.21)	0.47 (<0.01)
		Interested but Concerned			X	0.06 (0.72)	0.32 (<0.01)
		No way, No how				X	0.26 (0.11)
		Never Bicycled					X

8 ^aAdjusting for the effect of gender, race/ethnicity, age, and student-employee status

9 ^bIndirect effects through commute bicycling were not significantly different for this dependent variable and are not shown in this table.

Supplemental Table 4b. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Comfortable but Cautious Typology as Reference Group^a, Georgia State University-Bicycling Survey, 2014

Dependent Variable	Mediator	Bicyclist Typology	Strong and Fearless	Enthused and Confident	Interested but Concerned	No way, No how	Never Bicycled
			$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)
General Health Status ^b	Physical Activity	Strong and Fearless	X	-0.07 (0.01)	-0.19 (<0.01)	-0.25 (<0.01)	-0.21 (<0.01)
		Enthused and Confident		X	-0.12 (<0.01)	-0.18 (<0.01)	-0.14 (<0.01)
		Interested but Concerned			X	-0.06 (<0.01)	-0.02 (0.44)
		No way, No how				X	0.04 (0.21)
		Never Bicycled					X
Physically Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.02 (0.03)	-0.06 (<0.01)	-0.08 (<0.01)	-0.07 (<0.01)
		Enthused and Confident		X	-0.04 (<0.01)	-0.06 (<0.01)	-0.04 (<0.01)
		Interested but Concerned			X	-0.02 (0.02)	<-0.01 (0.46)
		No way, No how				X	0.01 (0.24)
		Never Bicycled					X
Mentally Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.03 (0.02)	-0.07 (<0.01)	-0.10 (<0.01)	-0.08 (<0.01)
		Enthused and Confident		X	-0.05 (<0.01)	-0.07 (<0.01)	-0.06 (<0.01)
		Interested but Concerned			X	-0.02 (0.01)	<-0.01 (0.45)
		No way, No how				X	0.01 (0.23)
		Never Bicycled					X
Activity Limited Days	Physical Activity	Strong and Fearless	X	-0.04 (0.02)	-0.09 (<0.01)	-0.12 (<0.01)	-0.10 (<0.01)
		Enthused and Confident		X	-0.06 (<0.01)	-0.09 (<0.01)	-0.07 (<0.01)
		Interested but Concerned			X	-0.03 (<0.01)	-0.01 (0.45)
		No way, No how				X	0.02 (0.22)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.01 (0.01)	0.32 (<0.01)	0.37 (0.05)	0.17 (<0.01)
		Enthused and Confident		X	0.27 (<0.01)	0.33 (0.08)	0.12 (<0.01)
		Interested but Concerned			X	0.06 (0.73)	-0.15 (0.03)
		No way, No how				X	-0.21 (0.22)
		Never Bicycled					X

^aAdjusting for the effect of gender, race/ethnicity, age, and student-employee status

^bIndirect effects through commute bicycling were not significantly different for this dependent variable and are not shown in this table.

Supplemental Table 4c. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with Interested but Concerned Typology as Reference Group^a, Georgia State University-Bicycling Survey, 2014

Dependent Variable	Mediator	Bicyclist Typology	Strong and Fearless	Enthused and Confident	Comfortable but Cautious	No way, No how	Never Bicycled
			$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)	$\Delta\Phi$ (p-value)
General Health Status ^b	Physical Activity	Strong and Fearless	X	-0.07 (0.01)	-0.12 (<0.01)	-0.25 (<0.01)	-0.21 (<0.01)
		Enthused and Confident		X	-0.05 (<0.01)	-0.18 (<0.01)	-0.14 (<0.01)
		Comfortable but Cautious			X	-0.12 (<0.01)	-0.09 (<0.01)
		No way, No how				X	0.04 (0.22)
		Never Bicycled					X
Physically Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.02 (0.03)	-0.04 (<0.01)	-0.08 (<0.01)	-0.07 (<0.01)
		Enthused and Confident		X	-0.02 (0.01)	-0.06 (<0.01)	-0.04 (<0.01)
		Comfortable but Cautious			X	-0.04 (<0.01)	-0.03 (0.48)
		No way, No how				X	0.01 (0.24)
		Never Bicycled					X
Mentally Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.03 (0.02)	-0.07 (<0.01)	-0.10 (<0.01)	-0.08 (<0.01)
		Enthused and Confident		X	-0.05 (<0.01)	-0.07 (<0.01)	-0.06 (<0.01)
		Comfortable but Cautious			X	-0.02 (0.01)	<-0.01 (0.45)
		No way, No how				X	0.01 (0.23)
		Never Bicycled					X
Activity Limited Days	Physical Activity	Strong and Fearless	X	-0.04 (0.02)	-0.05 (<0.01)	-0.10 (<0.01)	-0.08 (<0.01)
		Enthused and Confident		X	-0.02 (<0.01)	-0.07 (<0.01)	-0.06 (<0.01)
		Comfortable but Cautious			X	-0.05 (<0.01)	-0.03 (<0.01)
		No way, No how				X	0.01 (0.23)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.03 (0.03)	0.12 (<0.01)	0.28 (0.11)	0.24 (0.01)
		Enthused and Confident		X	0.09 (<0.01)	0.24 (0.14)	0.21 (0.01)
		Comfortable but Cautious			X	0.16 (0.29)	0.12 (0.03)
		No way, No how				X	-0.04 (0.74)
		Never Bicycled					X

^aAdjusting for the effect of gender, race/ethnicity, age, and student-employee status

^bIndirect effects through commute bicycling were not significantly different for this dependent variable and are not shown in this table.

21 *Supplemental Table 4d. Difference in Relative Indirect Effects of Bicyclist Typology on ALL HRQOL Dependent Variables with No Way, No How*
 22 *Typology as Reference Group^a, Georgia State University-Bicycling Survey, 2014*

Dependent Variable	Mediator	Bicyclist Typology	Strong and Fearless	Enthused and Confident	Comfortable but Cautious	Interested but Concerned	Never Bicycled
			$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)	$\Delta\Phi$ (<i>p-value</i>)
General Health Status ^b	Physical Activity	Strong and Fearless	X	-0.07 (0.01)	-0.12 (<0.01)	-0.19 (<0.01)	-0.21 (<0.01)
		Enthused and Confident		X	-0.05 (<0.01)	-0.12 (<0.01)	-0.14 (<0.01)
		Comfortable but Cautious			X	-0.07 (<0.01)	-0.09 (<0.01)
		Interested but Concerned				X	-0.02 (0.44)
		Never Bicycled					X
Physically Unhealthy Days ^b	Physical Activity	Strong and Fearless	X	-0.02 (0.03)	-0.04 (<0.01)	-0.06 (<0.01)	-0.07 (<0.01)
		Enthused and Confident		X	-0.02 (0.01)	-0.04 (<0.01)	-0.04 (<0.01)
		Comfortable but Cautious			X	-0.02 (<0.01)	-0.03 (<0.01)
		Interested but Concerned				X	<-0.01 (0.46)
		Never Bicycled					X
Mentally Unhealthy Days	Physical Activity	Strong and Fearless	X	-0.03 (0.02)	-0.05 (<0.01)	-0.07 (<0.01)	-0.08 (<0.01)
		Enthused and Confident		X	-0.05 (<0.01)	-0.07 (<0.01)	-0.06 (<0.01)
		Comfortable but Cautious			X	-0.02 (0.01)	<-0.01 (0.45)
		Interested but Concerned				X	0.01 (0.23)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.03 (0.03)	0.12 (<0.01)	0.24 (0.01)	0.28 (0.02)
		Enthused and Confident		X	0.09 (<0.01)	0.20 (0.01)	0.24 (0.03)
		Comfortable but Cautious			X	0.11 (0.03)	0.15 (0.08)
		Interested but Concerned				X	0.04 (0.58)
		Never Bicycled					X
Activity Limited Days	Physical Activity	Strong and Fearless	X	-0.04 (0.02)	-0.06 (<0.01)	-0.10 (<0.01)	-0.10 (<0.01)
		Enthused and Confident		X	-0.03 (<0.01)	-0.06 (<0.01)	-0.07 (<0.01)
		Comfortable but Cautious			X	-0.03 (<0.01)	-0.04 (<0.01)
		Interested but Concerned				X	-0.01 (0.45)
		Never Bicycled					X
	Commute Bicycling	Strong and Fearless	X	0.05 (0.01)	0.17 (<0.01)	0.32 (<0.01)	0.37 (<0.01)
		Enthused and Confident		X	0.12 (<0.01)	0.27 (<0.01)	0.33 (<0.01)
		Comfortable but Cautious			X	0.15 (0.01)	0.21 (0.05)
		Interested but Concerned				X	0.06 (0.57)
		Never Bicycled					X

23 ^aAdjusting for the effect of gender, race/ethnicity, age, and student-employee status

24 ^bIndirect effects through commute bicycling were not significantly different for this dependent variable and are not shown in this table.

25 *Supplemental Table 5. Comparing the Odds of Worse Health-Related Quality of Life for each Condition^a for Standard Subjects^b*
 26 *relative to each Bicyclist Typology*, Georgia State University-Bicycling Survey, 2014*

Reference Bicyclist Typology	Bicyclist Typology	General Health Status ^c		Physically Unhealthy Days ^d		Mentally Unhealthy Days ^d		Activity Limited Days ^d	
		<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>	<i>OR_{indirect}</i>	<i>OR_{direct}</i>
Enthused and Confident	Comfortable but Cautious	1.08	1.27	1.03	1.12	1.04	1.29	1.04	1.35
	Interested but Concerned	1.20	1.60	1.06	1.30	1.09	2.23	1.10	2.07
	No way, No how	1.31	1.46	1.09	1.21	1.15	1.88	1.15	1.63
	Never Bicycled	1.24	1.79	1.07	1.57	1.11	3.60	1.12	3.53
Comfortable but Cautious	Interested but Concerned	1.11	1.26	1.03	1.15	1.05	1.74	1.06	1.54
	No way, No how	1.21	1.15	1.06	1.07	1.10	1.46	1.11	1.21
	Never Bicycled	1.14	1.19	1.04	1.20	1.07	1.30	1.07	1.16
Interested but Concerned	No way, No how	1.09	0.91	1.03	0.93	1.05	0.81	1.05	0.77
	Never Bicycled	1.03	1.00	1.01	1.10	1.02	0.95	1.02	0.97
No Way, No How	Never Bicycled	0.95	1.12	0.98	1.20	0.97	1.25	0.97	1.36

27 *Except for the Strong and Fearless as those results were presented in Table 6

28 ^a $\Phi(1,1)$ estimated the odds for standard subjects who exercised 3 or more times a week and identified as the bicyclist typology of interest relative
 29 to the Strong and Fearless. $\Phi(1,0)$ estimated the odds for standard subjects who did not exercise 3 or more times a week and were the bicyclist
 30 typology of interest relative to the Strong and Fearless. $\Phi(0,0)$ estimated the odds for standard subjects who did not exercise 3 or more times a
 31 week and were Strong and Fearless

32 ^bFemale, white, Non-Hispanic, 30 years old, student, not commute cycle during past semester

33 ^cProbability of good, fair, or poor general health status versus very good or excellent

34 ^dProbability of more than three unhealthy days

35 ^e*OR_{indirect}* was calculated by dividing the odds from $\Phi(1,1)$ by the odds from $\Phi(1,0)$

36 ^f*OR_{direct}* was calculated by dividing the odds from $\Phi(1,0)$ by the odds from $\Phi(0,0)$

37 **7. Technical Appendix: Methodology for Calculating Odds Ratio from Probits**

38 If we were to leave the results in probit form, some readers may not be satisfied by just
39 knowing the direction and significance of the differences in probability. Rather, these readers
40 may be satiated by a better understanding of the comparisons of two probabilities in the form of
41 Odds Ratios – particularly, epidemiologists and other public health practitioners and
42 researchers more familiar with Odds Ratios than probits. This author agrees that such
43 comparisons are useful and, perhaps, practical.

44 Selecting a standard subject was necessary in order to compute and compare the odds of
45 worse health. We were interested in assessing the odds of worse health through the relative
46 direct effect of bicyclist typology and, separately, the odds of worse health through the relative
47 indirect effect of physical activity. Though the standard subject could have been arbitrarily
48 selected, ours was selected based on 1) among categorical covariates, the category with the
49 greatest number of respondents and 2) the mean age. This resulted in choosing a standard
50 subject who was female, white, Non-Hispanic, student, who had not commute bicycled during
51 past semester and who was 30 years old. Though our calculations revolve around this single
52 subject, they could reasonably be replicated for other subjects who may be of interest to
53 different parties or stakeholders (i.e. using the mean age of students instead of the entire
54 sample).

55 Our outcome variables were all ordinal. For this reason, we had to decide on a consistent
56 threshold to use for each outcome. Regarding General Health Status, we decided to estimate the
57 probability of good, fair, or poor self-reported health versus very good or excellent self-reported

58 health. This decision was made for at least two reasons. First, only a small proportion of the
59 sample appeared to think they were of either Fair (6.5%) or Poor (0.5%) health. Second, we
60 sought to conceptually distinguish persons who perceived themselves of being of a better health
61 status to persons who perceived themselves as not being one of the better health statuses. For all
62 of the Unhealthy Days measures, we estimated the probability of more than three unhealthy
63 days during the past 30 days. Again, this decision was two-fold. First, the vast minority of
64 participants reported eight or more unhealthy days for two of the measures (Physically
65 Unhealthy Days and Activity Limited Days). Second, we sought to distinguish between persons
66 who appear did not seem to experience much of a burden due to health and may have reported
67 only a few unhealthy days for any of the items and those who seemed to be somewhat more
68 burdened by poor health and may have reported at least four unhealthy days.

69 For the estimation of the probits, there had to be a reference group selected. We chose to
70 show the results when using the Strong and Fearless as the reference group throughout the
71 manuscript. Results when the other bicyclist typologies served as the reference group are
72 shown in Supplemental Tables 3, 4a-4d, and 5. The Strong and Fearless was selected as the
73 reference group of interest mainly due to health expectations for this bicyclist typology. We
74 were interested in estimating the probability and odds of worse health. To aide in the
75 interpretability, we wanted the results to consistently be relative to the group we expected to
76 have the best health outcomes. Also, by choosing this group as the referent, we can primarily
77 produce Odds Ratios that are greater than one, which are generally more easily understood by
78 the anticipated audience.

