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PERSON-ENVIRONMENT INTERACTIONS AND OLDER ADULT MOBILITY

A Dissertation in

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by

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Abstract

Maintenance of personal mobility is one of the most important components of lifespan development and indicators of successful aging. Given its associations with older adults' health and well-being, this dissertation takes a developmental approach in considering mobility an indicator of successful aging. Guided by theories by Hans Werner-Wahl and Paul Baltes, the dissertation aims to elucidate person-environment interactions in determining older adults' mobility. Though mobility research often conceptualizes mobility as driving versus not driving, this dissertation considers the full spectrum of older adult mobility including not only the modes of transportation older adults take but also multiple indicators of driving mobility in order to gain a fuller picture of older adults' mobility.

Both papers use data from the 2017 National Household Travel Survey (NHTS). The NHTS is a nationally representative sample of households in the 50 US states and the District of Columbia conducted by the Department of Transportation. The survey was conducted across twelve months of the year and seven days a week in order to provide a representative estimation of travel across seasons and weekends/weekdays. The NHTS surveyed 89,757 people 62 years and older from 62,289 households, ranging in age from 62 to 92 years of age (M=71.57, SD=7.48). About a fifth of participants (18%) reported a health-related travel difficulty, and 28% experienced in-person license renewal. Since the dataset includes multiple participants per household, each paper addresses the dependencies in the dataset in different ways.

Paper 1 examines a controversial social environmental predictor of older adults' mobility: license renewal policy. There is little evidence for the safety benefits of more stringent license renewal laws for older drivers in the United States. However, some work in the United States suggests that in-person license renewal policies in particular are associated with lower driving

mobility among older adults. Paper 1 is the first study to my knowledge that examines how health difficulties may interact with license renewal policies in predicting multiple indicators of driving mobility. Using information from the National Conference of State Legislatures, I created a database of license renewal laws for the 50 US states based on publications from the National Conference of State Legislatures with variables indicating whether the state had in-person license renewal requirements for older adults and the length of time in between in-person license renewals. Using generalized estimating equations (GEE) to account for multiple observations within a household in a sample of 89,757 older adults 62 years and older in the NHTS, Paper 1 found interactions between health-related travel difficulty and in-person license renewal. Among participants who experienced in-person license renewal, participants who reported health-related travel difficulty drove significantly fewer miles than participants who did not report such difficulty. For older adults with no health-related travel difficulty, a longer renewal cycle was associated with greater annual driving mileage. For older adults with health-related travel difficulty, there was no association between renewal cycle length and annual driving mileage.

Paper 2 uses latent class analysis (LCA) to identify groups of older adults based on their use of driving, walking, bicycling, and public transportation as a mode of transportation. Paper 2 uses a random subsample of older adults 62 and older from the NHTS (n=28,055) who did not share a household and replicates LCA results in a separate subsample. LCA identified three classes of older adults: Drivers Who Walk, Nondrivers, and Multimodal Drivers. Health-related travel difficulty and urban/rural status were related to the prevalence of each class. Regardless of urban/rural status, older adults without health limitations had a higher prevalence of Drivers Who Walk compared to older adults with health limitations. Most rural adults with health difficulties belonged to Drivers Who Walk. Both urban and rural groups without travel difficulties had small numbers of participants in the Nondrivers class, though urban older adults with no travel difficulties had a slightly higher prevalence compared to rural older adults with no difficulties. Multimodal Drivers had the fewest older adults in its class. Among urban older adults, there was a greater difference in prevalence of Multimodal Drivers between older adults who reported travel difficulties and those who did not compared to rural older adults.

Overall, Papers 1 and 2 highlight the need for research and policy to consider the role of health limitations, environment, and their interaction in determining older adults' mobility. Research and policy must also move from mobility as a binary variable and consider the many ways in which older adults are mobile. Advances in technology and policy approaches, such as advanced driver-assistance systems (ADAS) and mobility as a service (MaaS), are possible opportunities for environmental supports on maintaining older adults' mobility, particularly for older adults with health limitations and who live in rural areas. However, these changes must be implemented carefully in order to ensure that all older adults are able to fully participate in services to improve their mobility. The results of the current papers provide a unique contribution to our understanding of how older adults move around in their world and suggest ways that research and policy can work together to ensure older adults stay safely mobile throughout their lifespan.

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Chapter 1: Introduction

Maintenance of personal mobility is one of the most important markers of successful aging as evidenced by a wealth of empirical research showing the negative consequences of reduced mobility in older adults (Bentley et al., 2013; Boyle et al., 2010; Crowe et al., 2008; James et al., 2011; Xue et al., 2008). Though a large body of research on older adult mobility has focused on the negative consequences of losing driving as a means of mobility (e.g., Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Kim et al., 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008), mobility is a heterogenous concept that includes a variety of transportation modes beyond driving. Even within a single transportation mode, such as driving, mobility can be conceptualized in a variety of ways including annual driving mileage, traveling on a given travel day, and driving status. Mobility can also be multimodal; older adults may utilize different transportation modes to get around, such as taking a car for longer trips and using public transportation for shorter trips. While mobility has been assessed in a variety of ways across studies, the heterogeneity of mobility has not been a focus of older adult research.

Across modes and measures, older adult mobility is related to a variety of interpersonal factors, including cognitive, psychosocial, physical, and financial influences, and environmental factors, including weather, terrain, and traffic (Webber et al., 2010). Prominent lifespan developmental theories emphasize that development is also driven by interactions between the person and the environment, and that the need for environmental supports increases with age (Baltes, 1997; Wahl & Oswald, 2010). It follows that mobility will be influenced by person-environment interactions in addition to individual contributions from the person and the environment. However, research on older adult mobility has not examined how person-environment interactions are related to mobility. Guided by developmental theories on person-environmental influences on lifespan development, the current studies examine person-environment interactions in predicting multiple indicators of mobility for older adults: driving status, annual driving mileage, traveling on a given travel day, and use of alternate transportation modes beyond the car including walking, bicycling, and public transportation.

Importance of mobility

Mobility is one of the most important predictors of well-being in older adults. Mobility is a broad term referring to a person's ability to move themselves within a space (Webber et al., 2010). Mobility may refer to a specific mode of transportation, such as driving mobility, but it can also refer to total travel by any means, including walking, public transportation, and driving. Accumulating longitudinal evidence reveals that declines in general mobility are associated with diminished health-related quality of life (Bentley et al., 2013), frailty (Xue et al., 2008), cognitive decline (Crowe et al., 2008), Alzheimer's disease risk (James et al., 2011), and increased mortality risk (Boyle et al., 2010). Driving mobility is particularly critical for older adults' well-being: Driving cessation is associated with a number of negative outcomes, including reduced social engagement (Curl et al., 2013; Mezuk & Rebok, 2008), greater unmet leisure needs (Haustein & Siren, 2014), long term care entry (Freeman et al., 2006), depression (Marottoli et al., 1997; Ragland et al., 2005) and mortality (Edwards, Perkins, et al., 2009). Nondrivers have lower social engagement than drivers (Choi & DiNitto, 2015), and older adults who were once drivers but have given up driving are more likely to say they have reduced out of home activities (Kim et al., 2014).

The strong association between driving and health and well-being for older adults is likely related to the predominance of driving as a mode of transportation. In the United States, 85% of people 65 and older and 62% of people 85 years of age and older had their driver's license in 2017 (Federal Highway Administration, 2019). In addition to the practical utility of driving as a way to engage with friends, family, and services, driving also serves an important role in older adults' psychological well-being. Older adults see driving cessation as a loss of independence and autonomy (Adler & Rottunda, 2006). In fact, older adults report keeping their cars available for use even if no one in the household is licensed to drive because having a car is a symbol of independence (Davey, 2007). Qualitative studies show the striking psychological difficulties in driving cessation. In one study, an older adult said giving up driving was "like cutting off an arm or a leg" (Davey, 2007, p. 54). In another study, an older adult said, "When you stop driving, you become prisoner" (Adler & Rottunda, 2006, p. 232). Maintenance of mobility, particularly driving mobility, is clearly an important part of development in older adulthood and a component of successful aging.

Developmental theory and mobility

As mobility is an important part of development, theories of lifespan development and successful aging may guide understanding of the processes that determine mobility. Central to multiple theories of lifespan development is the principle that both personal and environmental factors influence development. One such theory is by Wahl and Oswald who present a theoretical framework for aging well in "Environmental Perspectives on Ageing" (Wahl & Oswald, 2010). In this model, the environment is conceptualized broadly and includes both the physical environment, such as physical characteristics of a neighborhood, and social environment, such as relationships with the family. The model describes person-environment processes which are aided by person-environment resources including experience, belonging, behavior, and agency. The way a person navigates person-environment processes leads to developmental outcomes including identity, well-being, and autonomy, which in turn lead to aging well. This process occurs over both the individual life course and across historical change.

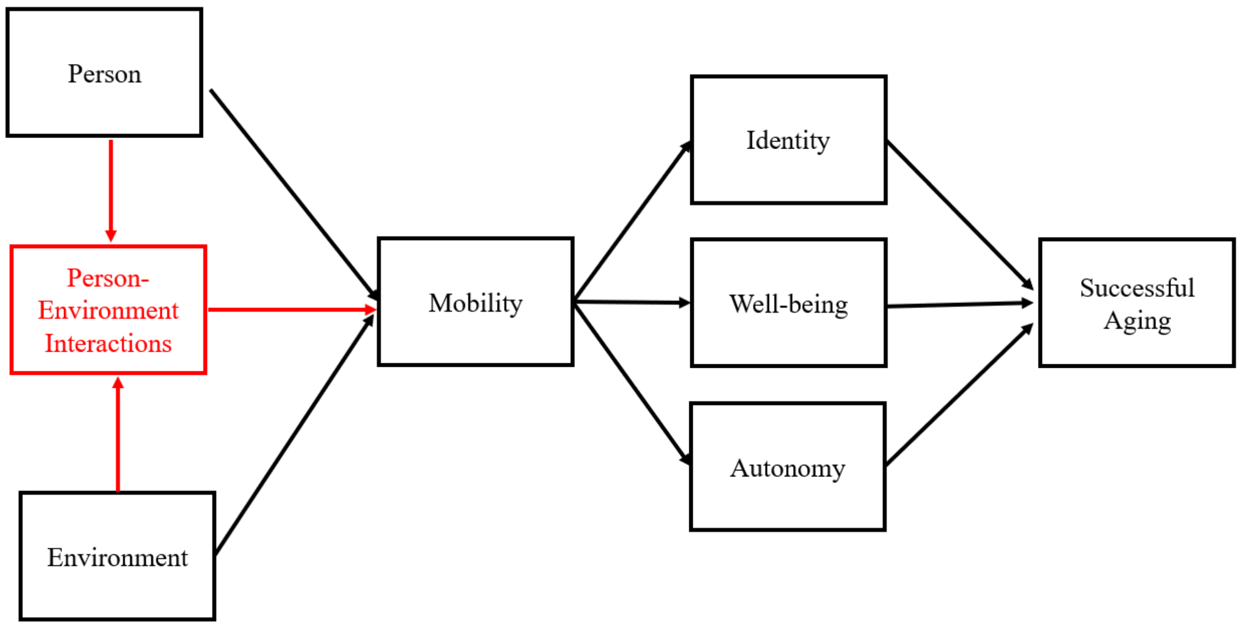

Figure 1. Conceptual model for dissertation. Adapted from Wahl (2012).

Figure 1 presents an adapted model based on this theory applied to mobility. In this model, both the person and the environment are directly related to mobility, and person-environment interactions are also related to mobility. Mobility is predictive of the developmental outcomes of identity, well-being, and autonomy. This is supported by research on the importance of mobility for older adults' psychological well-being. The developmental outcomes in turn lead to successful aging. The box in red indicates where the dissertation is contributing to the literature. Person-environment interactions have not been examined in the prediction of older adults' mobility.

Baltes is another prominent developmental theorist who presents a theory of lifespan development focused on person-environment interactions. Baltes' model (1997) uses the term "culture" rather than environment to refer to anything generated by humans that is outside of biology (i.e., interpersonal factors). In this model, the need for culture increases across the lifespan due to age-related biological declines. At the same time, the efficacy of culture decreases with age. This second point is related to the concept of plasticity which declines with age. Baltes does not specify the person-environment processes through which development occurs that are specified in Wahl and Oswald's model, but Baltes specifies the environment as increasing in importance as people age.

Figure 2 includes Baltes' original models in the top two figures and adapted models that are relevant to this dissertation in the bottom two figures. Rather than looking at age as a main predictor of mobility, this dissertation examines health difficulties as an aspect of the person that may increase with age. Health difficulties are a more specific way to understand elements of the person than age alone. In the bottom two figures, the need for environmental support increases as health difficulties increase, while the efficacy of environmental support decreases. Developmental outcomes are not explicitly included in Baltes' figures as they are in Wahl and Oswald's model. Baltes' model is meant to be a framework or meta-theory that can serve as the base of any developmental theory. The tenets of Baltes' theory can be applied to the conceptual model for older adult mobility presented in Figure 1. As people age, the role of the environment becomes even more important in person-environment interactions.

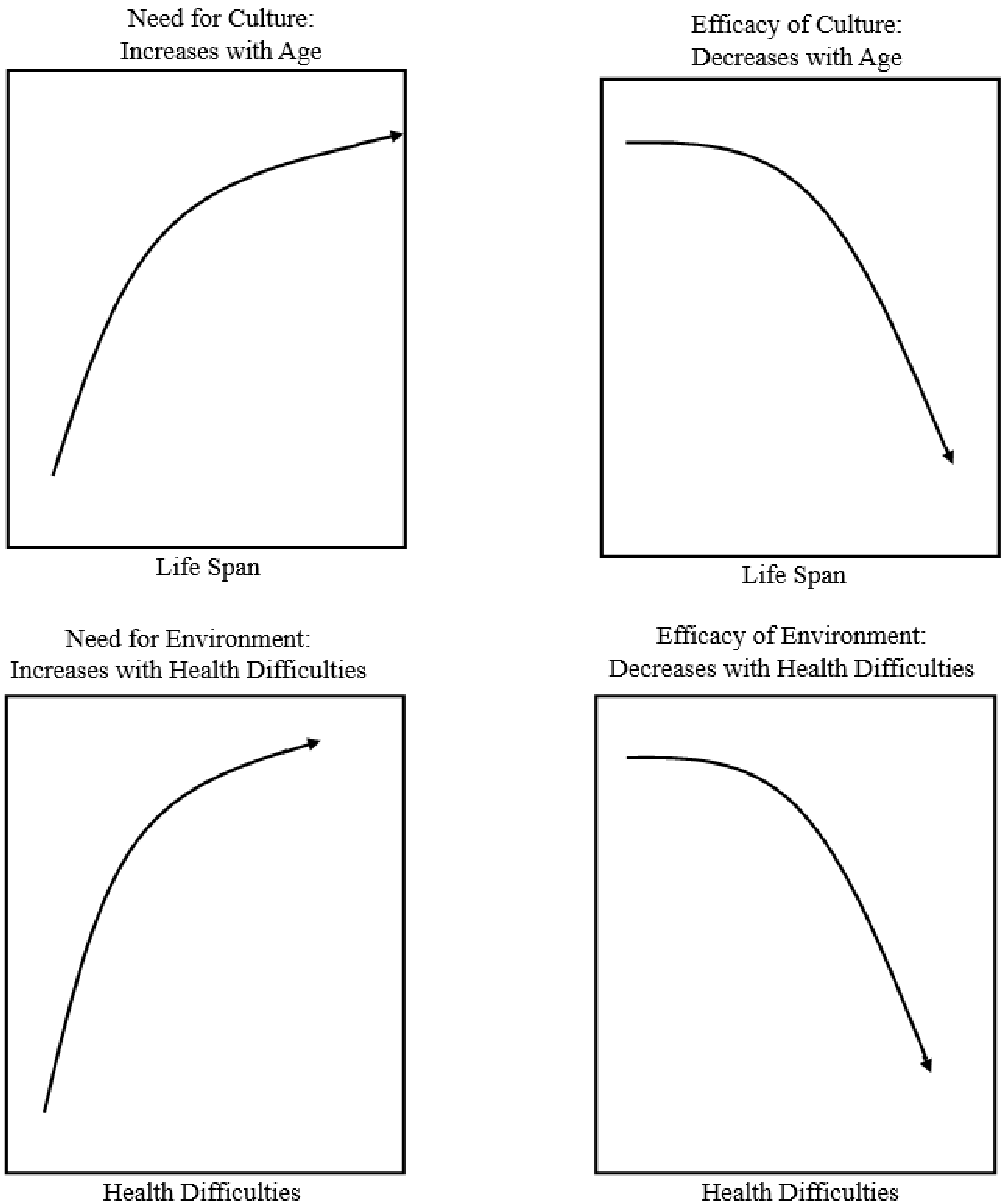

Figure 2. Model outlining the association between environment and health difficulties. Adapted from Baltes (1997).

According to both Wahl (2010) and Baltes (1997), only considering the influence of the environment or the person does not give the full picture of development. The way a person navigates person-environment interactions leads to different developmental outcomes depending on how the interactions are resolved. For example, two people may have the same health condition that limits their ability to drive safely. One person moves to a city where there is better access to public transportation, while the other person remains living in their rural home. The person who lives in the city has a greater chance of maintaining their mobility compared to the person who stayed in a rural area. Person-environment interactions such as these are particularly salient as people age because aging is accompanied by a decrease in functional capacity.

Though person-environment interactions are a key aspect of development, they are not often the focus of research on older adult mobility. Person-environment interactions must be considered in order to fully understand what determines mobility for older adults. Specifically, the laws and policies of a state or country and whether an area is considered rural or urban are important parts of the environment that can influence older adults' mobility. A person who lives in a rural area with limited public transportation options who also has health difficulties that make driving difficult, or a person who lives in a state with stringent license renewal policies who has health difficulties, may have poor person-environment fit. License renewal policies and urbanicity have the potential to impact older adults' mobility, but there is currently a lack of information on how license renewal policies and urbanicity interact with individual characteristics to determine older adults' mobility.

Heterogeneity of Mobility

Despite the predominance of driving as a means of transportation in the United States, older adults use a variety of other transportation modes including public transportation, walking, and bicycling. Older adults also use combinations of transportation modes, and the concept of driver versus non-driver which is prominent in research on older adult mobility does not give the full picture of how older adults move around. Even within driving, there are variations in how it is measured that may reflect different types of mobility. Mobility is a heterogenous concept. Outcomes such as miles driven per week, miles driven per year, time spent driving, and number of trips per week can give very different pictures of mobility. These differences are particularly salient for environmental differences in mobility. For example, two older adults may report driving 100 miles in the past two weeks. The rural older adult may have driven to the grocery store 10 miles away, whereas the urban older adult only drove two miles to the grocery store. Both older adults were able to access the grocery store, so mileage alone may not be a good indicator of whether or not each person had sufficient mobility.

The number of licensed drivers also does not give a complete picture of driving. Given the strong ties between driving status and identity and autonomy, it is likely that many older adults who no longer drive may still retain a driver’s license to fulfill psychological needs. In fact, some older adults report retaining their driver’s license for identification purposes or for a sense of identity (Siren & Haustein, 2016). Older adults may also have stopped driving before their driver’s license renewal has expired. In some states, older adults’ driver’s licenses expire after eight years. An older person may have renewed their license, driven for a year, and then stopped driving. They would still be categorized as a licensed driver for seven years even if they were no longer driving. While single measures of mobility contribute to the picture of older adults’ mobility, including multiple measures in research studies are needed to increase our understanding of how older adults move around.

Proposed Studies

Given the importance of mobility for older adults' developmental success, it is important to examine predictors of mobility. Previous work has also demonstrated that both driving mobility and general mobility are important for older adults' well-being. The field of older adult mobility would benefit from work focusing on person-environment interactions as determinants of mobility. The two studies contribute to the field of older adult mobility by examining person-environment interactions and by examining a variety of conceptualizations of mobility outcomes. Paper 1 examines the relationship between license renewal policies and driving mobility using generalized estimating equations analysis. A key aim of Paper 1 is to examine the interaction of health difficulties with license renewal policies in predicting driving mobility. The main hypothesis of Paper 1 is that health difficulties will moderate the association between license renewal policies and driving mobility, suggesting that older adults with health difficulties may be differentially impacted by stringent license renewal policies compared to older adults without health difficulties.

Paper 2 examines patterns of transportation mode use among older adults beyond driving a personal vehicle. Driving is not the only means of transportation for older adults. Not all older adults drive as the primary means of transportation, and some older adults do not drive at all. Paper 2 extends mobility beyond driving and also considers walking, bicycling, public transportation, and passenger behavior. The key interaction in Paper 2 is the interaction of medical conditions with rural versus urban environment in predicting general mobility. The aim of Paper 2 is to determine whether patterns of transportation mode use are related to general mobility and whether older adults who report medical conditions are more likely to belong in a specific transportation use class depending on whether they live in a rural or urban area.

Both studies use data from participants 62 years of age and older in the most recent National Household Travel Survey (NHTS) conducted by the US Department of Transportation (Federal Highway Administration, 2017). The 2017 NHTS is a publicly-available cross-sectional national dataset that provides in-depth information on participants' transportation mode use and mobility. The NHTS includes information from 89,757 participants 62 years and older from 62,289 households, representing all 50 states and the District of Columbia. The NHTS contains four sources of data: a household dataset with information on the household and basic information on each person in the household, a person dataset with detailed information for each person, a travel day dataset for each person which includes detailed information on each trip the participant took on the travel day, and a vehicle dataset which includes information on each household vehicle. The large, representative nature of the NHTS sample, coupled with the variety of mobility measures, make the NHTS an excellent dataset to use to answer the questions posed in the two dissertation papers.

Table 1. Mobility spectrum represented in Papers 1 and 2

Transportation mode	Use mode? Yes/No		Amount of use Low–High	
Driving	Paper 1	Paper 2	Paper 1	
Walking		Paper 2		
Bicycling		Paper 2		
Public Transportation		Paper 2		

The studies take different approaches to examining older adults' mobility. Paper 1 takes a sample-level approach to examining how license policy and medical conditions impact driving behavior. Paper 2 takes a person-centered approach, aiming to understand patterns of older adults' transportation use beyond the private vehicle and how another conceptualization of environment, urban/rural status, interacts with medical conditions to impact overall mobility. The two studies provide important information to the current knowledge of older adult mobility and its predictors. Table 1 presents the contributions of Paper 1 (green) and Paper 2 (blue) to research on the older adult mobility spectrum. Mobility can be conceptualized as using a particular mode of transportation and how much a person uses the mode of transportation. Paper 1 takes an in-depth look at driving, looking at both drivers and non-drivers and amount of use of driving as a transportation mode. Paper 2 takes a broader look at multiple transportation options, looking at whether or not a person is a user of driving, walking, bicycling, and public transportation as a mode of mobility. Understanding the mobility implications of license renewal policies, as well as how older adults may be particularly affected based on medical conditions and urbanicity, is necessary to improve license renewal policies to best serve the older adult population.

The results of Paper 1 can provide important information to states and suggest changes to those specific policies to help maintain older adults' mobility. The results of Paper 2 can inform resource allocation of community programs aimed at improving older adults' mobility. Understanding patterns of older adults' transportation mode use beyond the personal vehicle is a key step to understanding how to preserve older adults' mobility. For example, older adults who live in rural areas and have health conditions may need different types of transportation support than older adults who live in urban areas and have health conditions, or older adults who live in rural areas and do not have health conditions. Specific mobility solutions may be tailored to older adults based on medical condition and urbanicity, and older adults who are vulnerable based on these characteristics will not be left behind in interventions and public policy aimed at improving older adults' mobility.

Chapter 2: Paper 1

Introduction

Driving mobility is essential to older adults' well-being (Choi & DiNitto, 2015; Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Kim et al., 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008). While license renewal policies are aimed at improving driving safety, they may have unintended mobility consequences: Several studies have found that older adults who live in regions with license renewal policies aimed at older adults have less driving mobility than older adults who live in regions without such policies (Ichikawa et al., 2015; Keall & Woodbury, 2014; Kulikov, 2010; Ross et al., 2011). The finding that license renewal policies impact older adults is consistent with developmental theory which emphasizes the role of the environment in determining development. Based on developmental theories by Wahl (2010) and Baltes (1997), which emphasize person-environment interactions, license renewal policies may be more detrimental to the driving mobility of older adults who have personal characteristics that may make them more vulnerable to the effects of the environment.

Specifically, older adults who have functional limitations related to health conditions and who live in states with age-based license renewal policies may have particularly lower driving mobility compared to older adults without limitations and those who live in states without age-based license renewal policies. Older adults with functional limitations may have more difficulty or be less likely to travel to a licensing center even when it is required for license renewal, resulting in not renewing their licenses, even if they are safe drivers otherwise. Age-based license renewal laws may also affect older adults' driving confidence, leading to driving fewer miles per year. The current study examined the association between license renewal policy and three indicators of driving mobility (driving status, annual driving mileage, and traveling on a given travel day) in a national sample of older adults in the United States and the potential moderating role of health-related travel difficulties.

Licensing renewal policies for older adults in the United States

States employ a variety of license renewal requirements as a way of identifying potentially unsafe drivers. Within the United States, driver license renewal policies relevant to older adults differ by state on three basic requirements: length of renewal cycle, in-person requirement for renewal, and testing required for renewal. Length of renewal cycle refers to the frequency with which a person must renew their driver's license and varies widely from state to state. As of 2019, New York, Oregon, Wisconsin, and the District of Columbia have a renewal cycle of eight years for drivers of all ages, the longest renewal cycle in the United States (AAA Foundation for Traffic Safety, 2016). These states' renewal cycles apply to all drivers, regardless of age. Other states have specific renewal cycles according to driver age. For example, Illinois' four-year renewal cycle is reduced to two years for drivers 81 to 86 years of age and to one year for drivers 87 years of age and older. In Virginia, the eight-year renewal cycle drops to five years for drivers age 75 and older. Length of renewal cycle and the time in between renewal cycles vary widely from state to state and are mostly arbitrary.

Beyond length of renewal cycle, states may have specific requirements for older adults in order to renew their driver's licenses. One of the main ways that states differ is whether or not licenses must be renewed in-person, or if licenses may be renewed through mail or electronic renewal. As of 2019, in Alabama all drivers regardless of age can renew their license every four years through the mail and never need to come into a licensing center in-person to renew. However, in the neighboring state of Georgia, once drivers reach 64 years of age they cannot renew by mail or online renewal and must come to a licensing center in-person to renew their license every eight years. As of 2019, twenty out of fifty states in the US require in-person renewal for older drivers. About half US states do not require older adults to renew their license in-person at any age as of 2019, while six states have in-person renewal cycle lengths of less than five years.

Beyond in-person licensing renewal, some states also require drivers to pass specific tests or provide necessary qualifications for license renewal, known as age-based testing (ABT). The goal of ABT is to screen older adults applying to renew their driver's license and make predictions on driving safety based on test performance. The most common ABT requirement is passing a vision test consisting of a visual acuity and visual field test, which can be completed at a licensing center or at an off-site center such as a doctor's office (AAA Foundation for Traffic Safety, 2016). For example, as of 2019, Florida requires older drivers to pass a minimum visual acuity score of 20/50 with or without correction in either eye, and a visual field score of at least 130 degrees. Virginia's visual acuity requirement is 20/40 visual acuity and 110 degree visual field. As of 2019, two states (IL, NH) also require older drivers to pass a road test. Some states, such as the District of Columbia, require older adults to provide a statement from a physician certifying that the older adult is "physically and mentally competent to drive". States may also utilize license restriction, though this is done infrequently. Common restrictions include driving only during the day, under a maximum speed, and combinations of restrictions. However, few restricted licenses are actually issued in the United States. A recent review of restricted licensing policies in four states (IA, VA, FL, and MD) found that very few drivers had license restrictions, ranging from 0.05-1.70% of the total licensed older adult driver population (Joyce et al., 2018).