79 After establishing a standard subject and determining what we were estimating the
 80 probability of, we had to establish the calculations of marginal effects. We used Muthen's
 81 methodology for estimating the total indirect effect and direct effect in the form of odds ratios
 82 [48]. The general procedure was:

- 83 1. Calculate the standard normal distribution value by solving the estimated
- 84 equation(s) for each equation,
- 85 2. Calculate the probability of the outcome of interest from the standard
- 86 distribution value,
- 87 3. Calculate the odds of the outcome of interest, and
- 88 4. Calculate the odds ratios specific to the indirect effect and direct effect.

89 The first condition, $\Phi(1,1)$, estimated the z-score of the outcome of interest for standard
 90 subjects who performed physical activity three or more times during the past week and
 91 identified as the bicyclist typology of interest, keeping in mind that these calculation were
 92 relative to the bicyclist typology serving as the reference group. The equation below depicts
 93 how we solved for this first condition:

$$94 \text{ CDF}(\text{Bicyclist Typology of Interest: } 1,1) = |\beta_{01} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \\ 95 \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12}(\gamma p_{02} + \gamma p_1 X_1 + \gamma p_2 X_2 + \gamma p_3 X_3 + \gamma p_4 X_4 + \gamma p_5 X_5 + \gamma p_{10} X + \gamma p_{11} X) + \\ 96 \beta_{13}(\gamma c_1 X_1 + \gamma c_2 X_2 + \gamma c_3 X_3 + \gamma c_4 X_4 + \gamma c_5 X_5 + \gamma c_{10} X_{10} + \gamma c_{11} X_{11})| / \sqrt{\beta_1^2 \sigma_2^2 + 1}, \text{ where}$$

97 CDF = Standard Normal Distribution value (z-score).

98 β_{01} = Threshold value for calculating probability of previously described outcome of
 99 interest.

100 $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ = parameter estimate for regressing outcome of interest on each bicyclist
 101 typology. A value of 1 would be entered for X only for the bicyclist typology of
 102 interest and a value of 0 for all other bicyclist typologies.

103 β_{10} = parameter estimate for regressing outcome of interest on age. This value was
 104 multiplied by 30 for all analyses.

105 β_{11} = parameter estimate for regressing outcome of interest on student-employee status.
 106 This value was multiplied by 1 for all analyses.

107 β_{12} = parameter estimate for regressing outcome of interest on physical activity.

108 γp_{02} = threshold value for previously described physical activity level of interest.

109 $\gamma p_1, \gamma p_2, \gamma p_3, \gamma p_4, \gamma p_5$ = parameter estimate for regressing physical activity on each
 110 bicyclist typology. A value of 1 would be entered for X only for the bicyclist
 111 typology of interest and a value of 0 for all other bicyclist typologies.

112 γp_{10} = parameter estimate for regressing physical activity on age. This value was
 113 multiplied by 30 for all analyses.

114 γp_{11} = parameter estimate for regressing physical activity on student-employee status.
 115 This value was multiplied by 1 for all analyses.

116 β_{13} = parameter estimate for regressing outcome of interest on commute bicycling.

117 $\gamma c_1, \gamma c_2, \gamma c_3, \gamma c_4, \gamma c_5$ = parameter estimate for regressing commute bicycling on each
 118 bicyclist typology. A value of 1 would be entered for X only for the bicyclist
 119 typology of interest and a value of 0 for all other bicyclist typologies.

120 γc_{10} = parameter estimate for regressing commute bicycling on age. This value was
 121 multiplied by 30 for all analyses.

122 γc_{11} = parameter estimate for regressing commute bicycling on student-employee status.
 123 This value was multiplied by 1 for all analyses.

124 σ_2 = is the variance for the mediator of interest physical activity status.

125 Parameter estimates for each of the other covariates (sex and race/ethnicity dummy variables)
 126 were not included as they were multiplied by 0 for all analyses. When presenting the equations
 127 for the subsequent conditions, we will exclude the parameter estimates being multiplied by 0.

128 The second condition, $\Phi(1,0)$, estimated the z-score of a standard subject of the bicyclist
 129 typology of interest who did not perform physical activity three or more times during the past
 130 week would have the outcome of interest relative to the Strong and Fearless. The parameters
 131 identified below have the same meaning as in the aforementioned equation for the first
 132 condition. Parameter estimates for regressing physical activity on each bicyclist typology were

133 excluded in the equation below as compared to the equation for the first condition as they
 134 would be multiplied by 0:

$$135 \quad CDF(\text{Bicyclist Typology of Interest: } 1,0) = |\beta_{01} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \\
 136 \quad \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} (\gamma p_{02} + \gamma p_{10} X + \gamma p_{11} X) + \beta_{13} (\gamma c_1 X_1 + \gamma c_2 X_2 + \gamma c_3 X_3 + \gamma c_4 X_4 + \gamma c_5 X_5 + \\
 137 \quad \gamma c_{10} X_{10} + \gamma c_{11} X_{11})| / \sqrt{\beta_1^2 \sigma_2^2 + 1}$$

138 The third condition, $\Phi(0,0)$, estimated the z-score for the Strong and Fearless who did
 139 not perform physical activity three or more times during the past 30 days.

$$140 \quad CDF(\text{Bicyclist Typology of Interest: } 0,0) = |\beta_{01} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \\
 141 \quad \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} (\gamma p_{02} + \gamma p_{10} X + \gamma p_{11} X) + \beta_{13} (\gamma c_1 X_1 + \gamma c_2 X_2 + \gamma c_3 X_3 + \gamma c_4 X_4 + \gamma c_5 X_5 + \\
 142 \quad \gamma c_{10} X_{10} + \gamma c_{11} X_{11})| / \sqrt{\beta_1^2 \sigma_2^2 + 1}$$

143 The z-score resulting from each CDF for each condition was then converted to a
 144 probability in Microsoft Excel using the NORM.S.DIST function. Odds were then calculated
 145 from these probabilities. Finally, to calculate the odds ratios, we performed the following two
 146 calculations for each bicyclist typology of interest relative to the Strong and Fearless (except in
 147 the case of the Supplemental Tables previously identified):

- 148 1. Indirect Effect through Physical Activity: $\frac{\Phi[\text{probit}(1,1)]/(1-\Phi[\text{probit}(1,1)])}{\Phi[\text{probit}(1,0)]/(1-\Phi[\text{probit}(1,0)])}$
- 149 2. Direct Effect: $\frac{\Phi[\text{probit}(1,0)]/(1-\Phi[\text{probit}(1,0)])}{\Phi[\text{probit}(0,0)]/(1-\Phi[\text{probit}(0,0)])}$

150 In order to compare the odds of worse health through the indirect effect of physical activity for
 151 a bicyclist typology of interest relative to the reference typology, the odds produced from
 152 calculating $\Phi(1,1)$ was divided by the odds produced from calculating $\Phi(1,0)$. Similarly, to
 153 compare the odds of worse health through the direct effect of the bicyclist typology of interest
 154 relative to the reference typology, the odds calculated in $\Phi(1,0)$ were divided by the odds

155 calculated from $\Phi(0,0)$. Our calculation did assume there was no treatment-mediator

156 interaction. Future studies may find investigating this interaction worthwhile.

157

158

8. References

- 159 1. Centers for Disease Control and Prevention, National Center for Health Statistics,
160 *Underlying Cause of Death 1999-2014 on CDC WONDER Database, released 2015. Data are*
161 *from the Multiple Cause of Death Files, 1999-2014, as compiled from data provided by the 57*
162 *vital statistics jurisdictions through the Vital Statistics Cooperative Program.*
- 163 2. Hamer, M. and Y. Chida, *Active commuting and cardiovascular risk: A meta-analytic review.*
164 *Preventive Medicine, 2008. 46(1): p. 9-13.*
- 165 3. de Geus, B., et al., *Cycling to work: influence on indexes of health in untrained men and women*
166 *in Flanders. Coronary heart disease and quality of life. Scand J Med Sci Sports, 2008. 18(4): p.*
167 *498-510.*
- 168 4. United States Census Bureau. *2011-2015 American Community Survey 5-Year Estimates.*
169 *2017 [cited 2017 January 12, 2017]; Available from:*
170 *[https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_](https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_5YR_S0801&prodType=table)*
171 *15_5YR_S0801&prodType=table.*
- 172 5. Dill, J. and N. McNeil *Four Types of Cyclists? Examining a Typology to Better Understand*
173 *Bicycling Behavior and Potential.* 2012. 22.
- 174 6. Falconer, C.L., et al., *The tracking of active travel and its relationship with body composition in*
175 *UK adolescents. Journal of Transport & Health, 2015. 2(4): p. 483-489.*
- 176 7. Andersen, L.B., et al., *Cycling to school and cardiovascular risk factors: a longitudinal study. J*
177 *Phys Act Health, 2011. 8(8): p. 1025-33.*
- 178 8. Tainio, M., et al., *Can air pollution negate the health benefits of cycling and walking? Prev*
179 *Med, 2016. 87: p. 233-6.*
- 180 9. de Hartog, J.J., et al., *Do the Health Benefits of Cycling Outweigh the Risks? Ciencia & Saude*
181 *Coletiva, 2011. 16(12): p. 4731-4744.*
- 182 10. Rojas-Rueda, D., *The health risks and benefits of cycling in urban environments compared with*
183 *car use: health impact assessment study (vol 343, d4521, 2011). British Medical Journal, 2011.*
184 *343: p. 1.*
- 185 11. Rojas-Rueda, D., et al., *Replacing car trips by increasing bike and public transport in the*
186 *greater Barcelona metropolitan area: a health impact assessment study. Environ Int, 2012. 49: p.*
187 *100-9.*
- 188 12. Rojas-Rueda, D., et al., *Health impact assessment of increasing public transport and cycling use*
189 *in Barcelona: A morbidity and burden of disease approach. Preventive Medicine, 2013. 57(5):*
190 *p. 573-579.*
- 191 13. Pucher, J. and R. Buehler, *Making cycling irresistible: Lessons from the Netherlands, Denmark*
192 *and Germany. Transport Reviews, 2008. 28(4): p. 495-528.*
- 193 14. Geller, R. *Four Types of Cyclists.* 2006.
- 194 15. Fraser, S.D.S. and K. Lock, *Cycling for transport and public health: a systematic review of the*
195 *effect of the environment on cycling. European Journal of Public Health, 2011. 21(6): p. 738-*
196 *743.*
- 197 16. Saelens, B.E., J.F. Sallis, and L.D. Frank, *Environmental correlates of walking and cycling:*
198 *Findings from the transportation, urban design, and planning literatures. Annals of Behavioral*
199 *Medicine, 2003. 25(2): p. 80-91.*

- 200 17. Van Holle, V., et al., *Relationship between the physical environment and different domains of*
201 *physical activity in European adults: a systematic review*. BMC Public Health, 2012. **12**: p.
202 807.
- 203 18. Bryan, M., *Bicycling for Transportation: Health and Destination, Results of a survey of students*
204 *and employees from a southern urban university*. 2017, Georgia State University.
- 205 19. Dill, J. and N. McNeil, *Revisiting the Four Types of Cyclists*. Transportation Research
206 Record: Journal of the Transportation Research Board, 2016. **2587**: p. 90-99.
- 207 20. Dominick, K., et al., *Relationship of health-related quality of life to health care utilization and*
208 *mortality among older adults*. Aging Clinical and Experimental Research, 2002. **14**(6): p.
209 499-508.
- 210 21. Colsher, P.L. and R.B. Wallace, *Elderly men with histories of heavy drinking: correlates and*
211 *consequences*. Journal of studies on alcohol, 1990. **51**(6): p. 528-535.
- 212 22. Colsher, P.L., et al., *Demographic and health characteristics of elderly smokers: results from*
213 *established populations for epidemiologic studies of the elderly*. American journal of
214 preventive medicine, 1990. **6**(2): p. 61-70.
- 215 23. Lamb, K.L., et al., *A comparison of selected health-related data from surveys of a general*
216 *population and a sporting population*. Social Science & Medicine, 1991. **33**(7): p. 835-839.
- 217 24. De Forge, B.R., J. Sobal, and J.P. Krick, *Relation of Perceived Health with Psychosocial*
218 *Variables in Elderly Osteoarthritis Patients*. Psychological Reports, 1989. **64**(1): p. 147-156.
- 219 25. Permanyer-Miralda, G., et al., *Comparison of perceived health status and conventional*
220 *functional evaluation in stable patients with coronary artery disease*. Elsevier, 1991. **44**(8): p. 8.
- 221 26. Wannamethee, G. and A.G. Shaper, *Self-assessment of health status and mortality in middle-*
222 *aged British men*. International Journal of Epidemiology, 1991. **20**(1): p. 239-245.
- 223 27. Andresen, E.M., et al., *Retest reliability of surveillance questions on health related quality of*
224 *life*. Journal of Epidemiology and Community Health, 2003. **57**(5): p. 339-343.
- 225 28. Toet, J., H. Raat, and E.J. van Ameijden, *Validation of the Dutch Version of the CDC Core*
226 *Healthy Days Measures in a Community Sample*. Quality of Life Research, 2006. **15**(1): p.
227 179-184.
- 228 29. Pierannunzi, C., S.S. Hu, and L. Balluz, *A systematic review of publications assessing*
229 *reliability and validity of the Behavioral Risk Factor Surveillance System (BRFSS), 2004-2011*.
230 BMC Med Res Methodol, 2013. **13**: p. 49.
- 231 30. Ounpuu, S., et al., *Validity of the US Behavioral Risk Factor Surveillance System's health*
232 *related quality of life survey tool in a group of older Canadians*. Chronic diseases in Canada,
233 2001. **22**(3-4): p. 93-101.
- 234 31. Centers for Disease, C., *Health-related quality of life and activity limitation - eight states, 1995*.
235 Morbidity Mortality Weekly Report, 1998. **47**(7): p. 7.
- 236 32. Centers for Disease, C., *Health-related quality of life - Puerto Rico, 1996-2000*. Morbidity
237 Mortality Weekly Report, 2002. **51**(8): p. 3.
- 238 33. Andresen, E.M., et al., *Performance of health-related quality-of-life instruments in a spinal cord*
239 *injured population*. Archives of Physical Medicine and Rehabilitation, 1999. **80**(8): p. 877-
240 884.
- 241 34. Currey, S.S., et al., *Performance of a generic health-related quality of life measure in a clinic*
242 *population with rheumatic disease*. Arthritis Care & Research, 2003. **49**(5): p. 658-664.

- 243 35. Hayes, A.F. and K.J. Preacher, *Statistical mediation analysis with a multicategorical*
244 *independent variable*. British Journal of Mathematical and Statistical Psychology, 2014. **67**:
245 p. 20.
- 246 36. Hemmingsson, E., et al., *Increased physical activity in abdominally obese women through*
247 *support for changed commuting habits: a randomized clinical trial*. Int J Obes, 2009. **33**(6): p.
248 645-652.
- 249 37. Oja, P., I. Vuori, and O. Paronen, *Daily walking and cycling to work: their utility as health-*
250 *enhancing physical activity*. Patient Educ Couns, 1998. **33**(1 Suppl): p. S87-94.
- 251 38. Saelens, B.E., J.F. Sallis, and L.D. Frank, *Environmental correlates of walking and cycling:*
252 *findings from the transportation, urban design, and planning literatures*. Ann Behav Med,
253 2003. **25**(2): p. 80-91.
- 254 39. Sanders, R.L. and J.F. Cooper, *Do all roadway users want the same thing? Results from*
255 *roadway design survey of San Francisco bay area pedestrians, drivers, bicyclists, and transit*
256 *users*. Transportation Research Board: Journal of the Transportation Research Board,
257 2013. **2393**: p. 10.
- 258 40. Fishman, E., et al., *Factors influencing bike share membership: An analysis of Melbourne and*
259 *Brisbane*. Transportation Research Part A: Policy and Practice, 2015. **71**: p. 14.
- 260 41. Sener, I.N., N. Eluru, and C.R. Bhat, *An analysis of bicycle route choice preferences in Texas,*
261 *US*. Transportation, 2009. **36**: p. 29.
- 262 42. Broach, J., J. Dill, and J. Gliebe, *Where do cyclists ride? A route choice model developed with*
263 *revealed preference GPS data*. Transportation Research Part A: Policy and Practice, 2012.
264 **46**(10): p. 11.
- 265 43. Kang, L. and J.D. Fricker, *Bicyclist commuters' choice of on-street versus off-street route*
266 *segments*. Transportation, 2013. **40**: p. 16.
- 267 44. Winters, M. and K. Teschke, *Route preferences among adults in the near market for bicycling:*
268 *Findings of the cycling in cities study*. American Journal of Health Promotion, 2010. **25**(1):
269 p. 8.
- 270 45. Garrard, J., G. Rose, and S.K. Lo, *Promoting transportation cycling for women: The role of*
271 *bicycle infrastructure*. Preventive Medicine, 2008. **46**(1): p. 5.
- 272 46. Jackson, M. and E. Ruehr, *Let the people be heard: San Diego county bicycle use and attitude*
273 *survey*. Transportation Research Board: Journal of the Transportation Research Board,
274 1998. **1636**: p. 5.
- 275 47. Morckel, V.C., *Examining the relationships between perceived neighborhood mobility*
276 *characteristics, perceived incivilities, travel attitudes, and physical activity amongst university*
277 *faculty and staff*. Journal of Transport & Health, 2016. **3**(1): p. 86-95.
- 278 48. Muthen, B. *Applications of Causally Dened Direct and Indirect Effects in Mediation Analysis*
279 *using SEM in Mplus*. 2011. 95.

**Chapter 4: Investigating Patterns of Disposition toward Potential Commute Bicycling
Improvements at a Southern Urban University Campus**

**INVESTIGATING PATTERNS OF DISPOSITION TOWARD POTENTIAL COMMUTE
BICYCLING IMPROVEMENTS AT A SOUTHERN URBAN UNIVERSITY CAMPUS:
A LATENT CLASS ANALYSIS**

Katherine Masyn

Georgia State University
School of Public Health
One Park Place, Suite 662, Atlanta, Georgia 30303
Tel: 404-413-2343 Email: kmasyn@gsu.edu

Matthew Magee

Georgia State University
School of Public Health
One Park Place, Suite 700, Atlanta, Georgia 30303
Tel: 404-413-2344; Email: mjmagee@gsu.edu

John Steward

Georgia State University
School of Public Health
One Park Place, Suite 724, Atlanta, Georgia 30303
Tel: 404-413-1140; Email: jsteward@gsu.edu

J. Michael Bryan, Corresponding Author

Georgia State University
School of Public Health
1252 McLendon Drive, Decatur, Georgia 30033
Tel: 770-519-0337; Email: jbryan8@student.gsu.edu

Word count: 5,582 words

Submission Date: April 20, 2017

ABSTRACT

The first objective of this study was to develop profiles of disposition toward whether proposed commute bicycling improvements at a specific destination would increase the likelihood of commute bicycling. The second objective was to determine if the probability of profile membership was associated with demographic, bicyclist type, bicycling for transportation status, or mode of transportation. Data collected during the 2014 Georgia State University-Bicycling Survey included a convenience sample of students and employees at an urban university. A finite mixture modeling approach was used to develop a latent class measurement model. The manual 3-Step protocol was used to assess the effect of covariates germane to commute bicycling on the latent class measurement model. The seven-class solution was decided on as the final model. Three classes were characterized by uniform response patterns of either Agree, Neither agree nor disagree, or Disagree. Four classes had heterogeneous response patterns. Several covariates were determined to significantly impact the likelihood of class assignment: gender, age, race/ethnicity, bicyclist typology, residence disposition, bicycling for transportation, bicyclist status, and using the transport modes of motor vehicle, bicycle, and walking. Results of this analysis can assist policy makers in targeting and prioritizing commute bicycling interventions. Future research may take these results and assess pertinent outcomes of an individual's estimated class assignment.

Keywords: Commute, Bicycling, Latent Class Analysis, Destination, Infrastructure

1 INTRODUCTION

2 The intent of this study was to better understand the disposition of potential beneficiaries toward
3 proposed commute bicycling improvements at a specific destination. In this study, the potential
4 beneficiaries are students and employees at a southern urban university, while the specific
5 destination is the university campus. There were two primary objectives of this study: (a) to
6 develop a measurement model using student and employee disposition toward whether a campus
7 improvement would increase their likelihood of commute bicycling using a latent class analytic
8 approach and (b) to determine differences in the probability of belonging to the resulting classes
9 among subpopulations, including demographics, health, bicyclist characteristics, and mode of
10 transportation.

11 This analysis flows from previous research indicating the complexities of assessing the
12 role of the environment on modal choice due to individual-level heterogeneity [1]. Latent class
13 analysis allows such complexity to be somewhat simplified by identifying classes, or patterns, of
14 responses that may then be interpreted based on the response patterns within a class and further
15 comparing these patterns to those different classes. Placing respondents in these classes can
16 provide a perspective other analytic approaches have yet to do. In this study, the focus of the
17 latent class analysis is on the disposition of students and employees toward whether end-of-trip
18 improvements that are under the purview of the university will increase their likelihood of
19 commute bicycling to campus. Further, by understanding the predictors of these classes, the
20 needs of potential target audiences may be better met. For example, persons who would like to
21 commute bicycle, but are not willing to without bicycle facilities may have different needs
22 regarding campus improvements than either persons who will bicycle anywhere or persons who
23 are not motivated to commute bicycle. To the knowledge of these researchers, there is no

24 existing research that conceptualizes destination improvements in this way. This study may help
25 reframe future bicycle planning efforts for specific destinations.

26 **LITERATURE REVIEW**

27 The goal of this study was to assist the future commute bicycling-related plans and interventions
28 in targeting their efforts. This study builds on previous research by focusing only on dispositions
29 toward bicycling-related improvements to a specific destination among the potential
30 beneficiaries regardless of current commute bicycling status.

31 Existing methods of assessing the route environment have limited applicability for
32 destinations seeking to improve commute bicycling. As Buehler and Dill point out, measuring
33 bicycle routes, or networks, is still “emerging” [2]. Four existing methods, the Bicycle
34 Compatibility Index (BCI), the Link Level Bicycle Level of Service (BLOS), Duthie and
35 Unnikrishnan’s BLOS, and the Level of Traffic Stress each have unique conceptualizations of
36 the route environment [3-6]. Recent research indicates that these current models are able to
37 predict mode choice [7]. Though understandably important for planning organizations, these
38 route environment models do not focus on a specific destination. Hence, when policy makers at
39 destinations, like an urban university campus, are seeking to improve commute bicycling, these
40 route models are not helpful in prioritizing improvements.

41 Planning organizations have made use of several frameworks to guide bicycle facility
42 planning efforts. As with the route environment models, these frameworks may be missing
43 crucial information that could help better target bicycle planning. Planning organizations that use
44 models based on aggregate built environment measures to estimate mode choice may have
45 limited impact on bicycle facility planning at specific destinations [8]. Several frameworks in the
46 literature rely on objectively assessed route choice and/or bicycle facility levels [9-12]. Though

47 useful and feasible, these models may either not focus on a single destination or incorporate the
48 perspective of individuals. However, recent evidence suggests that mode choice is impacted by
49 both an individual's attitudes and the built environment [13, 14] This study builds on previous
50 research by focusing on a single destination and by seeking to understand the disposition of all –
51 cyclists and non-cyclists – proposed bicycling-specific improvements to a specific destination.

52 Commute bicycling research that does focus on specific destinations appears to exclude
53 feedback from an important potential target population for commute bicycling interventions –
54 non-cyclists. Previous attempts to inform bicycling improvement decisions may have focused on
55 current or “expert” cyclists [15]. Some efforts to understand the comfort of the route
56 environment focused only on current cyclists, thereby not considering the perspective of non-
57 cyclists or the contribution of destination factors on comfort [16]. Neglecting the perspective of
58 non-current or non-expert cyclists would appear to contrast with current bicycle planning goals.
59 In a seminal work on identifying the potential market for urban planners to consider regarding
60 commute bicycling, Geller advised that urban planning should prioritize the needs of persons
61 who would like to commute bicycle but are not comfortable doing so in the absence of bicycling
62 facilities [17]. Existing bicycle planning literature appear to disproportionately focus on the
63 feedback of current cyclists as compared to those who would like to commute bicycle.

64 Components of bicycle destination environments have been understudied. One study
65 looked at destination environmental factors association with rail transit stations that affect the
66 active transport modal choice [18]. However, that study was limited to objective measures of the
67 built environment. Though important for predicting the probability of commute bicycling,
68 policymakers may be interested in knowing more about what their community would like, or
69 what their community believes would increase the likelihood that they would commute bicycle.

70 Conversely, another study investigated the role of the destination environment on commute
71 bicycling and identified a number of environmental factors impacting mode choice, including
72 improved bicycle lanes, security at stations, and bicycle parking [19]. However, as previously
73 discussed, non-cyclists were not considered in that analysis; hence, feedback from the majority
74 of the potential audience – persons who would like to cycle if more bicycling facilities existed –
75 was missing.

76 This study attempts to understand the predictors of patterns of disposition to destination
77 improvements intended to increase commute bicycling behavior. It would be intuitive that an
78 individual who commutes by bicycle may have a different likelihood of belonging to a particular
79 pattern as compared to an individual who does not currently commute by bicycle. The needs of
80 the two groups may be different – one may need certain improvements to begin commuting by
81 bicycle, while the other may be interested in making existing commuting easier or more
82 pleasurable. Likewise, other potential target populations may be more or less likely to agree that
83 particular improvements to a single destination would increase their likelihood of commute
84 bicycling to that destination. The effect of built environment improvements on active
85 transportation modal choice may be different by sociodemographic status (e.g., sex,
86 race/ethnicity, age, employment) [1, 19]. End-of-trip facilities like showers, secure bicycle
87 parking, changing rooms, and storage facilities have been shown to be important to cyclists,
88 particularly females [20]. Females were less comfortable with and more fearful of commute
89 cycling and may need more resources to feel safe or comfortable commute bicycling than their
90 male counterparts [7, 21]. Students may have different bicycling needs as well as they are more
91 likely to walk to their destination and to live on campus as compared to employees of a
92 university [22]. Individuals who live farther away from a particular destination may have need of

93 different end-of-trip facilities than those who live more proximal to the destination [23].
94 Disparities in commute bicycling may be reduced by better targeting end-of-trip, or destination,
95 interventions on meeting the needs of particular subpopulations.

96

97

98

99

100 **METHOD**

101 This analysis comprises three parts. First, descriptive statistics on the final dataset were
102 performed by student-employee status. Second, a latent class analysis was performed using
103 responses from the destination improvement dispositions assessed. Third, the significance of
104 predictors of the latent classes was assessed.

105 **Data Source**

106 Data from the 2014 Georgia State University-Bicycling Survey (GSU-BS) were used for this
107 analysis. The GSU-BS was a convenience sample of students and employees at a southern urban
108 university. The questionnaire consisted of items capturing demographics, health and physical
109 activity status, lifetime bicycling experience, commute bicycling to campus experience, bicyclist
110 typology, mode of transportation to campus, and disposition toward bicycling-specific
111 improvements on campus. Study procedures have been described elsewhere [24]. The study
112 received approval from Georgia State University's Institutional Review Board and the Office of
113 Institutional Effectiveness. Persons unable to bicycle due to a permanent physical limitation were
114 excluded from this analysis. Also, respondents who did not answer at least one of the destination
115 improvement disposition questions were excluded. The final dataset included 4,186 observations.

116 **Descriptive Statistics**

117 Univariate statistics were performed on the final sample in order to determine the distribution of
118 demographics and disposition toward destination improvements. Bivariate analyses were also
119 performed by student-employee status. The Chi-Square test was used to determine if there were
120 significant differences in the distribution of the categorical variables by student-employee status,
121 while ANOVA was used to test for significant differences in age by student-employee status. All
122 descriptive statistics analyses were performed in SAS Version 9.4.

123 **Latent Class Analysis**

124 A methodology previously described by Masyn, was applied to perform the latent class analysis
125 [19]. A one-class model was initially fit. Additional classes were added to each subsequent
126 model until the addition of classes did not result in improved model fit. Model identification was
127 assessed by tracking: (1) the percent of models failing to converge, (2) the percent of models
128 whereby the best log-likelihood was not replicated, (3) the percent of respondents in smallest
129 class, and (4) the condition number. A number of fit indicators were used to help identify the
130 final “best” model, including Bayesian Information Criterion (BIC), Consistent Akaike
131 Information Criterion (CAIC), and Approximate Weight of Evidence Criterion (AWE). To
132 determine the relative fit, we evaluated the Adjusted Vuong, Lo, Mendel, Rubin Likelihood
133 Ratio Test (VLMR-LRT), Bayes Factor (BF), and the approximate correct model probability
134 (CMP_k). The most likely models were identified once all fit information was collected.