Another licensing provision is medical evaluation for fitness to drive; states can work with physicians to either allow for volunteer or mandated physician reporting of fitness to drive.

As of 2019, all 50 states allow physicians to voluntarily report medically at-risk drivers, though only 6 states mandate reporting (AAA Foundation for Traffic Safety, 2016). However, variations in medical fitness to drive evaluation from state to state make it difficult to compare states. A review of all-inclusive physician reporting forms as of 2008 found that no two states have the same medical evaluation form (Meuser et al., 2012). For example, only 5 states use forms that prompt the physician to obtain the patient's driving history, and 27 states' forms prompted for a license restriction recommendation. Studies within a single state have found that physician reporting is effective at getting severely impaired drivers off the road, such as a study of physician reporting in Missouri which found that physicians commonly made fitness-to-drive recommendations based on Alzheimer's disease diagnosis, cognitive impairment, or other acute brain injury (Meuser et al., 2015). However, a study of mandatory physician reporting in the United States found no relationship between mandatory physician reporting and crashes from 2004 to 2009 (Agimi et al., 2018). One of the problems with physician reporting is a lack of training: Physicians report that they do not feel as though they have adequate training and/or knowledge in assessing fitness-to-drive (Jang et al., 2007; Meuser et al., 2006), and physician assessments of driving competency do not have perfect agreement with on-road driving evaluations which are considered the "gold standard" of driving assessment (Meuser et al., 2016; Ranchet et al., 2016). The practical use of physician assessments in standard license renewal requirements or mandatory reporting remains unclear.

One of the main motivations for licensing policies is to increase road traffic safety. In particular, states may require in-person renewal as a way to "catch" more unsafe older drivers who come in to renew their license and are flagged by license center staff. However, a major limitation of driver licensing policies for older adults is that they are mostly not evidence-based.

In some cases, high-profile crashes involving older drivers have led to legislation that aims to make more restrictive licensing laws for older adults. In other cases, legislation is proposed based on statistics showing that the number of crashes increases at a certain age. Anecdotal evidence of high-profile crashes and statistics on older driver crashes played a role in the decision to increase the stringency of older driver licensing laws in Virginia in 2013. In 2013, Virginia legislators commissioned a report on older driver safety to determine whether Virginia should add more stringent criteria for older driver license renewal. The report shows that the number of crashes per licensed driver in Virginia decreases with age but the percent of drivers who are at-fault in crashes and percent of injuries or fatalities increases after age 65. The bill was also supported by a person whose brother was killed by an older driver. The bill, HB771, was passed and the age at which older drivers must renew their license in-person dropped from 80 to 75 and the length of in-person renewal dropped from 8 years to 5 years. However, some advocacy groups opposed the bill, such as AARP Virginia. Similar cases where more stringent legislation has been passed in response to high-profile crashes involving older adult drivers have happened in other states including Massachusetts (Shishkin, 2009, July 14) and Texas (Vertuno, 2007, September 1). License renewal policies for older adults may also be influenced by advocacy groups such as AARP, which does not believe that licensing laws based on age alone or appropriate or fair.

Licensing renewal policies and older adult safety

As the ultimate goal of licensing policy is improving road safety, the impact of licensing policy on older adult crashes has been a major focus of driving safety research. However, research suggests that licensing policies in the United States are not an effective method of reducing older adult crashes (Grabowski et al., 2004; Langford et al., 2008; Tefft, 2014).

Renewal requirements based on vision have particularly been under scrutiny (Langford et al., 2008; Langford & Koppel, 2006; Staplin & Freund, 2013), as observational research has not found associations between visual acuity and motor vehicle crashes (Cross et al., 2009; Wood et al., 2013). Tefft (2014) provides strong evidence in a longitudinal analysis of changes in driver licensing policies and changes in fatal crash rates that the association between crashes and vision testing depends on whether states also require in-person testing. Among states that required in-person license renewal, the requirement of a vision test at the renewal was not associated with crashes. Vision test requirements were only associated with reduced crashes among states that do not require in-person renewal and only for adults 85 years and older. Requiring older adults to renew their license in-person may be more relevant to crashes than requiring ABT at renewal, though there is also little evidence for the role of in-person testing requirements in reducing crashes. Studies that compare crashes in states with ABT and states without ABT that do not control for in-person testing may actually be comparing in-person renewal to online or mail renewal.

Another complication of license renewal policies is that their association with crashes may depend on driver age. For example, Agimi and colleagues found that after controlling for hospitalization rates of younger drivers, in-person vision testing was significantly related to hospitalization among drivers 60 to 64 but not older age groups in the United States (Agimi et al., 2018). A retrospective longitudinal study, also in the United States, found similar findings, though vision test requirements were only associated with reduced crashes for drivers between 65 to 74 years of age (Grabowski et al., 2004). In-person renewal was only significantly associated with reduced crashes for drivers 85 and older. These results suggest that license renewal policies may differentially impact older adults, which is unsurprising as the term "older adults" encompasses over a thirty-year age span and a heterogenous population.

There is also little evidence of a safety benefit of shorter renewal cycles for older adults. Longitudinal studies have not found evidence of fewer crashes in states with shorter renewal cycles (Grabowski et al., 2004; Tefft, 2014). Using middle-aged driver crashes as a control, a retrospective longitudinal study of all fatal crashes in the United States between 1990 and 2000 found that length of renewal cycle was not associated with crashes among older adults 65 and older (Grabowski et al., 2004). Another longitudinal study of older driver fatal crashes in the United States examined the association between renewal cycle length and crashes in 46 states. After controlling for the fatal crash rate of drivers between 40 and 54, there was no association between renewal cycle length and fatal crash involvement of drivers 55 and older (Tefft, 2014). Studies outside of the United States have also not found differences in crash rates related to ABT in Australia (Langford et al., 2008) or restricted driver licensing in Canada (Nasvadi & Wistner, 2009). A cross-sectional study in Canada did find higher crash rates in provinces with more strict licensing policies for older adults as determined by length of renewal cycle and testing requirements (Tay, 2012). However, this study was conducted outside of the United States so its generalizability to the license policy and crash situation in the United States is limited by differences in culture, geography, and other environmental factors.

Licensing renewal policies and mobility

Despite their intended goal of improving road safety, there is not strong evidence of more stringent license renewal policies improving older adults' driving safety. Given the lack of safety benefits, it is also important to consider the mobility implications of driver licensing policies, given the wealth of empirical evidence of the negative impacts of reduced driving mobility for older adults (Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008; Ragland et al., 2005). To my knowledge, in the last twenty years there have been two papers published examining the association between license renewal policies for older adults and older adults' mobility in the United States (Kulikov, 2010; Shen et al., 2020).

A 2010 study of license renewal policies and mobility among older adults in the United States used the Asset and Health Dynamics of the Oldest Old (AHEAD) study to examine associations between license renewal policy and driving mobility in 1993, 1995, 1998, and 2000 (Kulikov, 2010). The authors examined four aspects of licensing policies: accelerated renewal, in-person renewal at ages 70 and older, restricted licensing, and ABT. They found that all licensing policies examined were associated with a reduction in mobility, cessation, or both. A recent study examined license renewal policies and mobility in the United States using survey data from the 2003 to 2017 American Time Use Survey, a nationally-representative sample of community-dwelling adults in the United States (Shen et al., 2020). The survey included over 36,000 adults over 65 years of age. The authors found that renewal period regardless of in-person status was not associated with daily driving. However, in-person renewal period was associated with reduced driving among women 75 years and older but not men of any age. The results of this study support the hypothesis that in-person renewal is more important for older adults' mobility than any kind of renewal including mail and online.

Mobility consequences of stringent licensing policies for older adults have also been found in other countries. In three Australian states, older adults who would have experienced ABT based on their age and state of residence were less likely to drive than older adults who had not experienced ABT (Ross et al., 2011). Studies in Japan (Ichikawa et al., 2015) and New

Zealand (Keall & Woodbury, 2014) used a qualitative approach to examine patterns of mobility around the time an on-road test was implemented as an ABT for licensure. In both papers, there was no clear pattern of reduced crashes related to the implementation of the on-road test, but declines in mobility appeared to occur after policy implementation. In Japan, more older drivers 80 years and older seemed to surrender their license after the policy implementation compared to adults 75 to 80 who were also required to take the on-road test. Research suggests that driver's licensing policy aimed at improving older adults' driving safety may not actually improve safety but rather harm older adults' mobility, particularly among older age groups.

Person-environment interactions

Evidence of negative outcomes of driving cessation (Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008; Ragland et al., 2005) point to driving mobility as an important predictor of successful aging. Theories of lifespan development and successful aging offer a lens through which the impact of license renewal policy on older adults' mobility can be understood. Two prominent theories of lifespan development categorize influences on developmental outcomes into two sources: the person and the environment (Baltes, 1997; Wahl & Oswald, 2010). Baltes (1997) conceptualizes the "person" as anything related to biology and genetics, such as declines in visual function with age, while the environment refers to anything outside of the person. Wahl provides more detail on what constitutes the environment: The environment can be physical, such as the number of bus stops near the home, or social, such as the unemployment rate (Wahl & Oswald, 2010). Importantly, the environment can be supportive or restrictive to a person's development (Wahl & Oswald, 2010).

Applied to older adult driving mobility, function is an aspect of the person that plays an important role in determining older adults' mobility. Function can be conceptualized in different ways, including physical function, activities of daily living (ADL), and instrumental activities of daily living (IADL). Better performance on objectively-assessed physical function, assessed by tests such as the Turn 360 task and Short Physical Performance Battery, is associated with greater driving mobility (Antin et al., 2012; Ng et al., 2019; Phillips et al., 2016; Sims et al., 2007). Self-reported function is also associated with mobility in the general population and in specific subsamples. In a cross-sectional study of 150 Meals on Wheels recipients in suburban New York state, worse self-reported independent activities of daily living (IADL) was associated with less likelihood of being a driver (Hess et al., 2016). Among over 17,000 participants in the Health and Retirement Study, self-reported ADL and IADL difficulties were associated with greater odds of driving cessation across 10 years (Dugan & Lee, 2013). Studies on the association between licensing policies and older adult mobility and safety have also found differential associations depending on driver age (Agimi et al., 2018; Grabowski et al., 2004). It is likely that these associations emerge from differences in function rather than age alone. As noted by Hess and colleagues, (2016), while the role of age in driving has been emphasized, age may be a proxy for IADL and health status which are related to driving. Furthermore, Langford and Koppel (2006) note that there is significant variation within older adults even if they share the same medical condition, so standardized age-based testing may unfairly reduce some people's mobility.

License renewal policies can be considered as part of the social environment that influence a person's development and have the potential to be restrictive or supportive for older adults' mobility. A central tenet of developmental theory is the role of person-environment (P-E) interactions. Both Wahl (2010) and Baltes (1997) emphasize that interactions between the person and the environment are what drive development, and these interactions can either be done successfully or not successfully. Further, the role of the environment may become more important as people age and function decreases (Baltes, 1997). In understanding determinants of older adults' mobility, both the environment (license renewal policy) and the person (functional status) as well as interactions between the two must be considered.

To my knowledge, only one study of license renewal policy and mobility has included a variable capturing functional limitations. This study examined the association between license renewal policies and mobility in older adults while controlling for difficulty walking several blocks (Kulikov, 2010). The authors used data from over 9,000 participants 70 years and older living in the United States across seven years. The study's results were consistent with other studies of function and mobility: participants who reported difficulty walking several blocks were more likely to reduce their driving and cease driving across seven years (Kulikov, 2010). As developmental theory emphasizes the role of person-environment interactions in determining developmental outcomes, it would have been informative to see how function and license renewal policies interacted in the association with driving mobility. However, the paper did not report interactions between walking difficulty, license renewal policy, and driving cessation. Participants who reported difficulty walking several blocks and live in states with more stringent license renewal policies for older adults may report lower driving mobility than participants without reported walking difficulty because more stringent license renewal policies may discourage people with functional limitations from renewing their driver's licenses.

It is also important to examine multiple indicators of older adults' mobility. For example, in Kulikov's study (2010), older adults living in states with accelerated renewal policies for older drivers were more likely to reduce but not cease their driving compared to older adults in states without accelerated renewal policies. If the author only looked at driving status as an outcome, the association between accelerated renewal and driving mobility would not have been discovered. Research on function and driving mobility has also found different associations with different measures of driving mobility. In Phillips et al. (2016), grip strength was associated with changes in driving space and miles per week across five years, while Turn 360 and self-reported physical function was associated with exposure to high-risk driving situations and frequency. Different measures of driving mobility may provide different insights into an older person's mobility. For example, driving status gives information on whether or not an older person drives, but it does not provide information on differences in mobility between people who drive and people who do not drive. An older adult who identifies as a current driver but only drives five miles a week has different mobility than an older adult who identifies as a current driver but drives fifty miles a week. It is important to assess not only whether a person is a driver or nondriver but also multiple indicators of mobility to get a fuller picture of older people's mobility.

While there is an established link between function and driving mobility, and the environment and driving mobility, the field of older adult driving mobility and license renewal policy has not yet elucidated the role of interactions between function and the environment. Developmental theory on person-environment interactions would suggest that driving mobility in older adults cannot be fully understood unless interactions are also considered, as interactions are what drive development. It is likely that both the person and the environment interact in the association between license renewal policies and driving for older adults. No studies have examined person-environment interactions in licensing and mobility outcomes for older adults.

Older adults with lower levels of function may be more directly impacted by license renewal policies than older adults with higher levels of function. No papers on licensing and mobility have examined differences in outcomes by functional status and license renewal policy.

Aims and Hypotheses

The current study examined the association between three indicators of driving mobility and two license renewal policies for older adults in a national United States sample. Figure 3 presents the overall conceptual model for the three aims of Paper 1. Aim 1 was to examine the association between driving mobility and in-person license renewal policy for older adults and was accomplished by addressing three research questions: (1a) Does annual driving mileage differ between older adults who experienced in-person license renewal requirements and older adults who have not experienced in-person renewal license requirements? Next, are older adults who experienced in-person license renewal requirements more likely to (1b) not be a current driver, and (1c) not travel on a given travel day compared to older adults who have not experienced in-person license renewal requirements? Based on prior studies in the US (Kulikov, 2010; Shen et al., 2020) and other countries (Ichikawa et al., 2015; Keall & Woodbury, 2014; Ross et al., 2011), I hypothesized that older adults who experienced in-person license renewal requirements would report less annual driving mileage, be less likely to report traveling on a given travel day, and be less likely to be a current driver than older adults who have not experienced in-person license renewal requirements.

Aim 2 was to examine the interaction between health-related travel difficulty and in-person license renewal requirement in predicting each mobility outcome. I hypothesized that reported travel difficulty and in-person renewal requirements would interact such that the association between an in-person license renewal requirement and driving mobility will be greater for individuals who report health-related travel difficulty.

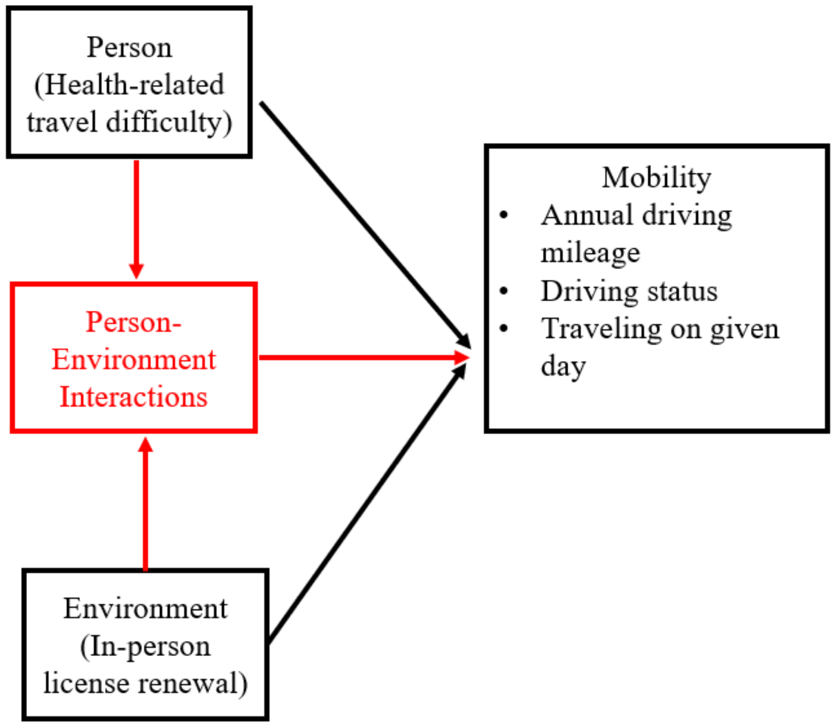

Figure 3. Conceptual model for Paper 1 with health-related travel difficulty moderating the association between in-person license renewal policy and three indicators of driving mobility.

Aim 3 was to examine the association between driving mobility and length of renewal cycle for older adults who live in states with an in-person license renewal policy. Aim 3 was accomplished by answering the following questions: Is length of renewal cycle associated with (3a) annual driving mileage, (3b) current driver status, and (3c) traveling on a given travel day? I hypothesized that a longer renewal cycle would be associated with greater annual mileage, greater likelihood of traveling on a given travel day, and greater likelihood of being a current driver.

Aim 4 examined the interaction between health-related travel difficulty and length of renewal cycle in predicting driving mobility. I hypothesized that health-related travel difficulty and length of renewal cycle would interact such that the association between renewal cycle and driving mobility will be greater for individuals who report health-related travel difficulties.

Methods

Study Design and Procedure

The current study used data from the 2017 National Household Travel Survey (NHTS). The NHTS is a cross-sectional national survey of US residential households in the 50 states and the District of Columbia conducted by the US Department of Transportation in 1969, 1977, 1983, 1990, 1995, 2001, 2009, and 2017 (Federal Highway Administration, 2017). A variety of federal, state, and regional agencies, including the Federal Transit Administration, Centers for Disease Control, and Environmental Protection Agency, and advocacy groups, such as the American Association of Retired People, use results from the NHTS to inform their work. The 2017 NHTS was funded by the Federal Highway Administration and 13 state and metropolitical planning organizations.

The 2017 NHTS used a random sampling frame with four strata based on geographical areas' population and access to heavy rail transit, plus additional participants sampled from each of the 13 add-on regions funding the survey. All households were eligible for the 2017 NHTS as long as they were residential and civilian (e.g., not a dormitory, prison, nursing home, or military barracks) and had at least one household member 18 years or older. Between March 2016 and May 2017, the NHTS sent letters to over 900,000 households asking them to participate in the survey and providing a $2 pre-incentive. Interested households completed a survey on household characteristics and provided information for each member of the household over the age of 5;

this survey could be completed via mail, phone, or web and could be completed in Spanish, English, or with the assistance of an English-speaking household member. About 5% of households completed the household recruitment survey via phone or online. In total, around 7% of recruitment letters were undeliverable and 65% of households did not respond, while the remaining 252,304 households completed the household survey.

In the second phase of the survey, each person in the household over the age of five years was asked to confirm household information provided in the recruitment survey and complete a survey providing their own information which could be completed via phone or online. Two thirds of the sample completed the survey online and the remainder completed the survey via telephone. Household members unable to respond for themselves could have a proxy report for them.

In addition to completing a questionnaire, each household was assigned a random travel day in which to record all of their travel behavior for a 24-hour period. Each participant provided detailed information on each trip they took on the travel day, including trip purpose (e.g., shopping, recreation), transportation mode (e.g., walking, bicycling, driving), time of day, day of the week, vehicle occupancy (e.g., driving alone, driving with one passenger), and trip duration. Participants provided travel day information on a scheduled phone call that occurred within 7 days of the travel day and received a $5 cash incentive along with their travel log. Data collection was balanced across the full sample to capture participant and household characteristics and travel characteristics across 12 months and 7 days a week.

Households received $20 when the entire household completed its individual surveys. Only households in which the household survey and individual survey were completed for each person were reported in the NHTS dataset, leaving a total of 129,696 usable households. The current study included participants 62 years of age and older who participated in the 2017 NHTS to account for the first age at which in-person license renewal requirements for older adults begins. The 2017 has 62,289 households with a person 62 years of age and older as a member and a total of 89,757 participants 62 and older. The 2017 NHTS has four datasets available. The household dataset contains information on the household reported by a household representative, such as age, gender, and driving status of each household member, and information about the household gathered from other national administrative datasets, including Census division and urban/rural status of the household's location. The person dataset contains information reported by each respondent about themselves, such as their employment status, annual driving mileage, and use of public transportation in the past month. The vehicle dataset includes information on each household vehicle, including make and model. Finally, the travel day dataset includes information on each trip a person took during their designated travel day, including the mode of transportation used for each trip and the duration of each trip. The current study used information from the person and household questionnaires, which include demographic information about participants and summary information about behavior during the travel day, available from the NHTS website (Federal Highway Administration, 2017).

Measures

Dependent variables. Three dependent variables assessing driving mobility were used. *Current driver status* was reported for all household members by the main household respondent, and participants can be current drivers (score of 1) or nondrivers (score of 0). Driving status is a common binary variable used as an indicator of older driver mobility. *Travel day mobility* was assessed using a derived variable in the NHTS dataset, where participants who did not travel anywhere on the specified travel day received a "no" (score of 0) for this variable. Participants who traveled at all received a "yes" (score of 1), regardless of their mode of transportation. This variable was included as an outcome to account for the fact that while some participants may identify as current drivers, they may not have traveled on their study travel day.

Annual driving mileage was assessed using the open-ended self-report item, "Please provide your best guess as to how many miles you personally drove during the past 12 months in all motorized vehicles." For the current study, participants who were nondrivers received a "0" for annual driving mileage. If participants were current drivers and reported an annual mileage of less than 2,000 or more than 30,000 miles during the past twelve months, they were prompted to confirm the amount. Annual driving mileage is a driving mobility variable that can provide more detailed information than driving status, as two older adults can be drivers but one drives 5,000 miles a year and the other one drives 500 miles a year.

Independent variables. The primary independent variable is whether a participant experienced an in-person license renewal requirement as of 2017. Based on previous research, in-person renewal requirements and renewal cycle length are the most salient predictors of driving outcomes for older adults (Shen et al., 2020; Tefft, 2014). I used information on age-based license renewal policies from the National Conference of State Legislators (NCSL) to create a database of licensing policies with two variables: accelerated renewal for older adults and length of in-person renewal for older adults (National Conference of State Legislatures, 2018). Table 2 provides information by state for in-person renewal cycle and length of in-person renewal cycle, and Figure 4 presents the information graphically. Using age and state of residence from the NHTS, a variable was created to indicate whether the participant likely experienced required in-person license renewal. For example, Alaska requires in-person license renewal beginning at age 69. If a participant lived in Alaska at the time of the survey and is 69 years or older, they received a value of 1 to indicate that they likely received required in-person license renewal. Participants living in Alaska at the time of the survey who are younger than 69 received a value of 0 indicating that they likely did not experience required in-person license renewal. Alabama does not require in-person license renewal for older drivers, so all participants living in Alabama received a value of 0 indicating that they likely did not experience required in-person license renewal. Each person received a score of either 0 or 1 based on their age and state of residence.

A variable was also created representing length of in-person renewal cycle for participants who live in states with required in-person renewal. If the state had no accelerated in-person renewal cycle, the length of in-person renewal cycle for older drivers was the same as the length of in-person renewal cycle for drivers of all ages. If the state had an accelerated renewal policy for older drivers, the length of in-person renewal cycle is based on the accelerated renewal policy. Some states have multiple ages at which renewal cycle changes. For example, in Indiana the three-year renewal cycle for older drivers 75 to 84 drops down to two years once a driver reaches 85 years of age. The current study only considers the first age at which license renewal frequency changes.

Moderating variable. Health-related travel difficulties were considered as a moderator of the association between licensing policy and driving mobility. Participants were asked, “Do you have a condition or handicap that makes it difficult to travel outside of the home?” (1=yes, 0=no).

Table 2. License renewal procedures for older adults by state, 2017

State	In-person renewal required for 62+?	Time between in-person renewal	When in-person renewal begins	Notes
AL	No	-	-	-
AK	Yes	5	69	
AZ	Yes	5	70	-
AR	No	-	-	-
CA	Yes	5	70	
CO	Yes	10	66	-
CT	No	-	-	-
DE	No	-	-	-
FL	Yes	24	16[1]	6 years at age 80
DC	Yes	8	70	-
GA	Yes	8	64	-
HI	Yes	4	72	-
ID	Yes	4	70	-
IL	Yes	4	75	2 years at age 81 and 1 year at age 87
IN	Yes	3	75	-
IA	Yes	4	70	2 years at age 71 and 1 year at age 72
KS	No	-	-	-
KY	No	-	-	-
LA	Yes	6	70	-
ME	Yes	4	62	-
MD	Yes	16	16[1]	-
MA	Yes	10	16[1]	5 years at age 75
MI	No	-	-	-
MN	No	-	-	-
MS	No	-	-	-
MO	No	-	-	-
MT	Yes	16	16[1]	4 years at age 70 (8 in-person)
NE	Yes	5	72	-
NV	Yes	8	65	-
NH	Yes	5[2]	16[1]	-
NJ	No	-	-	-
NM	Yes	1	75	-
NY	No	-	-	-
NC	No	-	-	-
ND	Yes	6	65	4 years at age 78
OH	No	-	-	-
OK	No	-	-	-
OR	Yes	8	16[1]	-
PA	No	-	-	-
RI	No	-	-	-
SC	No	-	-	-
SD	Yes	10	16[1]	-
TN	No	-	-	-
TX	Yes	6	79	2 years at age 85
UT	Yes	10	16[1]	-
VT	No	-	-	-
VA	Yes	5	75	-
WA	Yes	6	70	-
WV	No	-	-	-
WI	No	-	-	-
WY	No	-	-	-

[1]The rule on in-person renewal applies to drivers of all ages. [2]In-person at every renewal (Every other renewal if eligible for online renewal, indicated by a Renewal Identification Number on license)

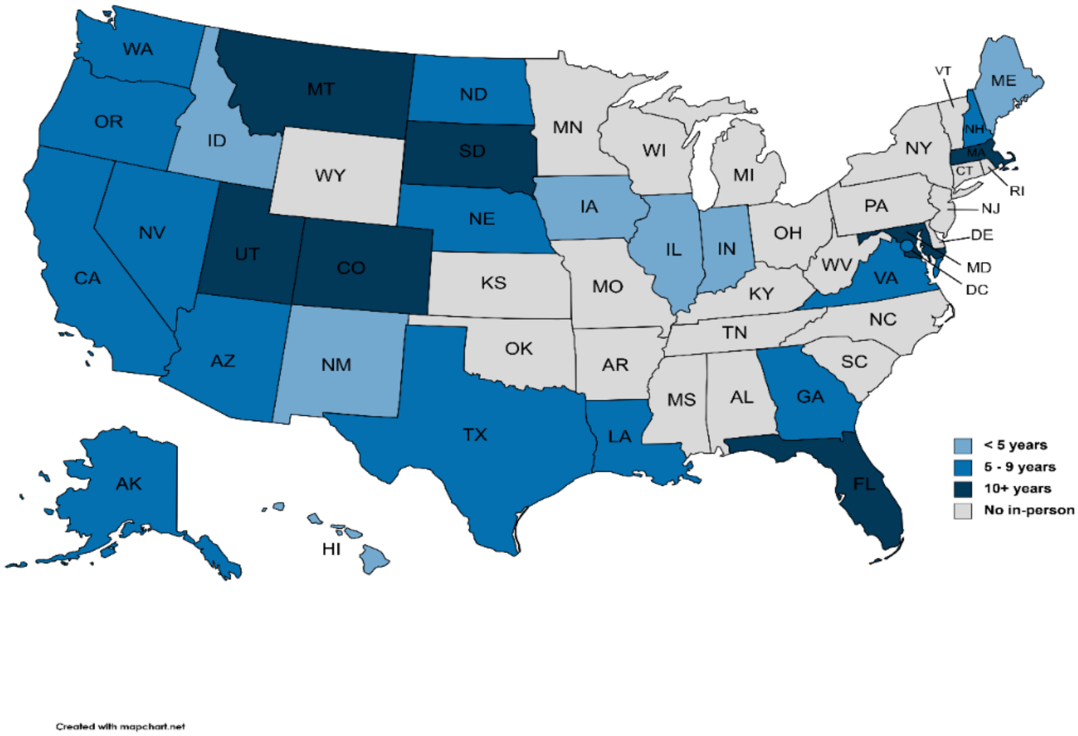

Figure 4. In-person license renewal laws by state, 2017.