135 Classification diagnostics were gathered on the most likely models, including overall
136 entropy, average posterior class probability, modal class assignment proportion (MCAP), and the
137 odds of correct classification (OCC). We reapplied this methodology to random split-half
138 samples to determine reliability of results.

139 **Predictors of Class Assignment**

140 We assessed the significance of class predictors, once the “best” model was identified,
141 using the manual 3-Step protocol as described by Asparouhov and Muthen [25]. Multinomial
142 logistic regression was performed to assess the effect of predictors on the established classes
143 from the “best” model. Predictors of interest included: gender, age, race/ethnicity, student-
144 employee status, bicyclist typology, physical activity status, commute bicycling status, general
145 health status, disposition to residential proximity status, and transport mode. All covariates were

146 used in the multinomial logistic regression model. The global Wald test was used to assess the
147 significance of each predictor. A *p-value* of less than 0.05 was considered significant. All latent
148 class analyses were performed using MPlus Version 7.4.

149 Arriving at this latent class analysis methodology required the determination of 1) which
150 items to include in the latent class analysis, 2) how best to discretize the included items, and 3)
151 whether to perform the analysis separately for students and faculty. Here we briefly describe the
152 approach taken to arrive at a latent class analysis of the entire sample using nine items with a
153 three-level discretization. Initially the *Residential proximity disposition* item described below
154 was one of the items included in the development of the latent class measurement model. This
155 item was removed from the development of the measurement model development component of
156 the latent class analysis for two reasons. First, it appeared to be the item least correlated with the
157 others. This poor correlation may help explain why, when *residential proximity disposition* was
158 included in the latent class analysis, there was poor separation between the classes. Second,
159 changing the proximity of a respondent's residence to campus was beyond the scope of the
160 anticipated bicycling plan. Its inclusion would have little practical implications.

161 In an effort to maintain as much data in the analysis as possible, the items were initially
162 left in their five-point Likert scale form. However, there were difficulties in convergence of
163 when performing the latent class analytic approach. One reason for these issues may have been
164 the sparseness with which respondents endorsed "Agree". To resolve the convergence issues we
165 consolidated the "Strongly Agree" and "Agree" response options. We then performed the latent
166 class analysis on the four-level items. Convergence did not appear to be a problem in this
167 approach. However, the substantiveness of the resulting profiles was questionable. There were
168 two profiles that were only different in their level of disagreement with the items – one profile

169 consisted of respondents who uniformly *disagreed* with each proposed improvement, while the
170 other consisted of respondents who uniformly *strongly disagreed* with each proposed
171 improvement. Since we aimed to maximize the practicality of the proposed analytic approach,
172 we further consolidated the “Strongly Disagree” and “Disagree” response options, thus leaving
173 us with three-level items differentiated by their overall disposition toward each item – agree,
174 neither agree nor disagree, disagree. Two profiles (still present in the final model) were identified
175 that were only different in their non-agreement with six of the items after performing the latent
176 class analysis on the set of three-level items – where one responded “Neither” the other
177 responded “Disagree”. Consideration was then given to dichotomizing the items such that one
178 level would consist of the “Agree” and “Strongly Agree” response option, while “Neither”,
179 “Disagree”, and “Strongly Disagree” would be the other. Ideally, dichotomizing the items in this
180 way would have alleviated barriers to interpreting the resulting profiles. However, the resulting
181 classes using dichotomized items differed greatly from the classes initially identified in the ‘best’
182 solutions with three-level items. Also, dichotomizing the items led to ‘best’ solutions with
183 weaker entropy than the ‘best’ solutions from the three-level items. This change in the resulting
184 ‘best’ profiles was considered as evidence that respondents who endorse ‘Neither’ are a
185 conceptually distinct group from those who disagree with the given items. Hence, we were left
186 with the three-level discretization of the nine items.

187 The latent class methodology was employed for students and employees separately.
188 Different classes may have emerged for each group since previous studies indicated students are
189 different from the general population in ways pertinent to this study [22]. Resulting ‘best’
190 models appeared to have similar profiles across each group. Once the decision was made to
191 combine the two groups, the latent class analysis was performed on a sample comprising a

192 random selection of students equal to the number of employees and all employees. These results
193 were then compared with the results from the overall sample to ensure that students were not
194 unduly weighting the results. The ‘best’ models for the equal numbers sample and the overall
195 sample were similar. It was thus concluded that the latent class analysis should be performed on
196 the overall sample and not on students and employees independently. Only the models following
197 these decisions are reported below.

198 **Measures and Definitions**

199 *Destination Improvement Disposition*

200 Items included in the latent class analysis were assessed with the prompt: “We would like your
201 opinions about possible improvements for the future. I would be more likely to bicycle for
202 transportation to, from or around GSU if...”, while individual items were worded as follows: (1)
203 “dedicated, separated bicycle lanes were found on downtown streets” (*cycle tracks*), (2)
204 “learning activities (skills, practical courses, etc.) about bicycling in the city were held on
205 campus” (*learning activities*), (3) “more information about routes for bicycling to, from, and
206 around the GSU campus were available” (*route information*), (4) “a facility on the GSU campus
207 to get help with bicycle repairs were available” (*repair facility*), (5) “bicycle parking was located
208 more conveniently to the places I go on campus” (*convenient parking*), (6) “better safety and
209 security for bicycle parking and storage areas on the GSU campus were available” (*safe and*
210 *secure parking*), (7) “a convenient place to shower and change clothing after bicycling were
211 available” (*amenities*), (8) “bicycles were available to borrow and use on campus at little or no
212 cost” (*bicycles available*), and (9) “better public transportation (bus or rail) were available to use
213 for part of the trip” (*public transportation*). As previously described, the five-point Likert scale

214 response options were discretized to reflect general disposition toward the specified
215 improvement: agree, neither agree nor disagree, and disagree.

216 *Latent Class Predictors*

217 **Demographics** Gender was dummy coded such that male respondents were entered into the
218 model. Age was treated as a continuous variable. Race/ethnicity was dummy coded, such that (1)
219 Black, Non-Hispanic, (2) Hispanic, and (3) Other, Non-Hispanic indicators were entered into the
220 model, indicating White, Non-Hispanic as the reference group. Employee status was also dummy
221 coded such that faculty were the reference group.

222 **Bicyclist Typology** Respondents were asked to identify their bicyclist typology. Bicyclist
223 typology options were based on Roger Geller's typology and take into account regional
224 transportation needs [17, 26]. Consistent with Geller's typology, current methods assessed
225 respondents' motivation to commute bicycle and willingness to commute bicycle across various
226 levels of bicycling facilities. Additionally, consistent with a previous study by Bryan *et al*,
227 bicyclist typology, as defined here, captures overall bicycling experience [24]. In doing so, this
228 bicyclist typology does not assume that persons who had never bicycled are the same as persons
229 not motivated to commute bicycle. *Supplemental Table 1* demonstrates the differences between
230 the typologies. Bicyclist typology was dummy coded such that *Strong & Fearless* respondents
231 were the reference group.

232 **Health** Physical activity status was dummy coded such that not having performed physical
233 activity or exercise in which the heart rate and breathing was above normal for more than ten
234 minutes (hereafter referred to as "physical activity") in the past month was the reference group.
235 Respondents who had (1) performed physical activity in the past month but not during the past
236 week and (2) performed physical activity during the past week were entered into the model.

237 Commute bicycling status was dummy coded whereby respondents who commute bicycled to,
238 from, or around campus during the past week were entered into the model, while all others serve
239 as the reference group. General health status was a two-level dummy coded variable whereby
240 respondents who reported either Fair or Poor health were entered into the model and respondents
241 who reported a Good, Very Good, or Excellent health status were the reference group.

242 **Transportation** *Residential proximity disposition* was dummy coded such that respondents who
243 (1) *Neither Agree nor Disagree* and (2) *Disagree that they would be more likely to bicycle for*
244 *transportation to, from, or around campus if their place of residence was closer to campus* were
245 entered into the model. Those who *Agree or Strongly Agree* served as the reference group. Each
246 transport mode assessed (Motor Vehicle, Bicycle, Public Transportation, School-Provided, and
247 Walking) was dummy coded such that respondents who reported *using a mode All or Most of the*
248 *Time to and from campus* were entered into the model. Respondents reporting *Sometimes,*
249 *Rarely, or Never* served as the reference group.

250

251

252

253

254 **RESULTS AND DISCUSSION**

255 **Descriptive Statistics**

256 Descriptive statistics of the sample by student-employee status are shown in *Table 1*.
257 Students were approximately 70% of the sample. Nearly two-thirds of the sample was female.
258 The distribution of sex and race/ethnicity was significantly different for students and employees,
259 as was the mean age. While almost two-thirds of university employee respondents were white,
260 non-Hispanic, there was no majority race/ethnicity among student respondents. The mean age of
261 students was significantly less than the mean age of employees. Responding that *learning*
262 *activities* and *cycle tracks* would increase the likelihood of commute bicycling to, from, or
263 around campus were agreed upon the least and most, respectively. The distribution of responses
264 that cycle tracks would increase the likelihood of bicycling to, from, or around campus was the
265 only destination improvement not significantly different by student-employee status ($p=0.11$).

266 **Latent Class Analysis**

267 *Measurement Model Development Results*

268 **Class Enumeration** Results from the class enumeration can be found in *Supplemental Table 1*.

269 The percent of models that converge began decreasing with the eight-class solution, while the
270 percent of models where the best log-likelihood is replicated decreased beginning with the
271 seven-class solution. There was no evidence of over-extraction of classes or of model non-
272 identification.

273 **Fit Indices** As depicted in *Table 2*, the Bayesian Information Criterion (BIC) and Approximate
274 Weight of Evidence Criterion were lowest for the seven-class solution. Beginning with the five-
275 class solution, each successive solution did not fit the data better than the solution with one more
276 class according to the VLMR-LRT. The BF indicated that the seven class solution fit the data

277 better than the eight class solution – the same is true for each successive model. According to the
278 CMP, the seven-class solution has a high probability of nearly being the correct model. As
279 indicated in *Supplemental Table 3*, the split-half sample cross-validation results were conflicting
280 as one sample indicated the six-class solution fit the data better, while the other sample indicated
281 the seven-class solution.

282 In spite of the split-half sample providing different indications of which solution is best,
283 the seven-class solution was selected as the best model for classifying destination improvement
284 dispositions for statistical and substantive reasons. The seven-class solution fit the data
285 significantly better than the six class solution in the total sample and in one split-half sample.
286 Two classes were identified in both the six and seven-class solution that were only different in
287 their non-agreement percentages - where one class endorsed “Neither” for items responded to
288 heterogeneously, the other class endorsed “Disagree.” Finally, as shown in *Supplementary Table*
289 *4*, the seven-class solution had a substantively meaningful profile, *Cycle Track Seekers*, that
290 primarily included respondents from a single profile from the six-class solution that would have
291 otherwise remained hidden if the six-class solution was chosen. Further, the seven-class solution
292 was the “best” solution when the latent class procedure was performed on students and
293 employees separately (results not shown).

294 **Classification Diagnostics** Classification diagnostic results are shown in *Supplementary Table*
295 *5*. The seven-class model had an adequate entropy of 0.79. The average posterior class
296 probability and odds of correct classification indicated sufficient separation between classes and
297 class precision. Modal class assignment proportions indicate that error within class assignment
298 for the seven-class solution was minimal.

299

300 *Profiles from Seven-Class Model*

301 The conditional item-specific probabilities of (a) agree or strongly agree, (b) neither agree nor
302 disagree, or (c) disagree or strongly disagree for each destination improvement are presented in
303 three line charts in *Figure 1*. The three profiles with uniform probabilities are not presented to
304 better visualize those profiles with heterogeneous response profiles. A description of each of the
305 profiles follows:

306 **Ripe for Change (39.0%, n=1632)** At least 79% of respondents belonging to the *Ripe for*
307 *Change* profile agree that each proposed change would increase their likelihood of commute
308 bicycling to, from, or around campus. Any destination improvement would appear to motivate
309 these respondents to commute bicycle. This was the *only* profile characterized by agreement with
310 six of the nine items: *bicycles available, amenities, public transportation, repair facility, route*
311 *information, and learning activities*.

312 **Rigid (10.2%, n=426)** From 91% to 100% of *Rigid* respondents disagree that each proposed
313 change would impact their commute bicycling behavior. None of the proposed changes were
314 likely to change the commute bicycling behavior of *Rigid* respondents.

315 **Ambivalent (5.1%, n=213)** At minimum, 79% of *Ambivalent* respondents neither agreed nor
316 disagreed that a proposed change would increase the likelihood they would commute bicycle.
317 *Ambivalent* respondents do not seem to know whether any proposed destination improvement
318 will impact their commute bicycling to that specific destination. The *Ambivalent* profile was the
319 smallest in the sample.

320 **Cycle Track Seeking (11.5%, n=480)** *Cycle Track Seeking* respondents are typified by the
321 large proportion (80%) agreeing that dedicated, separated bicycle lanes would increase their
322 likelihood of bicycling for transportation. All other items had heterogeneous responses for

323 respondents in this profile. *Cycle Track Seeking* respondents appear to believe that only
324 improved infrastructure of dedicated, separated bike lanes will change their commute bicycling
325 behavior.

326 **Infrastructure Oriented – Receptive (16.1%, n=672)** The *Infrastructure-Oriented - Receptive*
327 profile is characterized by at least 89% of respondents agreeing that infrastructure items will
328 increase their likelihood of bicycling for transportation, including: (1) *cycle tracks*, (2)
329 *convenient parking*, and (3) *safe and secure parking*. Contrary to the *Cycle Track Seeking*
330 profile, respondents belonging to this profile agree that a more broadly improved bicycling
331 infrastructure – cycle tracks *and* parking - will increase their likelihood of commute bicycling.