Covariates. A number of demographic characteristics have been identified in prior studies as predictors of driving mobility. Among older adults, people who are older (Coxon et al., 2015; Edwards et al., 2008; Emerson et al., 2012; Freeman et al., 2006; Hess et al., 2016; Hjorthol, 2013; Langford et al., 2013), women (Edwards et al., 2008; Freeman et al., 2005; Hess et al., 2016; Kulikov, 2010; Langford et al., 2013; Marie Dit Asse et al., 2014; Vivoda et al., 2017), non-white (Dugan et al., 2013; Kulikov, 2010; Vivoda et al., 2017), have less education (Dugan et al., 2013; Kulikov, 2010), are not working for pay (Kulikov, 2010), live in urban areas (Weeks et al., 2015) and have a lower household income (Dugan & Lee, 2013) have lower mobility than people who are younger, men, white, have more education, are working for pay, live in rural areas, and have a higher household income. The current study includes *age, gender, race, education, working status, urbanicity,* and *income* as covariates. The current study also included *household size* as a covariate, though the literature is mixed regarding the association between household size and driving mobility (Anstey et al., 2006; Kulikov, 2010; Ross et al., 2011; Weeks et al., 2015). For the current study, covariates were coded as follows: *age* (continuous), *gender* (1=man, 0=woman), *race* (1=white, 0=non-white), e*ducation* (1=college or higher, 0=Some college or less), *working status* (1=currently working, 0=not currently working), and income (0=Less than $24,000, 1=$25,000 to $49,000, 2=$50,000 to $99,999, and 3=$100,000 or more).

Urbanicity was also included as a covariate to account for physical aspects of the environment that are known to relate to mobility, such as intersection mix (Hess et al., 2016), roadway congestion (Vivoda et al., 2017), and population density (Klein et al., 2018). Urbanicity in the NHTS comes from the 2014 Claritas urban/rural continuum classification for participants' home address. The Claritas categorization provides a more granular assessment of urbanicity beyond the urban/rural classification used in the US Census and includes five categories based on population density score. Rural and small town areas receive the lowest population density scores and includes small towns, farming communities, small towns and villages, and other areas with low population density. Second city areas have higher population density than rural areas. These areas have similar population density scores to suburban areas, but second city areas are the population centers of their surrounding communities while suburban areas are located outside of a city center. Urban areas have the highest population density scores and include downtowns of major cities and surrounding neighborhoods. Urbanicity was recoded so 0=rural, 1=second city, 2=suburban, 3=small town, and 4=urban.

To control for potential effects of weather, cultural differences, and cost-of-living, the current study included *US Census division* as a covariate. For Aims 1 and 2, the nine-category

Census division variable was used, which was coded as a categorical variable: 0= New England, 1= Middle Atlantic, 2= East North Central, 3= West North Central, 4= South Atlantic, 5= East South Central, 6= West South Central, 7= Mountain, and 8= Pacific. For Aims 3 and 4, the four-category Census division variable was used which includes 0= Northeast, 1= Midwest, 2= South, and 3= West. The current study also included *travel day season* (0=winter, 1=fall, 2=summer, 3=spring), *travel day year* (0=2016,1=2017), and whether the travel day was on a *weekday* (0) *or weekend* (1) to control for potential weather differences or time differences in travel patterns.

Analytic Approach

The NHTS surveyed multiple participants per household, creating potential dependencies in the dataset. The dataset included 89,757 participants who lived in 62,289 households. Each participant had a household number which is shared with other members of their household and a person number which designated which person they are in the household. In the current dataset, there were 35,228 participants who were assigned a person ID of 1, 26,673 assigned a person ID of 2, 370 assigned a person ID of 3, 17 assigned a person ID of 4, and 1 person assigned a person ID of 5. Statistical adjustment is needed in datasets where multiple people share the same household. Intraclass correlation coefficients (ICCs) are a method of identifying the percent of variance attributable to within-cluster differences versus between cluster differences. ICCs can also be helpful in determining whether a multilevel model is needed to address dependencies in the data. Annual driving mileage was a continuous variable ranging from 0 to 200,000 miles. However, the variable is positively skewed, with skewness of 5.44 and kurtosis of 69.08. As participants were asked to confirm their annual mileage if it was higher than 30,000 miles, the extremely high values for annual mileage were retained in analyses as they are assumed to reflect real answers. However, analyses must account for the skewed distribution of the variable. ICCs for annual driving mileage were calculated assuming a Poisson distribution and using the generalized concordance correlation coefficient method described in Carrasco (2010). Using the *iccCounts* package in R Studio, the ICC for annual driving mileage was calculated to be 0.83, indicating 83% of the variance attributable to clustering.

To calculate ICC for the two binary outcome variables (driver status and traveling on a travel day), the ICC was calculated by dividing the intercept variance by the total variance. Total variance is calculated by adding the variance of the logistic distribution ($\pi^2/3$, or 3.29) to the intercept variance (Wu et al., 2012). The ICCs for driving status and traveling on a given travel day were both 0.98, indicating that 98% of the variance in these outcomes was attributable to clustering within a household. ICCs for binary variables were calculated using the *multgee* package in R Studio.

The ICCs for driving status, traveling on a given travel day, and annual driving mileage should be interpreted with caution as there are a large number of clusters in the dataset of people 65 and older with only one person. While there are no established cut points for ICC in determining whether a multilevel model is appropriate, it is best practice to use an analysis that addresses clustering in the data if clustering is known to exist. Models that do not account for clustering when clustering exists underestimate variance. The current study addressed clustering by conducting generalized estimating equations (GEE), or population average model. GEE is an extension of the generalized linear model that accounts for dependence in the data due to clustering (Liang & Zeger, 1986). GEE accounts for clustering via a "working" correlation matrix, in which the correlation of outcomes within clusters is specified in the model and is assumed to be equal for all clusters. GEE produces estimates which are identical to estimates from GLM and represent the association between variables that is consistent across all clusters.

GEE also produces robust standard errors which are derived from the “sandwich” estimator of the covariance matrix of regression coefficients.

GEE models were run in R Studio using the *gee* function. To accomplish Aim 1, a series of GEE models were conducted for each of the three mobility outcomes. Each GEE model specifies the identity correlation matrix, which assumes zero correlations within cluster. As long as data are missing completely at random, GEE produces consistent estimators of regression coefficients and robust standard errors even if the working correlation matrix is misspecified (Liang & Zeger, 1986). In the model predicting annual driving mileage, a Poisson distribution was specified. In the models predicting driving status and traveling on a given travel day, a binomial distribution was specified. Models for each outcome began with the main predictor variables *health-related travel difficulty* and *in-person license renewal.* In Model 2, all covariates were added. Categorical variables were entered into the models using dummy coding with the categories of value 0 as the reference variable. In Model 3, the interaction between health-related travel difficulty and in-person license renewal were added (Aim 2). All covariates (age, gender, race, education, working status, household size, urbanicity, Census division, season of travel day, year of travel day, and weekend/weekday travel day) were included in Models 2 and 3 based on a priori hypotheses. The model for driving status and traveling on a travel day is represented by the following equation which uses a logistic link function to transform the outcome and specify the probability density function associated with the log odds:

$$log\left(\frac{p(Yij)}{1-p(Yij)}\right) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij})$$

Model 2 is represented by the following equation in which all covariates are added:

$$log\left(\frac{p(Yij)}{1-p(Yij)}\right) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij}) + \beta_3(AGE_{ij}) + \beta_4(GENDER_{ij}) + \beta_5(RACE_{ij}) + \beta_6(EDUC_{ij}) + \beta_7(WORK_{ij}) + \beta_8(SIZE_{ij}) + \beta_9(INCOME_{ij}) + \beta_{10}(URBAN_{ij}) + \beta_{11}(CENSUS_{ij}) + \beta_{12}(SEASON_{ij}) + \beta_{13}(YEAR_{ij}) + \beta_{14}(WEEKEND_{ij})$$

Model 3 is represented by the following equation which adds in the interaction between in-person license renewal and medical condition:

$$log\left(\frac{p(Yij)}{1-p(Yij)}\right) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij}) + \beta_3(AGE_{ij}) + \beta_4(GENDER_{ij}) + \beta_5(RACE_{ij}) + \beta_6(EDUC_{ij}) + \beta_7(WORK_{ij}) + \beta_8(SIZE_{ij}) + \beta_9(INCOME_{ij}) + \beta_{10}(URBAN_{ij}) + \beta_{11}(CENSUS_{ij}) + \beta_{12}(SEASON_{ij}) + \beta_{13}(YEAR_{ij}) + \beta_{14}(WEEKEND_{ij}) + \beta_{15}(INPERSON_{ij} * HEALTH_{ij})$$

To predict annual driving mileage, I used a log link function and the probability mass function for the Poisson distribution. The equations for predicting annual driving mileage are represented below:

Model 1: $\log(\lambda_{ti}) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij})$

Model 2: $\log(\lambda_{ti}) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij}) + \beta_3(AGE_{ij}) + \beta_4(GENDER_{ij}) + \beta_5(RACE_{ij}) + \beta_6(EDUC_{ij}) + \beta_7(WORK_{ij}) + \beta_8(SIZE_{ij}) + \beta_9(INCOME_{ij}) + \beta_{10}(URBAN_{ij}) + \beta_{11}(CENSUS_{ij}) + \beta_{12}(SEASON_{ij}) + \beta_{13}(YEAR_{ij}) + \beta_{14}(WEEKEND_{ij})$

Model 3: $\log(\lambda_{ti}) = \beta_0 + \beta_1(INPERSON_{ij}) + \beta_2(HEALTH_{ij}) + \beta_3(AGE_{ij}) + \beta_4(GENDER_{ij}) + \beta_5(RACE_{ij}) + \beta_6(EDUC_{ij}) + \beta_7(WORK_{ij}) + \beta_8(SIZE_{ij}) + \beta_9(INCOME_{ij}) + \beta_{10}(URBAN_{ij}) + \beta_{11}(CENSUS_{ij}) + \beta_{12}(SEASON_{ij}) + \beta_{13}(YEAR_{ij}) + \beta_{14}(WEEKEND_{ij}) + \beta_{15}(INPERSON_{ij} * HEALTH_{ij})$

To accomplish Aims 3 and 4, similar stepwise models were run but within a subsample of participants who experienced in-person license renewal and using length of renewal cycle rather than in-person license renewal to predict mobility outcomes. Within participants who experienced in-person license renewal, participants are not evenly distributed across the nine Census division categories, with five Census divisions representing less than ten percent of the sample (New England= 2.9%, Middle Atlantic= 0.1%, East North Central= 1.2%, West North Central= 5.6%, Mountain= 9.3%). For analyses using the subsample of participants who experienced in-person license renewal (Aims 3 and 4), the four-category Census division variable was used (Northeast= 3.0%, Midwest= 6.8%, South= 39.6%, West= 50.6%). For all analyses, statistical significance was set at $p < .05$ and a 95% confidence interval for odds ratios. Confidence intervals for GEEs were calculated using robust standard errors (SE).

Results

Participants. Descriptive statistics for the study sample are located in Table 3. The age range for the current study was 62 to 92 years (M=71.57, SD=7.48). A little over half of the sample identified as women (53.6%), and 11.7% identified as a race other than white. Most participants were not working for pay, though 22.9% reported working part-time or full-time. Household size, which includes people living in the household younger than 62, ranged from one to twelve, though most participants (89%) lived in a two-person household. About equal numbers of participants reported a household income of less than $24,999 a year (18%) and more than $100,000 a year (21%). Some participants (4%) declined to answer the household income item.

Participants reported a wide range of annual driving mileage, from 0 miles in the past 12 months to 200,000 miles. The group of participants with a score of zero for annual driving mileage includes non-drivers who were assigned a score of zero for this variable and drivers who reported driving zero miles in the past year (n = 892). Participants drove an average of 8,020 miles (SD= 9,110) in the past year, with a median of 6,000 miles. Figure 5 displays a histogram of the annual driving mileage variable. To ensure fit on the figure, participants who reported over 100,000km/year were recoded as 100,000km/year (n=55) (Original values above 100,000km/year were retained in analyses). Figure 5 shows a high number of participants who reported driving zero miles per year, likely all non-drivers. There are bumps in the graph at 5,000, 10,000, 15,000, and 20,000 miles, likely because participants gave “even” numbers for their annual mileage. About a fifth of participants (n = 17,202) responded “I don’t know” when asked about annual mileage; these were coded as missing. A little over 20% of the sample did not travel on the study travel day. Consistent with other studies, the vast majority (90.9%) of the sample were current drivers.

Table 3. Descriptive statistics for sample of older adults in National Household Travel Survey (N=89,757)

	n (%)	M (SD)	Range
Age	-	71.57 (7.48)	62 - 92
Women	48,066 (53.6%)	-	-
Health-related travel difficulty	15,971 (17.8%)	-	-
Race (Not white)	10,538 (11.7%)	-	
Education, college or more	36,894 (41.4%)	-	
Currently working for pay	20,596 (22.9%)		
Current driver	81,576 (90.9%)	-	-
Annual driving mileage[1]	-	8020.07 (9110.93)	0 - 200,000
Experienced in-person renewal	25,410 (28.3%)	-	-
Any travel on travel day	69,611 (77.6%)		
Length of in-person renewal, years[2]	-	7.28 (4.53)	1 - 24
Household size	-	1.91 (0.79)	1 - 12
Household income[3]			
≤ $24,999	16,493 (18.4%)		
$25,000-$49,000	22,202 (24.7%)		
$50,000 to $99,999	27,902 (31.1%)		
≥$100,000	18.612 (20.7%)		
US Census division			
New England	1,378 (1.5%)		
Middle Atlantic	13,383 (14.9%)		
East North Central	10,112 (11.3%)		
West North Central	3,322 (3.7%)		
South Atlantic	20,385 (22.7%)		
East South Central	891 (1.0%)		
West South Central	16,671 (18.6%)		
Mountain	4,139 (4.6%)		
Pacific	19,476 (21.7%)		
Household urbanicity indicator			
Second City	15,652 (17.4%)		
Rural	24,917 (27.8%)		
Suburban	18,908 (21.1%)		
Small town	21,813 (24.3)		
Urban	8,387 (9.3%)		
Travel year 2017	29,570 (32.9%)		
Weekend travel day	19,736 (22.0%)		
Travel day season			
Spring	18,665 (20.8%)		
Summer	22,901 (25.5%		
Fall	23,708 (26.4%)		
Winter	24,483 (27.3%)		

[1]n=71,682 [2]n=25,410 [3]n=85,209

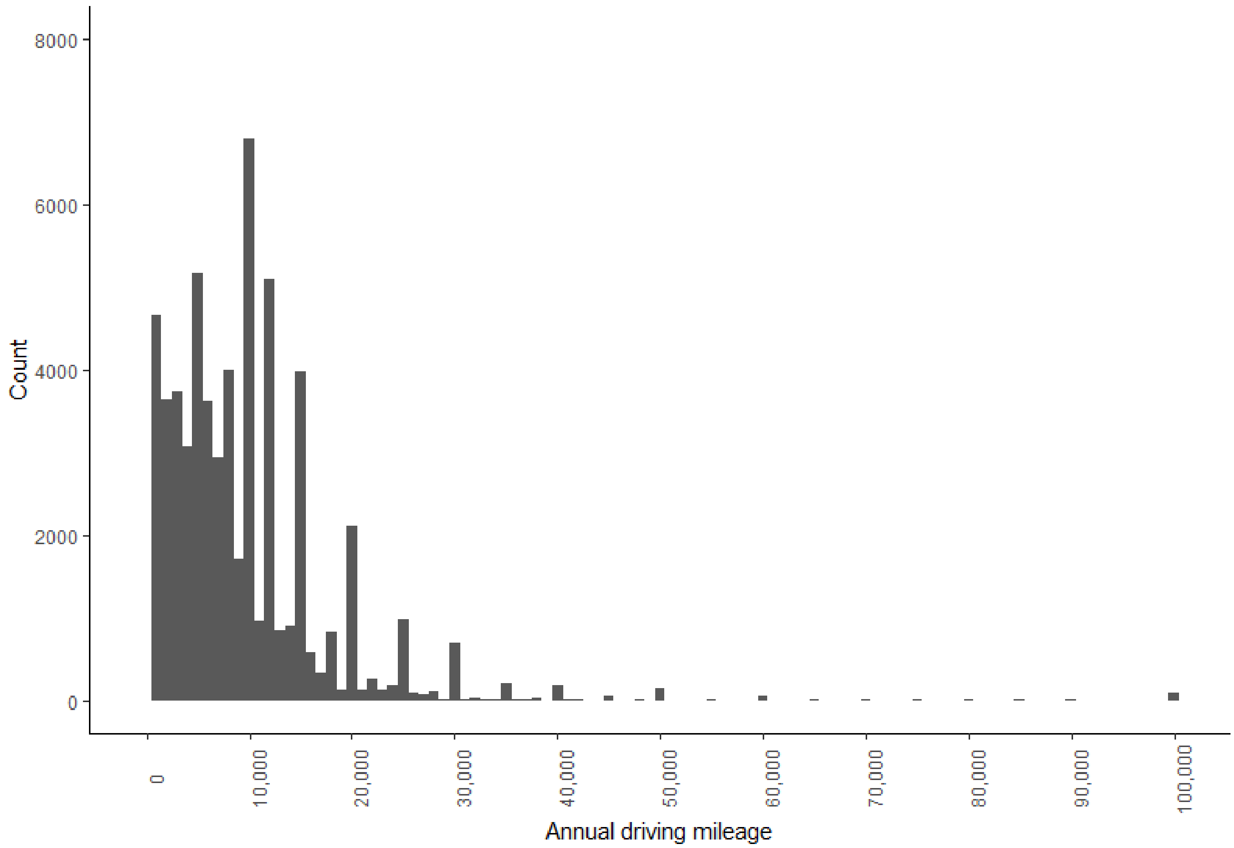

Figure 5. Distribution of annual driving mileage. Note: 55 participants reported annual driving mileage of 200,000km or more per year and are included in the bar for 100,000km.

Almost 30% of the sample had likely experienced an in-person license renewal policy based on their age and state of residence. Among participants who lived in states with in-person license renewal policies, the length between renewals ranged from one to 24 years (M=7.28, SD=4.53). As the NHTS evenly distributed data collection across seasons, it is unsurprising that travel day season was relatively evenly divided among spring, summer, fall, and winter. While 27.8% of participants lived in rural areas, less than ten percent of participants lived in urban areas.

Aim 1a and 2a: Predicting annual driving mileage. The first aim was to examine predictors of annual driving mileage. The GEE models predicting annual driving mileage include both drivers and non-drivers and are presented in Table 4. In Model 1 (no covariates), reporting a health-related travel difficulty and experiencing an in-person license renewal policy are significantly associated with fewer self-reported annual miles in the past year. In Model 2, health-related travel difficulty and in-person license renewal policy remain significant in predicting annual driving mileage after adding age, gender, working status, race, education, household size, urbanicity, travel day year, travel day weekend/weekday, travel day season, income, and Census division. In Model 3, the interaction between health-related travel difficulty and in-person license renewal policy is added. This interaction is significant and displayed in Figure 6. After controlling for a number of covariates, for participants who have health-related travel difficulty, the association between experiencing in-person license renewal and lower annual driving mileage is greater than for participants who do not have health-related travel difficulty.

Model covariates were associated with annual driving mileage in the expected direction: greater age and larger household size was associated with driving fewer miles in the past year. Men, employed people, people who completed college, and people who identify as white drove significantly more miles in the past year compared to women, unemployed people, people who did not complete college, and people who identified as a race other than white. In comparison to people who have a household income of less than $25,000 per year, people who belong to each of the higher household income categories drive significantly more miles per year. In comparison to people who live in rural households, people who live in second city, suburban, small town, and urban areas drove fewer miles in the past year.

Aim 1b and 2b: Driving status. In the model without covariates, reporting a health-related travel difficulty and experiencing in-person license renewal were negatively associated with being a current driver (Table 5). People who live in states with in-person license renewal requirements were 37% less likely to be a current driver compared to people who live in states without in-person license renewal requirements (95% CI: 0.60, 0.67). People who have a health-related travel difficulty were 91% less likely to be a current driver compared to people without such difficulty (0.09, 0.10). After adding demographic and household covariates in Model 2, the association between in-person license renewal became insignificant (OR=1.03, 95% CI: 0.95, 1.11). Reporting a health-related travel difficulty still significantly predicts a lower likelihood of being a current driver (OR=0.14, 95% CI=0.13, 0.15). In the final model, which added the interaction between health-related travel difficulty and in-person license renewal, the interaction was not significant (OR=0.95, 95% CI=0.84, 1.06).

Greater age and larger household size were associated with a lower likelihood of being a current driver. Men, employed people, and people who completed college were more likely to be current drivers than women, unemployed people, and people who did not complete college. People who identify as a race other than white were less likely to be current drivers than people who identify as white. Compared to people who live in rural areas, people who live in second city, suburban, small town, and urban areas were less likely to be current drivers. Household income also significantly predicted driving status, such that people with an income category above $25,000 were more likely to be current drivers than people reporting a household income lower than $25,000. Census division also significantly predicted driving status, where people who live in New England were less likely to be a current driver compared to people who live in East North Central, West North Central, South Atlantic, West South Central, Mountain, and Pacific regions.

Table 4. Generalized estimating equation models (Poisson) predicting annual driving mileage

	Model 1		Model 2		Model 3	
	Est	Robust SE	Est	Robust SE	Est	Robust SE
Step 1						
Intercept	9.17*	0.00	8.63*	0.03	8.62*	0.03
Travel difficulty	-0.98*	0.02	-0.65*	0.02	-0.61*	0.02
In-person license renewal	-0.24*	0.01	-0.02*	0.01	-0.01	0.01
Step 2						
Age			-0.02*	0.00	-0.02*	0.00
Gender (Men)			0.45*	0.01	0.45*	0.01
Working status (Employed)			0.35*	0.01	0.35*	0.01
Race (Non-white)			-0.14*	0.02	-0.14*	0.02
Education (College)			0.06*	0.01	0.06*	0.01
Household size			-0.10*	0.01	-0.10*	0.01
Urbanicity (reference=rural)						
Second city			-0.32*	0.01	-0.32*	0.01
Suburban			-0.28*	0.01	-0.28*	0.01
Small town			-0.15*	0.01	-0.15*	0.01
Urban			-0.53*	0.02	-0.53*	0.02
Travel year (2017)			0.00	0.01	0.00	0.01
Weekend travel day			0.01	0.01	0.00	0.01
Travel season (Ref=Winter)						
Spring			-0.01	0.01	-0.01	0.01
Summer			-0.01	0.01	-0.01	0.01
Fall			-0.00	0.01	-0.00	0.01
Income (Ref= < $25,000)						
$25,000-$49,999			0.37*	0.02	0.37*	0.02
$50,000-$99,999			0.49*	0.02	0.49*	0.02
$100,000 or more			0.54*	0.02	0.54*	0.02
Census (Ref=New England)						
Middle Atlantic			-0.03	0.03	-0.03	0.03
East North Central			-0.07*	0.03	0.07*	0.03
West North Central			0.11*	0.03	0.11*	0.03
South Atlantic			0.07*	0.03	0.07*	0.03
East South Central			0.08	0.06	0.08	0.06
West South Central			0.08*	0.03	0.08*	0.03
Mountain			0.03	0.03	0.03	0.03
Pacific			-0.00	0.03	-0.00	0.03
Step 3						
Travel difficulty*In-person					-0.15*	0.04

*p < .05

Aim 1c and 2c: Traveling on travel day. The GEE models predicting traveling on the given travel day are presented in Table 6. In the model without covariates, people who reported a health-related travel difficulty had 68% lower odds of traveling on the given travel day compared to people who do not report any difficulty (95% CI=0.31, 0.33). People who experienced in-person license renewal were 20% likely to travel on the given travel day than people who live in states without such requirement (95% CI=0.77, 0.83). After demographic and household covariates were added, the association between in-person license renewal and traveling on the given travel day was no longer significant (OR=0.99, 95% CI=0.93, 1.04). Health-related travel difficulty still significantly predicted traveling (OR=0.42, 95% CI=0.41, 0.44). In Model 3, the interaction between health-related travel difficulty and in-person license renewal was not significant (OR=1.02, 95% CI=0.94, 1.11).

Greater age and larger household size were significantly associated with less likelihood of traveling on a given travel day. For every year of age, people were 0.98 times less likely to travel on a given travel day (95% CI=0.98, 0.98). Each additional household member is associated with 24% lower odds of traveling (95% CI=0.74, 0.78). Men were 1.26 times more likely to travel on the given travel day compared to women (95% CI=1.22, 1.30). Working status, race, education, and household income were significantly associated with traveling on a given travel day. People who live in urban areas were 1.38 times more likely to travel on the given travel day than people who live in rural areas (95% CI=1.28, 1.49). Small town, suburban, and second city residences also had significantly higher odds of traveling on a given travel day compared to people who live in rural areas. None of the Census divisions were significantly different from New England in the odds of traveling on a given travel day.

Table 5. Generalized estimating equation models (logistic) predicting driving status

	Model 1		**Model 2**		**Model 3**	
	OR	95% CI	OR	95% CI	OR	95% CI
Step 1						
Intercept	27.05*	25.95, 28.20	31.10*	23.66, 40.88	30.72*	23.33, 40.45
Travel difficulty	0.09*	0.09, 0.10	0.14*	0.13, 0.15	0.14*	0.13, 0.16
In-person license renewal	0.63*	0.60, 0.67	1.03	0.95, 1.11	1.06	0.96, 1.16
Step 2						
Age			0.92*	0.92, 0.93	0.92*	0.92, 0.93
Gender (Men)			1.93*	1.82, 2.05	1.93*	1.82, 2.05
Working status (Employed)			2.34*	2.07, 2.64	2.35*	2.08, 2.65
Race (Non-white)			0.37*	0.35, 0.40	0.37*	0.35, 0.40
Education (College)			1.60*	1.50, 1.72	1.61*	1.50, 1.72
Household size			0.60*	0.58, 0.62	0.60*	0.58, 0.62
Urbanicity (reference=rural)						
Second city			0.49*	0.45, 0.53	0.49*	0.44, 0.53
Suburban			0.62*	0.56, 0.67	0.62*	0.56, 0.67
Small town			0.77*	0.70, 0.83	0.77*	0.70, 0.84
Urban			0.31*	0.27, 0.34	0.30*	0.27, 0.34
Travel year (2017)			1.03	0.94, 1.12	1.03	0.94, 1.12
Weekend travel day			1.01	0.94, 1.09	1.01	0.94, 1.09
Travel season (Ref=Winter)						
Spring			0.94	0.91, 1.08	0.94	0.91, 1.08
Summer			0.94	0.85, 1.03	0.94	0.85, 1.04
Fall			0.95	0.86, 1.05	0.95	0.86, 1.05
Income < $25,000 REF						
$25,000-$49,999			2.05*	1.91, 2.21	2.06*	1.91, 2.21
$50,000-$99,999			2.53*	2.33, 2.73	2.53*	2.33, 2.74
$100,000 or more			2.83*	2.55, 3.14	2.83*	2.55, 3.14
Census (Ref=New England)						
Middle Atlantic			0.95	0.74, 1.23	0.95	0.74, 1.23
East North Central			1.43*	1.10, 1.85	1.43*	1.10, 1.85
West North Central			1.75*	1.31, 2.34	1.75*	1.31, 2.35
South Atlantic			1.40*	1.09, 1.80	1.40*	1.09, 1.80
East South Central			1.37	0.94, 1.98	1.36	0.94, 1.98
West South Central			1.49*	1.16, 1.91	1.49*	1.16, 1.92
Mountain			1.93*	1.45, 2.57	1.93*	1.45, 2.57
Pacific			1.47*	1.14, 1.89	1.47*	1.14, 1.89
Step 3						
Travel difficulty*In-person					0.95	0.84, 1.06

*p < .05. 95% confidence intervals calculated from robust standard error.