332 **Infrastructure Oriented – Resistant (10.1%, n=421)** Akin to the *Infrastructure Oriented -*
333 *Receptive* profile, a large proportion of *Infrastructure Oriented – Resistant* respondents agreed
334 that bicycling infrastructure-related improvements will increase their likelihood of commute
335 bicycling. Where all of the non-agreement on the six non-infrastructure items in the
336 *Infrastructure Oriented – Receptive* profile is neither agreeing nor disagreeing, the non-
337 agreement in the *Infrastructure Oriented – Resistant* profile is primarily disagreement. Thus,
338 *Infrastructure Oriented – Receptive* respondents appear more open to changing their bicycling
339 behavior than *Infrastructure Oriented – Resistant* respondents given improvements in non-
340 infrastructure items.

341 **Facilitation Averse (8.2%, n=342)** *Facilitation Averse* respondents disagree that a few of the
342 proposed destination improvements - *route information, learning activities, and repair facilities* -
343 would increase their likelihood of commute bicycling. The remaining six items are
344 heterogeneously distributed. *Facilitation Averse* respondents do not appear motivated by any of
345 the proposed items to change their commute bicycling behavior; rather, they specifically disagree

346 that improvements meant to facilitate commute bicycling will increase their likelihood of
347 commute bicycling.

348 **Predictors of Profile Membership**

349 Student-Employee status, physical activity status, general health status, and the transportation
350 modes of public transportation and school-provided transport were not significantly associated
351 with profile membership when controlling for the effect of all the other predictors. *Figure 2*
352 provides the distribution of the destination factor profiles for each level of the significant
353 predictor variables. See *Supplemental Table 6* for all Wald test results and for the significance
354 and directionality of pairwise class comparisons of the effect of predictors.

355 *Figure 2a* demonstrates that there are some important differences in the probability of
356 class membership by demography. Females (0.08) had a lower chance of being *Facilitation*
357 *Averse* as compared to males (0.14). White, non-Hispanics had a greater probability of being
358 either Infrastructure Oriented – Receptive (0.24) or Infrastructure Oriented – Resistant (0.19) as
359 compared to their counterparts. Males (0.31) and non-white, Non-Hispanics (0.28) had a lower
360 probability of being *Ripe for Change* than their counterparts - females (0.42), black, Non-
361 hispanics (0.46), Hispanics (0.50), or other, Non-hispanics (0.46).

362 As depicted in *Figure 2b*, a respondent's motivation to commute bicycle and previous
363 bicycling experience influences their probability of belonging to a particular class. The No Way,
364 No How bicyclist typology had the lowest chance of being *Ripe for Change* (0.26) and the
365 greatest chance of being *Rigid* (0.10) and *Facilitation Averse* (0.13) than the other bicyclist
366 typologies. The Never Bicycled typology had the greatest probability of being *Ripe for Change*
367 (0.49).

368 An individual's bicyclist characteristics can be an important predictor of their class
369 assignment. Respondents who had bicycled during the past year or commute bicycled during the
370 past week had a lower probability of being *Ambivalent* – 0.02 and 0.01, respectively - as
371 compared to respondents with less bicycling behavior, at 0.05 and 0.04, respectively, as shown in
372 *Figure 2c*. Persons who had commute bicycled during the past week were more likely to be *Ripe*
373 *for Change* (0.44) than those who had not (0.37). Respondents who disagree that they would be
374 more likely to commute bicycle if their residence was closer to campus had greater chances of
375 being *Rigid* (0.32) and *Facilitation Averse* (0.18) than who agree, at 0.02 and 0.08, respectively.
376 Conversely, persons who agreed they would be more likely to commute bicycle if their residence
377 was closer to campus were more likely to be *Ripe for Change* (0.44) than those who disagree
378 (0.16).

379 An individual's current primary mode(s) of transportation may also influence their
380 probability of class membership. Respondents who did not bicycle to campus all or most of the
381 time had a lower probability of being *Ripe for Change* (0.37), but a higher probability of being
382 *Infrastructure Oriented – Receptive* (0.20) and *Facilitation Averse* (0.10) than respondents who
383 did (0.47, 0.07, and 0.06, respectively). Respondents who used a motor vehicle all or most of the
384 time were more likely to be *Infrastructure Oriented – Receptive* (0.17) than respondents who
385 already rode their bicycle to campus (0.07). These findings support the use of demographics,
386 bicyclist typology, bicycling characteristics, and some modes of transportation as key predictors
387 of profiles of disposition toward proposed improvements to a specific destination.

388 The emergent profiles and their predictors concurs with previous research concluding that
389 commuting mode choice is a complex process [27]. The development of dedicated, separated
390 bicycle lanes (*cycle tracks*) is important to increasing commute bicycling among four classes.

391 Evidence indicates that both bicyclists and non-bicyclists prefer *cycle tracks* over bicycles lanes
392 that are shared with cars or only separated by a white lane, especially women and inexperienced
393 bicyclists [28-32]. Parking that is both safe and convenient appears to be important for three
394 classes. Similarly, convenient parking and a safe environment are important to the success of
395 destinations to encourage commute bicycling [18, 19, 33, 34]. In concurrence with previous
396 research, our results indicate that environment which simplifies the decision-making process by
397 encouraging and/or reducing the barriers to commute bicycling for transportation may increase
398 the desired behavior of commute bicycling.

399

400

401 **CONCLUSIONS**

402 Results indicated there was seven statistically sound and meaningful profiles of dispositions
403 toward whether proposed destination improvements would increase the likelihood of commute
404 bicycling. The final model found that respondents might be classified by (1) a uniform response
405 towards proposed campus improvements, (2) their agreement with infrastructure-related campus
406 improvements, and (3) their disagreement with proposed campus improvements designed to
407 facilitate commute bicycling. Among the identified profiles typified by agreement, each includes
408 *cycle tracks* as one improvement they believe would change their commute bicycling behavior,
409 three agree that *cycle tracks* and improved parking safety and convenience would increase their
410 likelihood, while only one profile demonstrated agreement with the other six items. The results
411 of this model indicate that policies intending to enhance commute bicycling may seek to
412 prioritize cycle tracks and the safety and convenience of bicycle parking. Such a finding appears
413 to echo previous research indicating the import of dedicated, separated bicycle paths [15, 35, 36]
414 and convenient and safe parking [18-20, 33, 34] on transport mode choice. Evidence suggests
415 that developing *cycle tracks* can be an effective means to increase both the number and share of
416 commute bicycling trips [37-39].

417 Upon developing the initial measurement model, this study further demonstrates that
418 demography, motivation to commute bicycle, lifetime bicycling experience, bicyclist
419 characteristics, and mode of transportation significantly influence the probability of belonging to
420 a particular profile. Commute bicycling interventions may yield greater impact through a better
421 understanding of the target population(s). Women, race/ethnicity minorities, and persons who
422 had never bicycled, for example, appear to favor non-infrastructure improvements as compared
423 to their counterparts. As recommended by Geller [17], interventions targeting individuals who

424 are motivated to commute bicycle but require bicycle-specific facilities prior to doing so (e.g.,
425 the Comfortable but Cautious), may be more successful if they prioritize *cycle tracks* and *safe*
426 and *convenient parking* over *repair facilities*, *route information*, or *leaning activities*. Individuals
427 who primarily commute by motor vehicle appear to favor the improvement of *cycle tracks* and
428 convenient and safe parking as compared to persons already using the bicycle as their primary
429 means of transportation.

430 These results also indicate that there is heterogeneity in the probability of class
431 membership across each of the predictors. For example, No Way, No How respondents could
432 still be Ripe for Change, while persons who had actually commute bicycled during the past week
433 could be Facilitation Averse. Hence, bicycling interventions may not be effective for those who
434 appear most keen on commuting by bicycle, while they may motivate those who are currently
435 unmotivated.

436 These results have several limitations. We were unable to assess the directionality of the
437 causal pathways due to the data being cross-sectional. Confirming causality was beyond the
438 scope of this exploratory study, though future studies may build on these results to establish the
439 causal mechanism. This study did not account for current access to the destination of interest. As
440 with previous research, we encourage future studies to assess the potential moderating effect of
441 the current route environment and destination access or bicycle facilities on similar analyses [2,
442 40, 41]. Determining meaningful differences between the *Infrastructure Oriented* classes is
443 difficult. One solution for future studies to consider is omitting the response “Neither Agree nor
444 Disagree”, thereby forcing respondents to have a non-neutral disposition. The generalizability of
445 the results is limited to the responses used in this analysis. The objective of the study was to
446 perform an exploratory latent class analysis and to assess the effect of relevant predictors. Now

447 that there is initial evidence, future research may replicate the analysis with an appropriate study
448 design to ensure results are representative to the population(s) of interest.

449 Applying a latent class analysis allows one to assess if the distribution of a set of
450 responses is heterogeneous. This method was applied to responses from students and employees
451 at a southern urban university to gain an initial understanding of patterns of disposition toward
452 campus improvements. This analytic approach appears to have worked well as a final model was
453 established. Particularly, it allows for the conceptualization of patterns of dispositions towards a
454 set of potential improvements a single destination can influence. The significance of important
455 predictors of these classes was also determined. This approach is relatively new to the field and
456 will require further development as the impact of factors specific to destinations on commute
457 bicycling are better understood. Insights gained through this study may help inform the planning
458 efforts of specific destinations where a large number of people commute to and from each
459 working day.

460 **TABLES AND FIGURES**461 *Supplemental Table 1. Distinction of Bicyclist Typology Definitions.*

Bicyclist Typology	Motivated to Commute Bicycle	Willingness to Commute Bicycle ^a (5=Most, 1=Least)	Ever Bicycled
Strong and Fearless	Yes	5	Yes
Enthused and Confident	Yes	4	Yes
Comfortable but Cautious	Yes	3	Yes
Interested but Concerned	Yes	2	Yes
No way, No how	No	1	Yes
Never Bicycled	N/A	N/A	No

462 ^aIn the absence of bicycling facilities

Table 1. Student-Employee Status by Demographic and Destination Disposition Factor in the GSU-BS sample.

	Total Sample	Student	Employee	P-value ^a
N (%)	4186	2889 (69.1)	1290 (30.9)	
Mean Age (SD)	30.4 (12.4)	25.2 (8.4)	42.0 (12.1)	<0.01
Gender				<0.01
Male	34.2	32.4	38.2	
Female	65.8	67.6	61.8	
Race/Ethnicity				<0.01
White, Non-Hispanic	48.6	40.5	66.9	
Black, Non-Hispanic	28.0	31.3	20.6	
Hispanic	8.7	10.8	4.0	
Other, Non-Hispanic	14.7	17.4	8.5	
Destination Disposition Factor^b				
Bicycle Lanes	76.4	76.7	75.6	0.11
Convenient Parking	65.2	68.6	57.6	<0.01
Safe and Secure Parking	70.6	73.4	64.7	<0.01
Repair Facility	57.2	59.4	52.6	<0.01
Bicycles Available	60.8	64.9	51.9	<0.01
Amenities (e.g. shower)	54.1	52.0	58.8	<0.01
Public Transportation	56.2	58.9	50.3	<0.01
Route Information	60.4	63.6	53.5	<0.01
Learning Activities	39.0	42.8	30.9	<0.01

Note: For each demographic we present the percentage unless otherwise stated.

^aFrom chi-squared test for differences for categorical variables and Analysis of Variance for the continuous variable.

^bThe percent who either Strongly Agree or Agree that the specified destination factor will increase their likelihood of commute bicycling to campus is shown.

Supplemental Table 2. Class Enumeration Description of Latent Class Analysis of Destination Factor Dispositions, Southern Urban University, 2014

Model	Starts =		Final starting value sets converging		Log Likelihood Replication		Smallest Class		Condition Number
			<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	
1-class	100	50	50	100	50	100	4186	100	0.1×10^{-1}
2-class	100	50	50	100	50	100	816	19.5	0.7×10^{-2}
3-class	100	50	50	100	50	100	792	18.9	0.6×10^{-2}
4-class	100	50	50	100	46	92	492	11.8	0.2×10^{-3}
5-class	100	50	50	100	50	100	263	6.3	0.2×10^{-4}
6-class	100	50	50	100	32	76	250	6.0	0.8×10^{-3}
7-class	100	50	50	100	8	16	213	5.1	1.0×10^{-5}
7-class	500	250	250	100	37	14.8	213	5.1	1.0×10^{-5}
8-class	100	50	28	56	6	21.4	201	4.8	0.3×10^{-3}
9-class	100	50	17	34	2	11.8	159	3.8	0.1×10^{-4}
10-class	100	50	22	44	10	45.6	153	3.7	0.1×10^{-4}

Table 2. Fit Indices for Latent Class Analysis of Destination Factor Dispositions, Southern Urban University, 2014 (n=4186)

Model	LL	npar	BIC	CAIC	AWE	Adj. LMR-LRT		BF	cmP(K)
						X ² (df=19)	p-value		
1-class	-32773.3	18	65696.8	65629.9	65713.1	11959.7	<0.01	<0.01	<0.01
2-class	-26755.7	37	53820.0	53682.5	53853.5	4577.8	<0.01	<0.01	<0.01
3-class	-24452.4	56	49371.9	49163.7	49422.5	1504.0	<0.01	<0.01	<0.01
4-class	-23695.7	75	48016.8	47738.0	48084.6	933.1	<0.01	<0.01	<0.01
5-class	-23226.2	94	47236.3	46886.8	47321.2	326.3	0.07	<0.01	<0.01
6-class	-23062.0	113	47066.3	46646.2	47168.5	269.0	0.76	<0.01	<0.01
7-class	-22926.0	132	46954.0	46462.1	47072.2	149.5	0.76	54.0	1.00
8-class	-22851.4	151	46962.0	46400.6	47098.5	120.3	0.78	1.3 x 10⁸	0.02
9-class	-22790.8	170	46999.4	46367.4	47153.1	118.7	0.77	5.1 x 10¹²	<0.01
10-class	-22740.9	189	47057.9	46355.3	47228.8				<0.01

Supplemental Table 3. Fit Indices for 5-, 6-, 7-, and 8-Class Solutions with Split-Half Cross-validation, Southern Urban University, 2014