Aim 3a and 4a: Renewal cycle length and annual driving mileage. Aim 3 examined the association between length of renewal cycle and driving mobility outcomes among participants who experienced in-person license renewal based on their age and state of residence. The GEE model predicting annual driving mileage includes both drivers and non-drivers and is presented in Table 7. Participants who have a health-related travel difficulty drove significantly fewer miles in the past twelve months (estimate=-1.08, SE=0.03) compared to participants without a health-related travel difficulty. Living in a state with a longer renewal cycle was significantly associated with driving more miles in the past twelve months (estimate=0.02, SE=0.00). After demographic and household covariates were added in Model 2, length of renewal cycle was no longer significantly associated with annual driving mileage for participants who experienced in-person license renewal. Health-related travel difficulty remained significant in predicting annual driving mileage (estimate=-0.72, SE=0.03). In Model 3, the added interaction between health-related travel difficulty and length of renewal cycle was not significant (estimate=0.01, SE=0.01).

Among participants who experienced in-person license renewal, greater age and larger household size were associated with driving less miles in the past twelve months, while men, employed people, people who identify as white, and people who completed college drove more miles in the past twelve months. People who live in the Northeast drove significantly fewer miles in the past twelve months compared to people who live in the Midwest.

Aim 3b and 4b: Renewal cycle length and driving status. Results for renewal cycle length and driving status are displayed in Table 8. In the model without covariates, travel difficulty was associated with 0.10 lower odds of being a current driver among participants who experienced in-person license renewal compared to participants who do not report health-related travel difficulty (95% CI=0.09, 0.10).

Table 6. Generalized estimating equation models (logistic) predicting traveling on travel day

	Model 1		**Model 2**		**Model 3**	
	OR	95% CI	OR	95% CI	OR	95% CI
Step 1						
Intercept	4.77*	4.65, 4.88	3.79*	3,16, 4.53	3.80*	3.17, 4.54
Travel difficulty	0.32*	0.31, 0.33	0.42*	0.41, 0.44	0.42*	0.40, 0.44
In-person license renewal	0.80*	0.77, 0.83	0.99	0.93, 1.04	0.98	0.93, 1.04
Step 2						
Age			0.98*	0.98, 0.98	0.98*	0.98, 0.98
Gender (Men)			1.26*	1.22, 1.30	1.26*	1.22, 1.30
Working status (Employed)			2.11*	2.00, 2.23	2.11*	2.00, 2.23
Race (Non-white)			0.91	0.86, 0.96	0.91*	0.86, 0.96
Education (College)			1.42*	1.36, 1.48	1.42*	1.36, 1.48
Household size			0.76*	0.75, 0.78	0.76*	0.74, 0.78
Urbanicity (Ref=rural)						
Second city			1.37*	1.29, 1.45	1.37*	1.29, 1.45
Suburban			1.29*	1.22, 1.36	1.29*	1.22, 1.36
Small town			1.25*	1.18, 1.31	1.25*	1.18, 1.31
Urban			1.38*	1.28, 1.49	1.38*	1.28, 1.49
Travel year (2017)			0.86*	0.81, 0.91	0.86*	0.81, 0.91
Weekend travel day			0.75*	0.71, 0.78	0.75*	0.71, 0.78
Travel season (Ref=Winter)						
Spring			1.18*	1.14, 1.27	1.20*	1.14, 1.27
Summer			1.18*	1.11, 1.26	1.18*	1.11. 1.26
Fall			1.05	0.98, 1.12	1.05	0.98, 1.12
Income (Ref=< $25,000)						
$25,000-$49,999			1.90*	1.13, 1.25	1.19*	1.13, 1.25
$50,000-$99,999			1.32*	1.25, 1.39	1.32*	1.25, 1.39
$100,000 or more			1.33*	1.24, 1.42	1.33*	1.24, 1.42
Census (Ref=New England)						
Middle Atlantic			1.02	0.86, 1.21	1.02	0.86, 1.21
East North Central			1.06	0.89, 1.25	1.06	0.89, 1.25
West North Central			0.91	0.75, 1.10	0.91	0.75, 1.10
South Atlantic			1.02	0.87, 1.20	1.02	0.87, 1.20
East South Central			0.88	0.70, 1.13	0.88	0.70, 1.13
West South Central			0.87	0.74, 1.03	0.87	0.74, 1.03
Mountain			0.95	0.79, 1.14	0.95	0.79, 1.14
Pacific			0.86	0.73, 1.02	0.86	0.73, 1.02
Step 3						
Travel difficulty*In-person					1.02	0.94, 1.11

*p < .05. 95% confidence intervals calculated using robust standard error.

Length of renewal cycle was also significantly associated with current driver status: Every one-year increase in renewal cycle length was associated with 1.03 greater odds of being a current driver (95% CI=1.02, 1.05). After adding in covariates, the association between renewal cycle length and driving status among participants who experienced in-person license renewal requirements was no longer significant. Travel difficulty remained significant (OR=0.14, 95% CI=0.13, 0.16). Model 3 added the interaction between health-related travel difficulty and renewal cycle length, which was not significant (OR=0.99, 95% CI=0.96, 1.01).

Greater age and larger household size were significantly associated with lower likelihood of being a current driver among participants who live in states with in-person license renewal. Men, employed people, participants who identify as white, and people who completed college were significantly more likely to be a current driver. Compared to participants who live in the Midwest, participants who live in the Northeast and the South were less likely to be current drivers.

Aim 3c and 4c: Renewal cycle length and traveling on the given travel day. Results of the GEE model predicting traveling on a given travel day are presented in Table 9. Before covariates, people with a health-related travel difficulty were 67% less likely to travel on a given travel day compared to people without such difficulty (95% CI=0.31, 0.35). Longer renewal cycle was positively associated with traveling on a given travel day among participants who experienced in-person requirements (OR-1.02, 95% CI=1.01, 1.03). This association was no longer significant after covariates are added in Model 2 (OR=1.01, 95% CI=1.00, 1.02). In Model 3, the interaction between renewal cycle length and health-related travel difficulty was added and is significant (OR=0.98, 95% CI=0.97, 0.999).

Table 7. Generalized estimating equation models (Poisson) predicting annual driving mileage among participants who experienced in-person license renewal requirements

	Model 1		**Model 2**		**Model 3**	
	Est	Robust SE	Est	Robust SE	Est	Robust SE
Step 1						
Intercept	8.83*	0.02	8.81*	0.05	8.81*	0.05
Travel difficulty	-1.08*	0.03	-0.72*	0.03	-0.80*	0.06
Length of renewal cycle	0.02*	0.00	-0.00	0.00	-0.00	0.00
Step 2						
Age			-0.03*	0.00	-0.03*	0.00
Gender (Men)			0.50*	0.02	0.50*	0.02
Working status (Employed)			0.34*	0.02	0.34*	0.02
Race (Non-white)			-0.18*	0.04	-0.18*	0.04
Education (College)			0.08*	0.02	0.08*	0.02
Household size			-0.15*	0.01	-0.15*	0.01
Urbanicity (reference=rural)						
Second city			-0.32*	0.03	-0.32*	0.03
Suburban			-0.28*	0.02	-0.28*	0.02
Small town			-0.15*	0.02	-0.15*	0.02
Urban			-0.49*	0.03	-0.49*	0.03
Travel year (2017)			0.03	0.02	0.03	0.02
Weekend travel day			0.02	0.02	0.02	0.02
Travel season (Ref=Winter)						
Spring			-0.02	0.02	0.00	0.02
Summer			0.01	0.03	0.01	0.03
Fall			0.00	0.03	-0.02	0.03
Income (Ref=< $25,000)						
$25,000-$49,999			0.34*	0.03	0.34*	0.03
$50,000-$99,999			0.42*	0.03	0.42*	0.03
$100,000 or more			0.45*	0.03	0.46*	0.03
Census (Ref=Midwest)						
Northeast			-0.12*	0.05	-0.12*	0.05
South			-0.04*	0.04	-0.04	0.04
West			-0.06	0.03	-0.06	0.03
Step 3						
Travel difficulty*Renewal length					0.01	0.01

*p < .05

Table 8. Generalized estimating equation models (logistic) predicting driving status among participants who experienced in-person license renewal requirements

	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Step 1						
Intercept	13.21*	11.96, 14.59	85.53*	63.05, 116.01	82.43*	60.23, 112.82
Travel difficulty	0.10*	0.09, 0.10	0.14*	0.13, 0.16	0.15*	0.13, 1.19
Length of renewal cycle	1.03*	1.02, 1.05	1.00	0.98, 1.01	1.00	0.99, 1.02
Step 2						
Age			0.90*	0.90, 0.91	0.90*	0.90, 0.91
Gender (Men)			2.08*	1.88, 2.30	2.08*	1.88, 2.30
Working status (Employed)			3.15*	2.36, 4.20	3.14*	2.35, 4.19
Race (Non-white)			0.38*	0.33, 0.43	0.38*	0.34, 0.43
Education (College)			1.65*	1.47, 1.85	1.65*	1.48, 1.85
Household size			0.53*	0.50, 0.56	0.53*	0.50, 0.56
Urbanicity (reference=rural)						
Second city			0.53*	046, 0.61	0.53*	0.45, 0.61
Suburban			0.65*	0.56, 0.76	0.65*	0.55, 0.76
Small town			0.79*	0.67, 0.92	0.79*	0.67, 0.92
Urban			0.42*	0.36, 0.51	0.42*	0.36, 0.51
Travel year (2017)			1.07	0.92, 1.24	1.07	0.92, 1.24
Weekend travel day			1.03	0.92, 1.16	1.03	0.92, 1.16
Travel season (Ref=Winter)						
Spring			0.97	0.85, 1.12	0.97	0.85, 1.12
Summer			0.95	0.81, 1.12	0.95	0.81, 1.12
Fall			0.97	0.82, 1.15	0.97	0.82, 1.15
Income (Ref=< $25,000)						
$25,000-$49,999			1.82*	1.61, 2.06	1.82*	1.61, 2.06
$50,000-$99,999			1.99*	1.74, 2.27	1.99*	1.74, 2.27
$100,000 or more			2.10*	1.77, 2.48	2.10*	1.77, 2.48
Census (Ref=Midwest)						
Northeast			0.53*	0.35, 0.79	0.53*	0.35, 0.79
South			0.78*	0.63, 0.96	0.78*	0.63, 0.97
West			0.90	0.73, 1.10	0.90	0.73, 1.09
Step 3						
Travel difficulty*Renewal length					0.99	0.96, 1.01

*p < .05

The association between a longer renewal cycle and greater odds of traveling on a given travel day is smaller for participants with health-related travel difficulty. In other words, participants without health-related travel difficulty show a slight increase in probability of traveling on a given travel day with a longer renewal cycle, while participants with health-related travel difficulty show a slight decrease in probability of traveling on a given travel day with a longer renewal cycle.

Older age and larger household size were significantly associated with a lower likelihood of traveling on a given travel day. Men, employed people, people who identify as white, and people who completed college were significantly more likely to have traveled than women, unemployed people, people who identify as a race other than white, and people who did not complete college. Compared to people who live in rural areas, people who live in second city, suburban, small town, and urban areas were significantly more likely to travel on a given travel day. Census division was not a significant predictor of traveling on a given travel day.

Given the overdispersion of the annual driving mileage outcome variable, the same covariates in the models predicting annual driving mileage were included in models predicting an ordinal version of annual driving mileage. An ordinal categorical variable was created for annual driving mileage by dividing the variable into ten categories, representing the following percentiles of the continuous variable: 0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, and 91-100. Participants were fairly evenly distributed across categories, ranging from 6001 to 8769 participants in each category. Ordinal logistic generalized estimating equation models were run in R Studio using the *multgee* package.

Table 9. Generalized estimating equation models (logistic) predicting traveling on a travel day among participants who live in states with in-person license renewal requirements

	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Step 1						
Intercept	3.23*	3.02, 3.45	3.46*	2.82, 4.24	3.36*	2.74, 4.13
Travel difficulty	0.33*	0.31, 0.35	0.43*	0.40, 0.46	0.49*	0.43, 0.56
Length of renewal cycle	1.02*	1.01, 1.03	1.01	1.00, 1.02	1.01	1.00, 1.02
Step 2						
Age			0.97*	0.97, 0.98	0.97*	0.97, 0.98
Gender (Men)			1.28*	1.21, 1.35	1.28*	1.21, 1.36
Working status (Employed)			1.77*	1.58, 1.99	1.77*	1.58, 1.98
Race (Non-white)			0.87*	0.79, 0.96	0.87*	0.79, 0.96
Education (College)			1.42*	1.32, 1.53	1.42*	1.32, 1.53
Household size			0.74*	0.72, 0.78	0.75*	0.72, 0.78
Urbanicity (reference=rural)						
Second city			1.35*	1.21, 1.50	1.35*	1.21, 1.50
Suburban			1.32*	1.19, 1.47	1.32*	1.19, 1.46
Small town			1.19*	1.08, 1.32	1.19*	1.08, 1.32
Urban			1.33*	1.17, 1.50	1.32*	1.17, 1.50
Travel year (2017)			0.91	0.82, 1.01	0.91	0.82, 1.01
Weekend travel day			0.79*	0.73, 0.86	0.79*	0.73, 0.86
Travel season (Ref=Winter)						
Spring			1.23*	1.11, 1.36	1.23*	1.11, 1.36
Summer			1.22*	1.08, 1.37	1.22*	1.08, 1.37
Fall			1.06*	0.94, 1.19	1.06	0.94, 1.19
Income (Ref=< $25,000)						
$25,000-$49,999			1.22*	1.12, 1.35	1.23*	1.12, 1.35
$50,000-$99,999			1.28*	1.17, 1.42	1.28*	1.16, 1.42
$100,000 or more			1.29*	1.14, 1.45	1.28*	1.14, 1.45
Census (Ref=Midwest)						
Northeast			1.13	0.88, 1.45	1.13	0.88, 1.46
South			0.78	0.63, 0.96	0.97	0.83, 1.12
West			0.90	0.73, 1.10	1.00	0.87, 1.15
Step 3						
Travel difficulty*Renewal length					0.98*	0.97, 1.00

*p < .05

In the models predicting annual driving mileage category by in-person license renewal, travel difficulty, and covariates, the pattern of results did not differ from the results predicting continuous annual driving mileage. However, the interaction between in-person license renewal and travel difficulty was marginally significant (p=0.07) in predicting annual driving mileage category. In the models predicting annual driving mileage category by length of renewal cycle, travel difficulty, and covariates among participants who experienced in-person license renewal, the pattern of results did not differ from models predicting continuous annual driving mileage.

In summary, health-related travel difficulty was related to annual driving mileage, driving status, and probability of traveling on a given travel day after controlling for covariates. In-person license renewal was associated with annual driving mileage but not driving status or traveling on a given travel day after controlling for covariates. Among participants who experienced in-person license renewal, travel difficulty remained significant in predicting all three outcomes. Length of renewal cycle did not predict annual driving mileage or driving status, but significantly interacted with health-related travel difficulty in predicting a lower probability of traveling on a given travel day.

Discussion

The current study aimed to elucidate the association between in-person driver license renewal policies and mobility among older adults in the United States. Experiencing in-person license renewal was significantly associated with lower annual driving mileage, lower likelihood of being a current driver, and lower likelihood of traveling on a given travel day. However, after controlling for demographic and household characteristics, the only significant association remaining was between in-person license renewal and annual driving mileage.

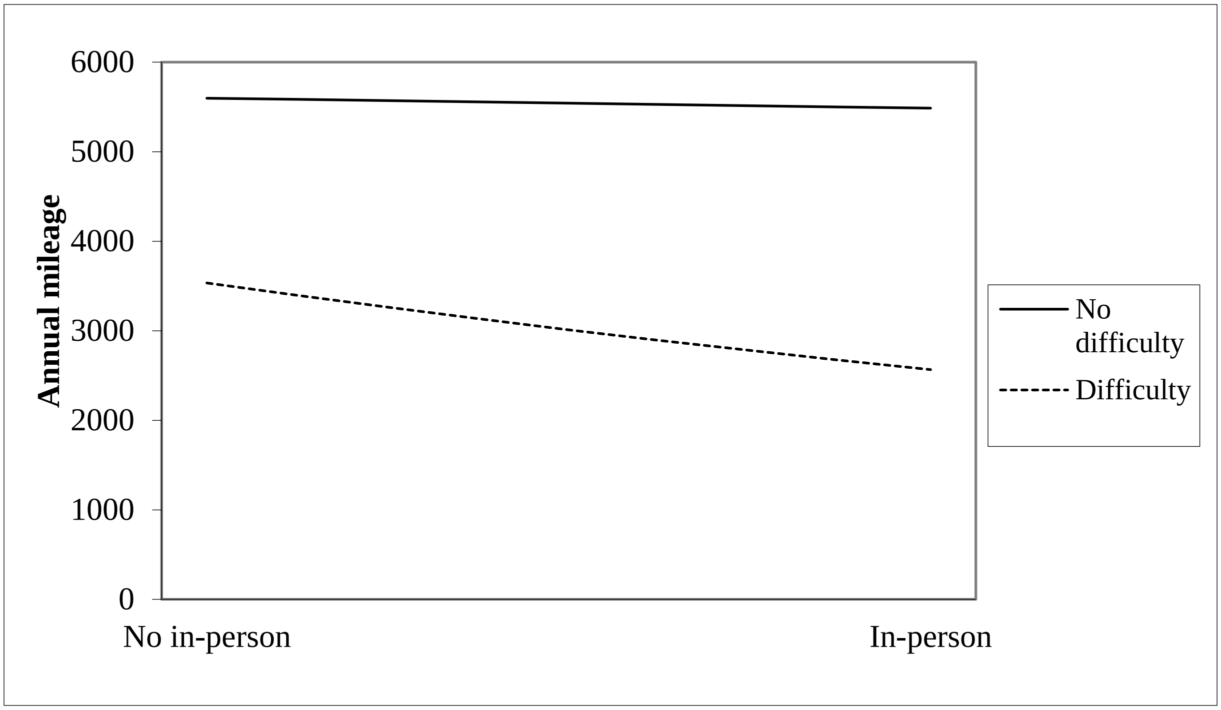

Figure 6. Health-related travel difficulty moderates the association between in-person license renewal and annual driving mileage.

After controlling for similar covariates as the current study, another study of US license renewal policy and mobility found that in-person renewal for adults 70 years and older was associated with limiting driving versus taking longer trips, but not being unable to drive versus taking longer trips (Kulikov, 2010). This finding is consistent with the current study which found that in-person renewal was associated with annual driving mileage but not driver status. It is surprising that in-person license renewal was associated with annual driving miles but not driver status, as hypothesized. In-person license renewal is meant to reduce the number of unfit older adults who have driver licenses, but the association between driver status and in-person renewal was not significant in either paper. The current study also examined the association between length of renewal cycle and driving mobility among older adults who experienced in-person license renewal. Before covariates, health-related travel difficulty and length of renewal cycle were significantly associated with lower annual driving mileage, less likelihood of being a current driver, and less likelihood of traveling on a given travel day. Older adults who live in states with longer renewal cycles drove more miles in the past twelve months, were more likely to be a current driver, and were more likely to travel on the given travel day. However, after controlling for covariates, renewal cycle length was no longer associated with any driving mobility outcome, contrary to hypotheses. Another study which examined the association between length of in-person renewal and mobility did not find an association between length of in-person renewal cycle and daily driving likelihood (Shen et al., 2020). However, the authors did find that daily driving duration was associated with length of in-person renewal among women 75 years and older.

Age, gender, working status, race, education, household size, urbanicity, and income consistently predicted annual driving mileage, driving status, and probability of traveling on a given travel day in the expected direction. The control variables related to the study travel day (travel year, weekend travel day, and travel day season) were not related to annual driving mileage or driver status. However, the variables were related to traveling on a given travel day. It is unclear why participants whose travel day was in 2017 traveled more than people whose travel day was in 2016. However, the finding that participants whose travel day was on a weekend were less likely to travel on a given travel day than participants who travel day was on a weekday makes sense. It is also unsurprising that people whose travel day was in the spring and summer were more likely to travel on a given travel day than people whose travel day was in the winter, as weather conditions in winter like snow and ice are less hospitable to travel.

Census division was related to driving status and annual driving mileage but not whether a person traveled on a given travel day. This suggests that census division is more related to measures of driving mobility rather than measures of overall mobility. For example, participants who lived in East North Central, West North Central, West South Central, Mountain, and Pacific regions were more likely to travel on a given travel day than participants who lived in New England. New England residents may have more public transportation options available, so they may be less likely to be current drivers because they use public transportation to travel. This would not impact their overall mobility or their likelihood to travel on a given travel day.

A key contribution of the current study was the examination of person-environment interactions and their association with older adult driving mobility in the context of driver license renewal policy. After demonstrating associations between the social environment (i.e., license policy) and mobility, the current study examined associations between the person (i.e., health-related travel difficulty) and mobility. Health-related travel difficulty was consistently associated with all three indicators of mobility, even after controlling for covariates. Participants who reported a health-related travel difficulty were significantly less likely to be a current driver and travel on the given travel day, and they drove fewer miles in the past twelve months than participants who did not report such difficulty. This result is consistent with other studies showing associations between self-report health measures and mobility, such as self-report independent activities of daily living (IADL; Dugan & Lee, 2013; Hess et al., 2016) and difficulty walking several blocks (Kulikov, 2010).

As hypothesized, there was a significant person-environment interaction between health-related travel difficulty and in-person license renewal: among participants who experienced in-person license renewal, participants who reported health-related travel difficulty drove significantly fewer miles than participants who did not report such difficulty. Older adults who have health-related travel difficulty may be more impacted by in-person license renewal than older adults without such difficulty. The interaction between health-related travel difficulty and renewal cycle length was also significant in predicting traveling on a given travel day, though the main effect of renewal cycle was not significant in a prior model controlling for covariates. For older adults with no health-related travel difficulty, a longer renewal cycle is associated with greater annual driving mileage. For older adults with health-related travel difficulty, there is no association between renewal cycle length and annual driving mileage. Older adults with health difficulties may not receive the benefit of greater mobility conferred by a longer time in between in-person renewal.

The cross-sectional nature of the study prohibits claims of causality of both in-person renewal policy and length of renewal. Longitudinal studies are needed which examine changes in license renewal policy and mobility and how older adults with health difficulties may be especially impacted by such changes. An additional caveat is that the interaction between in-person license renewal and health-related travel difficulty was only marginally significant when using an ordinal annual driving mileage variable that reduced dispersion. The overdispersion in the outcome variable of continuous annual driving mileage violated the dispersion assumption of Poisson regression, where the mean is the same as the variance, so results should be interpreted with caution. The association between in-person renewal and annual driving mileage category remained significant, as well as the association between health-related travel difficulty and annual driving mileage category, suggesting that person and environment associations with driving mileage are robust after addressing overdispersion.

The results of the current study and the two reviewed studies underscore the importance of looking at more than one indicator of driving mobility. Driving mobility is conceptualized in many different ways across studies. For example, in Shen et al. (2020), driving mobility was assessed by daily driving duration and likelihood of daily driving. Daily driving duration may have different meanings in different geographic contexts in the United States. For example, an older adult in a city who reported driving for two hours may have spent those two hours in traffic and only driven a few miles, while an older adult in a rural area may have driven a hundred miles in those two hours. The current study found in-person license renewal to be associated with annual driving miles but not driver status or the probability of traveling on a given travel day. If the only mobility outcomes examined was driver status, it may have been concluded that in-person license renewal was not related to driving mobility. People also may report being current drivers but have not driven recently. The dataset used in the current study attempted to address different indicators of mobility by asking current drivers to confirm their annual mileage if they reported a low value for annual driving mileage; however, there may have been some older adults who consider themselves drivers despite not driving many miles in the past year.

A possible explanation for the association between experiencing in-person license renewal and driving fewer miles per year and the association between in-person license renewal cycle length and traveling on a given travel day is that license renewal laws based on age may reduce older adults' confidence in their own driving ability. A 74-year old older person living in New Mexico who has driven safely for 55 years may lose some confidence in their driving if the state requires them to come in person to renew their license every year when they turn 75 years of age. Older adults who live in a state where the renewal laws change based on their current age may also limit their driving in fear of being pulled over and having their license revoked. There are several possibilities for why shorter in-person renewal cycles were related to a lower likelihood of being a current driver. One explanation is related to the idea behind shorter renewal cycles: that older adults who are unsafe drivers are identified by license authorities at renewal cycles and are taken off the road. Another explanation is that the process of renewing a driver's license is convenient, due to cost, long wait times, access to convenient locations, or other reasons, so people may be less likely to come in to renew their license when renewal cycle is more frequent.

Though out of the scope of this dissertation, future work using the NHTS could examine whether specific types of tests required at license renewal are associated with older adults' mobility, including road tests and vision tests. . For example, a study examined driving mobility before and after a policy mandating a three-hour class for all adults 70 years and older renewing their driver's license (Ichikawa et al., 2015). The authors found that driving mileage decreased after the three-hour class was mandated. Another study examined driving mobility related to a requirement for an on-road driving test every other year for license renewal of adults 80 years and older in new Zealand (Keall & Woodbury, 2014). After the test was no longer a requirement for license renewal, annual driving mileage increased among older adults 80 years and older. Future work could also use the NHTS to examine the association between vision tests at renewal and driving mobility. Though prior work using the American Time Use Survey (ATUS) did not find a significant association between vision tests at renewal and daily driving likelihood and duration (Shen et al., 2020), it is possible that vision tests may be associated with other indicators of mobility such as annual driving mileage and driving status. Analyses disentangling the contribution of in-person testing in general to mobility versus specific testing at renewal, such as analyses of crash risk reported in other studies (e.g., Grabowski et al., 2004; Tefft et al., 2014), would provide additional information on why in-person licensing is associated with lower mobility. Given research showing the importance of driving for older adults' identity and independence (Adler & Rottunda, 2006; Davey, 2007), it is likely that more restrictive testing at license renewal for older drivers may reduce older drivers' mobility through psychological processes such as self-esteem and autonomy.

The current study used generalized estimating equations (GEE) to account for the clustering of multiple participants within households in the dataset. GEE models are appropriate when there is a large number of clusters (i.e., households; Hubbard et al., 2010). The current study had a very large number of households, making GEE appropriate for the analyses. Another approach to addressing dependency in datasets is the use of multilevel models (MLM), also called random intercept models. MLM allows for the partitioning of variance between levels. In other words, with an MLM approach the current study could compare variation within a household and across households in driving mobility. However, the research questions of the current study were to understand how in-person license renewal and health-related travel difficulty are related to driving mobility across a population rather than modeling the effects of a household on mobility. Further, the dataset for the current study has a small number of people clustered in a household. Using a dataset where a large number of clusters have only one or two members may not allow for meaningful analyses of within-cluster variation.

There are several limitations in the current study that warrant discussion. First, the measure for experiencing in-person license renewal is an approximation based on age and state of residence. Participants may have moved states within a few years from the study date, or license renewal policies may have changed and affected participants differently. For example, in 2016, Georgia residents 60 years and older had to renew in-person every five years, which changed to every eight years in 2017 (National Conference of State Legislatures, 2018). Participants in the current study living in Georgia would have experienced a shorter renewal cycle length before the study period, so an eight-year renewal cycle length for Georgia for participants 62 and older in the current study is likely overestimating the renewal cycle for these participants. The license renewal variables in the current study also did not account for changes in license renewal by age in some states. For example, in Illinois in 2017 there was a four-year in-person renewal cycle for participants 75 and older; this cycle drops to every two years at age 81 and every year at 87. In the current study, only the first change in renewal cycle after age 62 was considered, so participants older than 75 in Illinois received the same value for renewal cycle length. This may have possibly led to underestimating the association between renewal cycle length in Illinois and driving mobility.

The current study was also limited by its use of a self-reported measure of travel difficulties. There is a growing body of work showing associations between objectively-assessed physical function and driving mobility (Antin et al., 2012; Ng et al., 2019; Phillips et al., 2016; Sims et al., 2007). There were no objective assessments of physical function in the NHTS so the current study could not examine whether the driving mobility of participants with worse physical function is particularly related to in-person license renewal policies. Health-related travel difficulty is also not directly comparable to physical function, and difficulties in travel related to medical conditions or disabilities reported by participants are likely related to much more than physical function. For example, a person with cataracts may find it more difficult to travel as a result of their condition, but they may score high on tests of physical function.

Importantly, there were also no driving safety outcomes available in the NHTS and the study was cross-sectional, so the current study was unable to assess whether in-person license renewal policies were associated with any safety improvements. However, other national studies in the US have found no association between more stringent in-person renewal requirements and crashes (Grabowski et al., 2004; Tefft, 2014). In light of these findings, the association between more stringent in-person renewal requirements and driving mobility in the current study suggests that these policies unnecessarily restrict the mobility of older drivers. However, the current study does not ask participants if they have restricted mobility, such as in other studies where participants are asked if they have missed activities or want to do more activities related to a lack of transportation (e.g., Kim, 2011; Hjorthol; 2013). While the current study found differences in annual driving mileage and driving status by certain license renewal policies, it did not assess whether these differences were perceived by participants as being a limitation to social engagement. For example, people may need to drive less when they retire, and their lower annual driving mileage may not reflect restricted mobility.

Conclusion

The current study demonstrated person-environment interactions in the context of in-person license renewal and older adult driving mobility in the United States. Older adults with health-related travel difficulties had a greater association between experiencing an in-person license renewal requirement and driving fewer miles per year compared to older adults without such difficulties. To my knowledge, only two other studies have examined the association between license renewal policy and mobility among older adults in the United States published in the past twenty years. The current study was the first study to look at interactions between health and license renewal policy in older adults. More research is needed to examine the mobility impacts of licensing policy and whether particular older adults may be more vulnerable to the mobility effects of more stringent license renewal policy. Results of the current study suggest that in-person renewal may be more important than length of renewal cycle, though more work is needed. Results of the current study and future study have important implications for designing license renewal policy. Given evidence from prior studies that more stringent license renewal policies are not associated with reduced crashes, license renewal policy for older adults in the United States needs to also the mobility implications of more stringent policies so that all older adults who are safe to drive can do so if they choose.

Chapter 3: Paper 2

Introduction

Older adults use a variety of transportation modes beyond driving a personal vehicle, including riding as a passenger, walking, cycling, and taking public transportation (Davis et al., 2011; Jones et al., 2018; King & Scott-Parker, 2017; Shen et al., 2017; Viljanen et al., 2016). Studies of older adults' transportation modes typically take sample-centered approaches to describing transportation among older adults, focusing on the most common transportation mode reported by a sample (e.g., King & Scott-Parker, 2017; Viljanen et al., 2016) or the percent of trips captured in travel diaries taken by each form of transportation (e.g., Davis et al., 2011; Shen et al., 2017). Additionally, mobility studies often focus on binary groups of older adults, such as the large body of work examining mobility differences between drivers and non-drivers (e.g., Choi & DiNitto, 2015; Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Kim et al., 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008). Little is known about *combinations* of transportation modes that older adults use, such as older adults who sometimes drive and sometimes take public transportation, and mobility outcomes.

Mobility is an important indicator of successful aging for older adults, evidenced by the impact of reduced overall mobility on health outcomes (Bentley et al., 2013; Boyle et al., 2010; Crowe et al., 2008; James et al., 2011; Xue et al., 2008). Theoretical perspectives on determinants of successful aging are therefore necessary to guide research on older adults' mobility and predictors. Theories on adult development and aging emphasize the importance of understanding person-environment interactions in determining successful aging (Baltes, 1997; Wahl & Oswald, 2010). To my knowledge, no study of transportation mode use has examined the interaction of person and environment in determining travel mode use of older adults. Latent-class analysis is a person-centered approach that allows for uncovering groups of older adults based on travel mode use, individual and environmental predictors of these groupings, and as mobility differences between these groupings. Description of users of different transportation modes can inform appropriate funding allocation to ensure the needs of diverse users are met. In particular, older adults with health limitations and older adults in rural areas may need more support for certain types of transportation modes. The current study uses latent class analysis to identify groups of older adults based on transportation mode use and to understand how a personal characteristic, health difficulties, and an environmental characteristic, urbanicity, interact to predict these groupings in a national sample of older adults in the United States.

Transportation mode use among older adults

In the United States, driving is the primary means of transportation for older adults. Results from the nationally-representative 2015 American Time Use Survey (ATUS) show that the majority of daily trips taken by older adults were in private vehicles as drivers (68-72%), followed by in private vehicles as passengers (18-24%), followed by walking at 5%, then all other modes of transportation including bus, train, and taxi at below 1% of trips (Shen et al., 2017). Another study of older adults in the United States with 2,990 older adult participants found that the most common source of transportation besides driving was riding as a passenger in a private vehicle, with 87% of the sample reporting using this mode of transportation in the past three months (Jones et al., 2018). Trains/subway were also rarely reported in this study, used by much fewer participants (17%), followed by taxis or rideshare programs (16%) and buses (12%). Older adults also do not include walking, public transportation, or taxis in their plans when they are no longer able to drive: When 402 older adults in the United States were asked in a nationally-representative survey how they will get around in case they are no longer able to drive, 60% said they would get a ride from family or friends (Kim, 2011). The next most common response was public transit and senior or community van service, followed by walking, then paratransit, then taxi, with no participants saying they would ride a bicycle. The prominence of driving as transportation and lack of public transportation use in the United States is also found in other countries such as Australia where older adults overwhelmingly prefer to drive themselves, followed by being driven by someone else, with public transportation and taxi travel rated the least preferred (King & Scott-Parker, 2017).

In European countries, however, the share of transportation modes among older adults varies. For example, in Spain, less than 40% of trips are taken by car, and around 30% of trips are taken by public transportation (Luiu et al., 2018). In contrast, in France, between 60 and 70% of trips are taken by car, with less than 20% of trips taken by public transportation. In a study of older adults in Finland, driving was not the primary means of transportation for older women, but instead being a passenger in a car, followed by public transportation, then car driving (Viljanen et al., 2016). A study of older adults in a large city in the United Kingdom found that only 42% of trips were made by driving a car, 16% as a passenger in a car, 31% by walking, less than 2% by cycling, 7% by bus, and less than 1% by train (Davis et al., 2011). The share of transportation mode use in these countries is in sharp contrast to the United States, where driving is the primary mode of transportation for older adults. Clearly, the environment plays a role in older adults' transportation mode use, as transportation mode use is dependent not only on whether someone lives in a large city but also in which country they live.

While understanding older adults' primary mode of transportation is a useful first step, research must go beyond comparisons of drivers versus non-drivers and reporting percent of trips in an entire sample taken by car versus by public transportation. None of the reviewed studies above reported combinations of transportation mode use among older adults (Davis et al., 2011; Jones et al., 2018; King & Scott-Parker, 2017; Shen et al., 2017; Viljanen et al., 2016). While there is a large body of useful work examining mobility differences between drivers and non-drivers and predictors of driving cessation (Curl et al., 2013; Edwards, Perkins, et al., 2009; Freeman et al., 2006; Haustein & Siren, 2014; Marottoli et al., 1997; Mezuk & Rebok, 2008; Ragland et al., 2005), there is little information on mobility differences between older adults who use different types of transportation such as public transportation or riding as a passenger. Additionally, studies using travel survey data report the percent of study trips taken by the whole sample that were taken by car, public transportation, walking, or other means. A single travel survey trip may not be representative of a person's typical travel behavior, and they only capture travel behavior on one day. Older adults may use different modes of transportation depending on the situation, such as the weather or day of the week. Asking older adults about their transportation mode use across a longer period of time may capture this heterogeneity in mode use better than a single travel day. Ultimately, understanding the patterns of transportation mode choice that older adults employ will help better serve older adults' transportation needs.

To my knowledge, the only study that has examined mobility outcomes between older adults who use different transportation modes beyond comparisons of drivers versus non-drivers was conducted by Viljanen and colleagues in 2016. This study of 848 older adults between 75 to 90 years of age in Finland found that lifespace did not differ between men or women who used public transportation and men or women who drove a car as the primary mode of transportation, but men and women who primarily rode in a car as a passenger were more likely to have restricted lifespace than primary car drivers (Viljanen et al., 2016). These results suggest that the type of transportation mode used by older adults has an impact on mobility.

Transit mode and the environment

The variability in transportation mode use within and across countries is unsurprising given that the environments are very different. Indeed, the role of both the physical and social environment in older adults' transportation is well-documented. Physical aspects such as proximity to a bus stop, intersection mix, and mix of residential and commercial land are associated with driving mobility (Hess et al., 2016). A study of 15,000 participants across seven waves of the Health and Retirement Study found that living in areas with a higher travel time index and roadway congestion index was associated with greater risk of driving cessation (Vivoda et al., 2017). Other environmental characteristics such as population density and walkability of neighborhood are also associated with transportation mode use (Klein et al., 2018). In theories of human development and successful aging, these aspects of the environment are part of the physical environment (Wahl et al., 2012) or culture (Baltes, 1997).

The potential role of person-environment interaction

While the environment is an important predictor of mobility, it cannot be considered by itself. A major tenet of lifespan developmental theory is that person-environment interactions drive development (Baltes, 1997; Wahl et al., 2012). Older adults' mobility cannot be understood by only looking at the environment in which they live. Personal characteristics are well-established as important determinants of older adults' mobility. Physical function seems to be a particularly salient personal characteristic in an older adult's mobility. Older adults who have difficulty walking several blocks are more likely to reduce or cease driving than older adults who do not (Kulikov, 2010). A study of 848 older adults in Finland found key interactions between function, conceptualized as having walking difficulties or not, and transportation mode use in predicting lifespace mobility, a broad measure of mobility that includes multiple modes of transportation (Viljanen et al., 2016). Among women without walking difficulties, lifespace mobility did not differ by transportation mode. However, among women with walking difficulties, car passengers had the highest odds for restricted lifespace, while car drivers had the smallest odds of restricted lifespace. These interactions were not found in men, suggesting that gender interacts with function to play a role in mobility and that among women, transportation mode use interacts with function to predict mobility.

Physical function is also predictive of older adults' mobility using specific transportation modes. A study of 1,172 older adults in the United Kingdom examined percent of trips across a seven-day travel survey period taken by each type of transportation (Davis et al., 2011). The authors used mobility aid use and scores on the short physical performance battery (SPPB) to predict trips per week for each type of transportation mode. Worse physical function and use of mobility aids was associated with fewer total trips per week and number of car driving trips per week and number of active transportation trips (i.e., walking or cycling), but not with trips as a passenger or public transportation. The authors did not look at whether physical function predicted which type of transportation an older adult was most likely to take, but rather the number of trips taken by each mode separately. It is possible that older adults with worse physical function are more likely to choose one type of transportation mode over another due to comfort, safety, or other reasons.

Though person-environment interactions are a key driver of development, to my knowledge, no study has examined the role of person-environment interactions in older adults' transportation mode use. It is important to understand not only how transportation mode use differs between different environments but also understand how this may be different for older adults with health limitations, given research showing that transportation mode use influences mobility and mobility is important for older adults' well-being. Based on theories of lifespan development and successful aging (Baltes, 1997; Wahl et al., 2012), it is likely that personal characteristics such as health limitations interact with social and physical aspects of the environment to determine transportation mode use. The extensive variation in social and physical environmental characteristics of urban and rural areas across the United States provides the opportunity to examine differences in transportation mode use by urbanicity and health limitations.

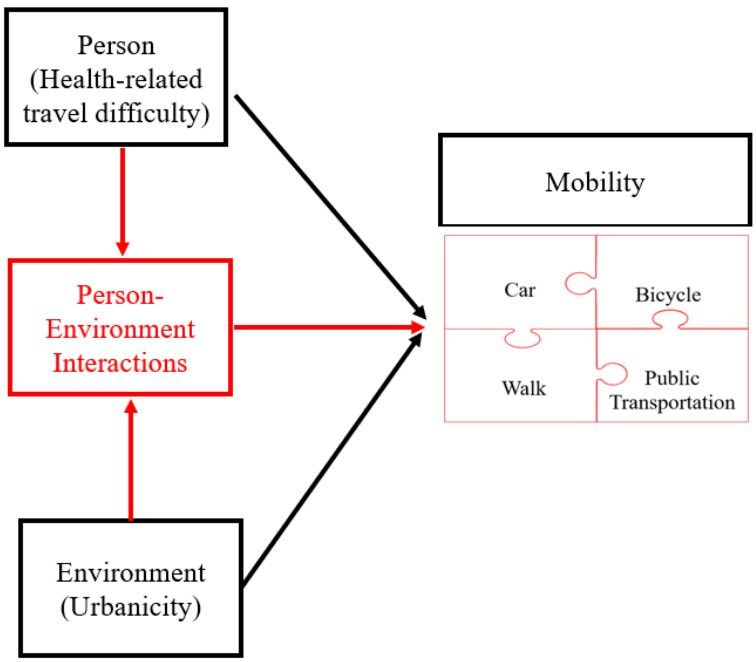

Figure 7. Conceptual model for Paper 2 Aims 1-3, with health-related travel difficulty and urban/rural status interacting to predict four indicators of mobility (car, bicycle, walking, and public transportation).

Aims and Hypotheses

The current study used latent class analysis to identify classes of older adults based on transportation mode use and characteristics of these classes, contributing to understanding of transportation mode use in older adults beyond driving. The conceptual model for the three aims of Paper 2 is depicted in Figure 7. The first aim was to identify classes of older adults' transportation mode use and the prevalence of these classes in a national sample of older adults. I hypothesized that the majority of the sample will belong to a class characterized by driving as a primary mode of transportation, replicating prior work showing that the majority of trips taken by older adults are taken by driving personal vehicles (Shen et al., 2017). Extending prior work, I hypothesized that there will be classes of older adults characterized by uses of multiple transportation modes, such as drivers and passengers, though these classes will have fewer older adults in them compared to the drivers-only class (Jones et al., 2018). Beyond these hypotheses, I did not hypothesize a specific number of classes or makeup of classes as there is not sufficient literature on older adult transportation mode combinations.

The second aim was to examine demographic, functional, and environmental predictors of latent class membership. Based on prior work on predictors of driving mobility, I hypothesized that gender, age, household composition, income, urbanicity, and health-related travel difficulty will be associated with latent class membership. Specifically, I hypothesized that men, younger people, people with higher incomes, people in rural areas, and people who report better health will be more likely to belong to a drivers-only class. The literature on household composition is mixed, so I do not hypothesize a specific direction for the association between household composition and class membership. Beyond the drivers-only class, I do not hypothesize any directionality regarding covariates and membership in any other classes that emerge.

Finally, the third aim was to analyze differences in class prevalence by urbanicity and health-related travel difficulty I hypothesized that older adults in rural areas and urban areas who have health difficulties will be less likely to belong to a drivers-only class compared to older adults without health difficulties in rural areas and urban areas, and older adults in urban areas regardless of health difficulties will be more likely to belong to a multimodal class due to availability of other transportation options.

Methods

Study Design and Procedure

The current study uses data from older adults 62 years of age and older in the 2017 National Household Travel Survey (NHTS), which has been described in Paper 1. Briefly, the NHTS surveyed 900,000 households across all 50 states and the District of Columbia between April 2016 and April 2017. The NHTS collected information on the household, such as household income and state of residence, and information on each household member over the age of 5 years. Participants also completed a travel diary for a 24-hour period in which they documented details of every trip taken, such as duration and mode of transportation. Data collection was balanced across households to represent weekends/weekdays and all twelve months of the year. The NHTS only includes data for households in which the household survey and individual survey were completed for each person. The current study includes data from 129,696 households with at least one person 62 years and older. This dataset included 89,757 participants 62 years and older, which includes people from the same household. The current study uses two random subsamples of the NHTS, labeled Sample 1 (n=28,055) and Sample 2 (n=28,482).

Measures

Transportation mode use. Five transportation mode use variables were created using measures from the NHTS person and household questionnaires. *Walking for travel* was measured by participants' responses to the question, "In the past 7 days, how many times did you take a walk outside including walks to exercise, go somewhere, or to walk the dog (e.g., walk to a friend's house, walk around the neighborhood, walk to the store, etc.)?" This question was followed by "How many of these walks were strictly for exercise?" Walking for travel was calculated by subtracting the number of walking trips for exercise from the number of all walking trips in the past 7 days. Possible scores for this variable ranged from 0 days to 7 days. *Bicycling for travel* was measured by participants' responses to the question, "In the past 7 days, how many times did you ride a bicycle outside including bicycling to exercise, or to go somewhere (e.g., bike to a friend's house, bike around the neighborhood, bike to the store, etc.)?" subtracting the number of bicycle rides that were strictly for exercise. Possible scores for this variable ranged from 0 days to 7 days. *Public transportation use* was measured by participants' response to the question, "In the past 30 days, about how many days have you used public transportation such as buses, subways, streetcars, or commuter trains? Do not include taxis." Possible scores for this variable ranged from 0 days to 30 days. *Driving status* was reported by the household respondent for all household members who participated in the study. Participants were either reported as drivers (1) or non-drivers (0).

Even though participants may be reported as current drivers, they may not be active drivers. In order to assess whether participants are active drivers, the current study includes a variable indicating whether the participant is the main driver of at least one household vehicle. *Main driver of household vehicle* was measured using participants' reports of who the main driver is for each household vehicle. If a participant is the main driver of at least one vehicle, they received a value of 1 for being the main driver of a vehicle. If a participant is not listed as the main driver of at least one vehicle, they received a value of 0.

Independent variables. Health-related travel difficulty is the primary independent variable and was assessed by participants' responses to the question, "Do you have a condition or handicap that makes it difficult to travel outside of the home?" Participants who responded "yes" received a score of 1, while participants who responded "no" received a score of 0. *Urban/rural status* is also a primary independent variable to control for aspects of the physical environment related to mobility that characterize urban/rural areas (Hess et al., 2016; Vivoda et al., 2017; Klein et al., 2018). Household urban/rural status in the NHTS dataset was based on the 2014 US Census TIGER classification for the participant home address. The Census defines urban areas based on total population, density, land use, and distance (Ratcliffe et al., 2016). Urban areas are more densely populated than rural areas, are closer together, and have a population of at least 2,500 people. Areas that do not meet this definition are considered rural; rural areas are less densely populated, are farther apart from one another, and have a population of less than 2,500 people. For the current study, participants who lived in an urban area received a score of 1 and participants who lived in a rural area received a score of 0.

Demographic variables are included as covariates in models predicting latent class membership. Given work showing that women are more likely to take public transportation (Viljanen et al., 2016) and active forms of transportation such as walking and bicycling (Davis et al., 2011; Shen et al., 2017) and are less likely to drive for transportation (Davis et al., 2011; King & Scott-Parker, 2017; Shen et al., 2017; Viljanen et al., 2016), *gender* was included as a covariate (0=woman, 1=man). Age was also included as a covariate given prior work showing that older people are less likely to drive and less likely to take public transportation and walk (Davis et al., 2011; King & Scott-Parker, 2017; Shen et al., 2017). Age is mean-centered in all analyses. *Income* is also considered as people with lower incomes are more likely to cease driving (Dugan & Lee, 2013) and report insufficient transportation (Kim, 2011). Income was assessed for the household and split into four categories: 0= less than $24,999, 1= $25,000 to $49,000, 2= $50,000 to $99,000, and 3= $100,000 or more. A binary *race* variable indicating whether a participant is white (0) or non-white (1) was included, as people who specify a non-white race are more likely to reduce and cease driving (Kulikov, 2010; Vivoda et al., 2017) and be a non-driver (Dugan & Lee, 2013). *Household size* was also included as a continuous variable as older adults who live with others are more likely to cease driving (Anstey et al., 2006; Vivoda et al., 2017). *Employment status* (1 = currently working for pay, 0=not currently working for pay) was included to account for research showing that older adults who are not working for pay drive less than older adults who are currently working for pay (Kulikov, 2010). Finally, *education* (1=college or higher, 0 = less than college) was included as a covariate, as people with more education are less likely to reduce their driving (Kulikov, 2010; Vivoda et al., 2017) and more likely to be current drivers (Dugan & Lee, 2013; Kulikov, 2010).

Analytic Approach

Latent class analysis (LCA) is a useful statistical technique for identifying subgroups of individuals based on their scores on multiple variables. LCA is a parsimonious way to summarize results from multiple scores, which will aid in capturing heterogeneity in transportation mode use. To accomplish Aim 1, I used LCA to characterize transportation mode use classes using five indicators: walking for travel, bicycling for travel, public transportation use, driver status, and whether the participant is the main driver of a household vehicle. LCA requires categorical indicator variables and produces categorical classes which are mutually exclusive and exhaustive, meaning that all participants are grouped into a class and participants can only belong to one class. The latent class model is depicted in Figure 8, where five indicator variables are used to group participants into latent classes. LCA assumes independence of observations, and multiple participants per household may violate this assumption. Therefore, a random subsample of participants identified as Person 1 in a household was selected to run initial latent class models (n = 28,055). A random subsample of remaining participants, also identified as Person 1, was selected for replication of models (n=28,482).

Latent class analyses were conducted in SAS using the PROC LCA procedure (Lanza et al., 2007), and a significance value of $p < .05$ is set for all analyses. LCA uses Maximum Likelihood (ML) estimation. There was no hypothesized number of classes, so fit statistics including Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used, as well as substantive interpretability, to select the optimum class solution. Once the optimal class solution was identified, the LCA was conducted in Sample 2 specifying the same number of predictors. Each latent class received a label based on theoretical interpretation, and LCA results include the proportion of the sample belonging to each class, item response probabilities for each indicator variable, and standard errors. Class prevalences, item response probabilities, and standard errors were compared across Sample 1 and Sample 2 to ensure replication. Missing data were considered missing at random, consistent with the PROC LCA procedure.

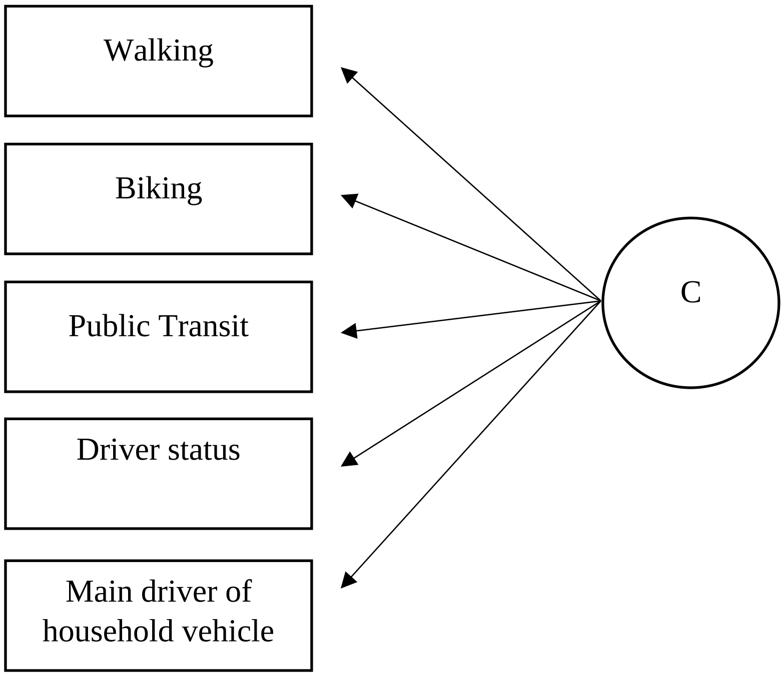

Figure 8**.** Latent class analysis for Aim 1

Another benefit of LCA is that it enables the researcher to examine predictors of class membership and outcomes of class membership. To accomplish Aim 2, analyses examined demographic, functional, and environmental predictors of latent class membership (Figure 9). Multinomial regression was used to assess the association of health-related travel difficulty, urbanicity, and covariates (gender, age, employment status, household size, and income) with latent class membership. The latent class model was estimated simultaneously with logistic regression parameters to account for uncertainty in class membership. A latent class was selected as a reference group in order to report the difference in odds of membership of other latent classes relative to the reference group according to health-related travel difficulty and other covariates. Logistic regression parameter estimates and 95% odds ratios were reported, and odds ratios not containing the value 1 indicated a significant effect of covariates. Participants with missing data for at least one covariate were excluded from regression analyses, as LCA removes cases with missing covariates from analysis.

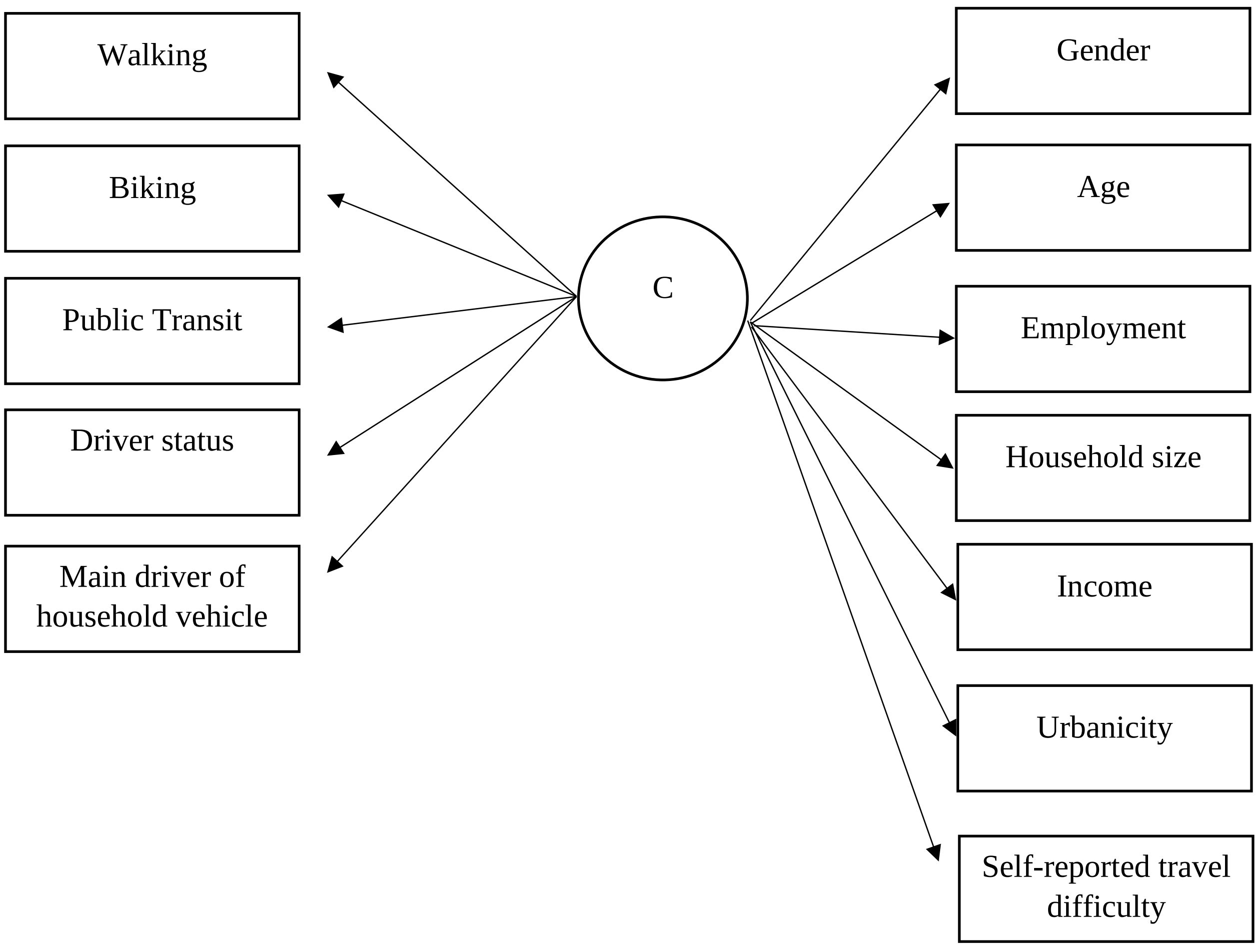

Figure 9**.** Latent class analysis for Aim 2.