Model	LL	npar	BIC	CAIC	AWE	Adj. LMR-LRT		BF	cmP(K)
						X ² (df=19)	p-value		
Sample 1									
5-class	-11766.73	94	24253.65	23940.23	24347.01	164.63	0.76	<0.01	<0.001
6-class	-11683.85	113	24233.45	23856.69	24345.68	130.81	0.73	1020.96	0.999
7-class	-11617.99	132	24247.31	23807.2	24378.41	98.26	0.76	1.34 x 10 ¹⁰	0.001
8-class	-11568.53	151	24293.94	23790.48	24443.91	87.20	0.41	3.50 x 10 ¹²	<0.001
Sample 2									
5-class	-11402.93	94	23523.16	23211.37	23616.90	176.60	0.23	<0.01	<0.001
6-class	-11314.02	113	23490.33	23115.52	23603.02	150.93	0.76	0.03	0.030
7-class	-11238.03	132	23483.35	23045.52	23614.98	87.81	0.74	1.93 x 10 ¹²	1.000
8-class	-11193.82	151	23539.92	23039.07	23690.50	74.07	0.08	1.94 x 10 ¹⁵	<0.001

Supplemental Table 4. Cross-tabulation of Respondents by Class, 6- and 7-Class Solutions, Southern Urban University, 2014

Frequency Row Percent Column Percent	Seven-Class Solution							
Six-Class Solution	Rigid	Ambivalent	Infrastructure Oriented - Receptive	Infrastructure Oriented - Resistant	Cycle Track Seekers	Facilitation Averse	Ripe for Change	Total
Facilitation Averse	0	0	0	15	16	318	0	349
	0	0	0	4.3	4.6	91.1	0	
	0	0	0	3.6	3.3	93.0	0	
Rigid	426	0	0	0	0	8	0	434
	98.2	0	0	0	0	1.8	0	
	100	0	0	0	0	2.3	0	
Ripe for Change	0	0	41	4	0	0	1589	1634
	0	0	2.5	0.2	0	0	97.3	
	0	0	6.1	1.0	0	0	97.4	
Ambivalent	0	209	0	0	39	2	0	250
	0	83.6	0	0	15.6	0.8	0	
	0	98.1	0	0	8.1	0.6	0	
Infrastructure Oriented - Resistant	0	0	18	377	0	14	1	410
	0	0	4.4	92.0	0	3.4	0.2	
	0	0	2.7	90.0	0	4.1	0.1	
Infrastructure Oriented - Receptive	0	4	613	25	425	0	42	1109
	0	0.4	55.3	2.3	38.3	0	3.8	
	0	1.9	91.2	5.9	88.5	0	2.6	
Total	426	213	672	421	480	342	1632	4186

Supplemental Table 5. Classification Diagnostics for the 7-Class Solution (Entropy=0.785, n=4186), Southern Urban University, 2014

Profile	$\hat{\pi}_k$	95% C.I.	$mcaP_k$	$AvePP_k$	OCC_k
Ripe for Change	0.35	0.32, 0.38	0.39	0.86	10.99
Rigid	0.10	0.08, 0.11	0.10	0.92	113.74
Ambivalent	0.05	0.04, 0.06	0.05	0.91	190.67
Cycle Track Seekers	0.11	0.09, 0.15	0.11	0.80	29.89
Infrastructure Oriented - Receptive	0.18	0.14, 0.22	0.16	0.79	16.72
Infrastructure Oriented - Resistant	0.12	0.10, 0.14	0.10	0.80	29.80
Facilitation Averse	0.09	0.07, 0.11	0.08	0.84	53.91

Figure 1. Estimated Percent of Respondents for each Disposition among Heterogeneously Endorsed Profiles by Factor to Increase Bicycling to, from, or around Campus, Southern Urban University, 2014