To accomplish Aim 3, rural/urban status was used as a grouping variable to assess whether the prevalence of each latent class varies across groups. In order to draw meaningful comparisons between groups, measurement invariance was imposed across the two groups, which constrains the item-response probabilities to be the same for both groups. In latent class analysis, a G^2 difference can be used to compare unrestricted and restricted models and provide significance values testing whether latent class probabilities significantly differ between groups.

However, a latent class model with freely estimated (unrestricted) latent class probabilities did not converge, so only descriptive results will be presented for this aim. A latent class model with urban/rural status as a grouping variable was conducted, followed by a latent class model using a six-category variable indicating urban/rural status and health-related travel difficulty to test whether health and environment interact to predict mobility patterns. The same LCA was conducted in Sample 2 for replication.

Results

Participants. Participant characteristics for the main study sample (Sample 1) are located in Table 10. The sample age ranged between 62 and 92, with an average age of 71.73 years (SD = 7.49). The sample was about evenly split between men (52.1%) and women (47.9%). Most of the participants were white (88.3%). About a quarter of participants lived in an urban household, and 15.7% of the sample reported a health-related travel difficulty. Most participants were current drivers and slightly fewer participants reported being the main driver of a household vehicle. Very few participants reported bicycling for travel in the past seven days (1.6%) or using public transportation in the past thirty days (8.3%). About 40% of participants reported walking for transportation in the past seven days. A random sample of 28,482 participants were selected to test replication of latent class analyses (Sample 2). There were no significant differences between Sample 1 and Sample 2 in average age of participants, percent of women, urban/rural status, and health-related travel difficulty (p's > .05).

Table 10. Descriptive statistics for subsample of older adults from the National Household Travel Survey, Sample 1 (n=28,055)

	n (%)	M (SD)	Range
Age	-	71.73 (7.49)	62 - 92
Household size	-	1.70 (0.72)	1 - 9
Women	13,441 (47.9%)	-	-
Health-related travel difficulty	4,413 (15.7%)	-	-
Race (Not white)	3,266 (11.7%)	-	
Education, college or more	12,553 (44.8%)	-	
Working status (Employed)	6,779 (24.2%)		
Household income[1]			
≤ $24,999	6,340 (22.6%)		
$25,000-$49,000	7,252 (25.9%)		
$50,000 to $99,999	8,000 (28.5%)		
≥$100,000	4,980 (17.8%)		
Urban household	7,459 (26.6%)		
Current driver	26,487 (94.4%)		
Main driver of household vehicle	25,352 (90.4%)		
Bicycling for travel (past 7 days)	450 (1.6%)		
Public transportation (past 30 days)	2,322 (8.3%)		
Walking for travel (past 7 days)	11,054 (39.9%)		

[1]n=26,572

Model selection. Goodness-of-fit criteria for models specifying one through five classes are presented in Table 11. Model 3 was chosen as the best-fitting model because there is a large drop in G^2, AIC, and BIC going from two to three classes. There is not a similar decrease going from three to four classes or four to five classes, and the model with five classes did not converge after 5,000 iterations. The AIC and BIC also increase from four to five classes. Thus, a three-class model was chosen for the best balance of goodness-of-fit criteria and parsimony.

Table 11. Goodness-of-fit criteria for latent class model solutions

Number of classes	Degrees of freedom	G^2	AIC	BIC
1	26	10245.09	10255.09	10296.30
2	20	577.52	599.52	690.19
3	**14**	**162.07**	**196.07**	**336.18**
4	8	113.68	159.68	349.25
5[1]	2	111.06	169.06	408.08

Notes. Bold indicates selected model. [1]Model did not converge in 5000 iterations.

To test for local independence, chi-square statistics were calculated for each pair of the five indicator variables. Chi-square results are presented in Table 12. All bivariate associations were significant except for the associations between current driver status and bicycling and current driver status and walking for transportation. Significant associations suggest that the assumption of local independence in LCA may be violated in the subsequent analyses.

Table 12. Chi-square analysis of LCA indicator variables.

	Current driver	Main driver	Bicycling	Walking	Public Transit
Current driver					
Main driver	X^2=16,356.14* N=28,482				
Bicycling	X^2=0.01 N=28,456	X^2=4.30* N=28,456			
Walking	X^2=0.44 N=28,133	X^2=8.30* N=28,133	X^2=110.792* N=28,115		
Public transit	X^2=1,846.87* N=28,436	X^2=1,975.98* N=28,436	X^2=89.61* N=28,417	X^2=433.95* N=28,105	

*$p < .05$. All degrees of freedom = 1.

Aim 1: Latent class model. The latent class prevalences and item-response probabilities for the three-class solution are presented in Table 12. Class 1 is characterized by a high probability of being a current driver and the main driver of at least one household vehicle, a moderate probability of walking for transportation (0.36), and very low probability of bicycling for transportation and using public transportation. Class 1 was named “Drivers who Walk”. Class 2 is characterized by a low probability of being a current driver (0.15) and very low probability of being the main driver of a household vehicle. Participants in Class 2 had a moderate probability of walking for transportation and using public transportation, and a very low probability of bicycling for transportation. Class 2 was named “Nondrivers”. Participants in class 3 had a high probability of being current drivers and being the main driver of a household vehicle, though this probability was a little lower than the probability for participants in Class 1. Participants in Class 3 had the highest response probability for walking for transportation, bicycling for transportation, and using public transportation. Class 3 was named “Multimodal Drivers”. Latent class prevalences are located above the item-response probabilities in Table 12. The most prevalent class among the sample was Drivers who Walk, and there were equal prevalences of Nondrivers and Multimodal Drivers. The 3-class model was replicated in Sample 2 and similar latent class prevalences and item-response probabilities were found (Table 14).

Table 13. Parameter estimates and standard errors for latent class model (Sample 1, n=28,055)

	Class 1 Drivers who Walk	Class 2 Nondrivers	Class 3 Multimodal Drivers
	Latent Class Prevalences (SE)		
	0.87	0.07	0.07
	(0.01)	(0.00)	(0.01)
Variables	Item-response probabilities		
Driver	1.00	0.15	1.00
	(0.00)	(0.03)	(0.00)
Walker	0.36	0.39	0.85
	(0.01)	(0.01)	(0.04)
Bikers	0.01	0.02	0.11
	(0.00)	(0.00)	(0.01)
Transit users	0.04	0.35	0.42
	(0.00)	(0.01)	(0.05)
Main vehicle driver	0.97	0.00	0.88
	(0.00)	(0.00)	(0.02)

Table 14. Parameter estimates and standard errors for latent class model (Replication Sample 2, n=28,482)

	Class 1 Drivers who Walk	Class 2 Nondrivers	Class 3 Multimodal Drivers
	Latent Class Prevalences (SE)		
	0.88	0.07	0.05
	(0.01)	(0.00)	(0.01)
Variables	Item-response probabilities		
Driver	1.00	0.12	1.00
	(0.00)	(0.02)	(0.00)
Walker	0.37	0.41	0.93
	(0.01)	(0.01)	(0.04)
Bikers	0.01	0.01	0.13
	(0.00)	(0.00)	(0.01)
Transit users	0.04	0.37	0.51
	(0.00)	(0.01)	(0.06)
Main vehicle driver	0.97	0.00	0.84
	(0.00)	(0.00)	(0.02)

Aim 2: Predictors of latent class membership. Aim 2 was to examine demographic, functional, and environmental predictors of latent class membership. The multinomial regression results are located in Table 15. Multinomial regression for latent class analysis automatically removes participants with missing data on at least one covariate, so the sample size for the analysis was 27,919. The first column compares membership in Nondrivers versus Drivers who Walk. All variables except household size significantly predicted membership in Nondrivers versus Drivers who Walk. Participants with a health-related travel difficulty were almost five times as likely to belong to Nondrivers class compared to participants without a health-related difficulty. Participants who lived in a rural household were 56% less likely to belong to the Nondrivers class than participants who lived in an urban household.

The second column compares membership in Multimodal Drivers versus Drivers who Walk. Gender and income (except a household income of $100,000 or more) did not significantly predict membership in Multimodal Drivers, but household size is significant in this model. Participants with larger household sizes are less likely to belong to Multimodal Drivers compared to participants with smaller household sizes. Participants with a health-related travel difficulty were 40% less likely to belong to Multimodal Drivers compared to participants without a health-related travel difficulty. Participants living in rural areas were 59% less likely to belong to Multimodal Drivers compared to participants living in urban areas. Participants who have a college degree or more were almost four times as likely to be a Multimodal Driver compared to participants without a college degree. The analyses were repeated in the replication sample (n=28,360) and the significant findings were replicated except in the case of income of $25,000 to $49,999, which was significant in the replication sample (OR=0.63, 95% CI= 0.49, 0.81).

Table 15. Multinomial regression model predicting class membership, Sample 1 (n=27,919)

	Nondrivers vs. Drivers who Walk		Multimodal Drivers vs. Drivers who Walk	
	OR	95% CI	OR	95% CI
Intercept	0.06	0.04, 0.08	0.33	0.20, 0.56
Health-related travel difficulty	4.84*	4.32, 5.42	0.60*	0.44, 0.80
Non-white race	3.10*	2.72, 3.55	1.37*	1.10, 1.71
Gender (men)	0.61*	0.54, 0.69	0.99	0.86, 1.15
Age	1.04*	1.04, 1.05	0.94*	0.93, 0.95
Working for pay	0.51*	0.41, 0.64	1.30*	1.12, 1.52
College or higher	0.77*	0.67, 0.88	3.87*	3.16, 4.75
Household size	1.04	0.95, 1.13	0.77*	0.68, 0.87
Rural household (REF= Urban)	0.44*	0.38, 0.51	0.41*	0.32, 0.51
Income (REF= ≤ $24,999)				
$25,000-$49,999	0.32*	0.28, 0.37	0.80	0.63, 1.03
$50,000-$99,999	0.22*	0.18, 0.26	1.00	0.80, 1.26
≥ $100,000	0.16*	0.12, 0.22	1.84*	1.45, 2.34

* p < .05

Aim 3: Latent class prevalence by urban/rural and health-related travel difficulty. To compare latent class prevalences between participants in urban and rural areas, a 3-class latent class model with urban/rural status as a grouping variable was conducted. Latent class prevalences by urban/rural status are presented in Figure 10. Prevalences for participants in urban areas are represented in blue, and participants in rural areas are orange. Consistent with the 3-class solution with no grouping variable, the majority of participants belonged to Drivers who Walk (n=25,219). The prevalence of the Drivers who Walk class was slightly higher in rural areas (Gamma = 0.96, SE = 0.00) compared to urban areas (Gamma=0.88, SE=0.96). A small number of participants belonged to the Nondrivers class (n=1,357) and Multimodal Drivers class, (n=1,253), and urban participants were more represented in these classes (Nondrivers Gamma=0.07, SE=0.00, Multimodal Drivers Gamma=0.06, SE=0.01) compared to rural participants (Nondrivers Gamma=0.03, SE=0.00, Multimodal Drivers Gamma=0.01, SE=0.00). Rural older adult Multimodal Drivers had the smallest number of participants per class (n=50). The three-class latent class model with urban/rural status as a grouping variable was replicated in Sample 2 and results were similar (Figure 11). The model with freely-estimated parameters did not converge, so no significance tests can be conducted to test whether prevalence significantly varies by group.

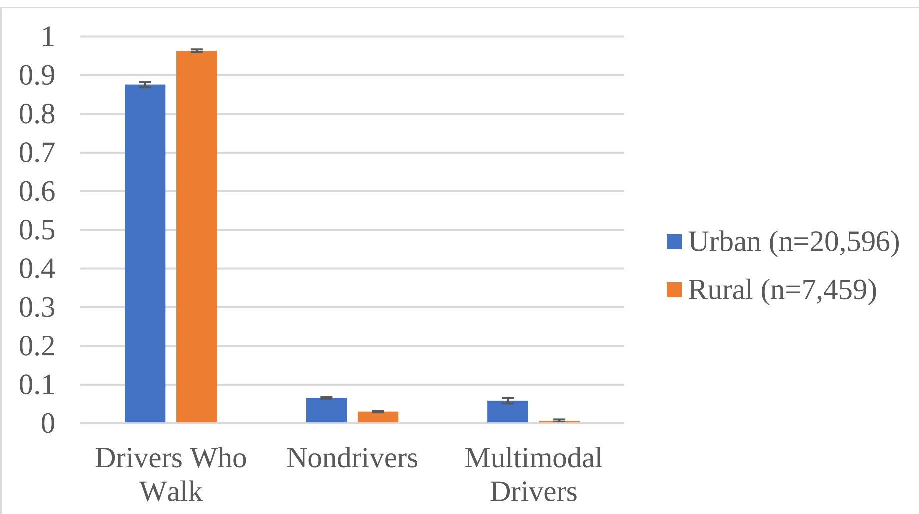

Figure 10. Latent class prevalences by urban and rural status (Sample 1). Error bars represent standard errors of Gamma (class membership probability) estimates. (n=28,055)

To test the interaction between health and environment, a three-class latent class model with health-related travel difficulty and urban/rural status was conducted. The latent class prevalences for each group are presented in Figure 12. There were 24,571 participants in the Drivers Who Walk class. The rural group with no health difficulties, depicted in gray bars, had the highest prevalence of Drivers Who Walk (Gamma= 0.97, SE=0.01), followed by the urban group with no health difficulties, depicted in yellow bars (Gamma=0.88, SE=0.01). The urban and rural groups with health difficulties had the lowest prevalence of Drivers Who Walk, but the prevalences were still high compared to other classes. The Nondrivers class consisted of 1,896 participants and had a much lower prevalence across all four groups compared to Drivers Who Walk. Urban older adults with health difficulties, depicted in blue bars, had the highest prevalence of Nondrivers (Gamma= 0.27, SE=0.01), followed by rural older adults with health difficulties, depicted in orange bars (Gamma=0.17, SE= 0.01). The number of participants in the Nondrivers class was similar for rural older adults without travel difficulties (n=106) and urban older adults without travel difficulties (n=704), though the prevalence among urban older adults without travel difficulties was slightly higher.

Finally, the Multimodal Drivers class had the fewest older adults at 1,588 older adult class members and the lowest prevalences across all four groups. Urban older adults with no travel difficulties had the highest prevalence of this class (Gamma= 0.08, SE=0.01), followed by a very small prevalence of urban older adults with health difficulties (n=88 out of 3,387), then rural older adults with no travel difficulties (Gamma= 0.02, SE=0.01, n=98 out of 6,433). There was zero prevalence in this group for rural older adults with travel difficulties. The latent class model with grouping variables was replicated in Sample 2 and results were similar (Figure 13). There was an interaction between health-related travel difficulty and urbanicity within the Multimodal Drivers Class (Figure 14). Among urban older adults, there was a greater difference in prevalence between older adults who reported travel difficulties and those who did not compared to rural older adults, though overall prevalences were small across all four groups.

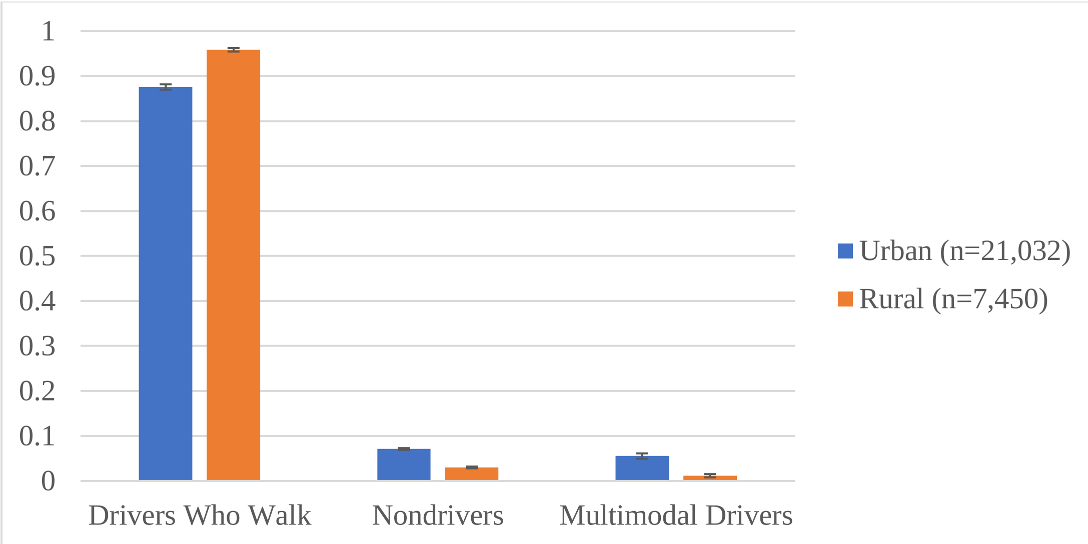

Figure 11. Replication of latent class prevalences by urban and rural status (Sample 2). Error bars represent standard errors of Gamma (class membership probability) estimates (n=28,482).

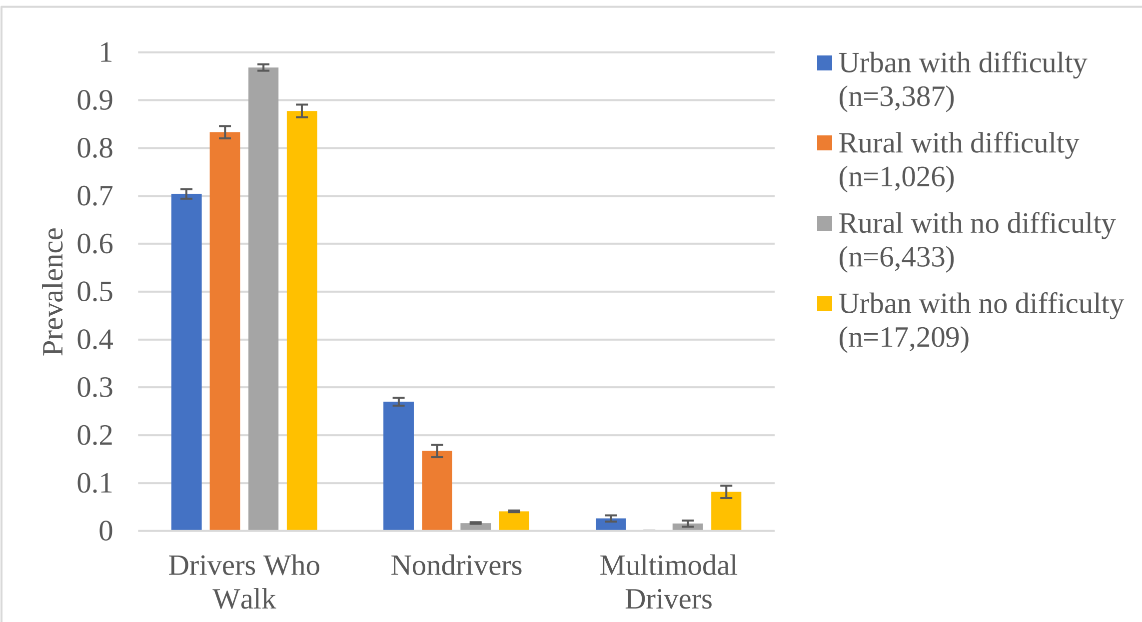

Figure 12. Latent class prevalences by urban/rural status and health-related travel difficulty (Sample 1). Error bars represent standard errors of Gamma (class membership probability) estimates (n=28,055).

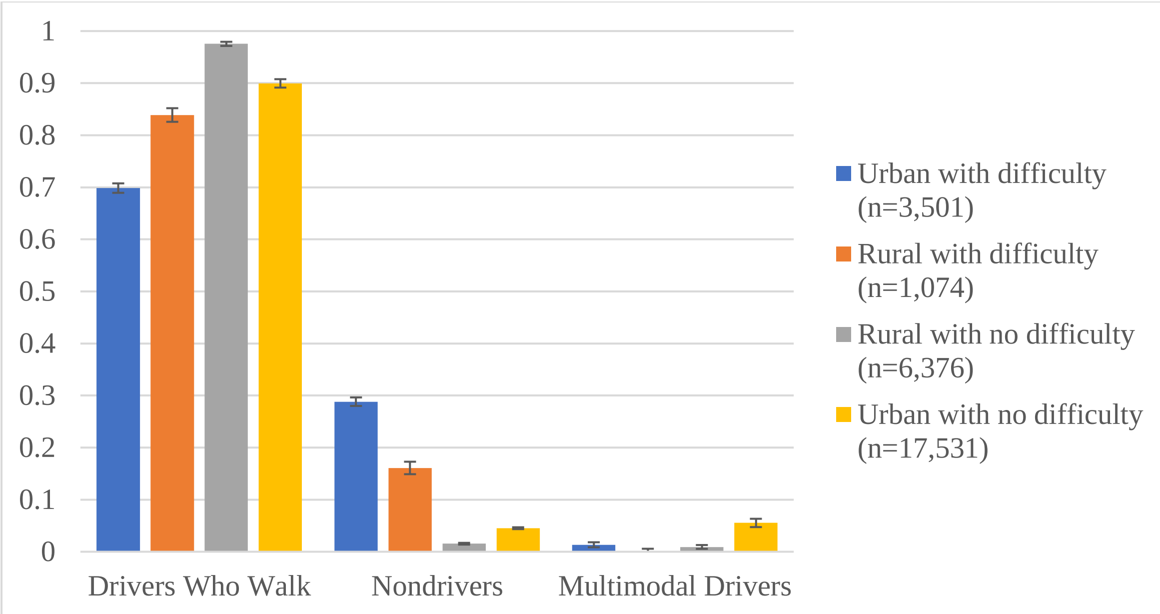

Figure 13. Replication of latent class prevalences by urban/rural status and health-related travel difficulty (Sample 2). Error bars represent standard errors of Gamma (class membership probability) estimates (n=28,482).

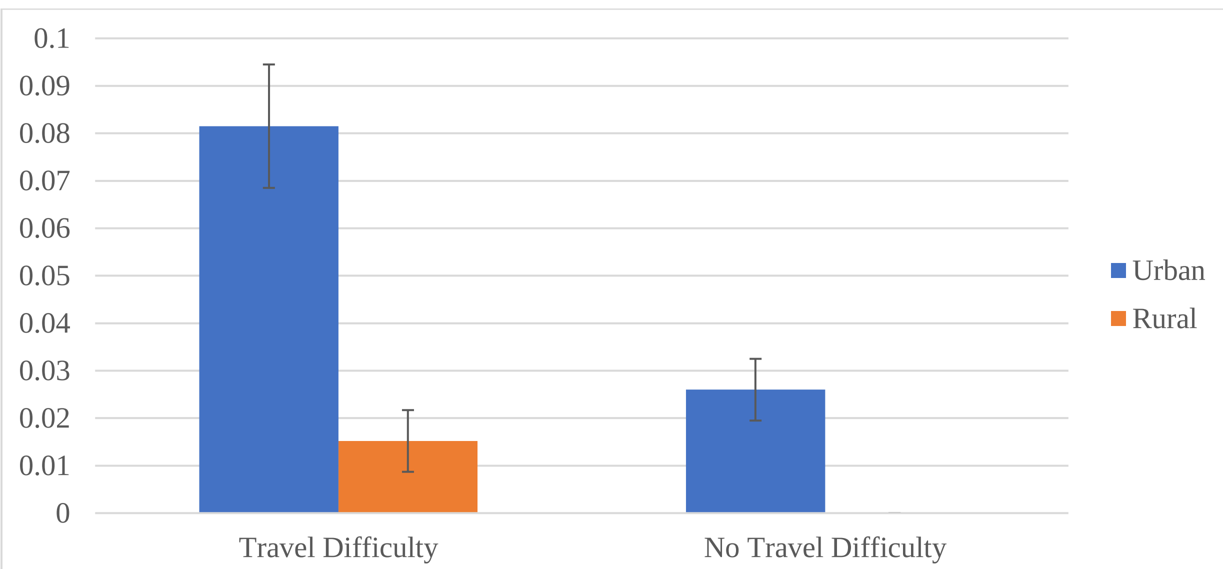

Figure 14. Interaction between urbanicity and health-related travel difficulty among Multimodal Drivers Class.

Discussion

The current study explored travel mode patterns in a national sample of adults 62 years and older in the United States. A latent class model identified a well-fitting model with three classes: Drivers who Walk, Nondrivers, and Multimodal Drivers. Drivers who Walk was the most common class, and two out of the three classes were characterized by a high probability of being a current driver and being the main driver of a household vehicle. The predominance of drivers in the latent class model is consistent with other nationally-representative studies documenting the predominance of driving among older adults in the United States (Jones et al., 2018; Shen et al., 2017). These other studies also found low rates of public transportation, walking, and bicycling (Jones et al., 2018; Shen et al., 2017). Among the general population of older adults, public transportation, walking, and bicycling appear to be utilized by few older adults as a means of transportation compared to driving.

Despite the predominance of driving among the sample, the current study found that even among drivers, there was considerable variation in transportation mode use. The current study contributes to the knowledge base of older adult transportation by documenting *combinations* of transportation mode use among older adults. Though the majority of the sample belonged to a latent class made up almost entirely of drivers, as hypothesized, this class was also characterized by walking for transportation in the past seven days, which was unexpected. There was also a class of older adults labeled Multimodal Drivers which reported not only a high probability of being a current driver but also walking for transportation, bicycling for transportation, and using public transportation. Though the prevalence of this class in the sample was small, the results demonstrate that there is a small group of older adults who use a variety of transportation modes. Typically, studies look at driving status as an outcome (e.g., Anstey et al., 2006; Antin et al., 2012; Dugan & Lee, 2013; Edwards, Bart, et al., 2009; Edwards et al., 2008; Emerson et al., 2012; Freeman et al., 2005; Hess et al., 2016; Hwang & Hong, 2018; Kulikov, 2010), or look at the percent of a sample using a particular travel mode (Davis et al., 2011; Jones et al., 2018; Luiu et al., 2018; Shen et al., 2017; Viljanen et al., 2016). This study expands upon current understanding of how older adults move around in their world.

Another interesting finding from the probabilities of the items that make up each latent class was that among Drivers who Walk and Multimodal Drivers, there was not the same probability of being a current driver and being the main driver of at least one household vehicle. This finding suggests that there are older adults who are reported as current drivers but may not actually drive as a primary mode of transportation. In particular, Multimodal Drivers were distinguishable from Drivers who Walk in that they had a lower probability of being the main driver of at least one household vehicle. The current study suggests that there may be older adults who are current drivers but are not the main driver of a household vehicle. The Nondrivers class also had a small probability of reporting being a current driver, but almost zero probability of being the main driver of a household vehicle. As suggested by some authors, there may be older adults who retain their driver’s licenses but do not actually drive (Langford et al., 2008; Ross et al., 2011). Similarly, there may be some older adults who report being current drivers but do not actually drive or do so infrequently. Another possibility is that drivers in the current study who report being current drivers but not the main driver of a household vehicle mainly ride as passengers in a private vehicle and only drive occasionally. The current study was not equipped to explore being a passenger in a vehicle as a mode of transportation, which is a limitation of the National Household Travel Survey. Another possibility is that these drivers share a vehicle with someone else, so while they are not the main driver, they drive the vehicle an equal amount as someone else. Studies with older adults should include multiple outcomes related to driving mobility in order to assess these nuances in driving behavior, including whether a person has a current driver's license, whether they consider themselves to be a current driver, and how often they have driven in the past few days or weeks.