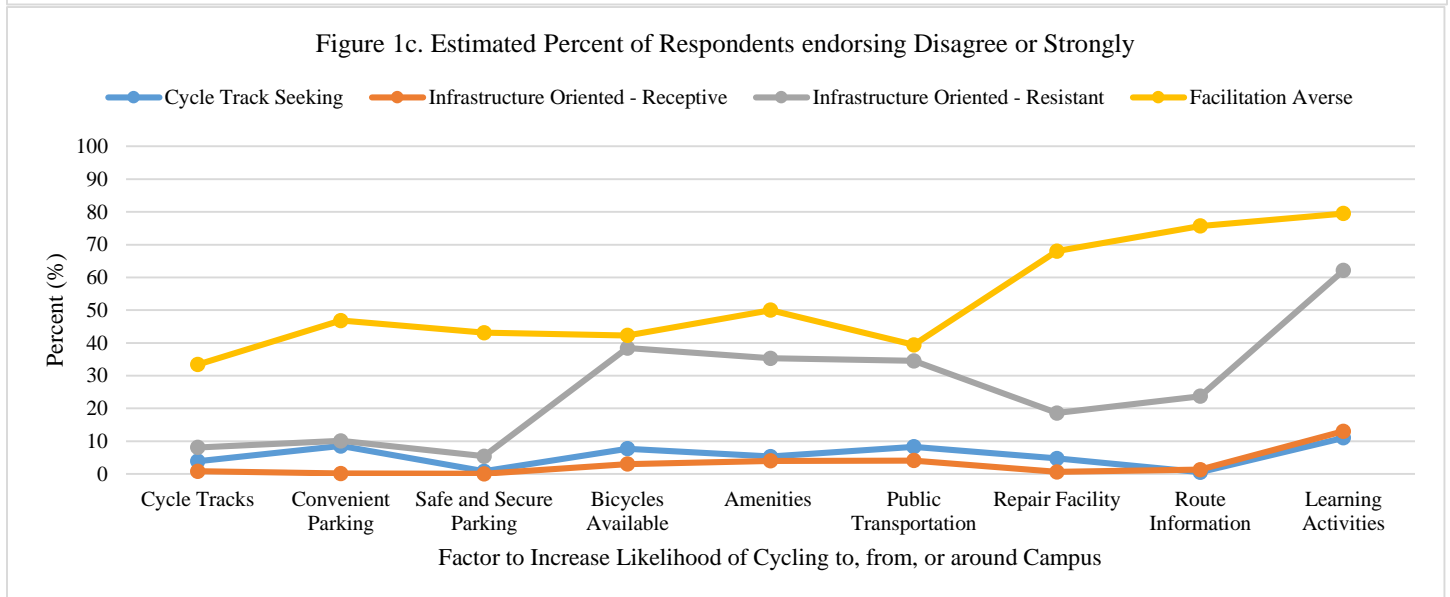
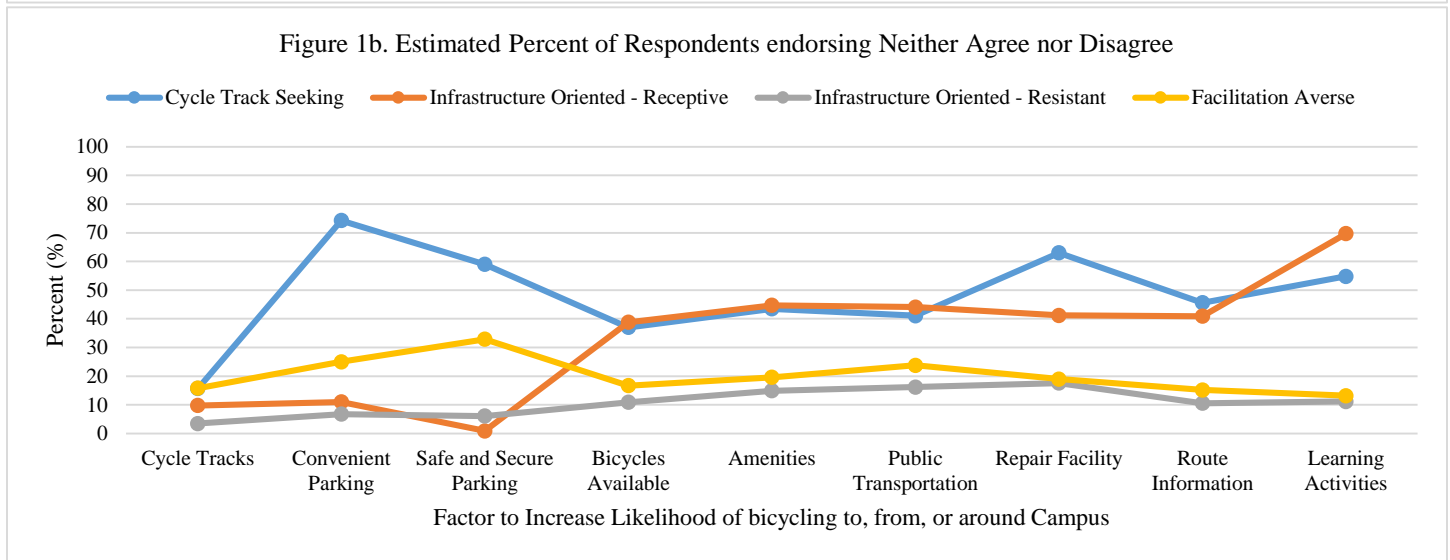
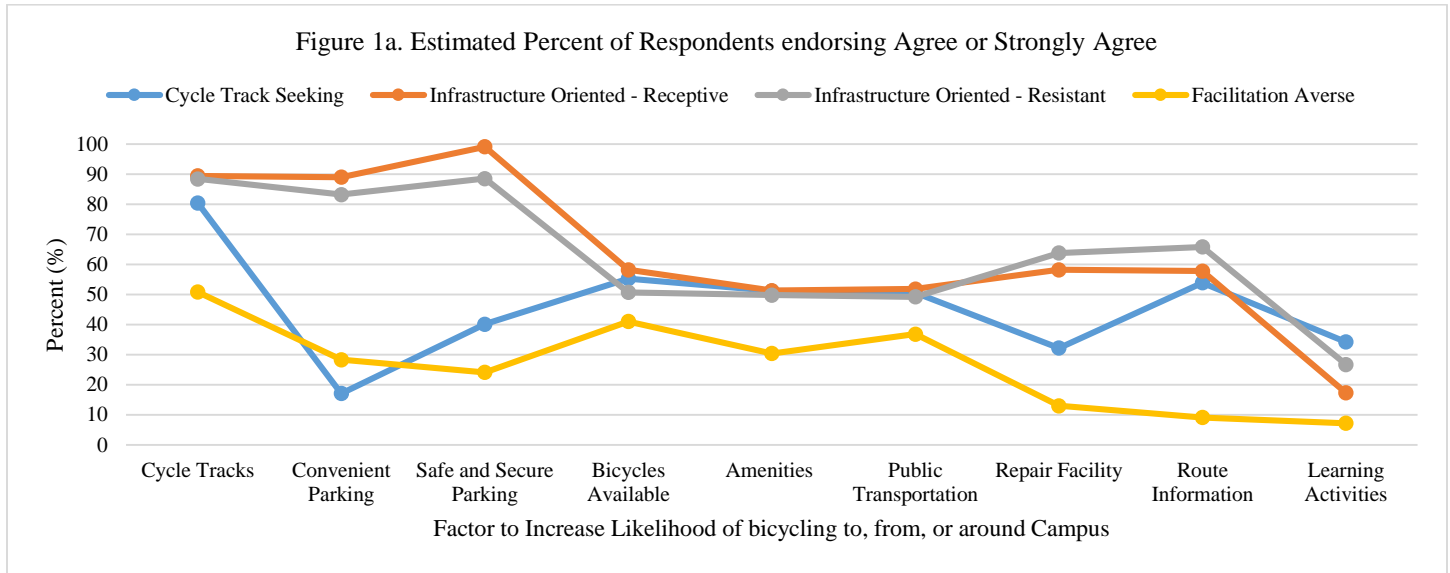
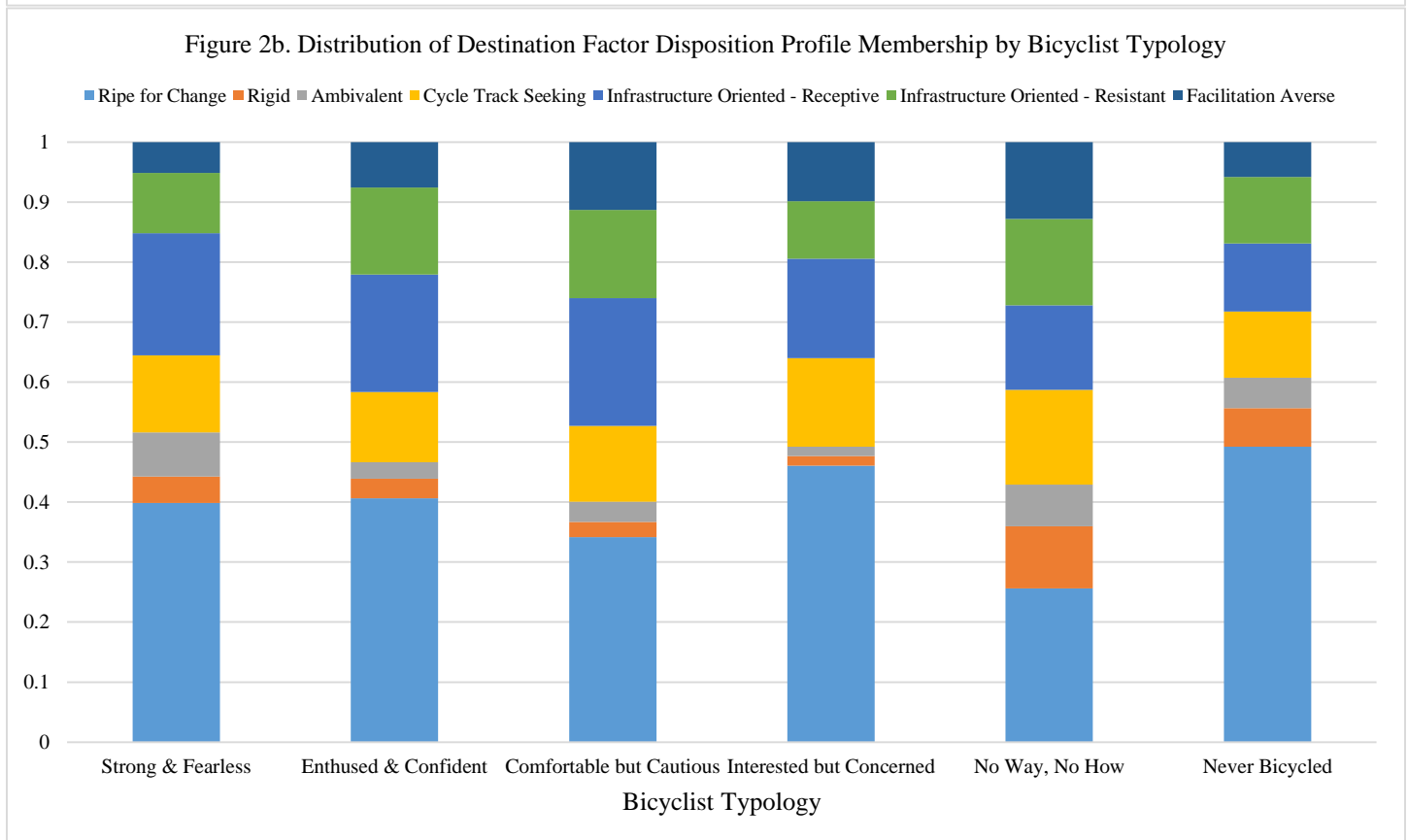
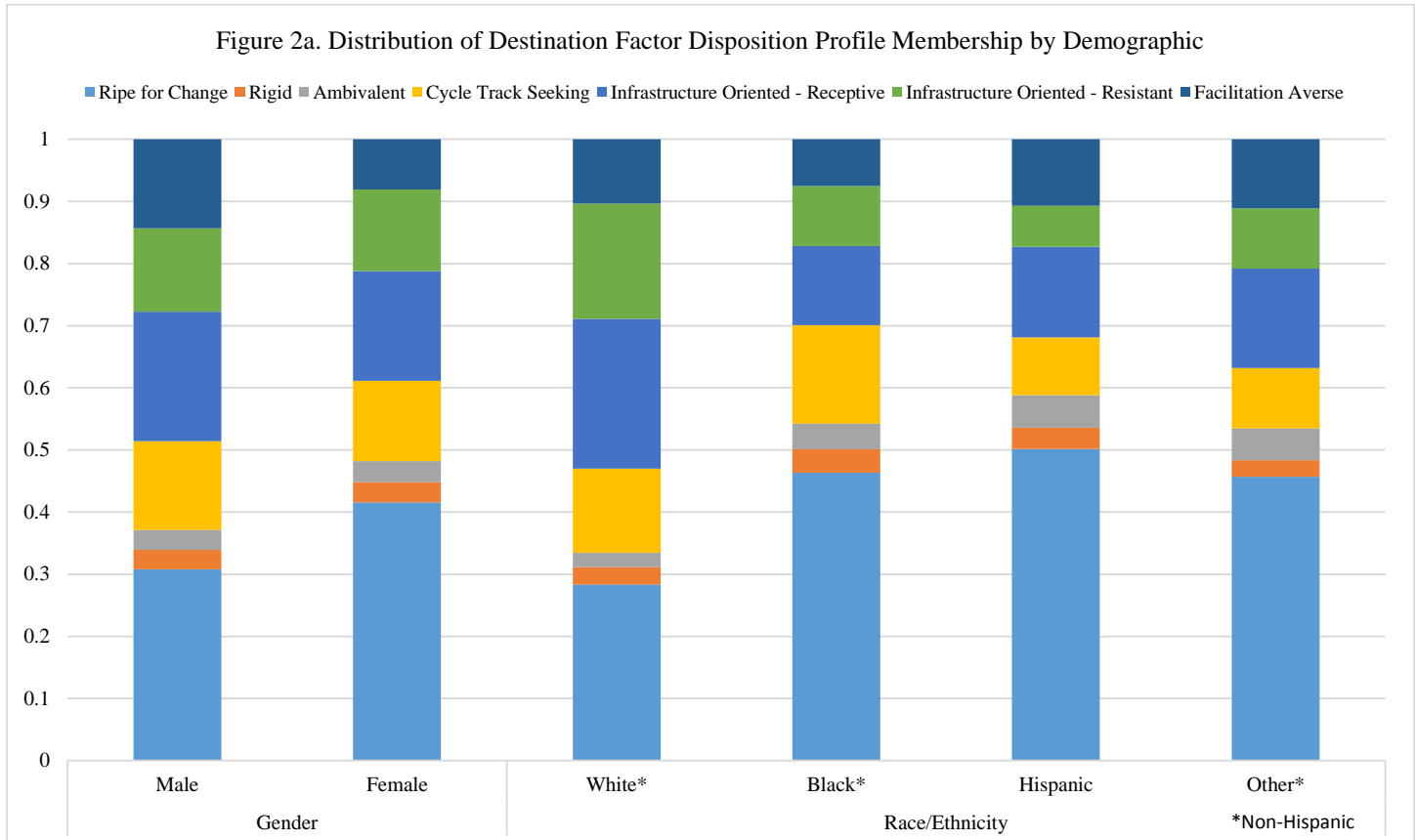
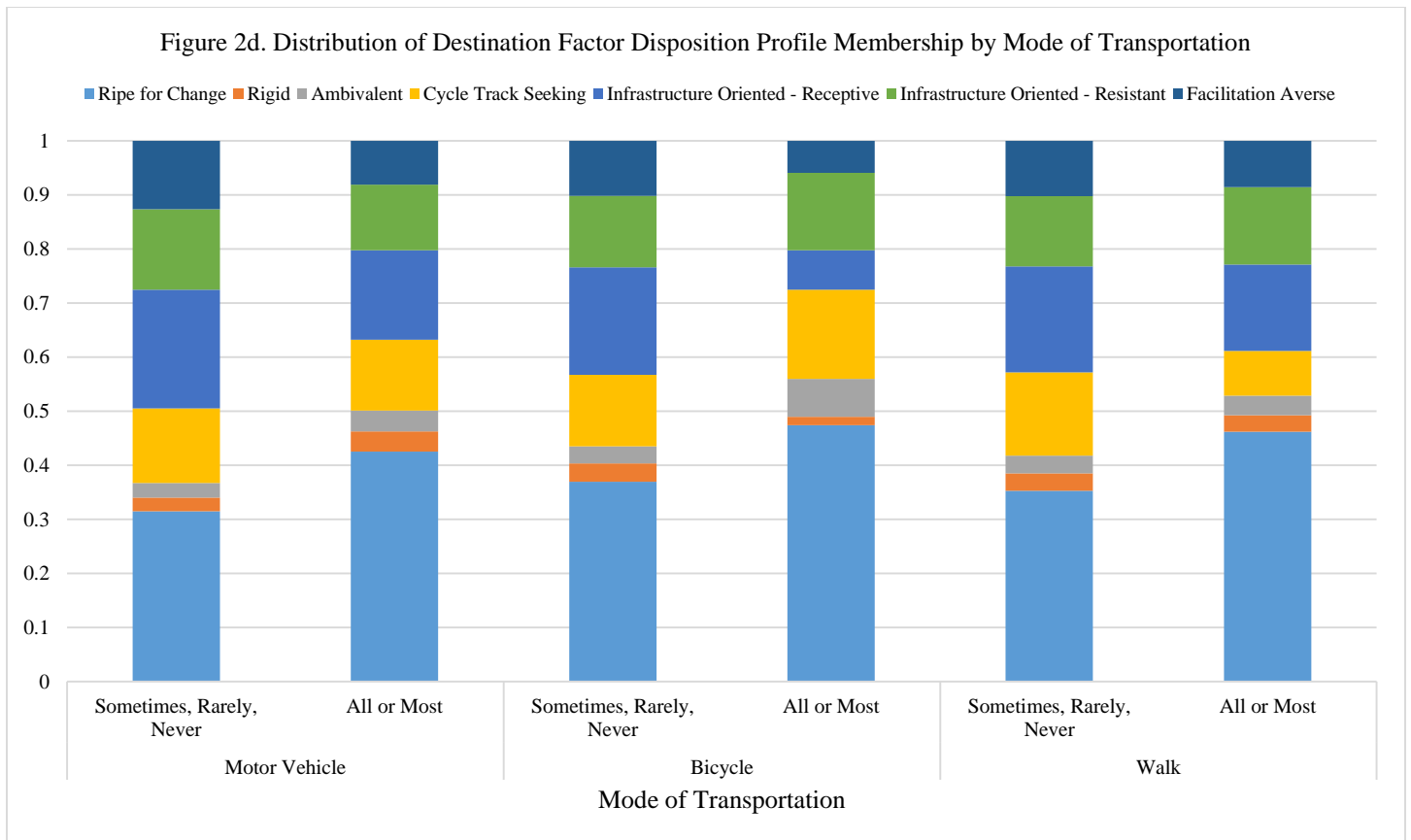
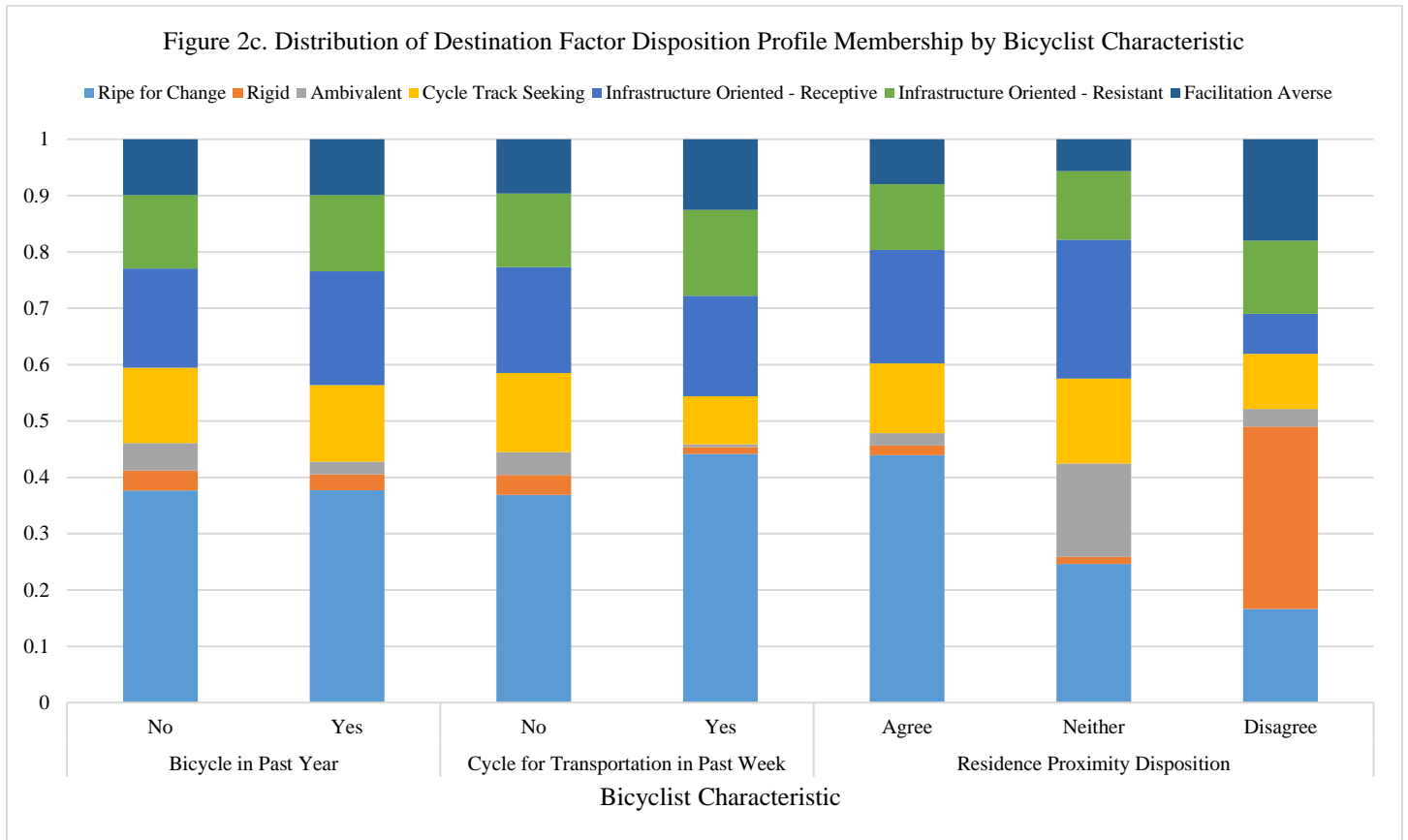


Figure 2. Distribution of Estimated Destination Factor Disposition Profile Membership by Significant Predictors, Southern Urban University, 2014





Supplementary Table 6. Significance of Predictors of Destination Factor Disposition Class Membership and Pairwise Comparisons, Southern Urban University, 2014

Covariates	Wald X ² (df, p)	Reference Class*^																							
		7					6					5				4			3		2				
		1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	1	2	1			
Gender (female as ref.)	30.2 (6, p<0.01)			+		+	+	-	-	-	-	-													
Age	13.1 (6, p=0.04)	+						+					+							+			+		
Race/Ethnicity (White, Non-Hispanic as ref.)	106.8 (18, p<0.01)																								
Black, Non-Hispanic				-	-	-	-	+	+			+			-	-	+	+				+	+		
Hispanic				-	-	-			+	-				+			+	+					+		
Other, Non-Hispanic		-		-	-	-			+	-				+			+	+					+		
Student (employee as ref.)	8.7 (6, p=0.19)					+																			
Physical Activity Status (No physical activity in past month as ref.)	10.4 (12, p=0.58)																								
Physical Activity in past month																								-	+
Physical Activity in past week					+																				
General Health Status (Good, Very Good, and Excellent as ref.)	0.7 (6, p=1.0)																								
Bicyclist Typology (Strong & Fearless as ref.)	150.0 (30, p<0.01)																								
Enthusied and Confident			-							-														-	
Comfortable but Cautious						+		-	-															-	
Interested but Concerned		-	-												-	-									-
No way, No how		+				+				-														+	
Never Bicycled																									
Residence Proximity Disposition (Agree as ref.)	572.5 (12, p<0.01)																								
Neither			+	+	+	+			+					+										+	-
Disagree		+	+		+	+	+	+		-	-	-	+		-		+							-	+
Bicycling for Transportation Status (Not during past 7 days as ref.)	27.4 (6, P<0.01)		-							-					-									-	
Bicyclist Status (Never bicycled or not bicycled in past 12 months as ref.)	14.7 (6, p=0.02)		-							-					-									-	
Transport Mode (Sometimes, Rarely, Never as ref.)																									
Motor Vehicle	23.9 (6, p<0.01)			-	-		-	+	+									+	+					+	+
Bicycle	13.9 (6, p=0.03)			-					+						-									-	+
Public Transportation	5.7 (6, p=0.46)																								
School-provided Transport	0.8 (6, p=0.99)																								
Walk	22.7 (6, p<0.01)			-		-	-								+		+								

*1: Rigid, 2: Uncertain, 3: Infrastructure Oriented – Receptive, 4: Infrastructure Oriented – Resistant, 5: bicycle Track Seeking, 6: Facilitation Averse, 7: Ripe for Change

^A '+' or '-' indicates significantly more or less likely to be a member of the listed class as compared to the reference class

REFERENCES

1. Guo, J., C. Bhat, and R. Copperman, *Effect of the Built Environment on Motorized and Nonmotorized Trip Making: Substitutive, Complementary, or Synergistic?* Transportation Research Record: Journal of the Transportation Research Board, 2007. **2010**: p. 1-11.
2. Buehler, R. and J. Dill, *Bikeway Networks: A Review of Effects on Cycling*. Transport Review, 2015: p. 19.
3. Klobucar, M.S. and J.D. Fricker, *Network evaluation tool to improve real and perceived bicycle safety*. Transportation Research Board: Journal of the Transportation Research Board, 2007. **2031**: p. 9.
4. Lowry, M.B., et al., *Assessment of communitywide bikeability with bicycle level of service*. Transportation Research Record: Journal of the Transportation Research Board, 2012. **2314**: p. 8.
5. Duthie, J. and A. Unnikrishnan, *Optimization framework for bicycle network design*. Journal of Transportation Engineering, 2014. **140**(7).
6. Mekuria, M.C., P.G. Furth, and H. Nixon, *Low-Stress bicycling and network connectivity*. 2012, Mineta Transportation Institute: San Jose, CA.
7. Broach, J. and J. Dill, *Using Predicted Bicyclist and Pedestrian Route Choice to Enhance Mode Choice Models*. Transportation Research Record: Journal of the Transportation Research Board, 2016. **2564**: p. 52-59.
8. Wang, K., *Causality Between Built Environment and Travel Behavior*. Transportation Research Record: Journal of the Transportation Research Board, 2013. **2397**: p. 80-88.
9. Swords, A., et al., *Analytical Framework for Prioritizing Bicycle and Pedestrian Investments: New Jersey's Statewide Master Plan Update, Phase 2*. Transportation Research Record: Journal of the Transportation Research Board, 2004. **1878**: p. 27-35.
10. Eash, R., *Destination and Mode Choice Models for Nonmotorized Travel*. Transportation Research Record: Journal of the Transportation Research Board, 1999. **1674**: p. 1-8.
11. Hyodo, T., N. Suzuki, and K. Takahashi, *Modeling of Bicycle Route and Destination Choice Behavior for Bicycle Road Network Plan*. Transportation Research Record: Journal of the Transportation Research Board, 2000. **1705**: p. 70-76.
12. Stinson, M., et al., *Modeling the Impacts of Bicycle Facilities on Work and Recreational Bike Trips in Los Angeles County, California*. Transportation Research Record: Journal of the Transportation Research Board, 2014. **2468**: p. 84-91.
13. Daisy, N.S. and M.A. Habib, *Investigating the Role of Built Environment and Lifestyle Choices in Active Travel for Weekly Home-Based Nonwork Trips*. Transportation Research Record: Journal of the Transportation Research Board, 2015. **2500**: p. 125-132.
14. Morckel, V.C., *Examining the relationships between perceived neighborhood mobility characteristics, perceived incivilities, travel attitudes, and physical activity amongst university faculty and staff*. Journal of Transport & Health, 2016. **3**(1): p. 86-95.
15. Howard, C. and E. Burns, *Cycling to Work in Phoenix: Route Choice, Travel Behavior, and Commuter Characteristics*. Transportation Research Record: Journal of the Transportation Research Board, 2001. **1773**: p. 39-46.
16. Blanc, B. and M. Figliozzi, *Modeling the Impacts of Facility Type, Trip Characteristics, and Trip Stressors on Cyclists' Comfort Levels Utilizing Crowdsourced Data*. Transportation Research Record: Journal of the Transportation Research Board, 2016. **2587**: p. 100-108.
17. Geller, R. *Four Types of Cyclists*. 2006.

18. Appleyard, B., *Sustainable and Healthy Travel Choices and the Built Environment*. Transportation Research Record: Journal of the Transportation Research Board, 2012. **2303**: p. 38-45.
19. Harvey, E., et al., *Bicycling to Rail Stations in New Jersey*. Transportation Research Record: Journal of the Transportation Research Board, 2016. **2587**: p. 50-60.
20. Ahmed, F., G. Rose, and C. Jakob, *Commuter Cyclist Travel Behavior*. Transportation Research Record: Journal of the Transportation Research Board, 2013. **2387**: p. 76-82.
21. Wittmann, K., et al., *Cycling to High School in Toronto, Ontario, Canada*. Transportation Research Record: Journal of the Transportation Research Board, 2015. **2500**: p. 9-16.
22. Wang, X., A. Khattak, and S. Son, *What Can Be Learned from Analyzing University Student Travel Demand?* Transportation Research Record: Journal of the Transportation Research Board, 2012. **2322**: p. 129-137.
23. He, S., *Effect of School Quality and Residential Environment on Mode Choice of School Trips*. Transportation Research Record: Journal of the Transportation Research Board, 2011. **2213**: p. 96-104.
24. Bryan, M., *Bicycling for Transportation: Health and Destination, Results of a survey of students and employees from a southern urban university*. 2017, Georgia State University.
25. Asparouhov, T. and B. Muthen, *Auxiliary Variables in Mixture Modeling: 3-Step Approaches Using MPlus; Mplus Web Notes: No. 15*. 2014.
26. Dill, J. and N. McNeil *Four Types of Cyclists? Examining a Typology to Better Understand Bicycling Behavior and Potential*. 2012. 22.
27. Guell, C., et al., *Towards a differentiated understanding of active travel behaviour: Using social theory to explore everyday commuting*. Social Science & Medicine, 2012. **75**(1): p. 233-239.
28. Broach, J., J. Dill, and J. Gliebe, *Where do cyclists ride? A route choice model developed with revealed preference GPS data*. Transportation Research Part A: Policy and Practice, 2012. **46**(10): p. 11.
29. Kang, L. and J.D. Fricker, *Bicyclist commuters' choice of on-street versus off-street route segments*. Transportation, 2013. **40**: p. 16.
30. Winters, M. and K. Teschke, *Route preferences among adults in the near market for bicycling: Findings of the cycling in cities study*. American Journal of Health Promotion, 2010. **25**(1): p. 8.
31. Garrard, J., G. Rose, and S.K. Lo, *Promoting transportation cycling for women: The role of bicycle infrastructure*. Preventive Medicine, 2008. **46**(1): p. 5.
32. Jackson, M. and E. Ruehr, *Let the people be heard: San Diego county bicycle use and attitude survey*. Transportation Research Board: Journal of the Transportation Research Board, 1998. **1636**: p. 5.
33. Singleton, P. and L. Wang, *Safety and Security in Discretionary Travel Decision Making*. Transportation Research Record: Journal of the Transportation Research Board, 2014. **2430**: p. 47-58.
34. Ferrell, C. and S. Mathur, *Influences of Neighborhood Crime on Mode Choice*. Transportation Research Record: Journal of the Transportation Research Board, 2012. **2320**: p. 55-63.

35. Nuworsoo, C. and E. Cooper, *Considerations for Integrating Bicycling and Walking Facilities into Urban Infrastructure*. Transportation Research Record: Journal of the Transportation Research Board, 2013. **2393**: p. 125-133.
36. Shafizadeh, K. and D. Niemeier, *Bicycle Journey-to-Work: Travel Behavior Characteristics and Spatial Attributes*. Transportation Research Record: Journal of the Transportation Research Board, 1997. **1578**: p. 84-90.
37. Barnes, G., K. Thompson, and K.J. Krizek, *A longitudinal analysis of the effect of bicycling facilities on the commute share*, in *Eighty-fifth transportation research board annual meeting*. 2006: Washington, DC.
38. Heinen, E., B. van Wee, and K. Maat, *Commuting by bicycle: An overview of the literature*. Transport Reviews, 2010. **20**(1): p. 38.
39. Parkin, J., M. Wardman, and M. Page, *Estimation of the determinants of bicycle mode share for the journey to work using census data*. Transportation, 2008. **35**: p. 17.
40. Akar, G. and K.J. Clifton, *Influence of individual perceptions and bicycle infrastructure on decision to bike*. Transportation Research Board: Journal of the Transportation Research Board, 2009. **2140**: p. 8.
41. Aultman-Hall, L., F.L. Hall, and B.B. Baetz, *Analysis of bicycle commuter routes using geographic information systems: Implications for bicycle planning*. Transportation Research Record: Journal of the Transportation Research Board, 1998. **1578**: p. 9.

Chapter 5: Dissertation Summary

Summary of Research

This dissertation revolved around an investigation of commute bicycling. Data from the 2014 Georgia State University-Bicycling Survey was used for each analysis. In this dissertation we:

- 1) Determined if bicyclist typology (here defined as the combination of an individual's motivation to and comfort with commute bicycling in varying levels of bicycle facilities and lifetime bicycling experience) was associated with health-related quality of life;
- 2) Determined if bicyclist typology had an indirect effect on health-related quality of life through physical activity and/or commute bicycling status; and
- 3) Developed patterns of disposition toward whether destination improvements would increase the likelihood of commute bicycling. These patterns were then characterized and the effect of important covariates on the probability of class assignment was assessed.

Findings from this dissertation contribute to the health and transportation literature in multiple important ways. Regarding the first component of our research, *we identified the existence of significant health disparities by: (a) motivation to commute bicycle, (b) level of comfort commute bicycling given varying levels of bicycle facilities, and (c) lifetime commute bicycling experience.* Having established the existence of a health disparity by bicyclist typology, *we then determined that, in large part, the health disparity by bicyclist typology could be explained by differences in physical activity and, to a lesser extent, by differences in commute bicycling behavior.* Persons more comfortable commute bicycling with less bicycling facilities were more likely to perform physical activity, while increases in physical activity were associated with *decreased* probability of worse health-related quality of life. Finally, in this dissertation *we*

identified seven classes of disposition toward whether specific destination changes would increase the likelihood of commute bicycling to that destination. These classes were then characterized, including the provision of an appropriate name (i.e., *Ripe for Change*, *Rigid*, *Ambivalent*, *Cycle Track Seeking*, *Infrastructure Oriented – Receptive*, *Infrastructure Oriented – Resistant*, and *Facilitation Averse*). Significant predictors of these classes, including gender, race/ethnicity, age, bicyclist typology, residence proximity disposition, commute bicycling, bicyclist status, and the transport modes of motor vehicle, bicycle, and walking.

Practical Implications

Analyses from this dissertation help to bridge urban planning and public health. Not only were we able to identify a previously unknown health disparity by bicyclist typology, we were able to at least partially explain why this disparity exists. Our results suggest that planning efforts making commute bicycling more comfortable for individuals motivated to commute bicycle, but require bicycling facilities to do so may reduce health disparities. Health interventions may consider promoting urban environments that make physical activity, including commute bicycling, more comfortable for a larger proportion of the population to perform as a means to help reduce the health burdens related to physical inactivity and/or obesity.

This dissertation provides a framework for future policy makers at specific destinations to better target and prioritize commute bicycling interventions. The latent class measurement model we developed can help conceptualize patterns of dispositions toward proposed interventions that may be anticipated by policymakers. Further, this analysis allows for a better understanding of how to meet the commute bicycling needs of different subgroups. For example, our research indicates that interventions aiming to increase commute bicycling by targeting persons who would like to commute bicycle, but are unwilling to do so in the absence of facilities may

consider prioritizing infrastructure improvements (e.g., cycle tracks and safe and convenient parking). Similarly, individuals who currently commute primarily by motor vehicle also appear to believe that cycle tracks and improved parking would increase their likelihood of commute bicycling. Further, planners may consider there was only a single profile motivated to change their commute bicycling behavior for six of the nine proposed changes; conversely, there were four profiles motivated to change their commute bicycling behavior with improvements of cycle tracks and/or parking. Hence, policy and decision makers may be empowered to make more informed and justifiable decisions using these and related results.

Future Research Directions

This dissertation has opened up multiple lines of research that would benefit public health. First, this dissertation questions the impact of motivation to and comfort with commute bicycling given varying levels of bicycling facilities on health outcomes. Future research may want to more directly or objectively assess the effect of environmental comfort on pertinent health behaviors (physical activity and active transportation) and health outcomes. Second, this dissertation assumed a directionality of effects. Variables used in these analyses had overlapping time scales at times. Hence, we were unable to assess if bicyclist typology caused health outcomes, physical activity, or commute bicycling. Similarly, we were not able to assess if proposed changes to the destination changed future behavior. Though beyond the scope of this dissertation, future research may pursue assessing these effects longitudinally. This study did not account for current access to the destination of interest. Though we did demonstrate that disposition towards commute bicycling given a residence more proximal to the destination affected profile membership, we did not account for current distance from residence to either campus, bicycle facilities, or public transportation. We encourage future research to assess the

role of current route environment on bicycling for transportation behavior, perhaps as a moderating variable in the latent class analysis. Finally, despite a large sample size of over 4,000, our results have limited generalizability. To provide policy makers and/or public health practitioners with even more relevant information, future research may seek to either perform a random sample and/or weight the data based on known characteristics. Doing so could, for example, allow researchers to determine the estimated distribution of a population in each profile.

Take Home Message

There are two broad “take home” messages from results in this dissertation. First, policies or interventions promoting the adoption of a version of Roger Geller’s bicyclist typology may have a positive impact on understanding the factors influencing the health of a large proportion of the population. As such, urban planning may inform efforts to reduce health disparities and may do so through changes in physical activity. Second, specific destinations serving as a place of employment and/or education for large numbers of persons may play an important role in increasing the healthy behavior of commute bicycling. Policy makers at these destinations may prioritize and target their efforts to increasing commute bicycling as there appears to be an audience receptive to changing their behavior given changes in the destination. Not every potential destination change will impact the intended audience equally. Subgroups may be targeted to enhance the effectiveness of the change. The single destination change that appears to be the most widely agreed upon across patterns of disposition is that increasing the availability of cycle tracks would increase the likelihood of bicycling for transportation to the given destination.