Covariates were mostly related to latent class membership in the expected direction. People who identified a race other than white were less likely to belong to the Drivers who Walk class compared to other classes. Prior work has found that people who identify as a race other than white have lower mobility than people who identify as white (Dugan et al., 2013; Kulikov, 2010; Vivoda et al., 2017). Importantly, it is likely not race itself that predicts mobility but factors related to race such as structural racism that drive differences in mobility. Men were significantly less likely to belong to the Nondrivers group compared to Drivers who Walk, consistent with a large body of work showing that women have lower mobility than men (Edwards et al., 2008; Freeman et al., 2005; Hess et al., 2016; Kulikov, 2010; Langford et al., 2013; Marie Dit Asse et al., 2014; Vivoda et al., 2017). Also consistent with prior work was the finding that people with greater household income were far less likely to belong to the Nondrivers class compared to Drivers who Walk; people with lower incomes have lower mobility (Dugan et al., 2013). However, only the highest income category at $100,000 or more per year was significantly associated with greater likelihood of being a Multimodal Driver compared to Driver who Walks compared to people in the lowest income category at less than $24,999 a year. A similar pattern was found for the working for pay variable, where people who were employed were less likely to be a Nondriver compared to a Driver who Walks but more likely to be a Multimodal Driver compared to a Driver who Walks. The comparisons between Multimodal Drivers and Drivers who Walk may reflect differences related to factors other than income and employment, such as where they live. Employed older adults who make $100,000 or more a year may live in a different neighborhood context not entirely captured by the rural/urban variable. This group may represent commuters who live in smaller cities and own a car and take the train to bigger cities, while people with lower household incomes who do not own a car are not included in the Multimodal Drivers class.

Finally, age was significantly associated with a greater likelihood of being a Nondriver compared to a Driver who Walks, consistent with a large body of work showing that greater age is associated with lower mobility older (Coxon et al., 2015; Edwards et al., 2008; Emerson et al., 2012; Freeman et al., 2006; Hess et al., 2016; Hjorthol, 2013; Langford et al., 2013). However, greater age was associated with a *lower* likelihood of being a Multimodal Driver compared to Drivers who Walk. This finding may relate to the potential characterization of Multimodal Drivers as commuters who own a car and take the train into the city; people over the retirement age of 65 may be less likely to work and therefore are less likely to belong to this Multimodal Drivers class. The odds ratios were close to 1 for comparisons of both classes to Drivers who Walk, suggesting that the age association in class membership is small. The small age association makes sense given that health-related travel difficulty was included in the model and had a strong association with class membership. Just as the comparisons with race, age itself is not a marker of function, but rather used as a proxy for other conditions that are related to mobility such as employment and health-related travel difficulty.

Beyond just significant predictors of transportation mode use, these results suggest that there are *disparities* in the modes of transportation older adults use to get around. For example, people who have a household income of $100,000 or more were 80% less likely to be Nondrivers versus Drivers who Walk compared to people who make less, and women were 40%

more likely to be a Nondriver versus a Driver who Walks compared to women. Older adults who specified a non-white race were three times more likely to be a Nondriver versus a Driver who Walks compared to older white adults. These results suggest that older adults with higher income who are white and are men have access to the preferred mode of transportation among older adults (King & Scott-Parker, 2017) and a mode of transportation that is associated with greater mobility compared to other forms of transportation (Viljanen et al., 2016; Weeks et al., 2015). As driving is the predominant mode of transportation in the United States, it is important to further explore disparities in access to driving and related mobility consequences.

Surprisingly, household size was not significantly associated with being in the Nondrivers class compared to Drivers who Walk. Prior work has shown that older adults who live with others are more likely to cease driving (Anstey et al., 2006; Vivoda et al., 2017). However, other studies have shown that older adults who live with others have greater mobility compared to older adults who live with others (Kulikov, 2010; Viljanen et al., 2016). Looking at who a person lives with may be more important in determining older adults' mobility. For example, one study compared older adults who live with their partner and older adults who live with their children (Kim, 2011). Older adults who lived with their children reported more transportation deficiency than older adults who lived with a partner. Some studies also compare older adults who live with a driver to older adults who do not live with a driver. Though one study did not find an association between having no other drivers in the house and driving cessation (Freeman et al., 2005), another study found that non-drivers who did not live with a driver reported greater transportation challenges than non-drivers with live with a driver (Weeks et al., 2015). Older adults who live with their adult children may have different mobility experiences than older adults who live with a spouse, and binary measures of living alone versus with others or continuous variables of household size cannot capture these differences. Additionally, driving status is just one component of mobility. An older adult who lives in a large household may be less likely to be a driver but may be more able to get rides from other household members, seeing little reduction in mobility after stopping driving.

While the comparison of Nondrivers to Drivers who Walk was partly replicating prior work comparing drivers and nondrivers on demographic predictors, exploring predictors of being a Multimodal Driver compared to a Driver who Walks provides a unique contribution to literature on older adult travel patterns. Like the comparison of Multimodal Drivers to Drivers who Walk, being nonwhite, younger, employed, and college-educated were significantly associated with a higher likelihood of being a Multimodal Driver compared to a Driver who Walks. Only the highest income category of $100,000 or more per year was significantly associated with being a Multimodal Driver. Living in a smaller household was significantly associated with a higher likelihood of being a Multimodal Driver compared to a Driver who Walks though there was restricted range in household size, with 93% of the sample living either alone or with one other person. A comparable study examined predictors of alternate transportation use among older adult drivers (Jones et al., 2018). The authors found that men, employed people, high income earners, and white people were more likely to use two or more alternate modes of transportation besides driving a private vehicle. The current study found that nonwhite participants were more likely to be multimodal compared to white participants, though only 11% of the sample identified as a race other than white. The comparisons between Multimodal Drivers and Drivers who Walk are interesting in that they are comparing older adult drivers who use public transportation, walking, and bicycling to older drivers who walk for transportation. The current study builds upon this work by examining predictors of *combinations* of transportation use among drivers, suggesting that nonwhite, employed, college-educated, high income earner, younger older adults who drive are more likely to also use multiple alternate modes of transportation compared to other older adult drivers.

In addition to demographic predictors of travel mode patterns, the current study demonstrated differences in older adults' travel mode patterns by health. In the multinomial regression, older adults with health-related travel difficulties were four times more likely to belong to the Nondrivers class compared to Drivers who Walk, even after controlling for age. This is consistent with other work showing differences in driving status by self-reported function, including difficulty walking several blocks (Kulikov, 2010) and self-reported independent activities of daily living (IADL; Dugan & Lee, 2013; Hess et al., 2016). The current study adds to this work by demonstrating differences in transportation n mode combinations in older adults by health-related travel difficulty. Nondrivers and Drivers who Walk had about equal probability of walking for transportation, but the groups were distinguished by public transportation use. The results suggest that older adults with health-related travel difficulty are more likely to take public transportation than drive.

In the multinomial regression comparing the probability of being a Multimodal Driver versus a Driver who Walks, older adults with health-related travel difficulties were less likely to be a Multimodal Driver than a Driver who Walks. This finding is intriguing because older adults with health-related travel difficulties were more likely to belong to the Nondrivers class compared to the Drivers who Walk class. The odds ratio for health-related travel difficulty was much higher in the comparison of Nondrivers versus Drivers who Walk compared to the analysis comparing Multimodal Drivers versus Drivers who walk. Among drivers, people with health-related travel difficulty seem to be less likely to be multimodal compared to people without such difficulty. When comparing nondrivers to drivers, people with health-related travel difficulty seem to be more likely to be nondrivers compared to drivers, and these people are more likely to use public transportation and walk. These results are consistent with a study which found that worse physical function was associated with fewer car driving trips per week but not with the number of trips using public transportation (Davis et al., 2011). However, this study did not look at combinations of transportation mode. The results of the current study again highlight the importance of looking at combinations of transportation use, such as looking at modes of alternate transportation among drivers.

The current study also demonstrated environmental differences in latent class membership. Consistent with hypotheses, older adults living in rural areas were about half as likely to be a Nondriver compared to the Drivers who Walk class. Rural older adults were also half as likely to be a Multimodal Driver compared to Drivers who Walk. This finding makes sense in light of urban and rural differences in availability of public transportation. Urban/rural differences were also apparent when examining latent class analysis with urban/rural status as a grouping variable. Drivers who Walk was a more prevalent class in the rural older adult group compared to the urban group. Though small, the prevalence of Nondrivers and Multimodal Drivers was higher among the urban group compared to the rural group.

Importantly, the current study explored person-environment interactions in travel mode patterns among older adults. Regardless of health, rural older adults were more likely than urban older adults to belong to the Drivers Who Walk class. This was not surprising, as rural areas offer less transportation options than urban areas. This suggests that rural older adults with health-related travel difficulties need to drive because of the environment in which they live, even if they may have safety concerns about driving. The LCA by group did not reveal person-environment interactions for the Drivers Who Walk group. There was a similar difference in prevalence of Drivers Who Walk by health-related travel difficulty between urban and rural groups, and a similar difference in prevalence of Drivers Who Walk by urbanicity between older adults with and without travel difficulties..

Regardless of urbanicity, older adults reporting a health-related travel difficulty were more likely to belong to the Nondrivers class. This is also not surprising as health is related to driving mobility. However, there was a higher prevalence of urban older adults with health difficulties in the Nondrivers group than rural older adults with health difficulties. Though they both have health limitations, urban older adults may have more transportation options than rural older adults besides driving. This is supported by the prevalence of Multimodal Drivers by health and urbanicity. Urban older adults with no health difficulties had the highest prevalence of Multimodal Drivers, which makes sense given that people without medical conditions are more likely to drive, and urban areas have more transportation options than rural areas. In contrast, there was an almost-zero prevalence of rural people with health difficulties in the Multimodal Drivers class. The difference in prevalence between older adults with and without travel difficulties was greater among urban older adults than rural older adults, suggesting person-environment interactions in this latent class. For urban older adults, health-related travel difficulties matter more in determining whether an older adult will be a Multimodal Driver or not. Travel difficulties may matter less for rural older adults' transportation mode choice, perhaps because there are less options for transportation in rural areas compared to urban areas. However, it was difficult to look at differences in prevalence of Multimodal Drivers by urbanicity and travel difficulty because the prevalence for each group was low (ranging from 88 to 1403 participants). An important caveat is that no significance testing was done for the interaction of health-related travel difficulty and environment due to small numbers of participants, so results are limited to descriptive statistics.

The current study did not assess how much participants used each mode of transportation. Instead, the current study used binary variables to indicate whether a person used public transportation at all in the past 30 days, rode a bicycle for transportation in the past seven days, or walked for transportation in the past seven days. Even though the current study identified differences in patterns of transportation mode by urban/rural and health-related travel difficulty, the results do not indicate the actual frequency of using these modes. The NHTS has a variable indicating annual driving mileage, but it does not have a similar measure for other forms of transportation so it is difficult to compare mobility across different modes. Kulikov and colleagues suggest that mileage may be a misleading indicator of mobility, since older adults who begin to self-regulate their driving may appear to be driving more mileage but this is due to driving longer distances to avoid high-risk situations such as highways (Kulikov, 2010). Extended to the current study, mobility itself may not be a good indicator of travel behavior. For example, looking at annual miles traveled by public transportation may be qualitatively different than annual miles traveled by driving and may be difficult for participants to estimate. Mileage or duration of trips and frequency of travel mode use are different but complementary measures of mobility.

To my knowledge, there has been one study that has examined mobility outcomes between older adults who use different transportation modes besides the personal vehicle. The study found that lifespace did not differ between older adults who used public transportation and older adults who drove a car as the primary mode of transportation, but older adults who primarily rode in a private vehicle as a passenger were more likely to have restricted lifespace than primary car drivers (Viljanen et al., 2016). The study was conducted in Finland, where the environment is likely to differ compared to the United States. For example, in the same study, driving was not the primary mode of transportation for older women. The share of trips taken by public transportation is high in other European countries such as Spain and France (Luiu et al., 2018), compared to in the United States where the percent of trips taken by public transportation can be as low as less than one percent (Shen et al., 2017). Differences in mobility by transportation mode may be more pronounced in the United States where there is a greater gap in mode use.

The current study had several strengths. The sample size was large and from a nationally-representative sample, making the study results generalizable to adults 62 years and older in the United States. By using latent class analysis, the current study was able to take a person-centered approach to understanding transportation mode use among older adults. Latent class models were replicated in an equivalent sample, strengthening the findings. However, there are several limitations that warrant discussion. First, the low prevalence of two out of three classes combined with the low prevalence of older adults reporting health-related travel difficulties prohibited significance tests of interactions of health by environment. Instead, descriptive analysis of latent class probability differences by a combination of urban/rural status and health-related travel difficulty were presented. Differences in latent class prevalences suggest that health and environment may significantly interact in predicting transportation mode use, though a future study will need to examine these interactions differently.

Second, the current study was limited by the variables available in the NHTS dataset. The NHTS did not have a measure of typical passenger behavior, so riding as a passenger in a private vehicle could not be examined as a transportation mode. A nationally-representative study found that the majority of older adults plan to get a ride from family or friends once they are no longer able to drive (Kim, 2011). Two additional nationally-representative surveys found that being a passenger in a private vehicle was the second-most common mode of transportation (besides driving) among older adults (Jones et al., 2018; Shen et al., 2017). The current study did not capture this mode of transportation which would have likely changed the makeup of each latent class and their prevalences in the sample. For example, rural older adults in particular may get rides from others due to a lack of alternate transportation options in rural areas. Older adults with health-related travel difficulty may also be more likely to get rides from others because their health limits them in both driving and other forms of transportation including walking, bicycling, and taking public transportation. The current study was also limited in its measure of health. Prior studies of driving outcomes in older adults use multiple measures of objectively-assessed physical function including the Turn 360 task and Short Physical Performance Battery (Antin et al., 2012; Ng et al., 2019; Phillips et al., 2016; Sims et al., 2007). Objective measures of physical function and health were not available in the NHTS, so a self-reported variable capturing health-related travel difficulty was used. It would be interesting to see whether objectively-assessed physical function interacts with urban/rural differences in predicting transportation mode use.

Importantly, there were significant associations among the five indicator variables in the LCA, threatening the assumption of local independence in LCA. Local dependence leads to biased estimates in LCA analyses. Therefore, the results of the LCA presented in the current study should be treated with caution. More advanced statistical analyses are able to run LCA models while relaxing the assumption of local independence (Reboussin et al., 2008). Further analyses of transportation mode use should consider using different indicator variables or analyses that do not require an assumption of local independence.

Conclusion

In conclusion, the current study demonstrated groups of older adults with distinct transportation mode use patterns and the role of health and the environment in predicting these patterns. To my knowledge, no study has documented combinations of transportation mode use among older adults, especially the role of health and the environment in predicting modes. The current study has important implications for both research and practice. First, future studies should ask older adults about what kinds of transportation they use, even if the sample consists of all current drivers. Furthermore, the inclusion of measures of health and function in studies of older adult mobility is essential, as there is evidence to suggest that transportation modes look different by a person's health and where they live.

Second, the current study provides key information that can be used in transportation policy and funding to better understand users of different modes of transportation. The current study has shown that not all older adults who use public transportation or walk for transportation are non-drivers. Additionally, there are potential disparities in transportation mode use. Older adults with health difficulties that impact their travel, regardless of whether they live in urban or rural areas are much more likely to be nondrivers. Transportation options behind driving, such as public transportation and walking, need to be accessible, particularly for older adults with health limitations. Transportation policy discourages older adults with functional limitations from driving, so there need to be other accessible options for this at-risk group. Low-cost accessibility improvements such as including benches along walking paths and at bus stops can make a big difference in improving older adults' mobility. Ultimately, it is imperative for researchers and policymakers to understand that older adults are a heterogenous group who use a variety of transportation modes, live in different environments, and have a variety of accessibility needs.

Chapter 4: Discussion

This dissertation examines older adult mobility through a developmental lens. By treating maintenance of personal mobility as a marker of successful aging, developmental theory necessitates the examination of both person and environment predictors, as well as their interactions, in predicting this developmental outcome. Two papers were presented which examine person environment interactions in predicting several dimensions of older adults' mobility. The findings of both papers highlight the need to examine functional measures, environmental measures, and their interactions in studies of older adult mobility using multiple indicators of mobility. The results of both papers have important implications for how future research studies are conducted in older adult mobility and how policy and practice can benefit all older adults. Papers 1 and 2 set out to explore person-environment interactions in older adults' mobility and heterogeneity in mobility.

Person-environment interactions

Paper 1 examined the interaction between a controversial environmental indicator, in-person licensing laws, and health-related travel difficulty in predicting three indicators of driving mobility. Reporting a health-related travel difficulty was significantly associated with driving fewer miles per year, being a non-driver, and not traveling on a given travel day. Experiencing an in-person license renewal requirement was significantly associated with driving fewer miles per year and not being a current driver. Importantly, the association between experiencing an in-person license renewal requirement and annual driving mileage was greater for older adults who report a health-related travel difficulty. Among participants who experienced in-person license renewal, a longer renewal cycle was not associated with any of the three mobility outcomes, while health-related travel difficulty was significantly associated with all three. However, there was a significant person-environment interaction for traveling on a given travel day, where participants with a health-related travel difficulty had the same likelihood of traveling on a given travel day regardless of renewal cycle length, while participants without a health-related travel difficulty had higher likelihood of traveling on a given travel day when the renewal length was longer.

Paper 2 examined how patterns of transportation mode use differ by urban/rural status and health-related travel difficulty. The most common pattern of transportation mode regardless of travel difficulty or urban/rural status was a group which were current drivers and also walked for transportation. However, the prevalence of this group differed by health-related travel difficulty and urban/rural status. Older adults who did not report any health-related travel difficulty had a higher prevalence of this class regardless of urban/rural status. Urban older adults reporting travel difficulty had the lowest prevalence of this class. Older adults with travel difficulties regardless of urban/rural status had a higher prevalence of non-drivers compared to older adults not reporting such difficulties. A key person-environment interaction emerged in a class of multimodal drivers: the difference in prevalence between urban older adults with and without travel difficulties was greater than for rural older adults. Ultimately, the results of Paper 2 suggest that both where a person lives and the travel difficulties they experience related to their health play a role in the transportation modes they utilize.

The conceptual model for the dissertation is presented in Figure 15. The results of Paper 1 and Paper 2 highlight the important role of person-environment interactions in older adults' mobility and transportation patterns. Given its importance to older adult well-being, mobility can be considered an indicator of successful aging that is important across the lifespan. Central to developmental science is the idea of person-environment interactions which are included in fundamental theories of human development (Baltes, 1997; Wahl & Oswald, 2010). The current study conceptualizes the environment according to Wahl and Oswald's "environmental perspectives on ageing", which include both the physical and social environment (2010). Paper 1 explores the social environment through license renewal laws, and Paper 2 explores the physical environment through urban/rural regions. In both papers, there were mobility differences by environment. In Paper 1, in-person license renewal requirements were associated with driving fewer miles per year. In Paper 2, urban/rural status was associated with different patterns of transportation mode use. In both papers, the interaction between environment and health-related travel difficulty is tested. The results of both papers suggest that the link between the environment and mobility may be greater for older adults who report a health-related travel difficulty, consistent with Baltes' theory which specifies that the role of the environment becomes more important as people age due to decreases in functional capacity (Baltes, 1997). Though the dissertation examined the first half of the figure, the conceptual model predicts that mobility will predict identity, well-being, and autonomy, which in turn predicts successful aging. This prediction is based on developmental theory from Wahl (2012) and literature showing the role driving plays in older adults' sense of identity and independence (Adler & Rottunda, 2006; Davey, 2007).

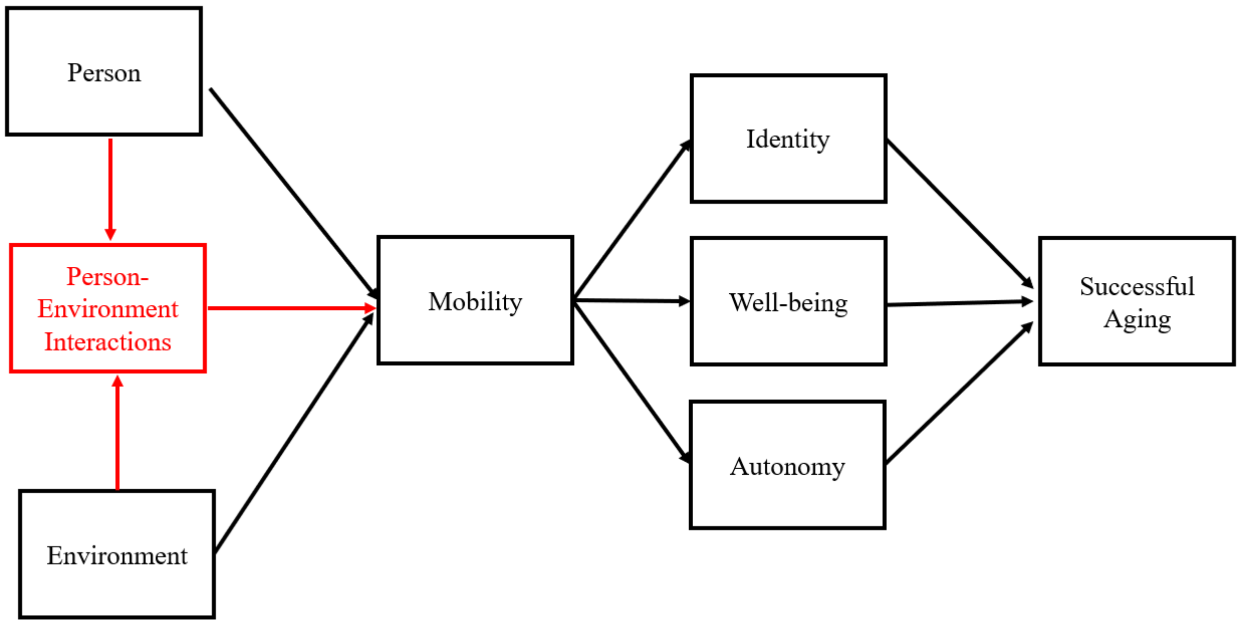

Figure 15. Conceptual model for dissertation. Adapted from Wahl (2012).

Given the increased role of the environment with age specified by developmental theory, the results of the two papers have implications for policy and practice. In light of findings that the social and physical environment play an especially important role for older adults with health-related travel difficulties, the role of policy and practice should be to support older adults regardless of functional capacity. Paper 1 shows that in-person license renewal policy is associated with lower driving mobility particularly for older adults with health-related travel difficulties. Given research not finding safety benefits of in-person license renewal for older adults, license renewal policies must be revised to ensure that the mobility of vulnerable older adults is not unnecessarily restricted. This may include a reexamination of the types of screening used at driver licensing centers to better identify older adults who are actually at-risk for crashes.

Paper 2 shows that patterns of transportation mode use differ by urban/rural environment and by health-related travel difficulty. In particular, the results suggest there may be groups of older adults who are not often considered in transportation research and planning when only the environment is considered. Baltes (1997) and Wahl (2010) both emphasize that only considering the influence of the environment or the person does not give a full picture of development. Similarly, given the results of Paper 2, only considering urban/rural status would indicate that the highest prevalence of current drivers is among rural older adults and the highest prevalence of multimodal drivers is among urban older adults. However, after considering health differences, urban older adults with health-related travel difficulties had the highest prevalence of drivers while rural older adults with health difficulties had the highest prevalence of multimodal drivers. Research and policy need to consider the specific needs of urban older adults with health difficulties who drive and rural older adults with health difficulties who use public transportation, walking, and bicycling.

In order to examine person-environment processes in older adult mobility, research studies need to include measures assessing both. In particular, large national surveys that include transportation items such as the National Household Travel Survey (NHTS) and the American Time Use Survey (ATUS) do not include objectively-assessed measures of physical function that are included in smaller studies of older adults' mobility, such as the Turn 360 and Short Physical Performance Battery tasks (Antin et al., 2012; Ng et al., 2019; Phillips et al., 2016; Sims et al., 2007). National studies are used by transportation agencies in planning purposes (Hwang et al., 2015), and the allocation of funding and services may be determined by study results. Therefore, it is imperative that older adults with health limitations receive the services they need to create a more supportive environment that enables their mobility.

Heterogeneity of mobility

In addition to objective measures of physical function, the results of both papers demonstrate the need for inclusion of multiple measures of mobility. Table 16 introduces a revised version of the coverage of the mobility spectrum by Papers 1 and 2. Mobility can be conceptualized as both the use/non-use of a particular mode of transportation, as well as the amount of use for each mode of transportation. Paper 1 demonstrated differentially associations between predictor variables depending on whether the mobility measure was use/non-use (driving status) or amount of use (annual driving mileage). In Paper 2, there were older adults who were reported as current drivers but were not the main driver of any household vehicle. There were also older adults who were reported as current drivers but also used a variety of other transportation modes.

Studies that compare drivers to non-drivers or look at a single measure of driving mobility such as annual mileage do not give a complete picture of older adults' mobility. Additionally, some measures of mobility may not be equivalent across environments. For example, older adults who live in areas where destinations are farther apart may drive more miles per year than older adults who live in more dense regions, though they may drive the same number of times per week. Older adults who walk to destinations may have a longer travel time than older adults who drive, but this longer travel time may not indicate greater mobility. Transportation studies with older adult samples and analyses of such studies need to include multiple indicators of mobility to get a fuller picture of older adults' mobility, especially given differences in mobility measures by environment.

Papers 1 and 2 did not cover the full range of the mobility spectrum for older adults. Though mode use was represented in both papers across four modes of transportation, amount of use was only examined for driving. It would have been informative to examine how much people in each class used public transportation, walking, and bicycling. Unfortunately, latent class analysis requires binary indicator variables, so this information could not be incorporated into class membership. As seen in Table 16, neither paper examined riding as a passenger as a measure of mobility, either use/non-use or amount of use. This was a limitation of the National Household Travel Survey which did not include a survey measure of riding as a passenger for transportation.

Table 16. Mobility spectrum represented in Papers 1 and 2

Transportation mode	User? Yes/No		Amount of use Low–High	
Driving	Paper 1	Paper 2	Paper 1	
Walking		Paper 2		
Bicycling		Paper 2		
Public Transportation		Paper 2		
Passenger				

Limitations

Both papers use the same dataset for analyses, so there are some shared limitations among them. First, the papers were limited by self-report measures. As discussed earlier, the NHTS does not assess objective physical function, so the papers were unable to examine whether physical function measures previously shown to be related to driving mobility are also related to the mobility measures in the current papers. The papers also used self-report mobility measures. Some research suggests that self-report measures of driving mobility do not always agree with objective measures, particularly when estimating annual driving mileage (Blanchard et al., 2010; Staplin et al., 2008). It is not clear whether self-report of other modes of transportation used in the current study such as using public transportation and walking also shows imperfect correspondence with objective measures.

A second limitation is that participants in the NHTS were assessed at one time point, limiting the analyses in the current papers to cross-sectional. Wahl's developmental theory specifies that person-environment interactions drive development (Wahl & Oswald, 2010). Though both papers found person-environment interactions in predicting mobility, a developmental process behind these interactions can only be inferred by cross-sectional data. It would also be informative to examine whether changes in environment and/or health limitations are related to changes in mobility. For example, how does the mobility of an older adult with health limitations change when they move from an urban or rural area? Future longitudinal studies of mobility should include both measures of health and the environment in order to examine this research question.

Implications

The findings of Papers 1 and 2 have implications for research and policy. First, research studies of older adults' mobility should include measures that can capture both person-environment interactions and multiple indicators of mobility. Large studies of older adult mobility often do not include objective measures of physical function. However, research has found objectively-assessed physical function to be associated with greater driving mobility (Antin et al., 2012; Ng et al., 2019; Phillips et al., 2016; Sims et al., 2007). Ideally, measures would be objective. However, this study and other studies (Dugan & Lee, 2013; Hess et al., 2016) found self-reported indicators of health were associated with driving mobility. If objective assessments of physical function are unavailable, self-reports of health should at least be included in studies of older adult driving mobility.

Research studies should also include multiple indicators of mobility that span across use/non-use and amount of use of transportation modes, as evidenced by the results of this and other studies (Kulikov, 2010; Phillips et al., 2016) showing that predictors of amount of use may not predict use versus non-use of certain transportation modes. Related, research studies look at predictors of mobility and outcomes of mobility should go beyond driving versus non-driving and instead examine use of multiple modes of transportation. Some work has examined how older adults who no longer drive get around, but there is little knowledge on older drivers who also use other modes of transportation. Obtaining information about the use of multiple transportation modes would provide specificity in predicting the negative outcomes from reduced mobility. For example, older adults who no longer drive but use public transportation may have higher mobility than older adults who get rides from friends and family members.

The results of Papers 1 and 2 also have implications for policy. According to Baltes' theory of lifespan development, the need for environmental supports increases as people age (Baltes, 1997). The role of the environment therefore becomes more important to protecting people's mobility as they age. Wahl proposes challenges for the future of environmental gerontology, and one of those challenges is identifying the role that technology plays in person-environment interactions (Wahl & Oswald, 2010). As a part of the environment, technology can be supportive or constraining. The development of supportive technology such as advanced driver-assistance systems (ADAS) can help older adults stay on the road longer. For example, an older adult whose physical health limits them from turning their head might be assisted by a blind spot warning in their vehicle which assists them in making left turns.

Mobility as a service (MaaS) is another emerging concept in mobility that can support older adults in particular. Both a policy and technology support, MaaS is the concept of connecting users from point A to point B using a single on-demand interface with no interruptions in service (Jittrapirom et al., 2017). Traditional multimodal mobility involves disconnected transportation modes along the course of a trip. For example, an older adult may want to travel from their house in the suburbs to a city center. In a traditional transportation system, the older would have to park their private car in a parking lot, buy a ticket at a train station and take a commuter train into the city, and then pay by cash to take a bus service to their final destination, repeating the whole process with the addition of paying a parking ticket on their return. With a MaaS solution, the parking, train, and bus would be integrated into one service system that the older adult could pay for ahead of time through a smartphone app. A main advantage of MaaS besides payment integrated onto one system is the emphasis on demand-responsive services. Some public transportation is sometimes considered to be unreliable and have limited service. MaaS emphasizes the inclusion of demand-responsive modes of transportation such as taxis, rideshare, and bikeshare, which offer a benefit over trains and busses with set service schedules. Public policies which employ a MaaS concept can support older adults' mobility, particularly for underserved older adults such as people living in rural areas and people with health difficulties.

Though technology has great potential to support older peoples' mobility, it also has the potential for negative effects on older people. First, the increasing automation of private vehicles might have negative impacts on older people's psychological well-being. In the conceptual model for this dissertation, mobility was related to autonomy, well-being, and identity. This theoretical model is supported by research showing that driving a private vehicle is a sign of independence and identity for older people (Adler & Rottunda, 2006; Davey, 2007). A fully-automated vehicle which does not require any input from the user may increase road safety, but it also may lose the connection between driving and psychological well-being. It remains to be determined whether “driving” an automated vehicle confers the same benefits of autonomy, well-being, and identity that driving a traditional vehicle provides.

Another potential constricting effect of technology and mobility is related to MaaS. MaaS systems are based on a single platform, often smartphone-based, in which all transportation is conducted. Older adults with limited smartphone experience may not feel comfortable using the technology required for this service, such as entering their credit card information and navigating the smartphone application. A possible downfall of MaaS is that transportation systems will completely get rid of paper tickets and machines in bus and train terminals, and older adults will be left behind. Older adults with health difficulties may find technology-based services particularly challenging due to limitations in vision or cognitive ability. Policies that use technology to improve service provision need to make sure that older adults are able to fully participate in these services.

Conclusion

Two papers are presented which demonstrate person-environment interactions in older adults’ mobility in a large national sample of older adults in the United States. Paper 1 suggests that health limitations may play a role in mobility outcomes of in-person license renewal laws; Paper 2 shows that patterns of transportation mode use are related to both urban/rural environment and health limitations. It can be concluded from both papers that only knowing about a person’s environment or their functional status gives an incomplete picture of their mobility. Knowing key information about both environment and health and their interaction is vital to ensuring that some older adults do not get left behind in transportation policy and practice. The results of the current papers provide a unique contribution to our understanding of how older adults move around in their world and suggest ways that research and policy can work together to ensure older adults stay safely mobile throughout their lifespan.

References

AAA Foundation for Traffic Safety. (2016). *Driver licensing policies and practice database*

Adler, G., & Rottunda, S. (2006). Older adults' perspectives on driving cessation. *Journal of Aging Studies*, *20*, 227-235. https://doi.org/10.1016/j.jaging.2005.09.003

Agimi, Y., Albert, S. M., You, A. O., Documet, P. I., & Steiner, C. A. (2018). Mandatory physician reporting of at-risk drivers: The older driver example. *The Gerontologist*, *58*(3), 578-587. https://doi.org/10.1093/geront/gnw209

Anstey, K. J., Windsor, T. D., Luszcz, M. A., & Andrews, G. R. (2006). Predicting driving cessation over 5 years in older adults: Psychological well-being and cognitive competence are stronger predictors than physical health. *Journal of the American Geriatrics Society*, *54*(1), 121-126. https://doi.org/10.1111/j.1532-5415.2005.00471.x

Antin, J. F., Lockhart, E., Stanley, L. M., & Guo, F. (2012). Comparing the impairment profiles of older drives and non-drivers: Toward the development of a fitness-to-drive model. *Safety Science*, *50*(2), 333-341. https://doi.org/10.1016/j.ssci.2011.09.013

Baltes, P. B. (1997). On the incomplete architecture of human ontogeny: Selection, optimization, and compensation as foundation of developmental theory. *American Psychologist*, *52*(4), 366-380.

Bentley, J. P., Brown, C. J., McGwin, G., Sawyer, P., Allman, R. M., & Roth, D. L. (2013). Functional status, life-space mobility, and quality of life: A longitudinal meditation analysis. *Quality of Life Research*, *22*, 1621-1632. https://doi.org/10.1007/s11136-012-0315-3

Blanchard, R. A., Myers, A. M., & Porter, M. M. (2010). Correspondence between self-reported and objective measures of driving exposure and patterns in older drivers.

Accident Analysis and Prevention, *42*(2), 523-529. https://doi.org/10.1016/j.aap.2009.09.018

Boyle, P. A., Buchman, A. S., Barnes, L. L., James, B. D., & Bennett, D. A. (2010). Association between life space and risk of mortality in advanced age. *Journal of American Geriatrics Society*, *58*(10), 1925-1930. https://doi.org/10.1111/j.1532-5415.2010.03058.x

Carrasco, J. L. (2010). A generalized concordance correlation coefficient based on the variance components generalized linear mixed models for overdispersed count data. *Biometrics*, *66*(3), 897-904. https://doi.org/10.HH/j.1541-0420.2009.0133

Choi, N. G., & DiNitto, D. M. (2015). Depressive symptoms among older adults who do not drive: Association with mobility resources and perceived transportation barriers. *The Gerontologist*, *56*(3), 432-443. https://doi.org/10.1093/geront/gnu116

Choi , N. G., & DiNitto, D. M. (2015). Depressive symptoms among older adults who do not drive: Association with mobility resources and perceived transportation barriers. *The Gerontologist*, *56*(3), 432-443. https://doi.org/10.1093/geront/gnu116

Coxon, K., Chevalier, A., Lo, S., Ivers, R., Brown, J., & Keay, L. (2015). Behind the wheel: Predictors of driving exposure in older drivers. *Journal of the American Geriatrics Society*, *VOL. 63*(No. 6), 1137-1145. https://doi.org/10.1111/jgs.13440

Cross, J. M., McGwin Jr, G., Rubin, G. S., Ball, K. K., West, S. K., Roenker, D. L., & Owsley, C. (2009). Visual and medical risk factors for motor vehicle collision involvement among older drivers. *The British Journal of Ophthalmology*, *93*(3), 400–404. https://doi.org/10.1136/bjo.2008.144584

Crowe, M., Andel, R., Wadley, V. G., Okonkwo, O. C., Sawyer, P., & Allman, R. M. (2008). Life-space and cognitive decline in a community-based sample of African American and Caucasian older adults. *Journals of Gerontology, Series A, Biological & Medical Sciences*, *63*(11), 1241-1245.

Curl, A. L., Stowe, J. D., Cooney, T. M., & Proulx, C. M. (2013). Giving up the keys: How driving cessation affects engagement in later life. *The Gerontologist*, *54*(3), 423-433. https://doi.org/10.1093/geront/gnt037

Davey, J. A. (2007). Older people and transport: Coping without a car. *Ageing & Society*, *27*, 49-65. https://doi.org/10.1017/S0144686X06005332

Davis, M. G., Fox, K. R., Hillsdon, M., Coulson, J. C., Sharp, D. J., Stathi, A., & Thompson, J. L. (2011). Getting out and about in older adults: The nature of daily trips and their association with objectively assessed physical activity. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(116), 1-9. https://doi.org/10.1186/1479-5868-8-116

Dugan, E., Barton, K. N., Coyle, C., & Lee, C. M. (2013). U.S. policies to enhance older driver safety: A systematic review of the literature. *Journal of Aging and Social Policy*, *25*(4), 335-352. https://doi.org/10.1080/08959420.2013.816163

Dugan, E., & Lee, C. M. (2013). Biopsychosocial risk factors for driving cessation: Findings from the Health and Retirement Study. *Journal of Aging and Health*, *25*(8), 1313-1328. https://doi.org/10.1177/0898264313503493

Edwards, J. D., Bart, E., O'Connor, M. L., & Cissell, G. M. (2009). Ten years down the road: Predictors of driving cessation. *The Gerontologist*, *50*(3), 393-399. https://doi.org/10.1093/geront/gnp127

Edwards, J. D., Perkins, M., Ross, L. A., & Reynolds, S. L. (2009). Driving status and three-year mortality among community-dwelling older adults. *Journals of Gerontology. Series A,* *Biological Sciences and Medical Sciences*, *64*(2), 300-305. https://doi.org/10.1093/gerona/gln019

Edwards, J. D., Ross, L. A., Ackerman, M. L., Small, B. J., Ball, K. K., Bradley, S., & Dodson, J. E. (2008). Longitudinal predictors of driving cessation among older adults from the ACTIVE clinical trial. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *63*(1), P6-P12. https://doi.org/10.1093/geronb/63.1.P6

Emerson, J. L., Johnson, A. M., Dawson, J. D., Uc, E. Y., Anderson, S. W., & Rizzo, M. (2012). Predictors of driving outcomes in advancing age. *Psychology and Aging*, *27*(3), 550-559. https://doi.org/10.1037/a0026359

Federal Highway Administration. (2019). *Highway Statistics 2017*. Washington, D.C. Retrieved from https://www.fhwa.dot.gov/policyinformation/statistics/2017/dl20.cfm

Federal Highway Administration. (2017). 2017 National Household Travel Survey, U.S. Department of Transportation, Washington, DC. Available online: https://nhts.ornl.gov.

Freeman, E. E., Gange, S. J., Muñoz, B., & West, S. K. (2006). Driving status and risk of entry into long-term care in older adults. *American Journal of Public Health*, *96*(7), 1254-1259. https://doi.org/10.2105/AJPH.2005.069146

Freeman, E. E., Muñoz, B., Turano, K. A., & West, S. K. (2005). Measures of visual function and time to driving cessation in older adults. *Optometry and Vision Science*, *82*(8), 765-773. https://doi.org/10.1097/01.opx.0000175008.88427.05

Grabowski, D. C., Campbell, C. M., & Morrisey, M. A. (2004). Elderly licensure laws and motor vehicle fatalities. *Journal of the American Medical Association*, *291*(23), 2840-2846. https://doi.org/10.1001/jama.291.23.2840

Haustein, S., & Siren, A. (2014). Seniors’ unmet mobility needs – how important is a driving licence? *Journal of Transport Geography*, *41*, 45-52. https://doi.org/10.1016/j.jtrangeo.2014.08.001

Hess, D. B., Norton, J. T., Park, J., & Street, D. A. (2016). Driving decisions of older adults receiving meal delivery: The influence of individual characteristics, the built environment, and neighborhood familiarity. *Transportation Research Part A: Policy and Practice*, *88*, 73-85. https://doi.org/10.1016/j.tra.2016.03.011

Hjorthol, R. (2013). Transport resources, mobility and unmet transportation needs in old age. *Ageing and Society*, *33*(7), 1190-1211. https://doi.org/10.1017/S0144686X12000517

Hubbard, A. E., Ahern, J., Fleischer, N. L., Van der Laan, M., Lippman, S. A., Jewell, N., . . . Satariano, W. A. (2010). To GEE or not to GEE: Comparing population average and mixed models for estimating the associations between neighborhood risk factors and health. *Epidemiology*, *21*(4), 467-474. https://doi.org/10.1097/EDE.0b013e3181caeb90

Hwang, H.-L., Wilson, D., Reuscher, T., Yang, J.-J., Taylor, R., & Chin, S.-M. (2015). *Travel Patterns and Characteristics of the Elderly Subpopulation in New York State*. New York State Department of Transportation

Hwang, Y., & Hong, G.-R. S. (2018). Predictors of driving cessation in community-dwelling older adults: A 3-year longitudinal study. *Transportation Research Part F: Traffic Psychology and Behavior*, *52*, 202-209. https://doi.org/10.1016/j.trf.2017.11.017

Ichikawa, M., Nakahara, S., & Inada, H. (2015). Impact of mandating a driving lesson for older drivers at license renewal in Japan. *Accident Analysis and Prevention*, *75*, 55-60. https://doi.org/10.1016/j.aap.2014.11.015

James, B. D., Boyle, P. A., Buchman, A. S., Barnes, L. L., & Bennett, D. A. (2011). Life space and risk of Alzheimer disease, mild cognitive impairment, and cognitive decline in old age. *The American Journal of Geriatric Psychiatry*, *19*(11), 961-969. https://doi.org/10.1097/JGP.0b013e318211c219

Jang, R. W., Man-Son-Hing, M., Molnar, F. J., Hogan, D. B., Marshall, S. C., Auger, J., . . . Naglie, G. (2007). Family physicians' attitudes and practices regarding assessments of medical fitness to drive in older persons. *Journal of General Internal Medicine*, *22*, 531-543. https://doi.org/10.1007/s11606-006-0043-x

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges. *Urban Planning*, *2*(2), 13-25. https://doi.org/10.17645/up.v2i2.931

Jones, V. C., Johnson, R. M., Rebok, G. W., Roth, K. B., Gielen, A., Molnar, L. J., . . . Li, G. (2018). Use of alternative sources of transportation among older adult drivers. *Journal of Transport & Health*, *10*, 284-289. https://doi.org/10.1016/j.jth.2018.07.001

Joyce, J., Lococo, K. H., Gish, K. W., Mastromatto, T., Stutts, J., Thomas, D., & Blomberg, R. (2018). *Older Driver Compliance with License Restrictions*. (DOT HS 812 486). Washington, DC: National Highway Traffic Safety Administration

Keall, M. D., & Woodbury, E. (2014). An analysis of changes in mobility and safety of older drivers associated with a specific older driver on-road licensing test: A population study. *BMC Public Health*, *14*. https://doi.org/10.1186/1471-2458-14-165

Kim, J.-K., Ulfarsson, G. F., & Sohn, K. (2014). Transportation deficiencies for Older Adults in Seoul, South Korea. *Transportation Research Record*, *2469*(1), 76-87. https://doi.org/10.3141/2469-09

Kim, S. (2011). Assessing mobility in an aging society: Personal and built environment factors associated with older people's subjective transportation deficiency in the US. *Transportation Research Part F*, *14*(5), 422-429. https://doi.org/10.1016/j.trf.2011.04.011

King, M. J., & Scott-Parker, B. J. (2017). Older male and female drivers in car-dependent settings: How much do they use other modes, and do they compensate for reduced driving to maintain mobility? *Ageing & Society*, *37*, 1249-1267.

Klein, N. J., Guerra, E., & Smart, M. J. (2018). The Philadelphia story: Age, race, gender and changing travel trends. *Journal of Transport Geography*, *69*, 19-25. https://doi.org/10.1016/j.jtrangeo.2018.04.009

Kulikov, E. (2010). The social and policy predictors of driving mobility among older adults. *Journal of Aging and Social Policy*, *23*(1), 1-18. https://doi.org/10.1080/08959420.2011.531991

Langford, J., Bohensky, M., Koppel, S., & Newstead, S. (2008). Do age-based mandatory assessments reduce older drivers' risk to other road users. *Accident Analysis and Prevention*, *40*(6), 1913-1918. https://doi.org/10.1016/j.aap.2008.08.010

Langford, J., Charlton, J. L., Koppel, S., Myers, A., Tuokko, H., Marshall, S., . . . Macdonald, W. (2013). Findings from the Candrive/Ozcandrive study: Low mileage older drivers, crash risk and reduced fitness to drive. *Accident Analysis and Prevention*, *61*, 304-310. https://doi.org/10.1016/j.aap.2013.02.006

Langford, J., & Koppel, S. (2006). The case for and against mandatory age-based assessment of older drivers. *Transportation Research Part F*, *9*(5), 353-362. https://doi.org/10.1016/j.trf.2006.06.009

Lanza, S. T., Collins, L. M., Lemmon, D. R., & Schafer, J. (2007). PROC LCA: A SAS procedure for latent class analysis. *Structural Equation Modeling*, *14*(4), 671-694. https://doi.org/10.1080/10705510701575602

Liang, K.-Y., & Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika*, *73*(1), 13-22. https://doi.org/10.1093/biomet/73.1.13

Luiu, C., Tight, M., & Burrow, M. (2018). Factors preventing the use of alternate transport modes to the car in later life. *Sustainability*, *10*(6), 1-21. https://doi.org/10.3390/su10061982

Marie Dit Asse, L., Fabrigoule, C., Helmer, C., Laumon, B., & Lafont, S. (2014). Automobile driving in older adults: Factors affecting driving restriction in men and women. *Journal of the American Geriatrics Society*, *62*(11), 2071-2078. https://doi.org/10.1111/jgs.13077

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., Berkman, L. F., & Tinetti, M. E. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. *Journal of the American Geriatrics Society*, *45*(2), 202-206. https://doi.org/10.1111/j.1532-5415.1997.tb04508.x

Meuser, T. M., Berg-Weger, M., Carr, D. B., Shi, S., & Stewart, D. (2016). Clinician effectiveness in assessing fitness to drive of medically at-risk older adults. *Journal of the American Geriatrics Society*, *64*(4). https://doi.org/10.1111/jgs.14022

Meuser, T. M., Berg-Weger, M., Niewoehner, P. M., Harmon, A. C., Kuenzie, J. C., Carr, D. B., & Barco, P. P. (2012). Physician input and licensing of at-risk drivers: A review of all-inclusive medical evaluation forms in the US and Canada. *Accident Analysis and Prevention*, *46*, 8-17. https://doi.org/10.1016/j.aap.2011.12.009

Meuser, T. M., Carr, D. B., Berg-Weger, M., Niewoehner, P., & Morris, J. C. (2006). Driving and dementia in older adults: Implementation and evaluation of a continuing education project. *The Gerontologist*, *46*(5), 680-687. https://doi.org/https://doi.org/10.1093/geront/46.5.680

Meuser, T. M., Carr, D. B., Unger, E. A., & Ulfarsson, G. F. (2015). Family reports of medically impaired drivers in Missouri: Cognitive concerns and licensing outcomes. *Accident Analysis and Prevention*, *74*, 17-23. https://doi.org/10.1016/j.aap.2014.10.002

Mezuk, B., & Rebok, G. W. (2008). Social integration and social support among older adults following driving cessation. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *63B*(5), S298-S303. https://doi.org/10.1093/geronb/63.5.S298

Nasvadi, G. C., & Wistner, A. (2009). Do restricted driver's licenses lower crash risk among older drivers? A survival analysis of insurance data from British Columbia. *The Gerontologist*, *49*(4), 474-484. https://doi.org/10.1093/geront/gnp039

National Conference of State Legislatures. (2018). *Traffic Safety Trends: State Legislative Action 2017*. https://www.ncsl.org/research/transportation/traffic-safety-trends-state-legislative-action-2017.aspx

Ng, L. S., Guralnik, J. M., Man, C., DiGuiseppi, C., Strogatz, D., Eby, D. W., . . . Team., L. R. (2019). Association of physical function with driving space and crashes among older adults. *The Gerontologist*, 1-11. https://doi.org/10.1093/geront/gny178

Phillips, C. B., Sprague, B. N., Freed, S. A., & Ross, L. A. (2016). Longitudinal associations between changes in physical function and driving mobility behaviors of older adults.

Journal of the Transportation Research Board, *2584*, 70-76. https://doi.org/10.3141/2584-09

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *60A*(3), 399-403. https://doi.org/10.1093/gerona/60.3.399

Ranchet, M., Akinwuntan, A. E., Tant, M., Salch, E., & Devos, N. H. (2016). Fitness-to-drive agreements after stroke: Medical versus practical recommendations. *European Journal of Neurology*, *23*(9), 1408-1414. https://doi.org/10.1111/ene.13050

Ratcliffe, M., Burd, C., Holder, K., & Fields, A. (2016). *Defining rural at the U.S. Census Bureau*. (ACSGEO-1). Washington, DC: U.S. Census Bureau

Reboussin, B. A., Ip, E. H., & Wolfson, M. (2008). Locally dependent latent class models with covariates: an application to under-age drinking in the USA. *J R Stat Soc Ser A Stat Soc*, *171*(4), 877-897. https://doi.org/10.1111/j.1467-985X.2008.00544.x

Ross, L. A., Browning, C., Luszcz, M. A., Mitchell, P., & Anstey, K. J. (2011). Age-based testing for driver's license renewal: Potential implications for older Australians. *Journal of the American Geriatrics Society*, *59*, 281-285. https://doi.org/10.1111/j.1532-5415.2010.03241.x

Shen, S., Koech, W., Feng, J., Rice, T. M., & Zhu, M. (2017). A cross-sectional study of travel patterns of older adults in the USA during 2015: Implications for mobility and traffic safety. *BMJ Open*, *7*(8), e015780. https://doi.org/10.1136/bmjopen-2016-015780

Shen, S., Ratnapradipa, K. L., Pervall, G. C., Sweeney, M., & Zhu, M. (2020). Driver license renewal laws and older adults' daily driving, United States, 2003-2017. *Journals of*

Gerontology: Social Sciences, *75*(10), 2268-2277. https://doi.org/10.1093/geronb/gbaa070

Shishkin, P. (2009, July 14). *Crashes fuel debate on rules for older drivers*. The Wall Street Journal. https://www.wsj.com/articles/SB100014240529702035773045742764423366625248

Sims, R. V., Ahmed, A., Sawyer, P., & Allman, R. M. (2007). Self-reported health and driving cessation in community-dwelling older drivers. *Journal of Gerontology*, *62A*(7), 789-793. https://doi.org/10.1093/gerona/62.7.789

Siren, A., & Haustein, S. (2016). Driving cessation anno 2010: Which older drivers give up their license and why? Evidence from Denmark. *Journal of Applied Gerontology*, *35*(1), 18-38. https://doi.org/10.1177/0733464814521690

Staplin, L., & Freund, K. (2013). Policy prescriptions to preserve mobility for seniors--A dose of realism. *Accident Analysis and Prevention*, *61*, 212-221. https://doi.org/10.1016/j.aap.2013.01.014

Staplin, L., Gish, K. W., & Joyce, J. (2008). 'Low mileage bias' and related policy implications: A cautionary note. *Accident Analysis and Prevention*, *40*(3), 1249-1252. https://doi.org/http://dx.doi.org/10.1016/j.aap.2007.10.012

Tay, R. (2012). Ageing driver licencing requirements and traffic safety. *Age & Society*, *32*(4), 655-672. https://doi.org/10.1017/S0144686X11000535

Tefft, B. C. (2014). Driving license renewal policies and fatal crash involvement rates of older drivers, United States, 1986-2011. *Injury Epidemiology*, *1*(1), 25. https://doi.org/10.1186/s40621-014-0025-0

Vertuno, J. (2007 September 1). *'Katie's Law' another hurdle for senior Texas drivers*. The Houston Chronicle. https://www.chron.com/news/houston-texas/article/Katie-s-Law-another-hurdle-for-senior-Texas-1815404.php

Viljanen, A., Mikkola, T. M., Rantakokko, M., Portegijs, E., & Rantanen, T. (2016). The association between transportation and life-space mobility in community-dwelling older people with or without walking difficulties. *Journal of Aging and Health, 28*(6), 1038-1054. https://doi.org/10.1177/0898264315618919

Vivoda, J. M., Heeringa, S. G., Schulz, A. J., Grengs, J., & Connell, C. M. (2017). The influence of the transportation environment on driving reduction and cessation. *The Gerontologist, 57*(5), 824-832. https://doi.org/10.1093/geront/gnw088

Wahl, H.-W., & Oswald, F. (2010). Environmental perspectives on ageing. In D. Dannefer & C. Phillipson (Eds.), *The SAGE Handbook of Social Gerontology* (pp. 111-124). SAGE. https://doi.org/10.4135/9781446200933.n8

Wahl, H. W., Iwarsson, S., & Oswald, F. (2012). Aging well and the environment: Toward an integrative model and research agenda for the future. *The Gerontologist*, *52*(3), 306-316. https://doi.org/10.1093/geront/gnr154

Webber, S. C., Porter, M. M., & Menec, V. H. (2010). Mobility in older adults: A comprehensive framework. *The Gerontologist, 50*(4), 443-450. https://doi.org/10.1093/geront/gnq013

Weeks, L. E., Stadnyk, R., Begley, L., & MacDonald, D. J. (2015). The influence of driving status on transportation challenges experienced by older adults. *Journal of Applied Gerontology, 34*(4), 501-517. https://doi.org/10.1177/0733464813487255

Wood, J. M., Horswill, M. S., Lacherez, P. F., & Anstey, K. J. (2013). Evaluation of screening tests for predicting older driver performance and safety assessed by an on-road test. *Accident Analysis and Prevention*, *50*, 1161-1168. https://doi.org/10.1016/j.aap.2012.09.009

Wu, S., Crespi, C. M., & Wong, W. K. (2012). Comparison of methods for estimating the intraclass correlation coefficient for binary responses in cancer prevention cluster randomized trials. *Contemp Clin Trials*, *33*(5), 869-880. https://doi.org/10.1016/j.cct.2012.05.004.

Xue, Q.-L., Fried, L. P., Glass, T. A., Laffan, A., & Chaves, P. H. M. (2008). Life-space construction, development of frailty, and the competing risk of mortality. *American Journal of Epidemiology*, *167*(2), 240-248. https://doi.org/10.1093/aje/kwm270

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SELECTED PUBLICATIONS

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Sprague, B. N., **Freed, S. A**., Webb, C. E., Hyun, J., Phillips, C. B., & Ross, L. A. (2019). The impact of behavioral interventions on cognitive function in healthy older adults: A systematic review. *Ageing Research Reviews*, *52,* 32-52. doi: 10.1016/j.arr.2019.04.002

Phillips, C. B., **Freed, S. A.,** & Ross, L. A. (2019). Older adult lifespace varies by driving status and residential population density. *Transportation Research Record, 2673*(7), 586–595. doi:10.1177/0361198119846092

Ross, L. A., **Freed, S. A.**, Phillips, C. B., Edwards, J. D., & Ball, K. (2016). The impact of three cognitive training programs on driving cessation across ten years: A randomized controlled trial. *The Gerontologist, 57* (5), 838-846. doi: 10.1093/geront/gnw143.

Phillips, C. B., Sprague, B. N., **Freed, S. A.**, & Ross, L.A. (2016). Longitudinal associations between changes in physical function and driving mobility behaviors among older adults. *Transportation Research Record, Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine, 2584,* 70-76. doi: 10.3141/2584-09.